IAS

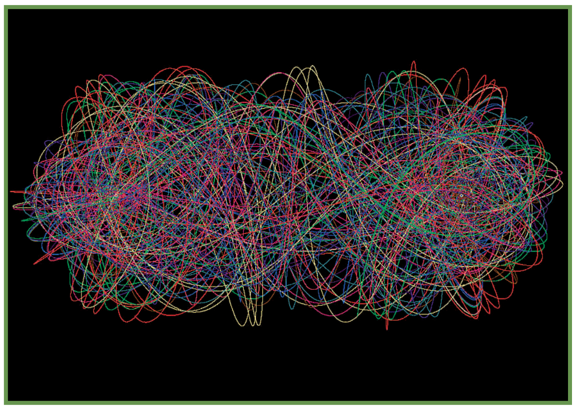
The Institute Letter

Institute for Advanced Study

Summer 2012

The Symplectic Piece

BY HELMUT HOFER AND DEREK BERMEL



This image (produced with a Java applet by Alec Jacobson at http://alecjacobson.com/programs/three-body-chaos) shows colorful trackings of the paths of satellites as they evolve from a simple single orbit to a complex multicolored tangle of orbits.

I can't understand why people are frightened of new ideas. I'm frightened of the old ones.

—JOHN CAGE

Helmut Hofer, Professor in the School of Mathematics, writes:

Last September, the School of Mathematics launched its yearlong program with my Member seminar talk "First Steps in Symplectic Dynamics." About two years earlier, it had become clear that certain important problems in dynamical systems could be solved with ideas coming from a different field, the field of symplectic geometry. The goal was then to bring researchers from the fields of dynamical systems and symplectic geometry together in a program aimed at the development of a common core and ideally leading to a new field—symplectic dynamics.

Not long before, in my 2010 inaugural public lecture at IAS, "From Celestial Mechanics to a Geometry Based on the Concept of Area," I had described the historical background and some of the interesting mathematical problems belonging to this anticipated field of symplectic dynamics. The lecture began with a computer program showing

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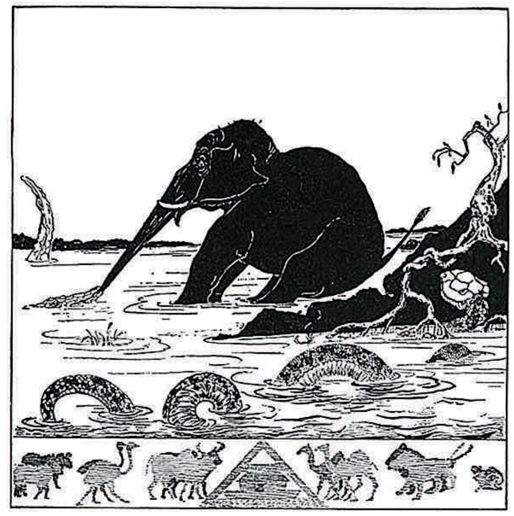
How Our Brains Operate: Questions Essential to Our Humanness

BY JOHN HOPFIELD



RUDYARD KIPLING

From Rudyard Kipling's "Just So" story "The Elephant's Child"

All of us who have watched as a friend or relative has disappeared into the fog of Alzheimer's arrive at the same truth. Although we recognize people by their visual appearance, what we *really* are as individual humans is determined by how our brains operate. The brain is certainly the least understood organ in the human body. If you ask a cardiologist how the heart works, she will give an engineering description of a pump based on muscle contraction and valves between chambers. If you ask a neurologist how the brain works, how thinking takes place, well . . . Do you remember Rudyard Kipling's *Just So Stories*, full of fantastical evolutionary explanations, such as the one about how the elephant got its trunk? They are remarkably similar to a medical description of how the brain works.

The annual meeting of the Society for Neuroscience attracts over thirty thousand registrants. It is not for lack of effort that we understand so little of how the brain functions. The problem is one of the size, complexity, and individuality of the human brain. Size: the human brain has approximately one hundred billion nerve cells, each connecting to one thousand others. Complexity: there are one hundred different types of nerve cells, each with its own

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Leon Levy Foundation Permanently Endows the Directorship

The Leon Levy Foundation has donated $20 million to the Institute for Advanced Study. This gift reflects continued support of the Institute by Trustee Shelby White and the Leon Levy Foundation, which was created in honor of White's late husband, Leon Levy, a leading financier who served on the Institute's Board of Trustees for fifteen years and as Vice Chairman and President of the Corporation from 1995–2003.

"This magnificent gift from the Leon Levy Foundation will help to further strengthen the Institute's endowment, which is essential to our continued success as a research institution of the highest standard," said Robbert Dijkgraaf, Director of the Institute and Leon Levy Professor. "Shelby White's and the Foundation's stalwart support has sustained important areas of research at the Institute, including the formation of an archives center and program, and this most recent donation moves us closer to our $200 million campaign goal. I am honored to be the first to hold the new endowed Directorship."

White, founding Trustee of the Leon Levy Foundation, commented, "My husband would have been proud to have the Institute Directorship named in his honor. He was a great believer in the Institute's mission and work, and he personally devoted many hours to its success. The Foundation is pleased that it can continue to support the Institute's important initiatives."

This major gift will be increased by $5 million from the $100 million challenge grant made by the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences in 2011 to create a $25 million Leon Levy Endowment Fund. In recognition of the gift, the Director of the Institute will carry a new title and titular professorship, Director and Leon Levy Professor, which will be permanently associated with the position. This donation brings the capital campaign total to more than $48 million, of the $100 million goal to meet the challenge grant (see page 15).

The Leon Levy Foundation, founded in 2004 to support scholarship at the highest level, has continually contributed to the Institute in significant ways. The New Initiatives Fund, established by Levy and White in 1998, helped to promote progress in new and important programs such as systems biology and theoretical computer science, and to support emerging research in mathematics and astrophysics. From 2005–12, the Foundation sponsored a Leon Levy Member in the School of Social Science. Past Leon Levy Members have included economists and political scientists who, through the support of the Foundation, have also delivered an annual Leon Levy Lecture on the nature of their work while in residence at the Institute. The Foundation funded the new landscaping of the courtyard entrance to Fuld Hall, completed in 2009, as well as other landscape improvements, and it supported a historic landscape study to fully understand the development of the Institute's campus. A $3.5 million gift from the Foundation in 2009 funded the creation of the Shelby White and Leon Levy Archives Center, which is enabling the conservation and collection of the Institute's current and future holdings of records and historical documents, Faculty papers, oral histories, photographs, and other significant documentation. ■

News of the Institute Community

JUAN MALDACENA, Professor in the School of Natural Sciences, has received the 2012 Pomeranchuk Prize of the Institute of Theoretical and Experimental Physics in Moscow, awarded for outstanding achievement in theoretical physics. Maldacena and former School of Natural Sciences Members LUIS FERNANDO ALDAY (2007, 2008–10) and AMIT SEVER (2011–12), along with Pedro Vieira, were awarded the *Journal of Physics A* Best Paper Prize 2012 for their paper "Y-system for Scattering Amplitudes" in *Journal of Physics A: Mathematical and Theoretical* 43 (2010). Alday is Professor at the Mathematical Institute of the University of Oxford, and Sever is a Senior Postdoctoral Fellow at the Perimeter Institute for Theoretical Physics.

JOAN WALLACH SCOTT, Harold F. Linder Professor in the School of Social Science, and KAREN UHLENBECK, Robert and Luisa Fernholz Visiting Professor (2012) in the School of Mathematics, have been awarded honorary degrees by Princeton University.

RICHARD TAYLOR, Professor in the School of Mathematics, and BRUCE KOVNER, an Institute Trustee and Chairman of Caxton Alternative Management LP, have been elected to the American Academy of Arts and Sciences, along with eight former Institute Members and Visitors.

CAROLINE WALKER BYNUM, Professor Emerita in the School of Historical Studies, has been elected to the Orden Pour le Mérite für Wissenschaften und Künste of the Federal Republic of Germany. Bynum is one of two new members elected by the membership to the Order, which has a total of thirty-seven German and thirty-six foreign members.

Berghahn Books has published *Myth and Modernity: Barlach's Drawings on the Nibelungen* by PETER PARET, Professor Emeritus in the School of Historical Studies, and Helga Thieme. The book addresses Ernst Barlach's sequence of large drawings on the medieval epic *The Song of the Nibelungen*, examining the epic's course through German history and the artist's biography as well as the place the drawings occupy in the art, culture, and politics of Germany.

Four Professors in the School of Natural Sciences—NIMA ARKANI-HAMED, JUAN MALDACENA, NATHAN SEIBERG, and EDWARD WITTEN—have each been awarded $3 million for their significant and path-breaking contributions to fundamental physics from the Milner Foundation. The inaugural Fundamental Physics Prize, created by Internet investor Yuri Milner to recognize transformative advances in the field and inspire interest in fundamental physics, was awarded to five additional recipients—former Members Maxim Kontsevich (1992–93 and 2002), Professor at the Institut des Hautes Études Scientifiques, and Ashoke Sen (1996–98), Professor at the Harish-Chandra Research Institute; Alan Guth of the Massachusetts Institute of Technology; Alexei Kitaev of the California Institute of Technology; and Andrei Linde of Stanford University. The physicists will serve on the selection committee for future recipients of the prize, which will be awarded annually. "These exceptional prizes are well-deserved recognition of the power of visionary ideas by daring individuals," said Robbert Dijkgraaf, Director of the Institute and Leon Levy Professor. "The Institute has a remarkable legacy in advancing our understanding of the fundamental laws of nature, and the work of these four current Faculty members illustrates the current strength and excellent future prospects of research in theoretical physics at the IAS. We wish to compliment Yuri Milner for his extraordinary generosity that we hope stimulates new generations of physicists."

Yale University Press has published *In God's Shadow: Politics in the Hebrew Bible* by MICHAEL WALZER, Professor Emeritus in the School of Social Science. Drawing on decades of thinking about Biblical politics, Walzer discusses the views of the ancient biblical writers on justice, hierarchy, war, the authority of kings and priests, and the experience of exile.

AVISHAI MARGALIT, former George F. Kennan Professor (2006–11), in the School of Historical Studies, has been awarded the Ernst Bloch Prize by the city of Ludwigshafen by the Rhine, which recognizes works important to a critical examination of the present. Margalit is now an Honorary Fellow at the Van Leer Jerusalem Institute.

ROBBERT DIJKGRAAF, Director of the Institute and Leon Levy Professor, has been made a Knight of the Order of the Netherlands Lion. Dijkgraaf, who is Distinguished University Professor of Mathematical Physics at the University of Amsterdam and past President of the Royal Netherlands Academy of Arts and Sciences (2008–12), also has been appointed as an honorary member of the Netherlands Physical Society and the Royal Netherlands Chemical Society.

GRAHAM FARMELO, a Director's Visitor, has been awarded the 2012 Kelvin Medal and Prize from the Institute of Physics for his outstanding work in communicating science to a broad audience, in particular for his book *The Strangest Man: The Hidden Life of Paul Dirac, Mystic of the Atom* (Basic Books, 2009), which he worked on during his stay at the Institute.

RUSSELL IMPAGLIAZZO, Visiting Professor (2007–12) and former Member (2003) in the School of Mathematics, is among twenty-one mathematicians, theoretical physicists, and theoretical computer scientists selected as Simons Investigators in 2012. The program, which is supported by the Simons Foundation and is in its inaugural year, is intended to enable outstanding scientists to undertake long-term study of fundamental questions. Impagliazzo is Professor at the University of California, San Diego. Eight former Institute Members and Visitors were also selected for the first class of Simons Investigators.

LÁSZLÓ LOVÁSZ, Visiting Professor (2011–12) in the School of Mathematics, and three former Institute Members have been elected to the National Academy of Sciences. Lovász is Professor at Eötvös Loránd University in Budapest.

Inscriptiones Atticae Euclidis anno posteriores. Ed. tertia. Pars I: Fasc. 5: Leges et decreta annorum 229/8–168/7 by STEPHEN TRACY, long-term Visitor in the School of Historical Studies, and Voula N. Bardani has been published by Walter De Gruyter. The work, which publishes 325 laws and decrees from the first year of independence from Macedonian occupation and the end of the third Macedonian War, was done under the auspices of the *Inscriptiones Graecae* project of the Berlin-Brandenburg Academy of Sciences.

SUBHANKAR BANERJEE, a former Director's Visitor (2011), is the recipient of a 2012 Lannan Cultural Freedom Award from the Lannan Foundation. Banerjee is a photographer and writer and the editor of *Arctic Voices: Resistance at the Tipping Point* (Seven Stories Press, 2012).

MAXIM KONTSEVICH, former Member (1992–93) in the Schools of Natural Sciences and Mathematics and Visitor (2002) in the School of Mathematics, has been awarded the 2012 Shaw Prize in Mathematical Sciences for his work in algebra, geometry, and mathematical physics. Kontsevich is Professor at the Institut des Hautes Études Scientifiques.

JOANNE MANCINI, former Visitor (2009–10) in the School of Social Science, has received the 2011 Patricia and Phillip Frost Essay Award from the editorial board of *American Art* for her article "Pedro Cambón's Asian Objects: A Transpacific Approach to 18th-Century California" (Spring 2011). Mancini is Lecturer at the National University of Ireland, Maynooth.

The 2012 Raymond and Beverly Sackler Prize in the Physical Sciences has been awarded to SARA SEAGER, former Member (1999–2002) in the School of Natural Sciences, for her analysis of the atmospheres and internal compositions of extrasolar planets. Seager is Class of 1941 Professor of Physics and Planetary Science at the Massachusetts Institute of Technology.

The Norwegian Academy of Science and Letters has awarded the 2012 Abel Prize to ENDRE SZEMERÉDI, former Member (2007–08, 2009–10) in the School of Mathematics, for his contributions to discrete mathematics and theoretical computer science, and their impact on additive number theory and ergodic theory. Szemerédi is State of New Jersey Professor of Computer Science at Rutgers, the State University of New Jersey, and Research Fellow at the Alfréd Rényi Institute of Mathematics, Hungarian Academy of Sciences, Budapest.

STEVEN VANDERPUTTEN, former Member (2005) in the School of Historical Studies, has received the Friedrich Wilhelm Bessel Research Award of the Alexander von Humboldt Foundation in recognition of his work on the social and cultural history of the Western Middle Ages. Vanderputten is a Professor at Ghent University.

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.

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Major Starr Foundation Grant Supports Simons Center for Systems Biology

A $7.5 million grant from the Starr Foundation to the School of Natural Sciences' Simons Center for Systems Biology will contribute to the creation of a permanent endowment to cover the core costs of the center's program and secure its position as a leading center for research and postdoctoral training in quantitative biology.

The grant completes the second of two challenge grants from the Simons Foundation to establish a permanent endowment; additionally, it counts toward the $100 million capital campaign challenge made by the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences in 2011. The Institute will add $7.5 million from the challenge grant to create a $15 million endowment to support a named Professorship and three Memberships in biology.

"We are incredibly grateful to the Starr Foundation for its generous endorsement of the Institute's work in theoretical biology," said Robbert Dijkgraaf, Director of the Institute and Leon Levy Professor. "This grant will enable the Institute to continue to attract the best scientists in the field, advance research into today's biological complexities, and chart new territory."

The grant complements the Starr Foundation's existing far-reaching achievements in supporting biomedical research. "Research in the fields of genomics, stem cells, and neuroscience has increased in complexity, but that complexity creates opportunities," said Maurice R. Greenberg, Chairman of the Starr Foundation. "It is exciting to see the collaborations among biologists, physicists, mathematicians, and chemists as they forge new paths to understanding diseases and possible cures. That is what our grantmaking is about: fostering the exploration and development of new opportunities."

