IAS

The Institute Letter

Institute for Advanced Study

Summer 2013

Political Economist Dani Rodrik Appointed to School of Social Science Faculty

ANDREA KANE

Dani Rodrik

Dani Rodrik, a leading political economist whose prescient and imaginative exploration of complex issues in international development, globalization, and economic policy have transformed the field and precipitated change, has been appointed as Albert O. Hirschman Professor in the School of Social Science. Rodrik comes to the Institute from Harvard University, where he was Rafiq Hariri Professor of International Political Economy at the John F. Kennedy School of Government. He succeeds Eric S. Maskin, who served on the Institute Faculty from 2000–12. At the Institute, Rodrik will bridge the realms of theory and public policy by combining rigorous research with an innovative examination of ideas across the field of economics—qualities embodied by development economist Albert O. Hirschman, a founder of the Institute's School of Social Science and former Professor who died in December 2012.

The School's intensive selection process for the appointment was open to all fields of economics at the international level. Didier Fassin, James D. Wolfensohn Professor in the School, stated, "Not only is Dani Rodrik one of the most distinguished economists worldwide, but he is also deeply involved in a dialogue between disciplines, which makes him a perfect successor to Albert Hirschman and a crucial addition to our School of Social Science."

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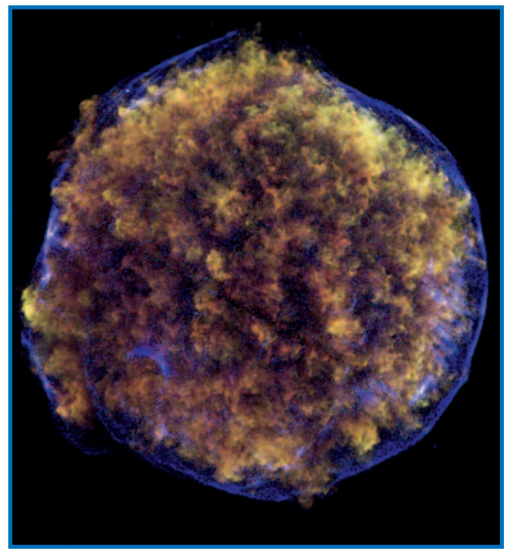
Unlike Previously Thought, Many Supernovae Result from Stellar Collisions

BY BOAZ KATZ, SUBO DONG, AND DORON KUSHNIR



NASA/CXC/CHINESE ACADEMY OF SCIENCES/F. LU ET AL.

Remnants of the type Ia supernova first observed by medieval astronomer Tycho Brahe

On the evening of November 11, 1572, twenty-six-year-old astronomer Tycho Brahe was about to make a discovery that would change his life and consequentially boost the scientific revolution significantly. While casually staring at the night sky, he suddenly noticed a very bright unfamiliar star in the Cassiopeia constellation. The star, which was as bright as Venus, was located in the inner parts of the famous W-shaped constellation, which was well known to many common people, let alone astronomers. What Tycho saw looked like the appearance of a new star (*nova stella*). He was so astonished that he sought the confirmation of others to assure himself that he was not hallucinating. Unknown to Tycho, such new stars had appeared during the previous centuries ("guest stars" in Chinese records), with a much brighter star reported in 1006. While these events

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Univalent Foundations and the Large-Scale Formalization of Mathematics

BY STEVE AWODEY AND THIERRY COQUAND

AMY RAMSEY

Participants in the School of Mathematics's special year on univalent foundations

In 2012–13, the Institute's School of Mathematics hosted a special year devoted to the topic "Univalent Foundations of Mathematics," organized by Steve Awodey, Professor at Carnegie Mellon University, Thierry Coquand, Professor at the University of Gothenburg, and Vladimir Voevodsky, Professor in the School of Mathematics. This research program was centered on developing new foundations of mathematics that are well suited to the use of computerized proof assistants as an aid in formalizing mathematics. Such proof systems can be used to verify the correctness of individual mathematical proofs and can also allow a community of mathematicians to build shared, searchable libraries of formalized definitions, theorems, and proofs, facilitating the large-scale formalization of mathematics.

The possibility of such computational tools is based ultimately on the idea of logical foundations of mathematics, a philosophically fascinating development that, since its beginnings in the nineteenth century, has, however, had little practical influence on everyday mathematics. But advances in computer formalizations in the last decade have increased the practical utility of logical foundations of mathematics. Univalent foundations is the next step in this development: a new foundation based on a logical system called type theory that is well suited both to human mathematical practice and to computer formalization. It draws moreover on new insights from homotopy theory—the branch of mathematics devoted to the study of continuous deformations in space. This is a particularly surprising source, since the field is generally seen as far distant from foundations.

For the special year, a team of thirty-two leading researchers in the areas of computer science, logic, and mathematics from around the world was assembled at IAS to develop this new foundation of mathematics. An ambitious program of weekly seminars, lectures, working groups, tutorials, and other activities led to a lively interaction and a vigorous exchange of ideas, skills, and viewpoints,

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News of the Institute Community

The University of Chicago Press has published *Education, Justice, and Democracy* (2013), edited by DANIELLE S. ALLEN, UPS Foundation Professor in the School of Social Science, and ROB REICH, Associate Professor at Stanford University and former Member (2009–10) in the School. The book collects essays developed over the course of the School's 2009–10 theme year, "The Dewey Seminar: Education, Schools, and the State."

JEAN BOURGAIN, IBM von Neumann Professor in the School of Mathematics, has been elected as a Foreign Member of the Royal Flemish Academy of Belgium for Science and the Arts.

ANGELOS CHANIOTIS, Professor in the School of Historical Studies, has edited *Unveiling Emotions: Sources and Methods for the Study of Emotions in the Greek World* (Franz Steiner Verlag, 2012). The volume presents the first results of research conducted through "The Social and Cultural Construction of Emotions: The Greek Paradigm," a project funded by the European Research Council.

PATRICIA CRONE, Andrew W. Mellon Professor in the School of Historical Studies, has been elected as an Honorary Fellow of Caius College, University of Cambridge.

DIDIER FASSIN, James D. Wolfensohn Professor in the School of Social Science, has authored *La Question Morale: Une Anthologie Critique* (Presses Universitaires de France, 2013), with Samuel Lézé, and *Enforcing Order: An Ethnography of Urban Policing* (Polity Press, 2013). Fassin was named Mellon Distinguished Scholar by the University of the Witwatersrand of Johannesburg and appointed Honorary Professor at the University of Hong Kong.

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

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

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Brandeis University Press has published *Language and Power in the Early Middle Ages* (2013) by PATRICK J. GEARY, Professor in the School of Historical Studies.

JUAN MALDACENA, Professor in the School of Natural Sciences, and AVI WIGDERSON, Herbert H. Maass Professor in the School of Mathematics, have been elected to the National Academy of Sciences. Four former Institute Members were also among the eighty-four new members elected in April.

Dumbarton Oaks has published *How to Defeat the Saracens* by William of Adam in a new translation and critical edition (2012) by GILES CONSTABLE, Professor Emeritus in the School of Historical Studies. *How to Defeat the Saracens* presents a five-pronged plan for retaking the Holy Land and was written around 1317 by a Dominican who traveled extensively in the eastern Mediterranean, Persia, and parts of India. The new edition provides a guide through the work's political, geographical, economic, military, and historical context.

Pindar Press has published the third volume of *Visible Spirit: The Art of Gian Lorenzo Bernini* (2013) by IRVING LAVIN, Professor Emeritus in the School of Historical Studies. This final volume, titled *Bernini at St. Peter's: The Pilgrimage*, completes a collection of Lavin's papers on Baroque artist Gian Lorenzo Bernini (1598–1680). In this work, Lavin defines the significance of a case unique in the history of European art, revealing a coherent strain of thought and design in the furnishing of the greatest church in Christendom under the aegis of a single artist in the service of six popes over a period of nearly six decades.

In recognition of his scholarly work, PETER PARET, Professor Emeritus in the School of Historical Studies, has been awarded the Great Cross of the Order of Merit of the Federal Republic of Germany. Paret has been an officer of the Order for the past decade.

MICHAEL WALZER, Professor Emeritus in the School of Social Science, has been awarded an honorary degree from the Hebrew University of Jerusalem.

ROBBERT DIJKGRAAF, Director of the Institute for Advanced Study and Leon Levy Professor, has been elected to the American Philosophical Society in its Mathematical and Physical Sciences Class. Among the thirty-four other leading scholars recently elected for membership are four former Institute Members and Visitors. Dijkgraaf has also been re-elected as Co-Chair of the InterAcademy Council and will serve a four-year term with Daya Reddy, President of the Academy of Sciences of South Africa.

A Curious Discovery: An Entrepreneur's Story by JOHN S. HENDRICKS, a Trustee of the Institute, has been published by HarperCollins (2013). Hendricks is Founder and Chairman of Discovery Communications.

DAVID M. RUBENSTEIN, a Trustee of the Institute, has received the Leonore and Walter Annenberg Award for Diplomacy through the Arts from the Foundation for Art and Preservation in Embassies. Rubenstein is Co-Founder and Co-Chief Executive Officer of the Carlyle Group.

The New Digital Age: Reshaping the Future of People, Nations, and Business by ERIC E. SCHMIDT, a Trustee of the Institute, and Jared Cohen, has been published by Alfred A. Knopf (2013). Schmidt is Executive Chairman of Google Inc.

DEREK BERMEL, Artist-in-Residence (2009–13), has been appointed Artistic Director of the American Composers Orchestra, which is dedicated to the creation, performance, and preservation of music by American composers.

RASHID SUNYAEV, Maureen and John Hendricks Visiting Professor in the School of Natural Sciences, has been awarded an Einstein Professorship by the Chinese Academy of Sciences.

The Society for Historians of American Foreign Relations has awarded the Robert H. Ferrell Book Prize to FRANK COSTIGLIOLA, former Member (2009–10) in the School of Historical Studies and former Director's Visitor (2011), for *Roosevelt's Lost Alliances: How Personal Politics Helped Start the Cold War* (Princeton University Press, 2012), which was completed at the Institute. Costigliola is Professor at the University of Connecticut.

PETER SCHÄFER, former Mellon Visiting Professor (1993, 1994–96) in the School of Historical Studies, has received Princeton University's Howard T. Behrman Award for Distinguished Achievement in the Humanities. Schäfer is the Ronald O. Perelman Professor of Jewish Studies at Princeton.

Jeffrey A. Harvey Appointed to Board of Trustees

LLOYD DEGRANE

Jeffrey A. Harvey, Enrico Fermi Distinguished Service Professor at the University of Chicago, has been appointed to the Board of Trustees of the Institute for Advanced Study. Harvey was nominated by the Institute's School of Natural Sciences. He succeeds Curtis Callan, James S. McDonnell Distinguished University Professor of Physics at Princeton University, who had served on the Institute's Board since 2008.

Harvey's research encompasses a broad range of topics in string theory, particle theory, mathematical physics, and cosmology. His current focus is on the connection between computations of the entropy of black holes in string theory and mock modular forms, as well as the "moonshine" connections between mock modular forms and the representation theory of certain finite groups.

Harvey received his undergraduate education at the University of Minnesota and earned his Ph.D. in physics from the California Institute of Technology in 1981. After a postdoctoral position at Princeton University, he served on Princeton's faculty as Assistant Professor, Associate Professor, and full Professor before joining the University of Chicago's faculty in 1990. He has been a Visitor in the Institute's School of Natural Sciences twice, in 1999–2000 and 2005.

Among other honors, Harvey is the recipient of the University of Chicago's Faculty Award for Excellence in Graduate Teaching and its Llewellyn John and Harriet Manchester Quantrell Award for Excellence in Undergraduate Teaching. He is a Member of the American Academy of Arts and Sciences, and he has been a Sloan Fellow, a National Science Foundation Presidential Young Investigator, and an American Physical Society Fellow. ■

The Utility of Literary Study

BY NIGEL SMITH

Nigel Smith, Member (2012–13) in the School of Historical Studies, is William and Annie S. Paton Foundation Professor of Ancient and Modern Literature at Princeton University. He is exploring the articulation of ideas of freedom in poetry and drama written in early Modern Europe in the period 1500 to 1700. This article is based on a talk he gave on this topic as part of After Hours Conversations (www.ids.ias.edu/after-hours-conversations), an informal program that aims to encourage cross-discipline communication at IAS.

I should admit at the outset to a guilty conscience. I should have been a physicist (it was my best subject), but around the age of fifteen was converted to the humanities by an enthusiastic English teacher who had been a professional actor. Plato's suspicion of the artist survives in me somewhere. When I went to university to read English and history, I thought studying literature would help me be a better person, that it would lead to some kind of moral and ethical wisdom, and that may finally be true, but not in any straightforward or obvious way. It did at least keep me out of harm's way by making the library the place I most wanted to be, reading books.

NATIONAL PORTRAIT GALLERY, LONDON

For Bacon, literary creativity and scientific inventiveness both arise from the mental facility capable of finding truth.

Since at least the eighteenth century, our sense of literature, when compared with science, has been characterized at a certain aesthetic extreme. Oscar Wilde's much quoted statement in the preface to *The Picture of Dorian Gray* is one of its best versions: "All art is quite useless." To be literature, a work of literary creativity must dissociate itself from that which is useful. In this sense, utility and artistic value must be separated, like Immanuel Kant's "purposeful purposelessness."

Yet even with these arguments in mind, we live with the inescapability of literature, and that its greatest examples elicit enthusiastic admiration and, in the reading, great pleasure. One typical lunchtime conversation in my year at IAS was concerned with the significance of Giovanni Boccaccio, drawing in a classical philosopher, an ancient historian, and a literary critic. Another was on the considerable influence of Cornelius Tacitus *as a writer*. In nearly every Monday lunchtime talk in the School of Historical Studies during the past academic year, the issue of the function of metaphor—one of the most central literary issues—surfaced. The case has recently been made that Kant derived an important part of his philosophy from an encounter with some of John Milton's lyrics, triggering effectively a revolution in the philosophy of mind.[1]

The Institute's Director, Robbert Dijkgraaf, praises modes of free reflection as the spur to scientific innovation (referring I believe to the original Latin sense of *scientia*, not just the investigation of the natural world but simply "knowledge"). Is this not the mental space that the complexity of great literary art also takes us to? This is where we find complex sequential expression (or the refusal of it), the special equivocatory powers of drama, or the rich verbal ambiguity of lyric tradition. Might there not also be a case for creative renewal and originality in an interdisciplinary encounter of all these forms of knowledge, where the arts of numbers and of words are in a relationship of mutual inspiration? I once introduced an Oxford mathematician to the numerically inflected stories of Italo Calvino, such as in *T Zero* (first edition, 1967), and he claimed to have gained many ideas from them. Truly great literary scholarship is, like physics, an art of measurement, beginning with the proportions of words and the study of matters like poetic meter, but building into more complex patterns of apprehension.

Truly great literary scholarship is, like physics, an art of measurement, beginning with the proportions of words and the study of matters like poetic meter, but building into more complex patterns of apprehension.

One important example of the challenge of literature comes from the man who is usually regarded as responsible for redividing the disciplines, and ensuring that "science" in the normally understood modern sense (i.e., the investigation of the natural world) was separated from literature and philosophy. This challenge is to be found in the writings of the "father of modern science" Francis Bacon, Viscount St. Alban (1561–1626). Latin *ingenium* for Bacon meant both the nature of a thing (its older meaning) and "wit." On the one hand, it represents the objects in nature that he sought to understand, and on the other, the intelligence that helped to understand them.

Ingenium is and is not "ingenuity." As the Oxford literary critic and intellectual historian Rhodri Lewis writes in a most important article: "In particular, it will become clear that in Bacon's hands, *ingenuity* represented a range of psychological attributes that demanded sustained attention and cultivation, but that were crucially distinct from those that empowered logical, philosophical, or otherwise discursive analysis."[2] That sounds very much like a kind of inventive or perceptive genius that is not the result of any particular training in the use of thought and language (famously Bacon was against most of the university education system of his day). *Ingenium* is thus not reason but something else, which, like art, should exist entirely "for its own sake." Bacon felt that human *ingenium* had been abused in the name of personal and disciplinary vanity.