In the last decade, the Simons Center has enabled a number of outstanding scientists to move into the forefront of the field and make an indelible impact at leading academic institutions and research laboratories around the world. The center was established in 2005 by Arnold J. Levine, now Professor Emeritus in the School

> *At the Simons Center, Faculty and Members are actively engaged in a number of areas of cancer research, including identifying the role genes play in the origins of cancers and the metabolism of cancer cells, developing strategies to profile specific cancers, and exploring means to improve cancer prevention and treatment strategies.*

of Natural Sciences, and was named for James H. Simons, a Trustee of the Institute and former Member (1972) in the School of Mathematics, and his wife, Marilyn Hawrys Simons. Stanislas Leibler, a Professor in the School of Natural Sciences who holds a faculty position jointly at the Institute and the Rockefeller University, is working to extend the interface between physics and biology to create new solutions and approaches to fundamental biological problems. Leibler and his colleagues are developing a theoretical understanding of biological functions—in one set of studies, they are investigating patterns of gene evolution that suggest how different parts of proteins interact.

Also at the Simons Center, Faculty and Members are actively engaged in a number of areas of cancer research, including identifying the role genes play in the origins of cancers and the metabolism of cancer cells, developing strategies to profile specific cancers, and exploring means to improve cancer prevention and treatment strategies. Studies also include path-breaking analyses of viruses, in particular the influenza genome and evolutionary changes that are the result of selection pressures in both virus and host. Additionally, the center is engaged in a four-year collaborative study, "Autism and Single Nucleotide Polymorphisms in the IGF Pathway," which investigates the frequency of Single Nucleotide Polymorphisms (SNPs) in selected genes that populate the interrelated signal transduction pathways in individuals with autism spectrum disorder.

Currently, two distinguished biologists, John Hopfield of Princeton University and Albert Libchaber of the Rockefeller University, are Visiting Professors at the Simons Center and are actively working with Members and others on key biological problems related to the dynamics of complex systems (see article, page 1). The establishment of a permanent endowment for the Simons Center will allow it to support the research of three permanent Professors and a total of up to fourteen Members or Visiting Professors. ■

Peter Goddard: Thoughts on Stepping Down as Director

The following text is excerpted from remarks given by Peter Goddard, the Institute's eighth Director (January 2004–June 2012), at a dinner with Trustees, Faculty, and others in May. Peter Goddard first came to the Institute as a Member in the School of Natural Sciences when he was twenty-nine in 1974. He returned to the Institute in 1988 as a Member in the School of Mathematics. A mathematical physicist, he is distinguished for his pioneering contributions in the areas of string theory, quantum field theory, and conformal field theory. Upon stepping down as Director at the end of June, he became a Professor in the School of Natural Sciences.

In some ways it seems like yesterday that the telephone rang in Cambridge and Steve Adler asked me whether I would be interested in being considered in the search for the next Director of the Institute. When I told my wife Helen, she said that it was an enormous honor to be approached in that way. And then a little while later, she said, "But, you are not taking it seriously, are you?"

■ When Lewis Strauss, who was chairing the search committee in 1946, consulted Albert Einstein about the qualities he should be seeking in the third Director of the Institute, Einstein told him he should look for a quiet man who would not disturb people who are trying to think. I have tried to satisfy the Einstein criterion.

■ Over the last eight and a half years, as I have welcomed each incoming group of new Members on behalf of the Institute, I have remarked on the warmth of the welcome Helen and I ourselves received when I first came to the Institute as a Member in 1974, and, even more, when I became Director. Trustees, Faculty, Staff, and Members all made us feel really at home. And that very special group, the Friends of the Institute, welcomed us into the wider community.

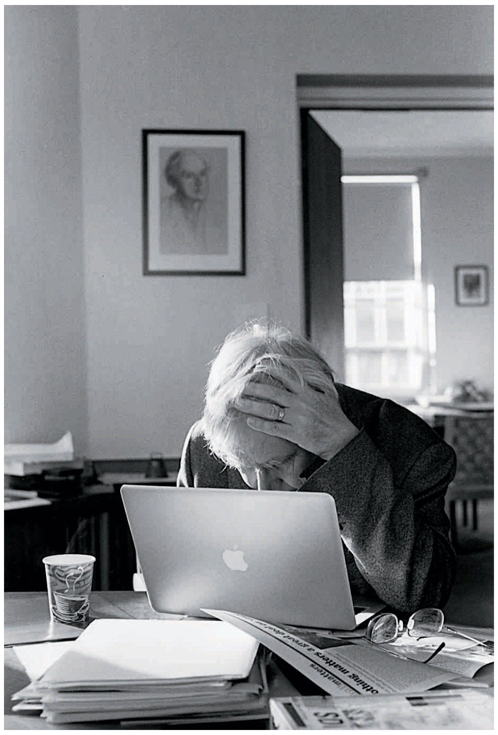
BRUCE WHITE

Rachel Gray [then Associate Director of the Institute] took us to meet Mary Keating, a founding member of the Friends, who entertained us to tea. And, she very kindly rang Rachel the next day to say how much she had enjoyed meeting us, but there was one point about which she was uncertain: she was not sure which one of us it was that would be becoming Director of the Institute. I am sure you all realize just how much I have depended on Helen's help, and what she has done for the Institute.

■ The last eight years have seen some challenging times because of the global economic crisis, which has affected us all in so many ways. But, I believe, the essentials of the academic life of the Institute have not been damaged. First, this is because of the extremely generous support provided by the Institute's Trustees. The Institute's founding Director, Abraham Flexner, told the Trustees, at their first meeting in 1930, "it is not the function of a board of trustees to be merely amiable." Nobody could accuse our Trustees of being "merely amiable"! Their commitment to the Institute continues to be quite extraordinary: a really great institute deserves really great trustees and vice-versa.

■ Also absolutely essential to our safe passage through these extraordinary economic times has been the way the Faculty and the Staff have worked together to reduce expenditure and increase income, all this without any major adverse impact on the Institute's work and life. For this, I am enormously grateful to them—the last thing I would have wished to preside over would have been a decline because of financial stringency in the freedoms and opportunities that the Institute provides.

■ The Trustees have already given me the best possible presents. Nothing could be a better gift as I step down as Director than to be able to hand on the Institute to someone as outstanding as Robbert Dijkgraaf. My congratulations and thanks go to the search committee for persuading Robbert, his wife Pia, and their family to move


SERGE J-F. LEVY

Peter Goddard served as the eighth Director of the Institute, from January 1, 2004, through June 30, 2012.

here and take on the Institute.

■ And the other gift, which I also value enormously, is to be able to stay here and work in the School of Natural Sciences, as a part of this community, without administrative duties. I am looking forward to irresponsibility!

■ But, that said, I shall really miss working with my colleagues in the Director's office and throughout the Institute. The administration here is focused, like no other institution I have known, on supporting the work of the Faculty and Members and not the theory and practice of administration for its own sake. Every year, the reports of the Members make this very evident. And I have felt deeply privileged to be Director of an institution with these ideals and ethos. ■

Pre-Dawn Higgs Celebration at IAS

BY GRAHAM FARMELO

On Wednesday, July 4, shortly after 4 a.m., the Institute's new Director, Robbert Dijkgraaf, was in Bloomberg Hall, cracking open three bottles of vintage champagne to begin a rather unusual party. He was among the scientists who had been in the Hall's lecture theater since 3 a.m. to watch a presentation from Geneva on the latest results from the CERN laboratory's Large Hadron Collider. In the closing moments, after CERN's Director-General Rolf Heuer cautiously claimed the discovery of a new sub-atomic particle—"I think we have it, yes?"—applause broke out in the CERN auditorium and in the Bloomberg Hall lecture theater. Within minutes, the IAS party was underway.

The new particle shows several signs that it is the Higgs boson, the only missing piece of the Standard Model, which gives an excellent account of nature's electromagnetic, weak, and strong interactions. Although some physicists had come to doubt whether the boson existed, Nima Arkani-Hamed, Professor in the Institute's School of Natural Sciences, was so confident that in 2007 he bet a year's salary that it would be detected at the Large Hadron Collider. In the week before the CERN presentation, Arkani-Hamed invited colleagues to the party and organized the catering. Convinced that he had won his bet, he bought three bottles of champagne, including two of Special Cuvée Bollinger.

The Higgs boson has played a central role in fundamental physics since 1964, when several theoreticians—including Peter Higgs at the University of Edinburgh—suggested an explanation of why most fundamental particles have mass. According to the theory, these particles acquire their mass from their interactions with the Higgs field, invisible and elusive but permeating the entire universe. As with all quantum fields, there is a particle associated with the Higgs field—the Higgs boson, which has no electrical charge, no spin, and a mass that is unfortunately not possible to calculate. This uncertainty about the mass of the particle is one of the factors that made its detection so difficult.

By the early 1990s, a combination of robust theoretical arguments and the well-attested experimental results, notably from Stanford and CERN, persuaded many particle physicists that the Higgs boson exists. Yet, by 2007, some theoreticians started to get cold feet and a few even began to wonder if the Standard Model might be about to crumble. Arkani-Hamed was having none of this, which is why he made the bet. A member of the public took him up on it, after a fashion, wagering \$100 plus an amount proportional to the mass of the Higgs, if it showed up. The amount was one dollar for each unit of the Higgs's mass, as measured in the physicists' preferred unit of GeV/c^2, a tad less than the mass of the lightest hydrogen atom.

Experimenters at the Large Hadron Collider announced last December that they had found the first signs of a particle consistent with the Higgs boson, with about 125 GeV/c^2. It remained to be seen whether the particle really did exist, or if the first hint had been a glitch in the data. A few months ago, when the CERN authorities announced that two of their experimental groups would announce their results jointly on July 4, the rumor mill began to grind noisily, especially on the Internet. A week earlier, it was common knowledge among physicists that something dramatic was afoot.

Arkani-Hamed expected between ten and fifteen colleagues to attend the screening of the presentation, but his prediction was not one of his most accurate—he was too low by a factor of three. The physicists watched mostly in silence as the experimenters' story unfolded—the particle appeared to exist and to decay into others, such as pairs of photons, at the expected rates (though with one tantalizing exception). Unusually for a seminar like this, the IAS audience—as well as the one in CERN—broke into applause several times and there were even a few gasps of delight. The same was happening all over the world, now that the quest for the Higgs boson was apparently coming to fruition.

Arkani-Hamed later said that he "never doubted for a second" that the Higgs particle would be detected and that he would win his bet: "All decent theorists have known for some time that there had to be a Higgs boson more or less where it was found." After a glass of champagne, he added: "Nature is extremely constrained—there aren't nymphs around every tree and dryads around every corner. Physics works."

The party was probably unique in the history of the Institute—no one could remember another occasion when its physicists quaffed champagne and speared Italian-style macerated strawberries after a seminar beginning in the middle of the night. Renée Hlozek, an astrophysicist at Princeton University, brought cookies decorated with a symbol denoting the Higgs field. On loan from Marilena LoVerde, a Member in the Institute's School of Natural Sciences, and Laura Newburgh, a physicist at Princeton University, was a diorama of CERN's huge ATLAS particle detector, delicately crafted from Peeps (marshmallow candies with hardened sugar shells), as well as paper and items molded from wax, held together with sticky tape.

A few hours after the party broke up, Robbert Dijkgraaf tweeted a photograph of the remnants of the celebration: "Decay products of 3 am #higgs event ... Never forget 1st week as Director!" By then, Arkani-Hamed had talked with the *New York Times*'s science correspondent Dennis Overbye and given him the quote that concluded his report on the Higgs-like particle: "It's a triumphant day for fundamental physics. Now some fun begins."

Soon afterward, Arkani-Hamed heard that the gentleman who bet against Higgs agreed to pay him his winnings, \$225. The check is, apparently, still in the mail. ■

Graham Farmelo is a By-Fellow at Churchill College, Cambridge. He wrote much of his biography of Paul Dirac, The Strangest Man: The Hidden Life of Paul Dirac, Mystic of the Atom *(Basic Books, 2009), and of his next book, on Winston Churchill and his nuclear physicists, as a Director's Visitor at the Institute.*

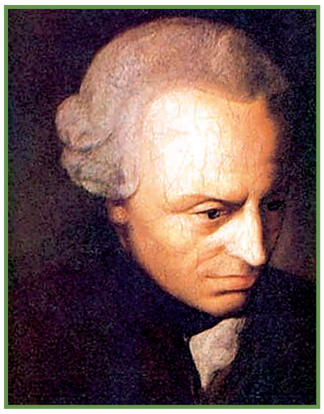
ALL PHOTOS GRAHAM FARMELO

In the pre-dawn of July 4, his fourth day as the ninth Director of the Institute, Robbert Dijkgraaf (top center and bottom left with School of Natural Sciences Professors Nima Arkani-Hamed, seated, and Edward Witten, standing, Chiara Nappi, left, and Member Marilena LoVerde, right) opened champagne in Bloomberg Hall for a celebration of CERN's discovery of a Higgs-like boson. Members witnessed the announcement in the lecture hall and later celebrated with macerated strawberries, Higgs-denoted cookies (bottom right), and a Peeps-populated diorama of CERN's ATLAS particle accelerator (top right).

Leibniz, Kant, and the Possibility of Metaphysics (and Some Ado about Nothing)

BY BRANDON C. LOOK

If the eighteenth century is to be seen as the "Age of Reason," then one of the crucial stories to be told is of the trajectory of philosophy from one of the most ardent proponents of the powers of human reason, Gottfried Wilhelm Leibniz (1646–1716), to the philosopher who subjected the claims of reason to their most serious critique, Immanuel Kant (1724–1804). Not only is the story of Kant's *Auseinandersetzung* with Leibniz important historically, it is also important philosophically, for it has implications about the nature and possibility of metaphysics, that branch of philosophy concerned with fundamental questions such as what there is, why there is anything at all, how existing things are causally connected, and how the mind latches onto the world. Like many philosophical debates, however, it is also prone to a kind of "eternal recurrence" to those who are ignorant of it.



Immanuel Kant

Leibniz was a "rationalist" philosopher; that is, he was committed to two theses: (i) he believed that the mind has certain innate ideas—it is *not*, as John Locke and his fellow empiricists say, a *tabula rasa* or blank slate; and (ii) he believed in—and, in fact, made explicit—the "principle of sufficient reason," according to which "there is nothing for which there is not a reason why it is so and not otherwise." This principle had enormous metaphysical consequences for Leibniz, for it allowed him to argue that the world, as a series of contingent things, could not have the reason for its existence within it; rather there must be an extramundane reason—God. Further, as a response to the mind-body problem, Leibniz advanced the theory of "pre-established harmony," according to which there is *no* interaction at all between substances; the mind proceeds and "unfolds" according to its own laws, and the body moves according to its own laws, but they do so in perfect harmony, as is fitting for something designed and created by God. Strictly speaking, however, Leibniz was not a dualist; he did not believe that there were minds *and* bodies—at least not in the same sense and at the most fundamental level of reality. Rather, in his mature metaphysical view, there are only simple substances, or *monads*, mind-like beings endowed with forces that ground all phenomena. Finally, according to Leibniz, since these simple substances are ontologically primary and ground the phenomena of matter and motion, space and time are *merely* the ordered relations derivative of the corporeal phenomena. Leibniz contrasted his view with that of Isaac Newton, according to whom there is a sense in which space and time can be considered absolute and space can be considered something substantial.

In his *Critique of Pure Reason* (1781; 2nd ed. 1787), Immanuel Kant presented a revolutionary philosophical view, one that challenged rationalist and empiricist orthodoxy and one that, he believed, provided answers to certain questions that had been the subject of perennial conflict. Kant advocated "transcendental idealism," according to which space and time are forms of sensibility—that is, everything that is given to our minds is given as an object in space and time—and there are certain (innate) pure concepts of the understanding that make experience possible. For example, Kant agreed with the empiricist David Hume, who had argued that the idea of *cause* or *necessary connection* cannot be traced to an immediate sense impression; yet he believed that the concept of *cause* must be in our minds in order for us to experience the world at all. A proposition expressing universality and necessity (as in claims of causation) is objectively valid *not* because of what we experience *out there* but because of the way our minds function. Kant also argued that there is an important distinction to be drawn between the appearances, or *phenomena,* and things in themselves, or *noumena.* According to Kant, we can only have knowledge (*Erkenntnis*) of things in the phenomenal realm or of the conditions for the possibility of experience; things outside of space and time or beyond the bounds of sense—the "supersensible"—are off limits for our knowledge claims. Thus, in Kant's view, metaphysics as a science of the supersensible as Leibniz and others had conceived it is doomed to failure; but a metaphysics that first establishes the boundaries of our knowledge claims and determines the conditions for the possibility of experience may indeed succeed.