BRUCE M. WHITE

One root of the modern English word "invention" was *ingenium*. It was envisaged as a gift for making connections between apparently different things or ideas, thereby providing an orator the wherewithal to generate metaphors. *Inventio* (meaning "discovery") was understood as the ability to find subject matter and was regarded as important as the facility to write eloquently. This is why Bacon had a host of literary admirers, writers who were not experimental scientists but who saw his insights as crucial to the definition of their own creativity. Among these were Milton, the author of *Paradise Lost*, and his contemporary Abraham Cowley, who was equally if not more highly regarded than Milton in their own lifetimes. With regard to poetry and the visual arts, and to quote Lewis again, "*Ingenium* was the imaginative talent through which the poet, painter, or sculptor was able to imitate, and even to surpass, the created world in his works." Andrew Marvell put this brilliantly when, in his poem "The Garden," he described the revelation that arrives from contemplation in a garden as "a green thought in a green shade." And indeed Bacon actually called the ability to order scientific experiments "literate experience." He did not see it as fundamentally separate from literary competence. Bacon called "Idols of the Theatre" the philosophical structures (like Aristotelian or scholastic categories) that prevented in his view a true understanding of nature, which may be inchoate and beyond the reach of merely human reason. In Bacon's view, science (or "natural philosophy" as he would have known it) and literature belong to each other. They are the keystones of human creativity.

It follows from this that I am highly skeptical of a recent move in the humanities that sees the findings of cognitive science as a driving force in humanities agendas—that literary imagination must now be seen as determined by deeply embedded aspects of human evolution.[3] I do not believe that culture can be reduced to an effect of biology. I would argue that cognitive science does not seem able to account effectively for a realm of reality that is often captured in literature and that we associate with extreme imagination: inspiration, prophecy, the striking if rare insights that lead to major breakthroughs in understanding. It is therefore comforting that the recent work of some evolutionary theorists has tried to account for these "genius" moments of great transformation by "rethinking evolutionary theory through the nonbinary and noncentralized imagery of exchange, interactivity, permeability, constructivity, flux, flow, and multiplicity."[4]

There were several who came to my talk at one of the Institute's After Hours Conversations on this topic who wanted to hear about the relevance or vitality of well-known literary categories like character or the representation of complex emotions. The significance of these aspects and qualities I do not at all deny. However, and especially in the current IAS context, where there is no literary specialist among the permanent Faculty (and where a very few literature scholars appear each year in the Schools of Historical Studies and Social Science), I wanted to point to a central connection seen between the scientific (as we would define it today) and literary imaginations. It was a connection seen by one of the greatest theorists of "natural philosophy," who lived with the sense that literary creativity and scientific inventiveness were part of the same precious mental facility capable of finding the truth of things. For Bacon, learning (as he saw it, conventional) philosophy or going to law school was not—rather it was a kind of idolatry. Without scholars to take care of the complexity of these processes of understanding and their realignment in the fullest way possible, we risk being lost to a kind of disciplinary philistinism, and our collective navigation powers will be fatally damaged. ■

1 Sanford Budick, *Kant and Milton* (Harvard University Press, 2010).

2 Rhodri Lewis, "Francis Bacon and Ingenuity," *Renaissance Quarterly* 67, no. 1 (2014), forthcoming; I am grateful to Dr. Lewis for allowing me to cite and quote from his article in advance of publication.

3 The view has recently gained widespread attention in Brian Boyd, *Why Lyrics Last: Evolution, Cognition, and Shakespeare's Sonnets* (Harvard University Press, 2012).

4 F. Elizabeth Hart, "The Epistemology of Cognitive Literary Studies," *Philosophy and Literature* 25, no. 2 (2001): 329.

What We Should be Doing with Diversity on Our College Campuses

BY DANIELLE S. ALLEN

College campuses struggle with how to think and talk about diversity of all kinds, a struggle that has gone on for more than two decades now. Every year, there are stories from around the country about anonymous hate speech and offensive theme parties with equally offensive T-shirts as well as controversies about "political correctness." Nor has there been a year in my roughly two decades in higher ed when I haven't read or heard someone wondering, "Why do all the black kids sit together in the cafeteria?"

What are the stakes for how well we deal with diversity on college campuses? There are two answers to this question, one concerning the stakes for the campuses themselves, the other the broader social stakes.

First, for campuses. Social scientists have long distinguished between two kinds of social tie: "bonding ties" that connect people who share similar backgrounds and "bridging ties" that link people who come from different social spaces. Since the 1970s, scholars have been aware that "bridging ties" are especially powerful for generating knowledge transmission; more recently, scholars have argued convincingly that teams and communities that, first, emphasize bridging ties and, second, successfully learn how to communicate across their differences outperform more homogenous teams and communities with regard to the development and deployment of knowledge.

When we think about social skills, we need to recognize that there is an art of bonding but also a separate art of bridging. Campuses that can successfully cultivate the art of bridging should be able to lift the general intellectual performance of their student body. Achieving a "connected campus," where students from diverse backgrounds have real and positive social relationships with one another, would support the intellectual mission of universities.

Yet the art of bridging that must be cultivated in colleges and universities if we are to take advantage of campus diversity has important ramifications well beyond the quads. In a variety of contexts, ranging from employment, to health, to education, scholars of network theory have shown that increased social connectivity through bridging ties, in particular, brings improved social outcomes.

The differences between these two categories of tie—bonding and bridging—really do matter. Research shows, for instance, that the majority of people who get a new job through information passed through a social network have acquired that information not from a close connection but from a distant one. This makes sense. One's closest connections share too much of one's world; they are a lot less likely to introduce new information.

We all know this intuitively. Whenever we are trying to help a friend who has been single too long, we scratch our brains to think of a further removed social connection who might connect our friend to a whole new pool of possibilities.

Recommended Reading: Danielle Allen served as part of the American Academy of Arts and Sciences's commission that produced the report *The Heart of the Matter*. The report responded to a bipartisan request from Congress to "assess the state of humanistic and social scientific scholarship and education." Among the many notable members of the commission are Institute Trustee Roger W. Ferguson, Jr., and former Institute scholars Robert Berdahl and Amy Gutmann. You may read the full report at www.humanitiescommission.org/_pdf/HSS_Report.pdf and listen to Allen discuss the report in an interview on WHYY radio: http://whyy.org/cms/radiotimes/2013/07/01/why-the-humanities-matter/.

Perhaps these seem like trivial examples. But the most important egalitarian impacts of social connectivity flow from bridging ties and their impact on the diffusion of knowledge. The relations between social connectedness and both employment and educational opportunity, in particular, are profound.

At the same time that successful bridging ties bring clear benefits to individuals and communities, another

DORLING KINDERSLEY

Scholars of network theory have shown that increased social connectivity through bridging ties, in particular, brings improved social outcomes.

body of research has identified a worrying phenomenon. In communities with higher levels of diversity, there are often also higher levels of distrust.

The issue in such situations, I believe, is that it is not enough just to stick people together. They need, as I said above, an art of bridging and that art is much harder to

Everybody needs opportunities both to bond and to bridge, and everybody therefore needs arts of both bonding and bridging. We also, importantly, need to learn ways of bonding that enable us to bridge.

come by than the art of bonding. Bonding ties, and their attendant curatorial art, take care of themselves, really. They start with the family and radiate out. Most of us begin learning the art of bonding from day one, upon our arrival in this world. And a large professional class of therapists devotes considerable energy to helping us improve our capacities to cultivate healthy bonding relationships.

But bridging ties are a matter of social structure. Schools, the military, political bodies—these have typically been the institutions that bring people from different backgrounds together. When our institutions are more effective at this—that is, when they bring a more diverse group together—participants face a heightened need for an art of bridging, and they may have had very little prior experience with such an art. After all, one of the most powerful lessons we teach young people is "don't talk to strangers."

If we wish in this country to undo the forms of economic inequality, political inequality, and social inequality that now characterize our democracy, we need, among other things, to build not only connected campuses but also, more generally, a connected society. This certainly requires institutional change so that we have more opportunities to form bridging ties, but it also requires the development of a skillset that is woefully undersupplied in our culture (the presence of a professional class of translators and interpreters, notwithstanding). We could learn something from the military about the art of bridging, and we could learn something from college campuses, if they themselves could get better at cultivating this. Yet the current sexual assault scandals in both contexts also make clear how much more both sets of institutions have to learn about gender and sexual diversity, specifically.

To say that we need an art of bridging is not, however, to say that we can ignore the art of bonding. For the sake of healthy psychological development, all people need bonding relationships. Bonding builds a sense of security and trust, supports for self-confidence that can, in the right contexts, undergird success. We black kids have good reason for sometimes wanting to sit together.