The importance of the *Critique of Pure Reason* cannot be disputed. This work fundamentally changed the way philosophers think of the big-ticket items of metaphysics—the existence of God, the immortality of the soul, the freedom of the will. Leibniz believed that we can know that God exists, that the soul is immortal, and that there is freedom (though in a mitigated sense, and here Leibniz is aware that certain aspects of his system lead him into trouble on this topic). Kant, on the other hand, believed that we have theoretical knowledge of none of these things, and in the *Critique of Pure Reason* famously showed how all arguments for the existence of God are flawed, that the received views about the simplicity and immortality of the soul were problematic, and that our freedom could never be cognized. Yet, all is not lost, for Kant believed that the existence of God, the immortality of the soul, and the freedom of the will must be considered as postulates of morality and not objects of knowledge. In this sense, for Kant, there is a primacy of practical philosophy (ethics) over theoretical philosophy.

While all previous philosophers were, in Kant's mind, guilty of various errors, Leibniz occupied a special position in his conception of the history of philosophy and the history of reason's pretensions. Indeed, according to Kant, Leibniz's metaphysical system was "an intrinsically correct *platonic* concept of the world." What exactly was the problem? In a short chapter of the *Critique of Pure Reason*, "On the Amphiboly of Concepts of Reflection," Kant makes explicit this disagreement. Put briefly, Kant believed that Leibniz failed to undertake a real critique of the powers of the human mind, failed to see the fundamental distinction between sensibility and understanding, considered perceptual experience a kind of conceptual confusion, and ultimately mistook appearances for things in themselves. More exactly, Kant argued that Leibniz's metaphysical system is the consequence of the fallacy of "amphiboly"—a fallacy that arises from ambiguities in grammatical form. Consider the following Marxist claim: "Last night I caught a prowler in my pajamas. What he was doing in my pajamas, I don't know." The joke, of course, turns on the ambiguity in the phrase "in my pajamas"—does it modify the speaker or the prowler? In a somewhat similar way, Kant argued that because Leibniz failed to distinguish the faculties of sensibility and understanding and to recognize the unique contribution of each in judgment, he attributed concepts appropriate to objects of the understanding to objects of sensibility and thereby made fallacious arguments. For example, Kant saw an amphibolous use of the concepts of comparison of identity and difference, which he argued allowed Leibniz to falsely extend beyond its legitimate scope the principle of the identity of indiscernibles (if two things are qualitatively identical, that is, indiscernible, then they are numerically identical). According to Kant, Leibniz, comparing the *concepts* of two individuals with each other, argued that they must be distinct, that is, discernible; and he then extended this principle to *objects* of the senses and claimed to have made a great discovery about nature: "there are never in nature two beings that are perfectly alike." *But* objects of the senses, objects found in nature, must *first* be given to us in space. Therefore, "the difference in place already makes the multiplicity and distinction of objects as appearances not only possible in itself but also necessary."

Gottfried Wilhelm Leibniz

While all previous philosophers were, in Kant's mind, guilty of various errors, Leibniz occupied a special position in his conception of the history of philosophy and the history of reason's pretensions.

The issues at the center of the debate between Leibniz and Kant are still with us—though they sometimes manifest themselves in different ways. For example, in a recent book, *A Universe from Nothing: Why There Is Something Rather than Nothing* (Free Press, 2012), the physicist Lawrence Krauss takes up what Leibniz considered the fundamental question of metaphysics. Krauss proposes that normal "material" objects of the universe are manifestations or arrangements of quantum fields and that it is possible for a quantum field to be arranged in such a way that no ordinary physical objects exist, but that this state is deeply unstable and most likely to go from a "null-object" state to a state with objects. Hence, something from nothing. Writing recently in the *New York Times*, the philosopher David Albert raises some pointed questions for Krauss: Where do the quantum fields come from? Why are the laws of nature what they are? And, still, why is there a world of quantum fields at all? None of these questions are answered by Krauss, and without answers to these questions it would seem philosophically presumptuous to claim to have answered the fundamental question of metaphysics. But even Albert's questions themselves presuppose Leibniz's principle of sufficient reason—that there is a reason for everything. For his part, however, Kant had argued that the principle of sufficient reason is valid *only* in the realm of experience and that it does not even have meaning when applied to things outside the world of sense (and prior to the origin of the world). In other words, the proper metaphysical view is that natural science, conceived as an inductive and deductive enterprise based on sense experience, can *never* give us an answer to the question *why is there something rather nothing?* But neither can rationalist metaphysics. In the end, Kant counsels philosophical humility.[1] ■

Brandon C. Look is University Research Professor in the Department of Philosophy at the University of Kentucky. He spent the 2011–12 academic year at the Institute as the Hans Kohn Member in the School of Historical Studies, where he worked on a book manuscript "Leibniz, Kant and the Possibility of Metaphysics."

1 But who wants to be humble? Consider the following concluding argument. Despite its tendency to pretentious nonsense,

(1) Metaphysics is better than nothing.

Colleagues in the School of Natural Sciences, however, certainly believe that

(2) Nothing is better than empirical science.

Colleagues in the School of Mathematics, meanwhile, surely believe in the transitivity relation: if $a > b$ and $b > c$, then $a > c$.

(3) Therefore, metaphysics is better than empirical science.

Despite the apparently rock-solid deductive form of this argument, colleagues in the School of Social Science likely see in it merely disciplinary posturing. As a philosopher, however, I must sadly (and humbly) admit that, even if the conclusion is true, the argument itself commits the fallacy of amphiboly, for it trades on the ambiguous meaning and grammar of "nothing" and expressions involving it. I suspect that any proposed answer to the question "Why is there something rather than nothing?" will flirt with other ambiguities attached to nothingness.

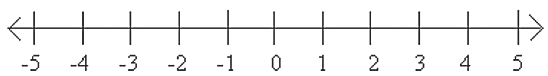
Modular Arithmetic: Driven by Inherent Beauty and Human Curiosity

BY RICHARD TAYLOR

Modular arithmetic has been a major concern of mathematicians for at least 250 years, and is still a very active topic of current research. In this article, I will explain what modular arithmetic is, illustrate why it is of importance for mathematicians, and discuss some recent breakthroughs.

For almost all its history, the study of modular arithmetic has been driven purely by its inherent beauty and by human curiosity. But in one of those strange pieces of serendipity which often characterize the advance of human knowledge, in the last half century modular arithmetic has found important applications in the "real world." Today, the theory of modular arithmetic (e.g., Reed-Solomon error correcting codes) is the basis for the way DVDs store or satellites transmit large amounts of data without corrupting it. Moreover, the cryptographic codes which keep, for example, our banking transactions secure are also closely connected with the theory of modular arithmetic.

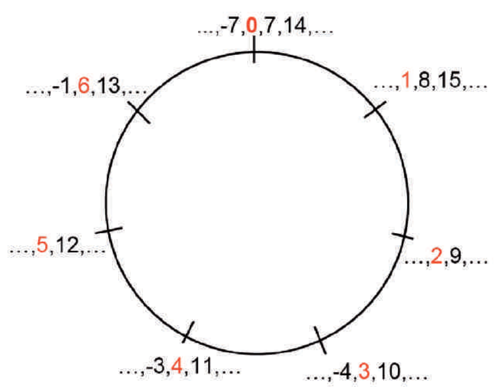
You can visualize the usual arithmetic as operating on points strung out along the "number line."



To add 3 and 5, you start at 0, count 3 to the right, and then a further 5 to the right, ending on 8. To multiply 3 by 5, you start at 0 and count 3 to the right 5 times ending up at 15. These sorts of operations should be familiar from elementary school.

In modular arithmetic, one thinks of the whole numbers arranged around a circle, like the hours on a clock, instead of along an infinite straight line. One needs to decide at the outset how many "hours" our clock is going to have. It can be any number, not necessarily 12. As a first illustration, let's suppose that we have seven "hours" on our clock—we say we are doing *arithmetic modulo* 7.

MODULO 7



To add 3 and 5 modulo 7, you start at 0, count 3 clockwise, and then a further 5 clockwise, this time ending on 1. To multiply 3 by 5 modulo 7, you start at 0 and count 3 clockwise 5 times, again ending up at 1. We would write

$$3 + 5 \equiv 1 \bmod 7 \quad \text{and} \quad 3 \times 5 \equiv 1 \bmod 7.$$

As we mentioned above, there is nothing special about 7. We can put any number of "hours" around our clock face and do arithmetic modulo any whole number. Our usual clocks can be used to do arithmetic modulo 12. If you go to a 2-hour movie starting at 11 o'clock, you will get out at 1 o'clock. This illustrates the following equality in arithmetic modulo 12:

$$11 + 2 \equiv 1 \bmod 12.$$

This may seem a rather trite variant on our usual arithmetic, and the reader could legitimately wonder if it is more than a curiosity. I hope this article will convince her that it is.

An important observation is that any arithmetic equality that is true in normal arithmetic is also true in modular arithmetic modulo any whole number you like. This easily results from the observation that one can wind the usual number line around the modular clock face, turning usual arithmetic into modular arithmetic.

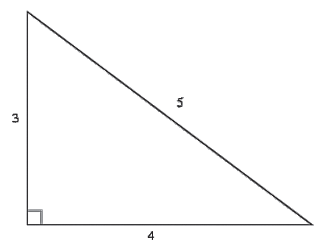
To illustrate a major reason why mathematicians care about modular arithmetic, let me start with one of the oldest questions in mathematics: Find Pythagorean triples, i.e., find whole number solutions, to the equation

$$X^2 + Y^2 = Z^2.$$

By Pythagoras's theorem, this is the same as finding right-angled triangles all of whose sides have lengths that are whole numbers (when measured in the same units). For instance

$$3^2 + 4^2 = 5^2$$

and there is a right-angled triangle:



The 3,800-year-old Babylonian tablet Plimpton 322 lists Pythagorean triples. The second column of the tablet lists values for X and the third column the corresponding value of Z; the value of Y is not listed.

In modern notation, the solutions listed on Plimpton 322 are as follows:

X	Y	Z
119	120	169
3367	3456	4825
4601	4800	6649
12709	13500	18541
65	72	97
319	360	481
2291	2700	3541
799	960	1249

X	Y	Z
481	600	769
4961	6480	8161
45	60	75
1679	2400	2929
161	240	289
1771	2700	3229
28	45	53

It is noteworthy that some of these solutions are quite complicated, but we don't know how they were generated. Could it have been trial and error, or did the Babylonians know an algorithm?

What is certain is that 1,500 years later the Greeks knew the algorithm to generate all whole number solutions to this equation. We know this because Euclid explained the method in Book X of his famous *Elements*. In modern algebraic notation, Euclid proves that every whole number solution to $X^2 + Y^2 = Z^2$ has the form

$$X = (a^2 - b^2)c/2 \quad Y = abc \quad Z = (a^2 + b^2)c/2$$

where a, b, and c are themselves whole numbers such that a, b, and c have the same parity (i.e., are both odd or both even).

But what if we change the problem slightly? What about asking for the solution of

$$X^2 + Y^2 = 2Z^2$$

or

$$X^2 + Y^2 = 3Z^2$$

in whole numbers? It turns out that as soon as we find one non-zero solution in whole numbers, the method described in Euclid's *Elements* applies, and we can describe all solutions in whole numbers explicitly. So for instance the equation

$$X^2 + Y^2 = 2Z^2$$

has a solution

$$X = 1 \quad Y = 1 \quad Z = 1$$

and one deduces that the general point with whole number coordinates is of the form

$$X = (a^2 + 2ab - b^2)c/2$$
$$Y = (-a^2 + 2ab + b^2)c/2 \quad Z = (a^2 + b^2)c/2$$

where a, b, and c are themselves whole numbers such that a, b, and c have the same parity.

However, if you search for non-zero whole number solutions to $X^2 + Y^2 = 3Z^2$, you won't find any. What is the difference between $X^2 + Y^2 = Z^2$ or $X^2 + Y^2 = 2Z^2$, and $X^2 + Y^2 = 3Z^2$? The answer comes from modular arithmetic.

Suppose there was a solution to

$$X^2 + Y^2 = 3Z^2,$$

with X, Y, and Z non-zero whole numbers. We can arrange that no whole number bigger than 1 divides all of X, Y, and Z. (If it did, simply divide each of X, Y, and Z by this common factor, and they still form a solution to the same equation. If need be, we repeat this process. Note that as the numbers X, Y, and Z get smaller in absolute value each time, but remain whole numbers, this procedure must eventually stop.) Then there would be a solution to the same equation in arithmetic modulo 3. But in arithmetic modulo 3 we have

$$3 \times Z^2 \equiv 0 \times Z^2 \equiv 0 \bmod 3$$

and

$$0^2 \equiv 0 \quad \text{and} \quad 1^2 \equiv 1 \quad \text{and} \quad 2^2 \equiv 1 \bmod 3,$$

i.e.,

$$X^2 \equiv 0 \text{ or } 1 \bmod 3 \quad \text{and} \quad Y^2 \equiv 0 \text{ or } 1 \bmod 3.$$

Richard Taylor, who became a Professor in the School of Mathematics in January, is a leader in number theory who, with his collaborators, has developed powerful new techniques that they have used to solve important long-standing problems. With Andrew Wiles, he developed the Taylor-Wiles method, which they used to help complete the proof of Fermat's Last Theorem. Together with Fred Diamond, Brian Conrad, and Christophe Breuil, he resolved completely the Shimura-Taniyama-Weil Conjecture in the theory of elliptic curves. With Michael Harris, he proved the local Langlands conjecture. More recently, Taylor established the Sato-Tate Conjecture, another long-standing problem in the theory of elliptic curves.

The only way we can have

$$X^2 + Y^2 \equiv 0 \bmod 3$$

is to have $X^2 \equiv Y^2 \equiv 0 \bmod 3$. This means that 3 divides X and Y; so that 9 divides $X^2 + Y^2 = 3Z^2$; so that 3 divides Z^2; so that 3 also divides Z. This is impossible, because we had arranged that no whole number greater than 1 divided each of X, Y, and Z. As we have reached a contradiction, the only possibility is that our initial assumption was flawed, i.e., there could not have been a solution to

$$X^2 + Y^2 = 3Z^2,$$

with X, Y, and Z non-zero whole numbers.

This sort of argument works not only for this particular equation. A beautiful theorem of Hermann Minkowski (1890) and Helmut Hasse (1924) says that if $Q(X_1, ..., X_d)$ is any homogeneous quadratic polynomial in any number of variables with whole number coefficients, then

$$Q(X_1, ..., X_d) = 0$$

has a non-zero solution in whole numbers if and only if it has a non-zero solution in all (real) numbers and a primitive solution modulo m for all positive whole numbers m. (We call $(X_1, ..., X_d)$ a *primitive* solution modulo m if

$$Q(X_1, ..., X_d) \equiv 0 \bmod m,$$

but no integer greater than 1 divides all the X_i.) This is actually a very practical criterion. It may appear that one needs to check for solutions to our equation in arithmetic modulo m for infinitely many m. However, one can find a single integer m_0 (which depends on the polynomial Q) with the property that, if $Q(X_1, ..., X_d) = 0$ has a primitive solution modulo m_0, then it also has a primitive solution modulo m for any other positive whole number m.

However, for higher degree equations, the corresponding theorem can fail. For instance

$$3X^3 + 4Y^3 + 5Z^3 = 0$$

has non-zero solutions modulo every positive whole number (and it has a solution in the real numbers), but it has no non-zero solution in whole numbers. (This famous example was found by Ernst Selmer, former IAS Member.) Nevertheless, when studying the whole number solutions to any polynomial equation, the study of solutions modulo m is often a key tool.

More than 1,800 years ago the Chinese text *Sun Zi Suan Jing* contained a statement of what is now referred to as the Chinese Remainder Theorem. This theorem gives a very efficient algorithm that reduces the study of the solutions to a polynomial equation in arithmetic modulo a whole number m, to the study of the same equation in arithmetic modulo the factors of m of the form p^a, where p is a prime number and a is a positive whole number. In fact, it turns out that the key case to consider is when m is a prime number. Thus, for the rest of this article, we will only consider arithmetic modulo a prime number p.

Recall that a prime number is a whole number greater than 1, which is only divisible by 1 and by itself. Examples are 2, 3, 5, 7, 11, 13, 17, and 19, but not for instance 15, which is divisible by 3 and 5. Every positive whole number can be written uniquely as a product of prime numbers (up to order). In some way, prime numbers are a bit like the atoms of which all other whole numbers are composed.

The first really great achievement in the study of modular arithmetic was Carl Friedrich Gauss's proof in 1796 of his celebrated *law of quadratic reciprocity*, which had previously been conjectured by Leonhard Euler and Joseph Lagrange. This was supposed to have been Gauss's favorite theorem, and he kept coming back to it during his life, giving eight different proofs. It states that

if p is a prime number, then the number of square roots of an integer n in arithmetic modulo p depends only on p modulo $4n$.

On the face of it, this may not seem surprising, but I would stress that there is no apparent reason why trying to solve the equation

$$X^2 \equiv n \bmod p$$

should have anything to do with p modulo $4n$. Thirty years after I first learnt how to prove this theorem, it still seems miraculous to me.

Gauss's theorem also provides a very effective way of determining the number of square roots a whole number has in arithmetic modulo a prime number p. For example, one could ask how many square roots 3 has in arithmetic modulo 20132011, which is a prime number. You could, in theory, check all the 20132011 possibilities and determine the answer, but (without a computer) this would take a very long time. On the other hand

$$20132011 = 1677667 \times 12 + 7$$

so that 3 has the same number of square roots in arithmetic modulo 20132011 as it does in arithmetic modulo 7. But it is very quick to list the squares modulo 7:

$$0^2 \equiv 0,\ 1^2 \equiv 1,\ 2^2 \equiv 4,\ 3^2 \equiv 2,\ 4^2 \equiv 2,\ 5^2 \equiv 4,\ 6^2 \equiv 1 \bmod 7.$$

Thus 3 has no square root in arithmetic modulo 7 and so by Gauss's theorem it has no square root in arithmetic modulo 20132011. (A good thing we didn't waste our time checking all 20132011 possibilities!)

One could ask for a similar method that given any number of polynomials in any number of variables helps one to determine the number of solutions to those equations in arithmetic modulo a variable prime number p. Such results are referred to as "reciprocity laws." In the 1920s, Emil Artin gave what was then thought to be the most general reciprocity law possible—his abelian reciprocity law. However, Artin's reciprocity still only applied to very special equations—equations with only one variable that have "abelian Galois group."

Stunningly, in 1954, Martin Eichler (former IAS Member) found a totally new reciprocity law, not included in Artin's theorem. (Such reciprocity laws are often referred to as non-abelian.) More specifically, he found a reciprocality law for the two variable equation

$$Y^2 + Y = X^3 - X^2.$$

He showed that the number of solutions to this equation in arithmetic modulo a prime number p differs from p by the coefficient of q^p in the formal (infinite) product

$$q(1-q)^2(1-q^{11})^2(1-q^2)^2(1-q^{22})^2(1-q^3)^2(1-q^{33})^2(1-q^4)^2... = q - 2q^2 - q^3 + 2q^4 + q^5 + 2q^6 - 2q^7 - 2q^9 - 2q^{10} + q^{11} - 2q^{12} + \ldots$$

For example, you see that the coefficient of q^5 is 1, so Eichler's theorem tells us that

$$Y^2 + Y = X^3 - X^2$$

should have $5 - 1 = 4$ solutions in arithmetic modulo 5. You can check this by checking the twenty-five possibilities for (X, Y) modulo 5, and indeed you will find exactly four solutions:

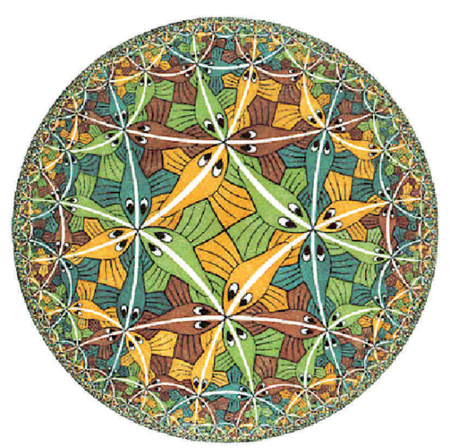
$$(X, Y) \equiv (0,0),\ (0,4),\ (1,0),\ (1,4) \bmod 5.$$

Within less than three years, Yutaka Taniyama and Goro Shimura (former IAS Member) proposed a daring generalization of Eichler's reciprocity law to all cubic equations in two variables. A decade later, André Weil (former IAS Professor) added precision to this conjecture, and found strong heuristic evidence supporting the Shimura-Taniyama reciprocity law. This conjecture completely changed the development of number theory.

In the mid-1980s, Gerhard Frey, Jean-Pierre Serre (former IAS Member), and Kenneth Ribet (former IAS Member) showed that the Shimura-Taniyama reciprocity law, if true, would imply Fermat's Last Theorem. Motivated by this, in 1995, Andrew Wiles (former IAS Member), partly in collaboration with the author, established many cases of the Shimura-Taniyama reciprocity law and hence finally proved Fermat's Last Theorem.

Meanwhile, in the mid-1970s, Robert Langlands (Professor Emeritus, School of Mathematics) had the extraordinary insight that the ideas of Eichler, Taniyama, and Shimura were a small part of a much bigger picture. He was able to conjecture the ultimate reciprocity law, an enormous generalization of what had gone before, which applies to any number of equations, of any degree in any number of variables. In the last ten years, using the ideas introduced by Wiles, there has been much progress made on Langlands's reciprocity conjecture, but much more still remains to be done.

One striking feature of all the non-abelian reciprocity laws is that the formula for the number of solutions is given in terms of symmetries of certain curved spaces—an extraordinary connection between solving algebraic equations and geometric symmetry. In the case of the Shimura-Taniyama reciprocity law, the relevant symmetries are those of the "hyperbolic plane." The hyperbolic plane can be thought of as a circular disc (without its boundary), but with an unusual notion of distance. For two points near the center of the disc, their "hyperbolic" distance is similar to their usual distance, but distances are increasingly distorted near the edge of the disc. The hyperbolic plane and its symmetries were illustrated in some of Escher's woodcuts, like the one below. In the hyperbolic world, all the fish in Escher's print are to be thought of as having the same size.



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Circle Limit III M. C. *Escher*

I will conclude by discussing one further question about modular arithmetic which has seen recent progress.

Instead of asking for a rule to predict how many solutions an equation will have in arithmetic modulo a varying prime p, one can ask about the statistical behavior of the number of solutions as the prime varies. Going back to the simple case of a quadratic equation in one variable, Lejeune Dirichlet showed in 1837 that for a fixed whole number m, which is not a prefect square, the equation

$$X^2 \equiv m \bmod p$$

(Continued on page 8)

MODULAR ARITHMETIC *(Continued from page 7)*

has two solutions for half of all prime numbers p and no solutions for half of all prime numbers p. This may seem a natural answer, but Dirichlet's proof was very subtle, combining Gauss's reciprocity law with ideas from complex analysis. In 1880, Ferdinand Frobenius generalized Dirichlet's theorem to any equation in one variable. For other equations, the correct answer may be harder to guess. For instance, the equation

$$X^4 \equiv 2 \bmod p$$

has no solution for 5/8 of all prime numbers p; has two solutions for 1/4 of all prime numbers p; and has four solutions for 1/8 of all prime numbers p.

What about such density theorems for equations in more than one variable, like

$$Y^2 + Y = X^3 - X^2?$$

In this case, Hasse showed in 1933 that the number of solutions in arithmetic modulo p, which we will denote N_p, is of the same order of magnitude as p. More precisely, he showed that N_p differed from p by at most $2\sqrt{p}$. He proved this for all cubic equations in two variables.

In 1949, Weil conjectured an enormous generalization of Hasse's bound to any number of equations in any number of variables of any degree. These celebrated conjectures led to a revolution in arithmetic algebraic geometry. Weil's conjectures were finally proved by Pierre Deligne (Professor Emeritus, School of Mathematics) in 1974.

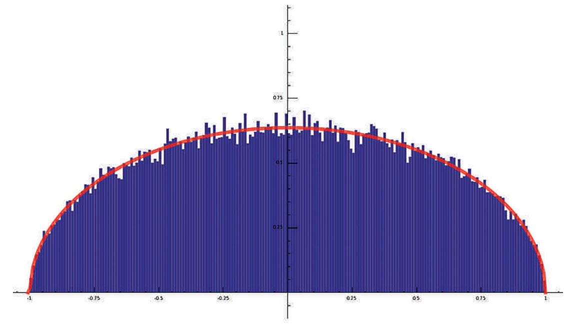
Returning to the equation

$$Y^2 + Y = X^3 - X^2,$$

Hasse's theorem tells us that asking for what fraction of primes this equation has—say, ten solutions in arithmetic modulo p—is not interesting; the answer will always be 0. Rather the natural question is to consider the normalized error term

$$\frac{N_p - p}{\sqrt{p}.}$$

By Hasse's theorem, this will be a (real) number lying between -2 and 2, and one can ask how it is distributed in this interval. Is the error often as large as Hasse's theorem allows, or is it usually smaller and only rarely at the extreme? In 1963, Mikio Sato and John Tate (both former IAS Members) independently conjectured the correct density theorem—the error should be distributed like $(1/2\pi)\sqrt{4 - t^2}$, a "squashed semi-circle."



Sato-Tate Distribution for Δ and p <1,000,000 (drawn by William Stein)

The Sato-Tate density theorem has recently been proven (by Laurent Clozel and Michael Harris, both former IAS Members; Nicholas Shepherd-Barron; and the author), not just for this equation, but for all cubic equations in two variables. The proof combines the arguments of Dirichlet and Frobenius with an infinite series of new cases of Langlands's reciprocity law. There should, of course, be density theorems for any number of equations in any number of variables of any degree, but these remain very much conjectural. The story is continuing ... ■

HOW OUR BRAINS OPERATE *(Continued from page 1)*

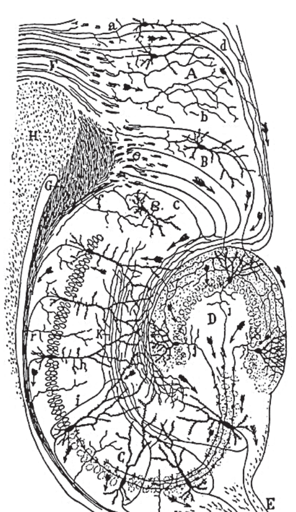
detailed properties. Individuality: all humans are similar, but the operation of each brain is critically dependent on its individual details. Your particular pattern of connections between nerve cells contains your personality, your language skills, your knowledge of family, your college education, and your golf swing.

We will never know the connectivity pattern of any individual human. But even without that, there are general questions essential to our humanness that can be addressed on the basis of the many neurobiological facts now available.

The existence of memory. The sense of time. Thinking. Human language. Consciousness. These properties are all collective, high-level descriptions of events that are implicitly caused by the activity of huge numbers of interacting nerve cells. Tornados are a high-level description of the motions of enormous numbers of interacting molecules. We want to understand how mind emerges from brain, just as we understand how tornados emerge from molecules. I will say a few words about the easiest and about the deepest items on the list: memory and consciousness.

The existence of memory. The sense of time. Thinking. Human language. Consciousness. These properties are all collective, high-level descriptions of events that are implicitly caused by the activity of huge numbers of interacting nerve cells. Tornados are a high-level description of the motions of enormous numbers of interacting molecules. We want to understand how mind emerges from brain, just as we understand how tornados emerge from molecules.

We have associative memory. If you went to a party last Saturday, the location of the party, whom you spoke with, what the meal was, the conversations you had are all linked together. Let's say someone asks you, "Have you seen Pat since last summer?" You might reply, "He was at a fabulous party last Saturday, where I heard that ..." and on. Items in your memory are linked together in a rich web, and reminding you of something immediately connects you with items that are *associated*. Recall is summoned up by association. By contrast, all digital computer memory is by address. You store information at a location and can retrieve it only by giving the location at which it is stored.



Neural circuitry of the rodent hippocampus drawn by Spanish scientist Ramón y Cajal in 1911

There is a simple mathematical model describing how a particular kind of nerve circuit will behave as an associative memory. The question of whether this model in fact describes how we have associative memories then becomes an experimental question of whether the part of the brain that is responsible for associative memory has the expected circuitry and uses it in the expected fashion. There is increasing evidence in the rat, one of our very distant cousins, that a region of the brain called the hippocampus has the expected properties, and has activity patterns consistent with associative memory. What about in humans, for our brains contain a hippocampus that is very similar to that of a rat? For humans the situation is more complex, and the current popular hypotheses are more a "Just So" story than a viable theoretical description.

Finally, on to consciousness. Let me ask each of you, "Are you conscious of your shoes pressing on your feet?" The pressure-sensing nerve cells in your feet were sending signals to your brain both before and after you heard that question, but somehow hearing that question switched your state of conscious awareness of your feet. There are no useful scientific descriptions of how this takes place, or of the neural activity that this state of awareness of my feet implies. The problem is that consciousness is an internal personal feeling. I can describe my conscious awareness of the world to you by using language, but you have no scientific way of verifying that description.

I have asked many brilliant scientists about consciousness and have heard an amazing diversity of answers. The artificial intelligence pioneer Marvin Minsky remarked that the really difficult things that a brain does are all done nonconsciously—tasks like perceiving the visual world as made up of separate objects. Minsky further pointed out experiments in which a decision that you declare you have made consciously had in fact been made and begun to be acted on before you were consciously aware of that decision. In Minsky's view, consciousness may be a feeble attempt of the human brain (a special kind of computer) to describe its own actions in terms of the behavior of an agent called "me."

I asked Francis Crick for his view of consciousness. He replied with a long monologue about the gene, beginning with Gregor Mendel and his discovery of the discrete nature of inheritance. It took a couple decades for Mendel's discovery to become understood as the central issue of biology. Slowly, the concept of a gene was developed. That concept began with no plausible basis in the physical or chemical world. It was more than a century between Mendel and the ultimate understanding of the basis of inheritance through knowing the genetic meaning of a DNA molecule. Through this century, biologists wrestled with a concept of a gene because they understood that inheritance stood at the heart of biology. Crick concluded this lecture (to me) with the simple statement "To me, consciousness is like that—ill-formulated, but lying at the center of what it is to be human."

I myself would not go quite that far. But I do share with Crick the belief that we will not understand the essence of what it is to be human until we have a viable theoretical understanding of how the human brain functions. It may take another century to produce. Present experimental facts are inevitably inadequate. But, like the genetic pioneers, we must try, for how the human brain works is the most fundamental scientific question that our humanity poses to us. ■

John Hopfield is the Martin A. and Helen Chooljian Visiting Professor in Biology in the School of Natural Sciences and the Howard A. Prior Professor in the Life Sciences, Emeritus, and Professor of Molecular Biology, Emeritus, at Princeton University, where he joined the faculty as a professor of physics in 1964. Hopfield's research has demonstrated how modeling biological processes in the brain can be used to solve complex computational problems. The beginning of the modern era of neural networks can be traced to his pioneering work in the early 1980s. His current research examines issues such as "thinking" and "perception" in the intersection between these two ideas.

Gathering Arctic Voices at the Institute, with the Woods to Inspire

BY SUBHANKAR BANERJEE

Prior to arriving at the Institute as a Director's Visitor last fall, I had heard about the Institute Woods, of which George Kennan had said:

> I have lived in the proximity of these Woods for over half a century. They are a friend, a source of inspiration and restoration, and were they to disappear it would be like the disappearance of an old, beloved, and respected friend.