A comprehensive 2008 study of student social life at the University of California, Los Angeles, published by Russell Sage as *The Diversity Challenge*, provides significant insight into the complex ways that bonding and bridging intersect with one another. The study traces in-group and out-group friendships for the four major ethnic groups on the UCLA campus (black, Latino, Asian, and white) as well as participation in ethnic organizations and fraternities and sororities, which are functionally ethnic organizations despite going by a different label. Students who come to campus having already had greater-than-average out-group contact continue in that direction, forming out-group friendships at far higher rates. Students of all ethnicities whose pre-collegiate experience has, in contrast, tended toward in-group bias (more positive feelings towards one's own group), anxiety about intercultural competence, and perceptions of discrimination are more likely to develop an extensively in-group friendship set. Yet the results of this proclivity to bond are different for different groups. On the negative side, this bonding further increases in-group bias, perceptions of discrimination, and interactional anxiety for all groups. Also on the negative side, for Latinos at UCLA during the time of the study, those in-group bonding relationships also led to lower motivation, attachment, and commitment. Yet for Asians and blacks in the study, these bonding experiences also led to higher commitment, and for blacks, they, in addition, led to greater attachment to the university and higher academic motivation, all indubitably good outcomes.

These data dramatically make the point that not all bonding is the same and that there is much work to be done to understand (1) the mechanisms that generate bonding's positive effects, (2) the mechanisms that generate its negative (anti-bridging) effects, and (3) the mechanisms by which bonding itself might serve to teach people how to bridge rather than be insular.

The important message, then, is this: everybody needs opportunities both to bond and to bridge, and everybody therefore needs arts of both bonding and bridging. We also, importantly, need to learn ways of bonding that enable us to bridge. On college campuses, and in a variety of other social contexts, we need to give more attention to understanding and cultivating these two intertwined arts.

But here we come to an impasse. If our families and our therapists help us learn how to bond, who helps us learn how to bridge? There remains much research to be done—by sociologists, psychologists, anthropologists, historians, and philosophers—to deepen our understanding of the art of bridging, in order that we may more effectively cultivate it. ■

Danielle S. Allen, UPS Foundation Professor in the School of Social Science since 2007, is a political theorist who has published broadly in democratic theory, political sociology, and the history of political thought. Widely known for her work on justice and citizenship in both ancient Athens and modern America, she was awarded a MacArthur Fellowship in 2002 for her ability to combine "the classicist's careful attention to texts and language with the political theorist's sophisticated and informed engagement." Her most recent book is "Our Declaration: A Reading of the Declaration of Independence in Defense of Equality," forthcoming from Norton/Liveright in 2014.

Hagar: Jewish-Arab Education for Equality, Creating a Common Future in Israel

BY CATHERINE ROTTENBERG

Although I came to the Institute to research twentieth-century African-American and Jewish-American fiction, I would actually like to share with you a formative experience I have had as a parent. It all began in 2005, when my oldest child was turning one. My partner and I were living in Be'er-Sheva, a city in southern Israel, and, like many new parents, we began to worry about our child's education. So one evening we invited a few friends, Jewish and Palestinian couples with young children, to our home to discuss daycare and school options for our toddlers. Like many parents around the world, we scouted the city to see what kinds of nurseries and kindergartens were available. The reality we found was depressing, since it was a reality of strict segregation between Arab and Jewish children.

Except for a handful of mixed cities like Haifa (which are also segregated by neighborhood), the 1,180 settlements in Israel are ethnically divided: they are either Jewish or Arab. This means that even though twenty percent of Israel's population is Arab, Jewish and Arab children rarely if ever get to know each other as they grow up. They go to separate schools, play in different neighborhood playgrounds, and really don't have an opportunity to meet one other until, perhaps, university. This segregation is not a result of legislation. There are no Jim Crow laws prohibiting Jews and Palestinians from learning together. Rather, the lack of contact has to do with, among other things, the way space has been organized.

Thus, what this small group of parents in Be'er-Sheva had in common was that we all wanted an educational institution in which our toddlers, Arabs and Jews, would meet and study together. We all wanted our children to be exposed to the other's language, customs, traditions, and narratives. We wanted a space where our children would not be indoctrinated by a hyper-nationalistic ideology that erases the history of the "other." Moreover, we were all convinced that one of the most important ways of countering the rising prejudices in Israel and instilling in our children the importance of respecting everyone's humanity was to create a space in which Jews and Arabs would meet each other—day in and day out—in an atmosphere of equality and tolerance, in which they would be encouraged to think critically about their environment and their society, and, perhaps most importantly, in which empathy for others would be considered one of the greatest human values.

We decided to establish an association called Hagar: Jewish-Arab Education for Equality whose goal was to create a school that would embody these principles. Before the Hagar School was created, there were only four other integrated Jewish-Arab schools in all of Israel (in which about 1,200 children were enrolled, out of more than 1.8 million school-age children). In September 2006, Hagar became the fifth and the newest of these integrated schools.

Hagar is located in Be'er-Sheva, which is in the Negev, a region that is home to about 627,000 people, about thirty percent of whom are Arab citizens of Israel, mostly Bedouins. Yet Hagar is the only nonsegregated school in the Negev. It is a public school recognized by the Ministry of Education. Its uniqueness stems from the fact that it has created a space in which Jewish and Palestinian children not only mix (each group makes up fifty percent of the student body) but learn together every day in a bilingual atmosphere of mutual respect.

In the 2012–13 school year, 225 children from nursery through fifth grade (it is a growing school) are attending this bilingual school, whose commitment to equality informs every aspect of its educational agenda. To ensure that Hebrew and Arabic are awarded equal status, for example, two teachers, one Jewish and the other Arab, are present in each and every classroom. There is not supposed to be any translation, and the two teachers work as a team—what in the United States is called team or co-teaching. The Arab teacher always speaks in Arabic and the Jewish one in Hebrew.

Children of the Hagar School and their families plant a community garden. The students learn to work as partners, using an array of skills.

It is well known that language can be both a bridge and a barrier, and Hagar attempts to use language as a bridge. But language is only one aspect of our pedagogical endeavor. Within this bilingual space, Hagar encourages direct contact with the heritage, customs, and historical narratives of each of the different ethnic groups. The teachers aim to promote tolerance and empathy, while being sensitive to nurture the personal identity of each child and each tradition.

Within a segregated, highly charged, ideological context, meaningful education that exposes children to a common sense of humanity is not a luxury but a necessity. The Hagar School reveals that educational spaces can be transformed into sites that help create a more democratic and just society.

Indeed, already by the age of two, children are celebrating the holidays and memorial days of both peoples and of the three monotheistic religions—since there are Jews, Muslims, and Christians in the Hagar community.

On Israeli Independence Day, Hagar emphasizes the notion of independence and its relation to responsibility. The community feels that these are the values young children should be exposed to during their first few encounters with these highly charged national days. On Nakba Day, the school emphasizes the idea of loss and suffering, accentuating the importance of empathy for the other. Everyone has experienced some kind of injury and grief. In the kindergarten, the children play out various scenarios about what it means to lose something precious, like a toy, and how it might make them feel. They also talk about what living together in a big house with many different kinds of children might look like. What kinds of compromises might they have to make? What kind of house could hold so many different children? And from the religious holidays we try to draw out their universal messages, like the meaning of liberation from slavery, which is commemorated during Passover.

The assumption is that by the time the children are old enough to learn that there are two conflicting national narratives, both of which are taught in the higher grades, they already have the necessary emotional and intellectual tools to deal with conflict through dialogue.

Hagar's educational objective, though, is not only to bring together Jews and Palestinians, teach both languages, and broaden the existing historical script, but also to create a pedagogy that fits the school's philosophy. The school's pedagogical team, of which I am part, believes it is crucial to alter basic pedagogical methods: from frontal teaching, which is the method used in the majority of Israeli public schools, to project-based and meaningful learning, where students are active participants in their own learning process. Last year, for example, the fourth graders were asked to build their own neighborhood. As part of their project, they went on field trips and visited various historical sites in Be'er-Sheva; they learned about the city's history, took pictures, and then broke up into groups of four—each group responsible for planning a certain section of the neighborhood. Thus, these children were writing their own texts while carrying out complicated measurements and conversions. They were also asked, once their neighborhood was near completion, to explain why they created their section in the way they had. The end-of-the-year presentations, in which these students explained their work to parents and younger students in both Arabic and Hebrew, were phenomenal.