I needed a source of inspiration, as I was editing an anthology *Arctic Voices: Resistance at the Tipping Point* at the time. So, I made a request of Peter Goddard, then Director of the Institute, and Yve-Alain Bois, Professor in the School of Historical Studies, who had facilitated my visit:

> If I am allowed, I would like to make my office in the IAS Woods rather than inside an office building where I might be given an office space. Each morning predawn I would like to walk for three hours in the Woods, and same around dusk, making it a full day of work.

Dr. Goddard responded:

> "It is good to hear that you are excited about the woods. You are of course free to walk there whenever you wish, but we will still allocate you a normal office!"

As it turned out, I really needed a "normal office" — where I worked long hours each day to complete my work on the Arctic anthology, a compilation of thirty-nine contributions by indigenous activists, writers, conservationists, scientists, and humanities scholars, as well as photographs and drawings by sixteen artists. What follows is an excerpt from my introduction in *Arctic Voices*.

How do we talk about the Arctic?
How do we think about the Arctic?
How do we relate to the Arctic?

And, why talk about the Arctic, now? These are some questions we explore, through stories, in this volume.

Along the way, we talk about big animals, big migrations, big hunting, big land, big rivers, big ocean, and big sky; and also about big coal, big oil, big warming, big spills, big pollution, big legislation, and big lawsuits.

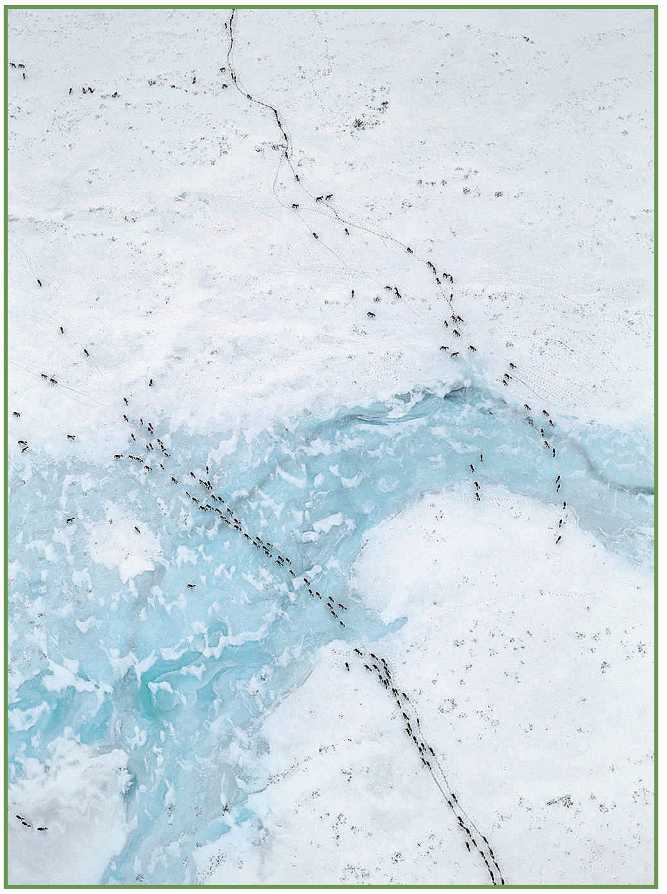
And we talk about small things, too—small animals, small migrations, small hunting, small rivers, small warming, small spills, small pollution, small legislation, and small lawsuits.

In the Arctic, impacts of climate change can be seen and/or experienced everywhere. Indeed, the Arctic is warming at a rate double that of the rest of the planet. We tell many stories of climate change in *Arctic Voices*.

At the same time, I am realizing that there is an Arctic paradox: that oil, coal, and gas, the burning of which has caused unprecedented Arctic warming, are the same nonrenewable resources whose extraction projects are expanding rapidly in the Arctic—terrestrial and offshore.

There are resource wars—for oil, gas, coal, and minerals—everywhere in the Arctic—from Alaska to Siberia, with Nunavut and Greenland along the way. In Arctic Alaska, these wars have intensified since I first arrived there more than a decade ago.

You might wonder how someone with an Indian-sounding name like mine, someone from the south, comes to concern himself with all things northern. Here is how it all began. In 2000, I left my career as a scientist and was wandering aimlessly from Florida to British Columbia looking for inspiration for a photography project; I had found none when, in late October, I arrived with two friends in Churchill in subarctic Canada—a popular tourist destination. There, polar bears gather along the Hudson Bay and wait on land for the bay to freeze over. Once on ice, they hunt and eat. I took a photo of one bear eating another—



Caribou Migration I, *from the series* Oil and the Caribou *(Arctic National Wildlife Refuge), 2002*

not normal, I was told, but no one in town said the Arctic was getting warmer. I now read that the bears of Hudson Bay will disappear within a few decades at best, or within a decade at worst, because these days ice is forming later in autumn and melting sooner in spring, leaving the bears longer on land, where they must wait and starve. This gruesome photograph of death produced in me a desire to live in the wild, with the polar bears.

I use photography to raise awareness about the Arctic, but I never would have imagined that my photographs would be used on the U.S. Senate floor to argue against oil drilling in the Arctic National Wildlife Refuge—yet that is exactly what Senator Barbara Boxer did and won a crucial vote on March 19, 2003. Nor did I imagine that my exhibition at the Smithsonian Institution would be censored and become the topic of a Senate hearing at which Senator Richard Durbin would support my work, or that later a Senate investigation would follow. But when then-Senator Ted Stevens during a May 2003 Senate debate said that President Jimmy Carter and I were giving "misinformation to the American public"—effectively calling us liars—then I did fear possible deportation, and realized that if I were to have a voice in conservation in the U.S., I must become a U.S. citizen. So I did.

Secretary of the Interior Gale A. Norton, during a March 12, 2003, congressional testimony, famously described the Arctic Refuge coastal plain as an object of conceptual art—"a flat white nothingness." … Then, on November 5, 2005, Senator Stevens said on *PBS NewsHour* with Jim Lehrer, "This is the area in wintertime. And I defy anyone to say that that is a beautiful place that has to be preserved for the future. It is a barren wasteland, frozen wasteland."

Arctic Voices paints a very different picture—we present the Arctic neither as a frozen wasteland nor as a pristine wilderness, but, instead, simply as *home* for numerous species—animal and human—who either visit for a while or live there year-round.

Over the past decade, many people have asked me, "Why should I care about the Arctic?" While I still may not have the whole answer, I've been putting together bits and pieces in response to that question.

Indeed, around the world, the Arctic is thought to be a remote place disconnected from our daily lives. On the contrary, hundreds of millions of birds migrate to the Arctic each spring from every corner of the earth—including Yellow Wagtail from Kolkata—for nesting and rearing their young, and resting—a planetary celebration of global interconnectedness. On the other hand, caribou, whale, and fish migrate hundreds and sometimes thousands of miles, connecting numerous indigenous communities through subsistence food harvests—local and regional interconnectedness. However, deadly industrial toxins migrate to the Arctic from every part of our planet, making animals and humans of the Arctic among the most contaminated inhabitants of the earth. The breast milk of high Arctic women in some parts of Greenland and northern Canada is scientifically regarded as being as toxic as hazardous waste—a planetary tragedy of global interconnectedness. Marla Cone tells this tragic story in this volume—she calls it "Arctic Paradox."

As you can see, the Arctic is far from being a remote place disconnected from our daily lives. Instead, we're all connected to the northern landscape. In this volume, we tell many stories of local, regional, and global interconnectedness—both celebratory and tragic.

The Arctic, after all, is big—it is the top of our earth, the ice cap, some call it, but it is so much more, and it's that so-much-more that this book is about.

The Arctic has become our planet's tipping point—climate change is wreaking havoc up there. Resource wars continue to spread. Industrial toxins continue to accumulate widely. But also, the voices of resistance are gathering, are getting louder and louder—and that is the story this volume presents. It is the noise and the music of all our voices bundled together.

Arctic Voices doesn't have a linear structure; it isn't arranged chronologically or even geographically, but rather as a web of interconnections with loosely defined themes that you may read in any order you wish. I have found plenty of things in common between essays—for example, the spectacled eiders that winter in the frozen Bering Sea, written about by Nancy Lord, also nest in the Teshekpuk Lake Wetland that Jeff Fair writes about; both writer Velma Wallis and artist Annie Pootoogook use stories and art as an outlet for healing as they both address alcoholism in their unique ways; and common words take on new meaning, for example, Seth Kantner and Matthew Gilbert put the word *subsistence* on its head, while Andri Snaer Magnason tells us how Alcoa hijacked the word *sustainability* in Iceland and Greenland. I'm sure you will find more such interconnectedness, and I surmise that you will begin to think and talk about the Arctic differently than you did before. And perhaps you'll find an answer to the question, "Why should I care about the Arctic?" ■

Excerpted from Arctic Voices: Resistance at the Tipping Point *edited by Subhankar Banerjee © 2012, reprinted by arrangement with Seven Stories Press, New York.*

Subhankar Banerjee, a Director's Visitor in fall 2011, is an Indian-born American photographer, writer, and activist. Over the past decade, he has worked for the conservation of ecoculturally significant areas of the Arctic and to raise awareness about indigenous human rights and climate change. He is the author of Arctic National Wildlife Refuge: Seasons of Life and Land *(Mountaineers Books, 2003), and his photographs have been exhibited in more than fifty museums. He will read from* Arctic Voices *(Seven Stories Press, 2012) at Labyrinth Books in Princeton on October 9. He received a 2012 Cultural Freedom Award from the Lannan Foundation.*

Liberal Democratic Legacies in Modern Egypt: The Role of the Intellectuals, 1900–1950

BY ISRAEL GERSHONI

"Freedom is the ultimate virtue of mankind"; "Democracy is the only political system of modern man and modern society"; "Therefore, Egypt must be committed to freedom and democracy." These are the words of 'Abbas Mahmud al-'Aqqad in his book *Hitlar fi al-Mizan* (*Hitler in the Balance*), which aroused sharp public interest in Egypt and the Arab world when it was published in Cairo in early June 1940. The book was written when Hitler was at the height of his military successes, and it was widely assumed that nothing would thwart his advances. 'Aqqad's book leveled a harsh attack on Hitler and Nazism. Through his analysis of Hitler's complex and deranged personality, 'Aqqad deconstructed Nazi racism, dictatorship, and imperialism. He portrayed Hitler and Nazism as the ultimate danger not only for freedom and democracy, but also for modernity, the very existence of modern man and enlightened culture. In 'Aqqad's view, the merits of a liberal democracy were rooted in: individual freedoms and civil liberties, constitutionalism, a parliamentary and multiparty system, the separation of powers, equality for all citizens, cultural pluralism, and the unquestionable legitimacy of political opposition.

When 'Aqqad (1889–1964) expressed these views in the early years of the Second World War, his liberal democratic worldview had fully coalesced. Already in his early fifties, he was an established and well-known intellectual active for more than three decades. In hundreds of articles published in the Egyptian press, and particularly in his book *The Absolute Rule of the 20th Century* (*al-*

Ruz al-Yusuf *reacting to the outbreak of the Second World War. "History repeats itself: The end of Hitler at the hands of democracy." Britain, France, and Egypt portrayed as Allied Forces against Nazi Germany. September 9, 1939.*

Hukm al-Mutlaq fi al-Qarn al-'Ishrin), published in 1929, 'Aqqad reaffirmed his commitment to democracy and his rejection of any form of absolutism, oligarchy, aristocracy, and autocratic monarchial rule, and in particular Fascism, Nazism, and, in a different way, Communism. As a representative of the Wafd party in the Egyptian parliament, and later as the intellectual leader of the Sa'adist Party and its representative in the Chamber of Deputies, 'Aqqad was one of the most consistently democratic activists in Egyptian politics and culture.

However, 'Aqqad was by no means exceptional. His ideas and activities aptly reflected the mainstream current within the intellectual community. In this article, I will first describe the salient features of this community and the contexts in which they operated, and then focus on the liberal modes of thought developed by two of the most representative intellectuals. This intellectual current coalesced and exerted its influence during the interwar era (1919–39) until the mid-1950s, galvanizing and institutionalizing a strong tradition of liberal democratic thought in Egypt and in the Arab Middle East. The intellectual community was active in a relatively sympathetic and friendly environment underpinned by two essential elements: the first was the very existence of parliamentarism; the second was the emergence and development of a strong civil society.

The effendiyya, groups of urban educated middle classes that emerged and expanded in the first half of the twentieth century, provided the fertile social grounds for the emergence of liberal, multivocal, and heterogeneous public spheres. They promoted and maintained freedom of the press, which encouraged and expanded public discourses both in Egypt and throughout the Arab world, and were responsible for the flourishing of a pluralistic culture of everyday life.

From 1923 to 1952, parliamentary government served as the basic framework within which Egyptian political, social, and cultural life evolved. Following the Great War, the eruption of the anti-colonial revolution of 1919 forced British authorities to grant Egypt formal independence in February 1922. Egyptian independence facilitated the promulgation of a liberal constitution in 1923 that called for a two-house Parliament, Chamber of Deputies, and Senate, and the immediate establishment of a parliamentary monarchy headed by King Fu'ad. For the ensuing thirty years, Egyptian political life consisted of a parliamentary system in which political parties competed for office in periodic national elections. This system endured until the July 1952 Revolution and the declaration of the Republic of Egypt in 1953. It dismantled the autocracy of the Khedival rule, eroded the authoritarian political culture of the late Egyptian-Ottoman oligarchy, and weakened British colonial rule. It encouraged ethnic pluralism and religious tolerance, reduced the presence of the police and army, and cultivated rich cultural activity with minimal state intervention.

The relative success of Egyptian parliamentary government was based on a mature civil society that developed distinct liberal public spheres. It emerged in the late nineteenth century, reached maturity after the Great War, and flourished during the interwar era. This civil society gave birth to a liberal public sphere, one that I define as the "*effendi* liberal public sphere." Indeed, this civil society originated in an *effendi* social milieu. The *effendiyya*, groups of urban educated middle classes that emerged and expanded in the first half of the twentieth century, provided the fertile social grounds for the emergence of liberal, multivocal, and heterogeneous public spheres. First, the *effendiyya* promoted and maintained freedom of the press, which facilitated the production of a diverse variety of hundreds of dailies, weeklies, and monthlies, and other print media products. Second, this explosion of print culture encouraged and expanded public discourses both in Egypt and throughout the Arab world. Third, the *effendiyya* was also responsible for the pluralistic culture of everyday life that flourished in coffee and teahouses, civil associations, entrepreneurial projects, political organizations, social clubs, cultural salons, and the theater and cinema industries. Old and young, men and women, Christians, Jews and Muslims, and elite and non-elite strata participated in this inclusive civil activity within public spheres. However, the intellectuals constituted the hardcore center of this *effendi* liberal public sphere: they were the idea makers, the cultural producers, the writers and artists.

Historically, intellectual efforts to liberalize and democratize Egyptian life were underway as early as the first decade of the twentieth century. In particular, the thought of Ahmad Lutfi al-Sayyid (1872–1963), his journal *al-Jarida*, and *Hizb al-Umma* (the "Party of the Nation") laid the groundwork for the emergence of a liberal democratic worldview from 1907–15. True, this was a patronizing, elitist concept of a democracy that assumed the intellectuals would play the Platonian role of philosopher-kings whose mission was to guide and control the democratic process. Because of the masses' ignorance and irrationality, they were not supposed to take part in the liberal democratic milieu. Most of the liberal intellectual leaders whom I will discuss started their careers as disciples of Lutfi al-Sayyid and the *al-Jarida* school. With time, they would go on to challenge this elitist idea of a democracy and champion a more inclusive notion of a liberal democracy. This intellectual activity reached its zenith during the interwar era when its social, political, and cultural impact was most discernible.

How did these intellectuals conceive of a liberal democracy? Generally, one can say that for them, a liberal democracy was an organizing form of society and polity whose declared goal was to establish a liberal and just order that would guarantee the free will of all of its citizens, while defending civil rights and liberties. A liberal democratic government was to mediate between the wills of individuals and the collective interests of society through elections, representation, and majority-based decision-making that protects the minority. Its aim was to facilitate the institutionalization of courts and agencies, which would arbitrate conflicting interests. This democracy would not pose any limitations on individual freedoms except when the individual's deed infringed upon the rights of others, the collective, or the system itself.