In this way, these students learn to work together as partners, using an array of skills. They develop math, history, and linguistic skills through creative and meaningful projects—usually at a much higher level than their counterparts in other public schools.

Finally, the school has itself created a community. Approximately 150 Jewish and Arab families join monthly community outings, where they hike and break bread together. Today, it is not unusual to hear that the Hagar community has its own school rather than the other way around.

In Israel, a self-declared Jewish state, the need for integrated schools like Hagar might seem obvious, and yet most Israeli Jews are unwilling to send their children to such schools. This is tragic because within a segregated, highly charged, ideological context, meaningful education that exposes children to a common sense of humanity is not a luxury but a necessity. The Hagar School reveals that educational spaces can be transformed into sites that help create a more democratic and just society. And we desperately need more spaces like Hagar. Otherwise, the dominant narratives of hate and violence will ultimately destroy any hope of a common future in Israel. ■

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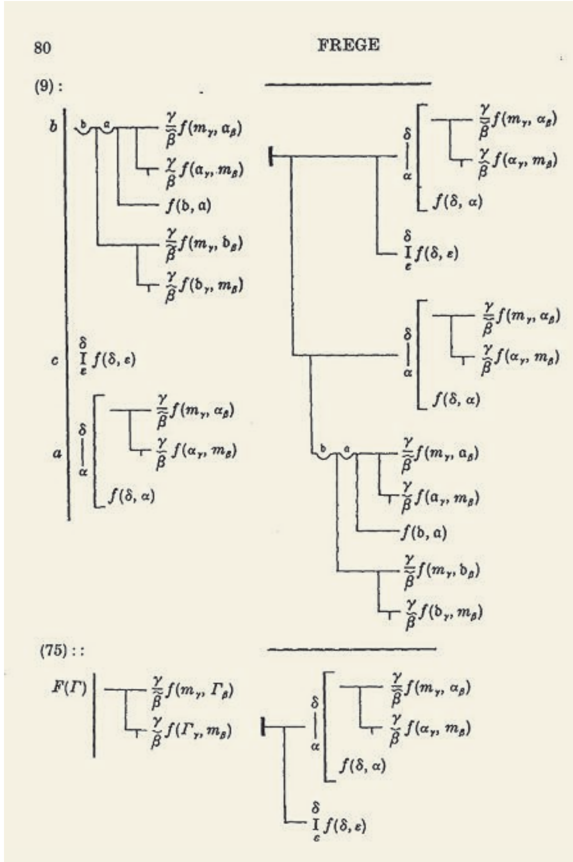
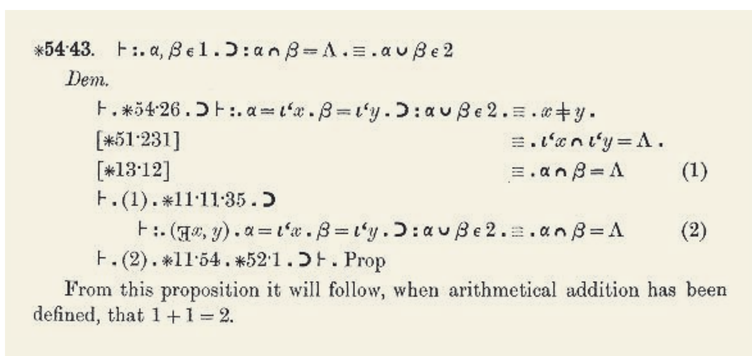


A page from Frege's Begriffsschrift *of 1879, which introduced a system of logical deductions that Bertrand Russell discovered contained a contradiction. This had the effect that mathematicians otherwise unconcerned with logic began to pay increased attention to logical precision.*

resulting in numerous collaborations among the participants. The program's goals were realized beyond expectations, producing a powerful and flexible new foundational system called homotopy type theory, based on earlier systems of type theory that were originally intended for constructive mathematics and computer programming, and augmented by new principles motivated by homotopy theory. In addition to a body of theoretical results pertaining to the foundations, a substantial amount of mathematics was developed in this new system, including basic results in homotopy theory, higher category theory, set theory, and the beginnings of real analysis. In parallel, efforts were focused on the development of new and existing computer proof assistants for the formalization of these and future results. An extensive library of code was established on which future work can be built, and formalized proofs of significant results in homotopy theory were given, such as computing many homotopy groups of spheres. In a remarkable, collaborative effort, a textbook was also written by the special-year participants, developing both the foundations and various specialized areas of mathematics in the new logical system. This book not only serves as a record of the results of the special year, but also as a useful introduction for future researchers entering the field.

The idea of logical foundations of mathematics goes back at least to Gottlob Frege's *Begriffsschrift* of 1879, which set out to show that arithmetic could be deduced entirely from logic in a way that was "free of gaps" and thus requiring no leaps of intuition. Frege's system of logical deductions—which looked a bit like complicated wiring diagrams—was soon discovered by Bertrand Russell to contain a contradiction: a disastrous logical inconsistency, which had the effect that mathematicians otherwise unconcerned with logic began to pay increased attention to logical precision. Russell himself proposed a solution based on what he called the theory of types, and Ernst Zermelo proposed another based on axioms for Georg Cantor's set theory. During the 1920s and '30s, mathematicians as prominent as David Hilbert, Hermann Weyl (Professor, 1933–51), and John von Neumann (Professor, 1933–57) worked on the foundations of mathematics, culminating in the famous discoveries of Kurt Gödel (Member, beginning in 1933; Professor, 1953–76) about the limits of logical formalization. Gödel showed namely that a complete and consistent logical formalization of even arithmetic was mathematically impossible; moreover, this result agreed with the practical experience of many mathematicians, that the formalization of even the most basic mathematical theories was impractically complicated and irrelevantly elaborate. Russell's system arrived at the result that 1 + 1 = 2 only after 362 pages of laborious formal deductions!



∗54·43. $\vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . {*}54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

$[{*}51{\cdot}231] \qquad \equiv . \iota`x \cap \iota`y = \Lambda .$

$[{*}13{\cdot}12] \qquad \equiv . \alpha \cap \beta = \Lambda \qquad (1)$

$\vdash . (1) . {*}11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \qquad (2)$

$\vdash . (2) . {*}11{\cdot}54 . {*}52{\cdot}1 . \supset \vdash .$ Prop

From this proposition it will follow, when arithmetical addition has been defined, that 1 + 1 = 2.

A formal proof that 1 + 1 = 2, from Whitehead and Russell's Principia Mathematica *of 1910*

By the 1950s, a consensus had settled in mathematics that the program of logical foundations, while perhaps interesting in principle or as its own branch of mathematics, was going to be of little use to the general practice of mathematics as a whole. This view was only reinforced by the results of Gödel and Paul Cohen (Member, 1959–61, 67) on the formal undecidability of the famous continuum hypothesis. Much subsequent research in logical theory was related instead to the new field of computation; indeed, it was the early work in logic that had led to the development of the modern computer, and subsequent advances in theoretical and practical computation were closely tied to logical research.

But with recent advances in the speed and capacity of modern computers and theoretical advances in their programming has come a remarkable and somewhat ironic possibility: the use of computers to aid in the nearly forgotten program of formalization of mathematics. For what was once too complicated or tedious to be done by a human could now become the job of a computer. With this advance comes the very real potential that logical foundations, in the form of computer formalizations, could finally become a practical aid to the mathematician's everyday work, through verifying the correctness of definitions and proofs, organizing large-scale theories, making use of libraries of formalized results, and facilitating collaboration on the development of a unified system of formalized mathematics. Gödel may have shown that mathematics cannot be entirely formalized in principle, but in practice there are still great benefits to be had from formalization when sophisticated computer systems can be brought to bear.

Recommended Reading: For more information, visit http://homotopytypetheory.org, a website for the collection and dissemination of research, resources, and tools for the investigation of homotopy type theory.

This new conception of foundations of mathematics, so closely tied to the use of computers to provide the guarantee of formal rigor and to aid in handling the explosion of complexity, seems so natural that future historians of mathematics may well wonder how Frege and Russell could have invented the idea of formal systems of foundations before there were any computers to run them on. Nor is it a coincidence that foundations work so well in combination with computers; as already stated, the modern computer was essentially born from the early research in logic, and its modern programs and operating systems are still closely related to the logical systems from which they evolved. In a sense, modern computers can be said to "run on logic."