This concept of a liberal democracy originated in three major sources. The first was the Mediterranean Greco-Roman legacy, particularly Plato and Aristotle, and the Roman republican constitutionalist tradition as expressed by Polybius and Cicero. The second major source was the British political tradition of the seventeenth through nineteenth centuries as well as the political thought from the French Enlightenment of the eighteenth century. Egyptian intellectuals demonstrated intimate familiarity with the Greco-Roman intellectual tradition, part of which was translated into Arabic first in the Middle Ages, and later in the modern era. They also read Hobbes, Locke, Montesquieu, Voltaire, Rousseau, and the nineteenth-century writings of Bentham, Mill, and Tocqueville. As activists, they tended to select the liberal themes, principles, and practices that were most easily translatable to their society's needs and conditions. They were dedicated to comprehending and adapting these bodies of thought to their local political culture and to disseminating liberal democratic principles and practices among broader sectors of society in order to create a solid tradition of an Egyptian-Arab liberal democracy. The third and perhaps secondary source from which these intellectuals drew inspiration was local. They extracted insights and theories from classical

Israel Gershoni, a Member in the School of Historical Studies (2011–12), is teaching the history of the modern Middle East at Tel Aviv University. His recent book, coauthored with James Jankowski, Confronting Fascism in Egypt: Dictatorship versus Democracy in the 1930s*, was published by Stanford University Press in 2010.*

Islamic political philosophers, particularly, al-Farabi, Ibn Sina, Ibn Rushd, and Ibn Khaldun.

Despite their reliance on classical texts, Egyptian intellectuals emphasized that an Egyptian liberal democracy was principally a modern concept. From their perspective, it was an integral part of the formation of a modern secular worldview and way of life. Therefore, their liberal democratic *weltanshauung* was formulated as an antagonist to institutionalized religion, Khedival autocracy, authoritarian Ottoman political norms, and the Egyptian-Ottoman aristocracy and oligarchy. This democratic liberalism was inextricably linked to rationalism, the primacy of human reason, science, progress, modernism, secularism, humanism, and a strain of separation between religion and the nation-state. As Albert Hourani described their worldviews in his classical book *Arabic Thought in the Liberal Age, 1789–1939* (1962), "according to such thinkers, human society is standing, by the irreversible and irresistible natural law of progress, towards an ideal state, of which the marks will be the domination of reason, the extension of individual liberty … and the replacement of relations based on custom and status by those based on free contract and individual interest."

Prominent within this intellectual community of discourse were about thirty luminary liberal intellectuals. Some of them were more dominant: ʻAbbas Mahmud al-ʻAqqad, Ahmad Amin, Salama Musa, Taufiq al-Hakim, ʻAli ʻAbd al-Raziq, and ʻAbd al-Razzaq al-Sanhuri. The intellectual voices of women were equally important, particularly those of Huda Shaʻarawi, Nabawiyya Musa, and Labiba Ahmad. All of these intellectuals were of the same generation. They were born at the end of the nineteenth century and were active as public intellectuals, particularly in the interwar era. Two of these, however, were most exceptional: Taha Husayn (1889–1973) and Muhammad Husayn Haykal (1888–1956). The Egyptian-Arab public considered these two individuals to be representative thinkers of the day and the most authoritative proponents of a liberal democracy.

Taha Husayn—referred to as the "Doyen of Arab Culture"—was revered as the greatest thinker of this generation. He was the most influential promoter of a liberal democracy in Egypt and the Arab world. His impact on larger educated publics was unprecedented. As early as the 1920s, Husayn developed a solid liberal democratic worldview, which was rooted first in the Greco-Roman tradition, particularly in Aristotelian thought. However, in contrast to Aristotle, who was hesitant to confer democracy on the whole body of citizens, Husayn's perspective was all-inclusive. He held that sovereignty emanates from the people and therefore "democracy is a political system of the people, by the people, for the people." Democracy was always preferable to monarchy, aristocracy, or oligarchy, and in modern times, to Fascism, Nazism, and Communism. Husayn was highly conversant with eighteenth-century French Enlightenment thought, especially that of Rousseau. Husayn did his second Ph.D. in the Sorbonne in Paris (1913–19) and among his studies was French modern philosophy. In line with Rousseau's ideas, he regarded society as a community of citizens possessing inalienable natural rights of freedom and justice. To ensure these rights, Husayn was a proponent of state subordination to an agreed-upon constitution that protects citizens from tyranny. Like Rousseau, Husayn's solution to the inherent tension between the ruler and the ruled was that "men can be both ruled and free if they rule themselves." Thus, government would ensure the natural rights to freedom of its citizens, and citizens, in turn, would demonstrate loyalty to the state and participate in its conduct through representative parliamentary institutions. All citizens—including women—had the natural right to participate in the political democratic process. In such a system, freedom of thought, freedom of the press, public opinion, and cultural pluralism reign.

As part of his promotion of liberal democratic principles and values, Husayn waged a scathing attack on Islamic orthodoxy; he sought to neutralize its power and authority in society, politics, and culture. Within his struggle, he attempted to subordinate al-Azhar, the traditional Muslim institution of academic learning, to the Ministry of Education and to reduce its sway over public education. He was also a republican by nature and strove to undermine the authority of the monarch, which with al-Azhar's support, tried to establish an autocratic form of government. On a different level, in his quest for democracy, Husayn turned his sights against Fascism. He viewed it as a dictatorial system that silenced freedom of thought, suppressed civil rights, and transformed human beings into mere atoms within state machinery, thereby imprisoning them. In taking man's freedom, Fascism—by its very nature—deprived man of his humanity.

However, Husayn understood that there was a built-in structural problem in his society: a majority illiterate populace in a liberal democracy. He never ignored the divide between the thin layer of the educated elite and the broader illiterate sectors of his society. Disturbed by the structural problem of illiteracy, Husayn dedicated his life and career to education, which he regarded as the most effective agent of democratization and liberalization of Egyptian life. Following Plato, Rousseau, and Mill, he held that through education and literacy, one could enlighten and refine the broader sectors of society and include them in civil democratic politics. He espoused the notion that education should be developed and promoted by the government, which should regard the education of all citizens as its ultimate priority. He worked for the spread of education through the Egyptian University and his governmental service, which culminated in his appointment as Minister of Education in the last Wafd government (1950–1952). Without proper education, Husayn held that one cannot comprehend the essence of democracy, its ideas, institutions, and its modus operandi.

In his most important book, *Mustaqbal al-Thaqafa fi Misr* (*The Future of Culture/Education in Egypt*), which was published in 1938, Husayn discussed the inextricable bond between democracy and education. He argued that education for democracy must begin in elementary school and should be the highest priority of "the future of culture in Egypt." Borrowing from Rousseau, he posited that men are naturally free. He wrote: "One who gives up his freedom, gives up his humanity." The negation of freedom

Taha Husayn held that through education and literacy, one could enlighten and refine the broader sectors of society and include them in civil democratic politics. He espoused the notion that education should be developed and promoted by the government, which should regard the education of all citizens as its ultimate priority.

contradicts the nature of man. A human being is both an individual and a social entity: society must ensure a citizen's freedom and, in turn, a citizen must contribute to society. For Husayn, such a social contract and relations were achievable only in a liberal democracy.

Husayn promoted the idea that only a truly free democratic citizen can be a loyal patriot. Thus, the purpose of education was to instill the notion of proper citizenship alongside loyalty to the nation-state, since only educated and free citizens who understand the depths of their own freedom will be willing to sacrifice themselves for their nation's freedom. Husayn's definition of Egyptian nationality was highly liberal and inclusive, extending to all dwellers of the Nile Valley—irrespective of their ethnic origin, language, and religion. In his book *Mustaqbal al-Thaqafa,* he explicitly excluded language and religion from his conception of Egyptian national identity. As such, Muslims, Christians, Jews, and other ethnic or linguistic communities were all equally Egyptians. Husayn's liberal, inclusive approach to Egyptian collective identity assumed that all Egyptians were equal citizens who should elect their representatives through the institutions and mechanisms of multiparty parliamentary government.

Al-Ithnayn wa al-Dunya *responding to Fascist Italy's brutal conquest of Albania during spring 1939. "Her guardian . . . [her robber]. Mussolini: Come my dear, I will hug you because I want you. Albania: Please, loosen your grip, I am dying." April 17, 1939*

Muhammad Husayn Haykal, an equally influential contemporary of Husayn's, was committed to similar liberal principles. Haykal was more a liberal than he was a democrat. If Husayn was a republican, then Haykal was a monarchist. Whereas Husayn appealed to the entire body politic, Haykal was primarily concerned with the educated elite. Husayn assumed that liberty and equality were compatible, while Haykal assumed that they were dramatically opposed and contradictory. Haykal, a conservative liberal, regarded freedom as an asset mainly of the enlightened sophisticated elite. If democracy were open to all, it would not award sovereignty to the people, but to the crowd. The crowd in its nature was illiterate, irrational, imbued with superstitions, and not in need of freedom, but stability and security, which only a more authoritarian or autocratic government could provide.

Haykal was highly influenced by Plato's notion of philosopher-kings and the reworking of this notion set forth by the prominent tenth-century philosopher, al-Farabi. Haykal regarded the philosopher-kings of Egyptian society as those refined and talented individuals who underwent massive Europeanization and received a modern education. From a social perspective, he regarded the landed elite as the source for these philosopher-kings. Like Husayn, Haykal challenged the old Egyptian-Ottoman oligarchy but sought to replace it with a new aristocracy defined by its virtue and education and sheltered by the constitutionalist monarchy. Haykal believed that a liberal democratic government should first defend the free thought and activity of this educated elite, who would protect freedom and civil rights for all and lead and control the processes of modernization and progress.

Despite his elitist concept, Haykal did not preclude open entry into this educated governing elite. Anyone, men and women, who met the criteria of education and

(Continued on page 15)

chaos in the restricted three-body problem. This problem describes the movement of a satellite under the gravity of two big bodies, say the earth and the moon, in a rotating coordinates system in which the earth and the moon stay at fixed positions. The chaos in the system is illustrated by putting about ten satellites initially at almost the same position with almost the same velocity.

When the system starts evolving, the program shows colorful trackings of the paths of the satellites as they evolve from a simple single orbit to a complex multicolored tangle of orbits, once the orbits of the different satellites start separating.

Among those in the audience at my 2010 IAS lecture was composer Derek Bermel, then the newly appointed Artist-in-Residence. As I got to know Derek, I realized that he was interested in mathematics. So when I began planning my upcoming program in symplectic dynamics, I thought it would be quite something if our resident composer wrote what we would come to refer to as "The Symplectic Piece"—a musical composition inspired by symplectic geometry.

Symplectic geometry is a large field in mathematics, with connections to physics, low-dimensional topology, and geometry, as well as the theory of dynamical systems. The modern fields of symplectic geometry and dynamical systems originate in Henri Poincaré's work on celestial mechanics. The term "symplectic" was introduced in 1939 by Hermann Weyl, a Faculty member at IAS, as *a verbum pro verbo* for "complex" in his important work on the classical groups—the so-called line complex group became the symplectic group.

Derek and I had several conversations during lunches about the potential for "The Symplectic Piece." And he continued to attend occasional lectures on the subject, searching for a way to map symplectic geometry onto a musical score. But despite many entertaining discussions, the crucial inspirational idea was missing. With the start of the symplectic dynamics program last fall, "The Symplectic Piece" was still just floating around in the ether.

Then one day Derek mentioned that he had been invited by the Look and Listen Festival in New York to compose a commissioned work to mark the one-hundredth birthday of the avant-garde composer John Cage, said to be one of the most influential American composers of the twentieth century. However, besides having too many commitments already, Derek felt that a Cage composition might be beyond his comfort zone as a composer, so he declined the offer.

But as Cage once said: "Ideas are one thing and what happens is another."

Or, to put it another way, I just had to talk Derek into it.

Since good preparation is everything, I conducted some research via my subscription to the music service Rhapsody, searching for John Cage and selecting "Play All Top Tracks." Initially, it seemed my one-month-old headset was already broken. Further investigation revealed that the most popular track—*4'33"*—was a three-movement composition for any instrument where the score explicitly instructs performers not to play for the duration of four minutes and 33 seconds, the listener's experience consisting merely of ambient sounds in the surrounding environment. Composed in 1952, this ostensibly silent work caused an uproar. Around this time in his career, Cage began to incorporate chance elements—chance operations and chance techniques—into his compositions.

Here was the perfect inspiration for symplectic music. Chance, chaos, stability, and comfort zone: these were the connections. Symplectic dynamics studies dynamical systems, which in general show a whole spectrum of behaviors from stable motions to deterministic chaos—from the "comfort" of stability, the system evolves to be governed completely by chance.

Certain simple-looking systems exhibit interesting complex dynamics. The aforementioned movement of a satellite in the gravitational field of the earth and the moon is one of them. The satellite can exhibit stability if parked with the right momentum at one of the triangular Lagrange points. On the other hand, the structure of the possible orbits that the satellite can trace out, if given the appropriate initial data, allows for many random patterns of transitions between earth and moon.

One day at lunch, Derek pressed me on the question of deterministic chaos. He joked that it could be an ideal starting point for a Cage-inspired composition. I pounced on the opportunity and suggested that he now had no excuse not to accept the commission. Over several more lunches with Derek, he became convinced. We continued to discuss the logistics of how to map some of the formal aspects of the three-body problem onto a live musical performance. Members Peter Albers and Alvaro Pelayo provided input as did local mathematician and painter Ed Belbruno, whose ideas for using dynamical systems and chaos theory to obtain new low-energy pathways to the moon resulted in the rescue of the Japanese spacecraft *Hiten* in 1991.

"The Symplectic Piece" would be a musical representation of the "gravitational choreography." A body enters another body's neighborhood, orbits around it and then leaves, perhaps visiting another body, returning, and so on. Working from this idea, Derek set to work developing a musical algorithm for three or more players.

But how exactly would Derek do this? This was the big question …

Derek Bermel, Artist-in-Residence, writes:

Once I decided to take the bait and write "The Symplectic Piece," I tried to narrow down my options. My first questions: How could I create an auditory manifestation of something as abstract and complicated as symplectic dynamics? What kind of piece would this be? Would it carry hallmarks of a particular musical style? What instruments would play? What would make sense for a tribute to John Cage? I was daunted by many issues, not the least of which was the specter of serial composition, which had produced a good deal of drab music.

One of my problems with serialism is that, though it aspires to be "mathematical" in its ordering, its underpinnings nonetheless seem to involve little more than basic arithmetic (pitch sets, inversions, retrogrades, retrograde-inversions, etc.) rather than higher-order concepts. I was searching for an open approach that was less chained to formal details and more genuinely inspired by symplectic dynamics' principles. Other (in my opinion) more successful models existed for music based on mathematical processes—such as the stochastic music of Iannis Xenakis or the spectral music of Gérard Grisey and Tristan Murail. But these were more closely linked to probability theory and Fourier analysis, respectively, and seemed therefore only tangentially related to symplectic systems.

Then there was the problem of abstraction. Since music is composed of vibrating atoms of air, I needed an analogy that was dynamic. Helmut suggested the title *Orbit Design* to me. It refers to the design of a route for a scientific space mission, using the varying gravitational fields of the planets to find pathways that are both scientifically interesting and energy efficient. Orbit design seemed like a good model because it deals with the physical relationships of celestial bodies, where Newton's gravitational law is expressed through their chaotic dynamical interaction.

Of course, besides the mathematical imperatives mentioned above, John Cage was looming. I decided to embrace his ghostly presence not only in spirit but also in form. Cage wrote many compositions for open instrumentation (including *4'33"*). I was drawn to this concept for "The Symplectic Piece," since it would inject an element of controlled unpredictability—or "deterministic chaos"—into the performance. While an undergrad at Yale, I played several of Cage's *Variations* compositions (1958–67), in which the performers are given instructions for producing sound, but no actual notation of rhythm, pitch, or anything else. Though their actual manifestations could be compared to other 1960s "happenings," the formal structure of the *Variations* tends to be more rigorous and specific. Something similar seemed suited to my needs. If I tweaked the approach, I could produce a kind of algorithm—or "game"—that would allow musicians to choose their own musical material, map out a unique composition using this material, and interact with the other performers.