This new conception of foundations of mathematics, so closely tied to the use of computers, seems so natural that future historians of mathematics may well wonder how Frege and Russell could have invented the idea of formal systems of foundations before there were any computers to run them on.

This is the starting point of the univalent foundations program: the idea that the time is now ripe for the development of computer proof assistants based on new foundations of mathematics. But it is not only the advance in technology that has made this program feasible today; recent breakthroughs in logical theory also play an important role. One such advance was the discovery of a connection between the system of type theory used by some modern proof systems and the mathematical field of homotopy theory, which usually requires a high level of mathematical abstraction to even get off the ground. This connection permits direct, logical formalizations of some important concepts having broad application in various fields of mathematics. An important example is the fundamental notion of a set, which in univalent foundations turns out to be definable from more primitive concepts, as was recently discovered by Voevodsky. A related discovery, also due to Voevodsky, is the univalence axiom, which states, roughly, that isomorphic mathematical objects may be identified. This powerful new principle of reasoning, which agrees with everyday mathematical practice but is not part of the traditional set-theoretic foundation, is fully compatible with the homotopical view, and indeed strengthens it, while greatly simplifying the use of type theory as a system of foundations. Finally, the discovery of direct, logical descriptions of some basic mathematical spaces, such as the n-dimensional spheres S^n, and various other fundamental constructions, has led to a system that is both comprehensive and powerful, while still being closely tied to implementation on a computer. ■

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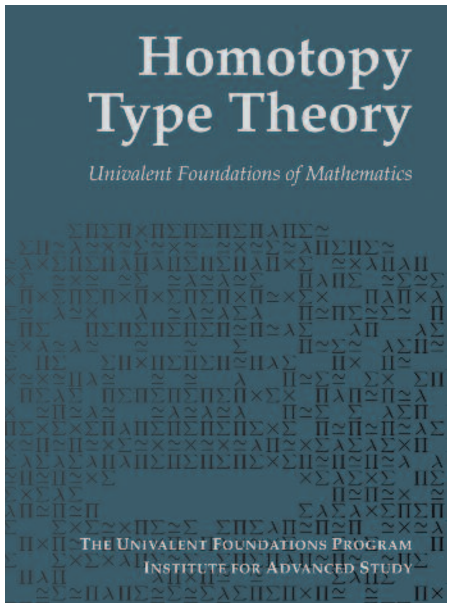
Homotopy Type Theory Permits 'Logic of Homotopy Types'

The following text is excerpted from the introduction to the book Homotopy Type Theory: Univalent Foundations of Mathematics, *written jointly by the participants of the special year on univalent foundations, which may be obtained at http://homotopytypetheory.org/book/.*

Homotopy type theory is a new branch of mathematics that combines aspects of several different fields in a surprising way. It is based on a recently discovered connection between *homotopy theory* and *type theory*. Homotopy theory is an outgrowth of algebraic topology and homological algebra, with relationships to higher category theory, while type theory is a branch of mathematical logic and theoretical computer science. Although the connections between the two are currently the focus of intense investigation, it is increasingly clear that they are just the beginning of a subject that will take more time and more hard work to fully understand. It touches on topics as seemingly distant as the homotopy groups of spheres, the algorithms for type checking, and the definition of weak ∞-groupoids.



Homotopy type theory also brings new ideas into the very foundation of mathematics. On the one hand, there is Voevodsky's subtle and beautiful *univalence axiom*. The univalence axiom implies, in particular, that isomorphic structures can be identified, a principle that mathematicians have been happily using on workdays, despite its incompatibility with the "official" doctrines of conventional foundations. On the other hand, we have *higher inductive types*, which provide direct, logical descriptions of some of the basic spaces and constructions of homotopy theory: spheres, cylinders, truncations, localizations, etc. When combined in homotopy type theory, these innovations permit an entirely new kind of "logic of homotopy types."

This suggests a new conception of foundations of mathematics with intrinsic homotopical content, an "invariant" conception of the objects of mathematics, and convenient machine implementations, which can serve as a practical aid to the working mathematician. This is the univalent foundations program. The present book is intended as a first systematic exposition of the basics of univalent foundations and a collection of examples of this new style of reasoning—but without requiring the reader to know or learn any formal logic or to use any computer proof assistant.

We emphasize that homotopy type theory is a young field, and univalent foundations is very much a work in progress. This book should be regarded as a "snapshot" of the state of the field at the time it was written, rather than a polished exposition of an established edifice. As we will discuss briefly later, there are many aspects of homotopy type theory that are not yet fully understood—but as of this writing, its broad outlines seem clear enough. The eventual theory will probably not look exactly like the one described in this book, but it will certainly be at least as capable and powerful; given the results presented here, we therefore believe that univalent foundations could eventually replace set theory as the "implicit foundation" for the un-formalized mathematics done by most mathematicians.

The basic idea of the univalence axiom can be explained as follows. In type theory, one can have a universe U, the terms of which are themselves types, $A : U$, etc. Those types that are terms of U are commonly called small types. Like any type, U has an identity type Id_U, which expresses the identity relation $A = B$ between small types. Thinking of types as spaces, U is a space, the points of which are spaces; to understand its identity type, we must ask, what is a path between spaces in U? The univalence axiom says that such paths correspond to homotopy equivalences $A \simeq B$. At the risk of oversimplifying, we can state this succinctly as follows:

Univalence Axiom: $(A = B) \simeq (A \simeq B)$.

In other words, identity is equivalent to equivalence. In particular, one may say that "equivalent types are identical."

From the homotopical point of view, univalence implies that spaces of the same homotopy type are connected by a path in the universe U, in accord with the intuition of a classifying space for (small) spaces. From the logical point of view, however, it is a radically new idea: it says that isomorphic things can be identified! Mathematicians are of course used to identifying isomorphic structures in practice, but they generally do so by "abuse of notation," or some other informal device, knowing that the objects involved are not "really" identical. But in this new foundational scheme, such structures can be formally identified, in the logical sense that every property or construction involving one also applies to the other. Indeed, the identification is now made explicit and properties and constructions can be systematically transported along it. Moreover, the different ways in which such identifications may be made themselves form a structure that one can (and should!) take into account.

By using the identification of paths with identities in homotopy type theory, these sorts of "inductively defined spaces" can be characterized in type theory by "induction

(Continued on page 8)

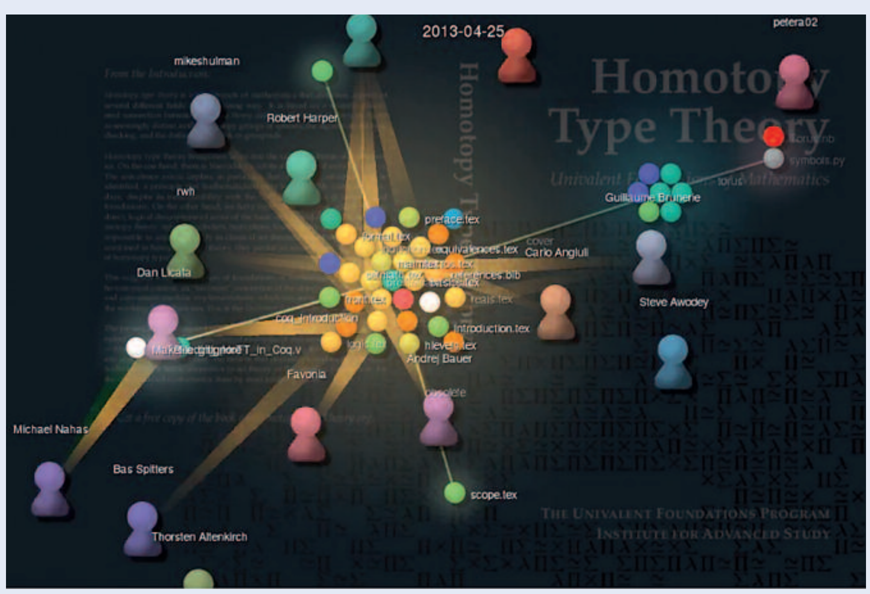
Socio-Technological Aspects of Making the HoTT Book

BY ANDREJ BAUER

Since spring, and even before that, I have participated in a great collaborative effort to write a book on homotopy type theory. It is finally finished and ready for public consumption. You can get the book freely at http://homotopytypetheory.org/book/. Mike Shulman has written about the contents of the book (http://golem.ph.utexas.edu/category/2013/06/the_hott_book.html), so I am not going to repeat that here. Instead, I would like to comment on the socio-technological aspects of making the book and in particular about what we learned from the open-source community about collaborative research.