I also found inspiration in John Zorn's *Cobra* and Butch Morris's early *Conductions*, works from the 1980s that present a series of ground rules from which a composition takes shape. I eschewed the use of Cage's "chance" in favor of "risk," since (as Morris writes) "risk insinuates a certain kind of challenge; chance doesn't necessarily do that."

I titled the work *Orbit Design, for three or more performers*. A set of guidelines assists the performers to structure a path of decision-making as events unfold. The piece taxes their skills and perception via material chosen by them. I therefore leave the decisions—the "risk"—in the hands of the performers themselves. As Cage wrote, "My work became an exploration of non-intention … making my responsibility that of asking questions instead of making choices."

In *Orbit Design*, each performer establishes a unique vocabulary by making a selection from various musical parameters. Typical parameters might include: *pitch* (frequency—organized into modes, microtones, chords, and scales, which suggest the notion of *octave equivalence*, or other sets); *pulse* (elemental rhythmic units); *note length* (which might include *articulation*); *tempo* (speed); *volume* (loudness); *color* (timbre, including specific effects and strength of timbral modulation); and *spatial placement/motion* (physical location of performers).

Combining these parameters generates compound musical events comprising series, sequences, or patterns. These compound parameters include: *density* (pulse + tempo); *duration* (pitch + pulse layer + tempo); *melody* (pitch + pulse); and *contour* (register + tempo).

A third, more complex level of relationship that occurs between performers—the overall language of the piece—includes: *rhythm* (layers of pulse); *orchestration* (layers of timbre); *harmony/cadence* (layers of pitch); and *counterpoint* (layers of pitch + pulse).

My actual "composition" merely supplies instructions as a sort of musical grammar to the performers. Each performer must select their own narrow range of values that apply to their own musical parameters. For example, a flute player might choose initial pitch (and register) values by selecting the set of chromatic half steps between c3 and f#3 inclusive; for initial pulse and tempo values, the flutist might select half notes (semiminims) and quarter notes (crotchets) at sixty beats per minute. The flutist continues to select value ranges for volume, timbre, spatial placement in the room, and any other data relevant to the performers' vocabulary, making sure it is clearly notated.

The performers then decide which parameters will remain static (constant) and which ones will expand. For *dynamic* parameters, the performers indicate how (in which direction) they will expand and set *range limits* for this expansion. For example, the flutist might set the range of pulse values so that it expands to incorporate whole notes (as well as the initial quarter and half notes). The performer might allow the pitch range to expand to all chromatic notes between c3 and c4 inclusive, and could also decide that the volume will remain constant, at *mp*. In this case, volume would be considered an *inert* parameter.

Finally, the performers decide in which order the parameters will expand. Only one parameter at a time can be dynamic, so that the players can concentrate on tracking its expansion. The performer then remains at the outer limit of each completed parameter while expanding the following one, and so on, until the end of the piece. After all the parameters, their ranges, and the order of expansion have been determined, the performers assemble to try them out together. After a first playing/hearing, each performer makes adjustments to the scope of their own material, in order to complement their collaborators' particular design.

The most improvisatory, or "chaotic," element of the performance is *orbiting*. Orbiting requires a relationship with the other players, which involves hearing and interacting with what the others play from a vantage point that changes

(Continued on page 13)

Finding Structure in Big Data

BY ANKUR MOITRA

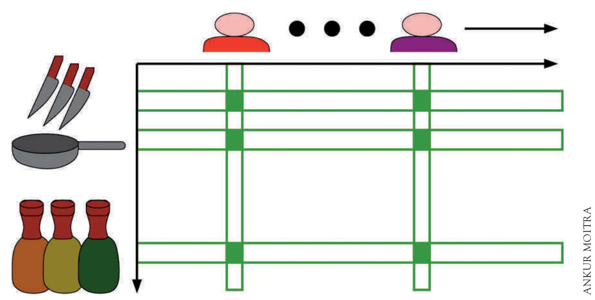
How do we navigate the vast amount of data at our disposal? How do we choose a movie to watch, out of the 75,000 movies available on Netflix? Or a new book to read, among the 800,000 listed on Amazon? Or which news articles to read, out of the thousands written everyday? Increasingly, these tasks are being delegated to computers—*recommendation systems* analyze a large amount of data on user behavior, and use what they learn to make personalized recommendations for each one of us.

In fact, you probably encounter recommendation systems on an everyday basis: from Netflix to Amazon to Google News, better recommendation systems translate to a better user experience. There are some basic questions we should ask: How good are these recommendations? In fact, a more basic question: What does "good" mean? And how do they do it? As we will see, there are a number of interesting mathematical questions at the heart of these issues—most importantly, there are many widely used algorithms (in practice) whose behavior we cannot explain. Why do these algorithms work so well? Obviously, we would like to put these algorithms on a rigorous theoretical foundation and understand the computational complexity of the problems they are trying to solve.

Here, I will focus on one running example and use this to explain the basic problems in detail, and some of the mathematical abstractions. Consider the case of Amazon. I have purchased some items on Amazon recently: a fancy set of cutting knives and a top-of-the-line skillet. What other products might I be interested in? The basic tenet of designing a recommendation system is that the more data you have available, the better your recommendations will be. For example, Amazon could search through its vast collection of user data for another customer (Alex) who has purchased the same two items. We both bought knives and a skillet, and Amazon can deduce that we have a common interest in cooking. The key is: perhaps Alex has bought another item, say a collection of cooking spices, and this is a good item to recommend to me, because I am also interested in cooking. So the message is: lots of data (about similar customers) helps!

Of course, Amazon's job is not so easy. I also bought a Kindle. And what if someone else (Jeff) also bought a Kindle? I buy math books online, but maybe Jeff is more of a Harry Potter aficionado. Just because we both bought the same item (a Kindle) does not mean that you should recommend Harry Potter books to me, and you certainly would not want to recommend math books to Jeff! The key is: What do the items I have purchased tell Amazon about my *interests*? Ideally, similar customers help us identify similar products, and vice-versa.

So how do they do it? Typically, the first step is to form a big table—rows represent items and columns represent users. And an entry indicates if a customer bought the corresponding item. What is the structure in this data? This is ultimately what we hope to use to make good recommendations. The basic idea is that a common interest is defined by a set of users (who share this interest) and a set of items. And we expect each customer to have bought many items in the set. We will call this a *combinatorial rectangle* (see image). The basic hypothesis is that the entire table of data we observe can be "explained" as a small number of these rectangles. So in this table containing information about millions of items and millions of users, we hope to "explain" the behavior of the users by a small number of rectangles—each representing a common interest.



If two customers have a common interest in cooking, Amazon can use information about which items one of them has bought to make good recommendations to the other and vice-versa. Ankur Moitra is trying to develop rigorous theoretical foundations for widely used algorithms whose behavior we cannot explain.

The fundamental mathematical problem is: If the data can be "explained" by a small number of rectangles, can we find them? This problem is called *nonnegative matrix factorization*, and it plays a large role in the design of real recommendation systems.[1] In fact, there are many algorithms that work quite well in practice (on real data). But is there an efficient algorithm that *provably* works on every input? Recently, we showed that the answer is yes![2]

Our algorithm is based on a connection to a purely algebraic question: Starting with the foundational work of Alfred Tarski and Abraham Seidenberg, a long line of research has focused on the task of deciding if a system of polynomial inequalities has a solution. This problem can be solved efficiently provided the number of distinct variables is small.[3] And indeed, whether or not our table of data has a "good" nonnegative matrix factorization can be rephrased equivalently as whether or not a certain system of polynomial inequalities has a solution. So if our goal is to design fast algorithms, the operative question is: Can we reduce the number of variables? This is precisely the route we took, and it led us to a (much faster) provable algorithm for nonnegative matrix factorization whose running time is optimal under standard complexity assumptions.

Another fundamental mathematical question is: Can we give a theoretical explanation for why heuristics for these problems work so well in practice? There must be some property of the problems that we actually want to solve that makes them easier. In another work, we found a condition, which has been suggested within the machine learning community, that makes these problems much easier than in the worst case.[4] The crux of the assumption is that for every "interest," there must be some item that (if you buy it) is a strong indicator of your interest. For example, whoever buys a top-of-the-line skillet is probably interested in cooking. This assumption is known in the machine-learning literature as *separability*.[5] In many instances of real data, practitioners have observed that this condition is met by the parameters that their algorithm finds. And what we showed is that under this condition, there are simple, fast algorithms that *provably* compute a nonnegative matrix factorization.

In fact, this is just one instance of a broader agenda: I believe that exploring these types of questions will be an important step in building bridges between theory and practice. Our goal should not be to find a theoretical framework in which recommendations (and learning, more generally) are computationally hard problems, but rather one in which learning is easy—one that explains (for example) why *simple* recommendation systems are so good. These questions lie somewhere between statistics and computer science, because the question is *not*: How much data do you need to make good recommendations (e.g., the statistical efficiency of an estimator)? Algorithms that use the bare minimum amount of data are all too often very hard to compute. The emerging question is: What are the best tradeoffs between making the most of your data, and running in some reasonable amount of time? The mathematical challenges abound in bringing these perspectives into not just recommendation systems—but into machine learning in general. ■

Ankur Moitra is an NSF Computing and Innovation Fellow in the School of Mathematics at the Institute. His primary research interests are in algorithms, learning, and convex geometry. Prior to joining IAS, he received his Ph.D. in 2011 and his M.S. in 2009 from the Massachusetts Institute of Technology, both in theoretical computer science.

1 "Learning the Parts of an Object by Nonnegative Matrix Factorization," Daniel Lee and H. Sebastian Seung, *Nature* 401, October 21, 1999

2 "Computing a Nonnegative Matrix Factorization—Provably," Sanjeev Arora, Rong Ge, Ravi Kannan, and Ankur Moitra, *Symposium on Theory of Computing*, 2012

3 "On the Computational Complexity and Geometry of the First-Order Theory of the Reals," James Renegar, *Journal of Symbolic Computation* 13: 3, March 1992

4 "Learning Topic Models—Going Beyond SVD," Sanjeev Arora, Rong Ge, and Ankur Moitra, http://arxiv.org/abs/1204.1956, 2012

5 "When does Nonnegative Matrix Factorization give a Correct Decomposition into Parts?" David Donoho and Victoria Stodden, *Advances in Neural Information Processing Systems* 16, 2003

SYMPLECTIC PIECE *(Continued from page 12)*

with time. As the performers develop and become comfortable with their own chosen material, it becomes easier to move in and out of each other's orbits.

Over the course of our discussions, Helmut pointed out that the notion of orbiting around something is not exactly defined in physics. Nonetheless, if the bodies' masses were about the same size, they could be said to orbit each other. He also drew a chart, which showed that if three celestial bodies A, B, C exist, they could be located either close to each other (ABC), far away from each other (A—B—C), or in various other configurations: (AB)—C, (BC)—A, (AC)—B. Also, if B and C were of comparable size and A was much bigger, then the system (BC) could be said to orbit around A, and so forth. I felt that these maxims could apply directly to performers in *Orbit Design*.

Helmut had also noted that solutions exist to the three-body problem in which the bodies move from one configuration to another in random order. For example:

(ABC) >> (AB)—C >> (ABC) >> A—B—C >> (AC)—B >> (AB)—C >>, etc.

Such a "sentence" could map one realization of a performance of *Orbit Design*. Of course, there are many, many others. Indeed, as a consequence of the "open" nature of the score (which, as noted, consists only of written instructions), each performance necessarily ends up being distinct.

Recognizing the unique element, the festival directors scheduled the premiere on three successive nights with three completely different ensembles. On the first night, *Orbit Design* was performed by a percussion sextet featuring So Percussion Quartet, Doug Perkins, and Bobby Previte; the second night it was played by the trio Forbidden Flute; and the third night it was realized by the string quartet Brooklyn Rider. The three incarnations differed vastly; each had its own profile and dynamic shape. The percussion was sprawling yet serene, the flutes sporadic and sinuous, the string quartet alternately comic and blissful. The players performed with formidable concentration, and afterward they expressed deep satisfaction with the opportunity to build their own compositions from "scratch."

As the date of the premiere grew near, I decided that there was no reason to restrict *Orbit Design* to musical realizations, as the instructions could apply equally well to dancers, actors, jugglers, or any kind of performer. My friend, choreographer Abigail Levine, who had helped me hone some of the formal concepts, attended the performances and decided to choreograph the work for an upcoming project with Movement Research at the Judson Church in New York City. She paired it with a dance for three performers, titled *Distance Measures*, and I participated as one of the musicians, alongside Forbidden Flute. Thus the gravitational "choreography" to which Helmut alluded finally had a chance to manifest itself in real time and evolve into another dimension. ■

Andrew W. Mellon Foundation Provides Critical Support for Assistant Professors

The Institute has received a $3 million grant from the Andrew W. Mellon Foundation to support one-year fellowships for assistant professors in the Institute's School of Historical Studies. The donation will be matched by $3 million funded from the $100 million challenge grant provided by the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences to initiate the Institute's current $200 million campaign to strengthen its endowment. This will create a $6 million Andrew W. Mellon Fellowships for Assistant Professors Fund to provide a permanent endowment for fellowships to enable scholars to work at the Institute at a critical point in their careers.

The Mellon Foundation has been funding fellowships at the Institute for historians in the early stages of their careers since 1996. The new grant will provide stable and secure funding for the program, enabling future generations of scholars to benefit from the Institute's distinct environment, where they are free to pursue long-term goals away from the teaching and administrative demands of university positions, and to interact with the Institute's permanent Faculty and other more senior colleagues.

Since the inception of the program, some forty-four scholars have benefited from the Mellon Foundation fellowships. These fellows have come from many institutions and a diverse range of fields of historical study. "My time at the IAS was one of the most intellectually stimulating and productive periods of my life," said Lauren Minsky, Assistant Professor at New York University in Abu Dhabi and former Member (2009–10) in the School of Historical Studies. "My fellowship allowed me the crucial opportunity to research, think, read, and reflect for a full year without the teaching and administrative commitments that come with regular academic life. I also had the invaluable opportunity to interact with other scholars from a wide range of fields and disciplines as colleagues and friends. It is impossible to fully express just how important and meaningful this opportunity was."

The Andrew W. Mellon Foundation (www.mellon.org), formed in 1969 by the consolidation of foundations established by the children of Andrew W. Mellon, supports five core program areas: higher education and scholarship; scholarly communications and information technology; art history, conservation, and museums; the performing arts; and conservation and the environment. The Foundation develops thoughtful, long-term collaborations with grant recipients and invests sufficient funds for an extended period to accomplish the purpose at hand and achieve meaningful results. ■

ANDREW W. MELLON FOUNDATION FELLOWSHIPS FOR ASSISTANT PROFESSORS, 2011–12

Yair Mintzker, Assistant Professor of European History, Princeton University

Supported by a Mellon fellowship, I spent this year working on two separate projects. The first was a book about German city walls. The early modern German city was legally, politically, and culturally defined through its borders—the city walls. While around 1700 practically all German cities were surrounded by a wall, little over a century later very few still had one. The political causes and implications of the dramatic and often traumatic demolition of these centuries-old borders are the topic of my book "The Defortification of the German City, 1689–1866" (forthcoming from Cambridge University Press), which I completed while at the Institute.

The second project is in its early stages. Tentatively called "The Multiple Deaths of 'Jew Süss,'" it is a new history of one of the most famous (and horrific) trials in eighteenth-century Germany: the trial of Joseph Süss Oppenheimer, a Court Jew in Stuttgart, who was arrested, put on trial, and finally executed in February 1738. Since the sources about Oppenheimer's trial are often contradictory, the book offers four different versions of what happened during the trial—a *Rashomon*-like history that encourages the reader to choose between four different historical accounts of the same event. My year at the Institute provided me with the time and resources to work on these projects. I especially appreciated the opportunity to exchange ideas with IAS Faculty and fellow Members. The experience was rewarding, humbling, and incredibly inspiring all at the same time.