We are a group of two dozen mathematicians who wrote a six-hundred-page book in less than half a year. This is quite amazing since mathematicians do not normally work together in large groups. A small group can get away with using obsolete technology, such as sending each other source LaTeX files by email, but with two dozen people even Dropbox or any other file synchronization system would have failed miserably. Luckily, many of us are computer scientists disguised as mathematicians, so we knew how to tackle the logistics. We used Git and GitHub.com. In the beginning, it took some convincing and getting used to, although it was not too bad. In the end, the repository served not only as an archive for our files but also as a central hub for planning and discussions. For several months, I checked GitHub more often than email and Facebook.

Recommended Viewing: An animated visualization of the GitHub collaborations of over two dozen mathematicians working on the HoTT book over a period of six months may be viewed at http://vimeo.com/68761218/.



ANDREJ BAUER

But more importantly, the spirit of collaboration that pervaded our group at the Institute for Advanced Study was truly amazing. We did not fragment. We talked, shared ideas, explained things to each other, and completely forgot who did what (so much in fact that we had to put some effort into reconstruction of history lest it be forgotten forever). The result was a substantial increase in productivity. There is a lesson to be learned here (other than the fact that the Institute is the world's premier research institution), namely that mathematicians benefit from being a little less possessive about their ideas and results. I know, I know, academic careers depend on proper credit being given and so on but really those are just the idiosyncrasies of our time. If we can get mathematicians to share half-baked ideas, not to worry who contributed what to a paper, or even who the authors are, then we will reach a new and unimagined level of productivity. Progress is made by those who dare to break the rules.

Truly open research habitats cannot be obstructed by copyright, publishers, patents, commercial secrets, and funding schemes that are based on faulty achievement metrics. Unfortunately, we are all caught up in a system that suffers from all of these evils. But we made a small step in the right direction by making the book source code freely available under a permissive Creative Commons license. Anyone can take the book and modify it, send us improvements and corrections, translate it, or even sell it without giving us any money. (If you twitched a little bit when you read that sentence, the system has gotten to you.)

(Continued on page 8)

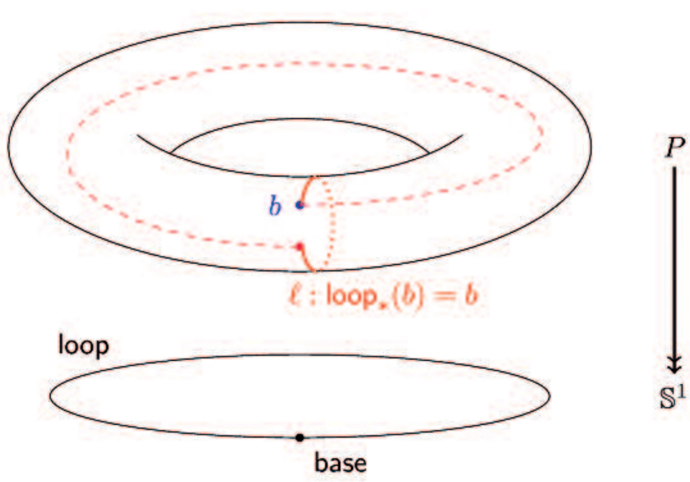
HOMOTOPY TYPE THEORY *(Continued from page 7)*

principles," entirely analogous to classical examples such as the natural numbers and the disjoint union. The resulting higher inductive types give a direct "logical" way to reason about familiar spaces such as spheres, which (in combination with univalence) can be used to perform familiar arguments from homotopy theory, such as calculating homotopy groups of spheres, in a purely formal way. The resulting proofs are a marriage of classical homotopy-theoretic ideas with classical type-theoretic ones, yielding new insight into both disciplines.

Moreover, this is only the tip of the iceberg: many abstract constructions from homotopy theory, such as homotopy colimits, suspensions, Postnikov towers, localization, completion, and spectrification, can also be expressed as higher inductive types.... Thus, the combination of univalence and higher inductive types suggests the possibility of a revolution, of sorts, in the practice of homotopy theory.

One difficulty often encountered by the classical mathematician when faced with learning about type theory is that it is usually presented as a fully or partially formalized deductive system. This style, which is very useful for proof-theoretic investigations, is not particularly convenient for use in applied, informal reasoning. Nor is it even familiar to most working mathematicians, even those who might be interested in foundations of mathematics. One objective of the present work is to develop an informal style of doing mathematics in univalent foundations that is at once rigorous and precise, but is also closer to the language and style of presentation of everyday mathematics.

In present-day mathematics, one usually constructs and reasons about mathematical objects in a way that could in principle, one presumes, be formalized in a system of elementary set theory, such as ZFC (the Zermelo–Fraenkel axioms plus the axiom of choice)—at least given enough ingenuity and patience. For the most part, one does not even need to be aware of this possibility, since it largely coincides with the condition that a proof be "fully rigorous" (in the sense that all mathematicians have come to understand intuitively through education and experience). But one does need to learn to be careful about a few aspects of "informal set theory": the use of collections too large or inchoate to be sets; the axiom of choice and its equivalents; even (for undergraduates) the method of proof by contradiction; and so on. Adopting a new foundational system such as homotopy type theory as the implicit formal basis of informal reasoning will require adjusting some of one's instincts and practices. The present text is intended to serve as an example of this "new kind of mathematics," which is still informal, but could now in principle be formalized in homotopy type theory, rather than ZFC, again given enough ingenuity and patience.



A figure from the book Homotopy Type Theory*, illustrating the principle of "circle induction." In homotopy type theory, basic geometric objects such as the circle are implemented using the same kind of inductive definitions typically used for the natural numbers, allowing for reasoning "by induction" in an entirely new form. In this case, if a property holds at the base point, and it holds "continuously in the loop," then it holds everywhere on the circle.*

It is worth emphasizing that, in this new system, such formalization can have real practical benefits. The formal system of type theory is suited to computer systems and has been implemented in existing proof assistants. A proof assistant is a computer program that guides the user in construction of a fully formal proof, only allowing valid steps of reasoning. It also provides some degree of automation, can search libraries for existing theorems, and can even extract numerical algorithms from the resulting (constructive) proofs.

We believe that this aspect of the univalent foundations program distinguishes it from other approaches to foundations, potentially providing a new practical utility for the working mathematician. Indeed, proof assistants based on older type theories have already been used to formalize substantial mathematical proofs, such as the four-color theorem and the Feit–Thompson theorem. Computer implementations of univalent foundations are presently works in progress (like the theory itself). However, even its currently available implementations (which are mostly small modifications to existing proof assistants such as Coq) have already demonstrated their worth, not only in the formalization of known proofs but in the discovery of new ones. Indeed, many of the proofs described in this book were actually first done in a fully formalized form in a proof assistant and are only now being "unformalized" for the first time—a reversal of the usual relation between formal and informal mathematics.

One can imagine a not-too-distant future when it will be possible for mathematicians to verify the correctness of their own papers by working within the system of univalent foundations, formalized in a proof assistant, and that doing so will become as natural as typesetting their own papers in TeX. (Whether this proves to be the publishers' dream or their nightmare remains to be seen.) In principle, this could be equally true for any other foundational system, but we believe it to be more practically attainable using univalent foundations, as witnessed by the present work and its formal counterpart. ■

MAKING THE HoTT BOOK *(Continued from page 7)*

We decided not to publish the book with an academic publisher at present because we wanted to make it available to everyone fast and at no cost. The book can be freely downloaded, as well as bought inexpensively in hardcover and paperback versions from Lulu.com. (When was the last time you paid under $30 for a six-hundred-page hardcover academic monograph?) Again, I can sense some people thinking, "Oh, but a real academic publisher bestows quality." This sort of thinking is reminiscent of Wikipedia vs. *Britannica* arguments, and we all know how that story ended. Yes, good quality research must be ensured. But once we accept the fact that anyone can publish anything on the Internet for the whole world to see and make a cheap, professional-looking book out of it, we quickly realize that censure is not effective anymore. Instead we need a decentralized system of endorsements that cannot be manipulated by special interest groups. Things are moving in this direction with the recently established Selected Papers Network (https://selectedpapers.net) and similar efforts. I hope these will catch on.