Matthias Richter, Assistant Professor of Chinese, University of Colorado at Boulder

Based on several years of previous research, I have been able to use the two terms of my stay at the Institute to complete a book manuscript and submit it to the publisher. The book "Reincarnating the Disembodied Text: Textual Identity in Early Chinese Manuscripts" addresses the important methodological issue of how we can interpret the newly discovered manuscripts from pre-imperial China, i.e., before the late third century B.C.E., without assimilating them anachronistically to the hitherto known literature from that period, which had been reconstructed in the Imperial Library in the late first century B.C.E. Centering on a detailed and comprehensive study of the material and textual properties of a 300 B.C.E. bamboo manuscript from the Southern Chinese state Chu, as well as some other manuscripts of similar provenance, the book demonstrates that early Chinese literature did not only consist of linear, logically consistent texts. One manuscript could combine different types of texts, e.g., a coherent argument could be supplemented with didactic catalogues that merely functioned as memory pegs, referring the reader in an indexical manner to previous instructions outside the text. In other cases, written texts merely functioned as repositories of textual material, often variants of the same content. Only in later redactions were such texts reinterpreted and shaped into the coherent linear texts, which were then transmitted to us through the two millennia of the Chinese empire.

Vimalin Rujivacharakul, Associate Professor, Architecture and Critical Architectural Historiography, University of Delaware

Holding an Andrew W. Mellon Fellowship for Assistant Professors at the Institute for Advanced Study is both a privilege and an opportunity to do things that are otherwise difficult to achieve. My project focuses on an unusual subject—a set of pictorial diaries of a Japanese architectural historian who traveled the world at the turn of the twentieth century. The project's scope is ambitious and its layers of cultural and historical elements complicate its context. Moreover, because I approach my subject through an unorthodox method that juxtaposes visual representation against written texts, I place my project squarely at the crossroads of intellectual history and architectural history. A transdisciplinary project like this is normally a challenge to launch, especially for an early-career scholar with a full-time teaching responsibility. However, not only did the Mellon fellowship enable me to take a yearlong leave to work on this project, it also allowed me to gain access to excellent research resources. I have been inspired by ideas garnered at seminars and lunchtime conversations; some sparked new perspectives and some redefined my original thinking. This is a place where I have friends, research support, and superb intellectual stimulation—an ideal research community.

PLANNED GIVING

Daniel H. Saracino Endowment Supports Visiting Professorship in School of Mathematics

A bequest made by Daniel H. Saracino, the Neil R. Grabois Professor of Mathematics at Colgate University and former Visitor (1986) in the Institute's School of Mathematics, will enable the endowment of a Visiting Professorship in the School. The Daniel H. Saracino Endowment will provide the School with the ability to invite a senior mathematician for a year or more to work with the School's Faculty and Members in an environment devoted to fundamental research across many areas of pure mathematics, theoretical computer science, mathematical physics, and applied mathematics. Saracino was prompted to include the Institute in his estate plans out of his deep admiration and respect for the mission and work of the School and its Faculty, and in fond acknowledgment of his time as a Visitor.

"The Institute epitomizes excellence in mathematics, and I appreciate the way in which the School of Mathematics makes it possible for its Members and Visitors to devote themselves to their research in an ideal atmosphere, free of distractions and other responsibilities," said Saracino. "My bequest to the School provides a way of doing what I can to further its work."

Saracino's current research interests include model theory—especially model theoretic algebra (existentially complete, quantifier-eliminable, and homogeneous structures in algebra) —and combinatorics. He earned his Ph.D. from Princeton University in 1972, and taught at Yale and Wesleyan before coming to Colgate. The recipient of Colgate's Alumni Corporation Award for Distinguished Teaching (2003) and Phi Eta Sigma Professor of the Year (1995), Saracino has been recognized throughout his career for his outstanding teaching and mentoring, and was recently included in Princeton Review's *The Best 300 Professors*. ■

A planned gift may be tailored to meet a donor's wishes and interests and help the Institute achieve its goals. It is hoped that former Members and Visitors will consider the Institute in the same way in which they would their alumni institutions, and plan accordingly. To learn more about what a planned gift can accomplish for the donor and the Institute for Advanced Study, please contact Catie Newcombe, Senior Development Officer, at cnewcombe@ias.edu or (609) 951-4542.

Benedict H. Gross Elected to the Board of Trustees

Benedict H. Gross

The Institute has appointed Benedict H. Gross, the George Vasmer Leverett Professor of Mathematics at Harvard University, to its Board of Trustees, effective July 1, 2012. Gross was nominated by the Institute's School of Mathematics and succeeds Andrew J. Wiles, Royal Society Research Professor at the University of Oxford, who had served on the Institute's Board since 2007.

Gross, whose research is in number theory, received his undergraduate degree from Harvard in 1971, a master's degree from the University of Oxford in 1974, and his doctorate from Harvard in 1978. He served as Assistant Professor at Princeton University from 1978–82, Associate Professor at Brown University from 1982–85, and Professor at Harvard beginning in 1985. He was Dean for Undergraduate Education at Harvard from 2002–03 and Dean of Harvard College from 2003–07; in these positions, he oversaw the first review of undergraduate education at Harvard in nearly thirty years.

The American Mathematical Society awarded Gross and his collaborators the Frank Nelson Cole Prize in Number Theory in 1987 for work on the L-functions of elliptic curves. Among other honors, he is the recipient of a MacArthur Fellowship and a member of the American Academy of Arts and Sciences and the National Academy of Sciences.

Gross is the author, with Joe Harris, of *The Magic of Numbers* (Prentice Hall, 2003), which introduces non-mathematicians to the mathematical mode of thought. A course on abstract algebra taught by Gross is available at www.extension.harvard.edu/open-learning-initiative/abstract-algebra. ■

IAS The Campaign for the Institute

Friends Bolster Campaign to Raise Capital Funds

The $200 million Campaign for the Institute, initiated in 2011 with a $100 million challenge grant from the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences, is well underway and will continue through June 30, 2015. With major pledges from the Leon Levy Foundation (see page 1), the Starr Foundation (see page 3), the Andrew W. Mellon Foundation (see page 14), and others, the total raised now stands at more than $48 million, almost halfway toward qualifying for the $100 million challenge grant. Support from the entire Institute community will be essential to complete the Campaign, which is aimed at strengthening the endowment on which the Institute relies heavily—covering as much as 80 percent of annual operating expense in recent years.

The Friends of the Institute, whose generosity has made an indelible impact on the Institute's financial well-being over the past three decades by providing IAS with its most significant source of unrestricted financial support, have joined the effort to raise capital funds for the Campaign. Building on years of success securing annual funds from Friends (over $778,000 was raised in 2011–12), Chair Jack Kerr, former Chairs Carolyn Sanderson and John Rassweiler, and members of the Development Committee have been working to engage Friends in the Campaign, with great results. Friends have already committed more than $500,000 in gifts and pledges and the Committee is looking to increase that sum significantly, as all Friends are given the chance to participate in the Campaign over the next three years.

"We want to see this unique opportunity for scholars continue into the future, building on the Institute's phenomenal success since its founding," notes Kerr and his wife Nora, Friends since 1998. "Access to the Institute enriches our lives in many ways. There are frequent opportunities open to the Friends to participate in the life of the Institute, whether at formal lectures about current research, informal lunches with Members in the dining hall, or the numerous social events organized by the Friends. The scholars in this community are very approachable and love to talk about their work, which is always interesting. It's a terrific opportunity to engage the brightest minds of our generation."

To learn more about the Campaign for the Institute, please contact Michael Gehret, Associate Director for Development and Public Affairs, at (609) 734-8218 or mgehret@ias.edu. To learn more about the Friends, please contact Pamela Hughes, Senior Development Officer and Friends Liaison, at (609) 734-8204 or phughes@ias.edu, or visit the Friends pages on the Institute's website, www.ias.edu/people/friends. ■

Executive Committee of the Friends in May, front row: Cynthia Hillas, Vicky Corrodi, Emily Firmenich, Peter Goddard (then Director of the Institute), Carolyn Sanderson, Debbie Lunder, Francesca Liechenstein, Tina Greenberg, Florence Kahn, Vivian Shapiro; back row: Jack McCarthy, Lew Maltby, Jack Kerr, John Haines, John Rassweiler, Weezie Steffens, Michael Morandi, Luke Visconti, Lynn Johnston, Martin Chooljian, Brig Gebert

LIBERAL DEMOCRATIC LEGACIES *(Continued from page 11)*

cultural refinement could take part in this aristocracy. In contrast to Husayn and his activity within the popular-oriented Wafd, Haykal was the intellectual leader of the Liberal Constitutionalist Party, which promoted a patronizing and paternalistic liberalism and was largely a continuation of the early *Hizb al-Umma* and *al-Jarida*. While Husayn viewed himself as a challenger of this school, Haykal viewed himself as a guardian of its social philosophy. Haykal assumed that the masses would follow the charismatic power of the prophetic philosopher-kings and would accept their authority as the embodiment of the collective general will. Thus, the masses would be led to a modern democratic system "unaware" and without really understanding its essence.

However, at critical junctures, Haykal also demonstrated that he was in fact a liberal democrat. In the early 1930s when the dictatorial regime of Isma'il Sidqi (1930–33) undermined the 1923 constitution and thereby threatened to destroy the parliamentary government, Haykal led a democratic struggle against Sidqi. In his book *al-Siyasa al-Misriyya wa al-Inqilab al-Dusturi* (*Egyptian Politics and the Constitutionalist Coup*), published in 1931, Haykal waged a fierce and unrelenting defense of democracy from any authoritarian options of autocracy or dictatorship.

The collapse of Sidqi's authoritative government and the restoration of the constitution and the reassertion of parliamentary life toward the mid-1930s were a triumph for Haykal and his liberal democratic orientation.

The defense of liberal democracy by Haykal, Husayn, and many of these intellectuals suffered from limitations, two of which I'd like to emphasize. The first is that the parliamentary system did not function smoothly throughout the entire period. In particular, the 1930s, '40s, and early '50s saw episodes of bitter conflict between contending forces that resulted in occasional constitutional adjustments, which impeded parliamentary performance. While the monarch conspired to undermine the democratic government and to guide it toward a more authoritarian orientation, radical extra-parliamentary forces, led by Young Egypt and to a lesser extent also by the Society of the Muslim Brothers, strove to delegitimize its very existence. British colonial intervention in politics similarly hindered its ability to function.

The second limitation was more substantial. It involved the question: to what extent was such an aim realizable within the colonial or semi-colonial context? Can intellectuals promote a true liberal democracy in a colonized environment? To be sure, the intellectuals whom I've discussed also grappled with these questions, and concluded that it was feasible. They assumed that their efforts were an integral element in Egypt's struggle for liberation from colonial rule. They did not anticipate that the national struggle would be lengthy and that British colonial rule would last until the late 50s. It became increasingly difficult for them to overcome a glaring obstacle: the fact that the very European Western culture that provided concepts and models for liberal democratic ideas and institutions was simultaneously the imperial power that threatened their local culture. As newer and more radical forces emerged in the cultural and political arena, they rejected liberalism as a foreign imperialist institution. Worse yet, they claimed that Western liberal democracy's purported freedom was a tool in the service of a narrow Western elite promoting Western colonial discourse, which usurped the freedom of the masses through its sham parliamentary system.

A newer radicalized nationalism aimed at decolonialization of Egypt and the Arab Middle East undermined the intellectual project to institutionalize a liberal democracy in Egypt and the Arab world. The Free Officers' coup d'etat of July 1952 and the emergence of the authoritarian republican regime abruptly ended this project. However, from a historical perspective, the intellectuals' liberal democratic legacy has proven to be enduring. Their liberal texts were canonized and remained popular years after their deaths. They were continuously consumed by successive generations. To what extent this legacy may serve as a source of inspiration and legitimization in current conditions in Egypt remains to be seen. ■

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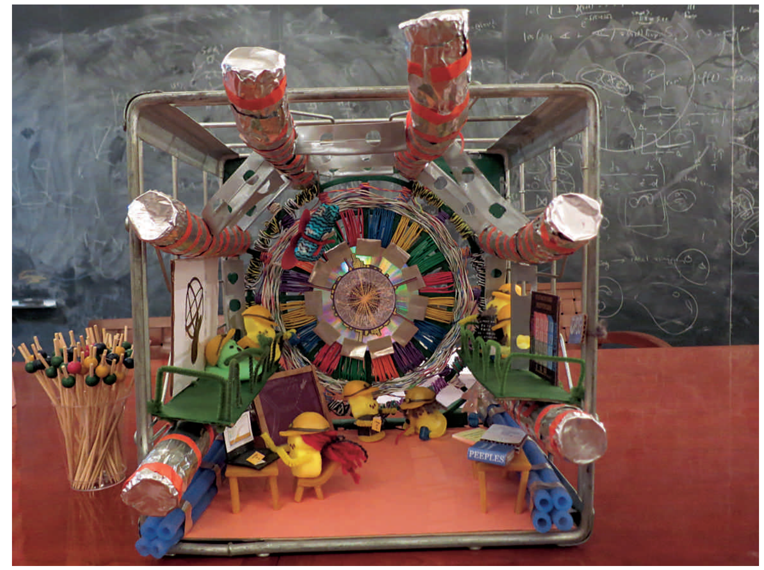

GRAHAM FARMELO

A diorama of CERN's ATLAS particle detector, created by Marilena LoVerde, Member in the School of Natural Sciences, and Laura Newburgh, a physicist at Princeton University

Before dawn on July 4, CERN scientists announced the discovery of a new particle consistent with the boson predicted nearly fifty years ago by Peter Higgs. He gave one of his first seminars on his theory at the Institute at the invitation of Professor Freeman Dyson, now Emeritus in the School of Natural Sciences. During his 1966 seminar, Higgs presented his theory of how most fundamental particles acquire mass as they interact with an energy field that exists everywhere in the universe. Soon after the CERN announcement, Dyson sent a message to Higgs through a colleague, David Derbes: "Please give my warm congratulations to Peter if you see him. What he did was beautiful and will outlast the temporary flood of hype." Derbes met Higgs for dinner in Glasgow on July 24, and reported back to Dyson: "I think he was very appreciative."

After nearly five decades of searching for confirmation of the existence of the Higgs particle that would result if Higgs's theory is correct, Faculty and Members—along with Robbert Dijkgraaf on his fourth day as the ninth Director of the Institute—attended a pre-dawn celebration in Bloomberg Hall to witness the announcement by Rolf Heuer, Director-General of CERN (page 4). The news was momentous. Faculty and Members at the Institute have contributed many of the theoretical foundations of the Standard Model, which describes the fundamental building blocks of the universe, and its possible modifications. The discovery of a particle that looks much like the Higgs—the final element of the Standard Model that needs to be confirmed experimentally—promises to further understanding of the origin of mass and help clarify some long-standing mysteries.

The late Marston Morse, Professor in the School of Mathematics, believed that mathematicians, physicists, and artists are bound through a willingness to admit uncertainty and to try to understand it. In the following pages, **John Hopfield**, Visiting Professor in the School of Natural Sciences, writes about wanting to understand how mind emerges from brain (page 1); **Helmut Hofer**, Professor in the School of Mathematics, and **Derek Bermel**, Artist-in-Residence, find a common ground between symplectic dynamics, music, and John Cage (page 1); **Brandon Look**, Member in the School of Historical Studies, delves into the likelihood of understanding, from a metaphysical perspective, why there is something rather than nothing (page 5); and **Richard Taylor**, Professor in the School of Mathematics, explains the curiosity and beauty of modular arithmetic, which has led to real-world applications, such as the way DVDs store or satellites transmit large amounts of data without corrupting it (page 6). Morse proposed a psychological and spiritual affinity between these types of explorations pursued by the individual who "chooses one pattern for beauty's sake, and pulls it down to earth, no one knows how. Afterwards the logic of words and of forms sets the pattern right. Only then can one tell someone else. The first pattern remains in the shadows of the mind."

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