The spirit of collaboration that pervaded our group at the Institute for Advanced Study was truly amazing. We did not fragment. We talked, shared ideas, explained things to each other, and completely forgot who did what. The result was a substantial increase in productivity.

However, there is something else we can do. It is more radical but also more useful. Rather than letting people only evaluate papers, why not give them a chance to participate and improve them as well? Put all your papers on GitHub and let others discuss them, open issues, fork them, improve them, and send you corrections. Does it sound crazy? Of course it does. Open source also sounded crazy when Richard Stallman announced his manifesto. Let us be honest, who is going to steal your LaTeX source code? There are much more valuable things to be stolen. If you are a tenured professor, you can afford to lead the way. Have your grad student teach you Git and put your stuff somewhere publicly. Do not be afraid; they tenured you to do such things.

We are inviting everyone to help us improve the HoTT book by participating on GitHub. You can leave comments, point out errors, or even better, make corrections yourself! We are not going to worry about who you are, how much you are contributing, and who shall take credit. The only thing that matters is whether your contributions are any good.

My last observation is about formalization of mathematics. Mathematicians like to imagine that their papers could in principle be formalized in set theory. This gives them a feeling of security, not unlike the one experienced by a devout man entering a venerable cathedral. It is a form of faith professed by logicians. Homotopy type theory is an alternative foundation to set theory. We too claim that ordinary mathematics can in principle be formalized in homotopy type theory. But you do not have to take our word for it! We have formalized the hardest parts of the HoTT book and verified the proofs with computer proof assistants. Not once but twice. And we formalized first, then we wrote the book, because it was easier to formalize. We win on all counts (if there is a race). I hope you like the book. It contains an amazing amount of new mathematics. ■

Andrej Bauer, Member (2012) in the School of Mathematics, is broadly interested in computation and the computational nature of mathematics, approaching the subject through logic, category theory, type theory, and constructive mathematics. He also works on mathematical foundations of programming languages with emphasis on their mathematical semantics. The text excerpted here first appeared at http://math.andrej.com/2013/06/20/the-hott-book/.

How Open-Source Ideas Can Help Us Study Exoplanets

BY HANNO REIN

Pluto, the ninth planet in our solar system[1] was discovered in 1930, the same year the Institute was founded. While the Institute hosted more than five thousand members in the following sixty-five years, not a single new planet was discovered during the same time.

Finally, in 1995, astronomers spotted an object they called 51 Pegasi b. It was the first discovery of a planet in over half a century. Not only that, it was also the first planet around a Sun-like star outside our own solar system. We now call these planets extrasolar planets, or in short, exoplanets.

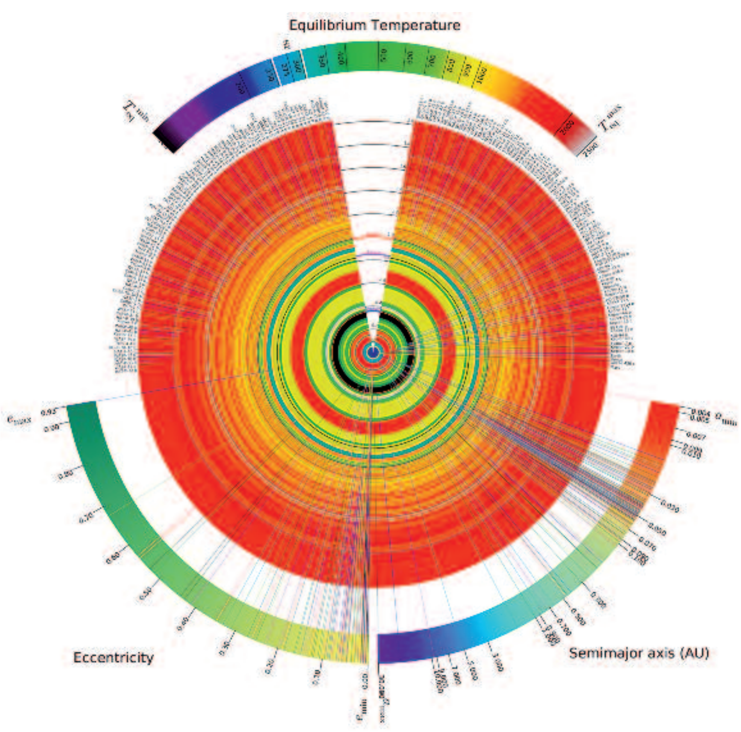
As it turns out, 51 Pegasi b is a pretty weird object. It is almost as massive as Jupiter, but it orbits its host star in only four days. Jupiter, as a comparison, needs twelve years to go around the Sun once. Because 51 Pegasi b is very close to the star, its equilibrium temperature is very high. These types of planets are often referred to as "hot Jupiters."

Since the first exoplanet was discovered, the technology has improved dramatically, and worldwide efforts by astronomers to detect exoplanets now yield a large number of planet detections each year. In 2011, 189 planets were discovered, approximately the number of visiting Members at the Institute every year. In 2012, 130 new planets were found. As of May 20 of this year, the total number of confirmed exoplanets was 892 in 691 different planetary systems.

Personally, I am very interested in the formation of these systems. We have so much information about every planet in our solar system, but little is known about all of these 892 exoplanets. Digging into this limited data set and trying to find out how exoplanets obtain their present-day orbits is very exciting. Many questions pop up by just looking at 51 Pegasi b. Why is it a hundred times closer to its star than Jupiter? Did it form farther out? Was it not too different from our own Jupiter in the past? For 51 Pegasi b, we think we know the answer. We believe that it formed at a farther distance from its star where conditions such as temperature are more favorable for planet formation, and then it moved inwards in a process called planet migration. For many of the other 891 planets, the story is more complicated, especially when multiple planets are involved. The diversity of planetary systems that have been found is tremendous. We haven't discovered a single system that looks remotely similar to our own solar system. This makes exoplanetary systems so exciting to study!

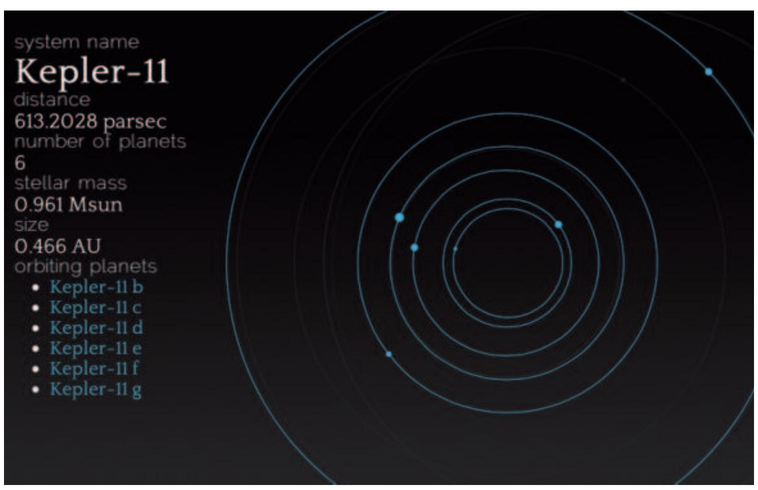
To do this kind of research, one needs a catalogue of all exoplanets. Several such databases exist, but they all share one fundamental flaw: they are not "open." These databases are maintained either by a single person or by a small group of scientists. It is impossible to make contributions to the database if one is not part of this inner circle. This bothered me because it is not the most efficient way, and it does not encourage collaboration among scientists. I therefore started a new project during my time at the Institute, the Open Exoplanet Catalogue. As the name suggests, this database, in comparison to others, is indeed "open." Everyone is welcome to contribute, make corrections, or add new data. Think of it as the Wikipedia version of an astronomical database.

The same idea has been extremely successful in the software world. With an open-source license, programmers provide anyone with the rights to study, modify, and distribute the software that they have written—for free. The obvious advantages are affordability and transparency. But maybe more importantly, perpetuity, flexibility, and interoperability are vastly improved by making the source code of software publicly available.



JORGE ZULUAGA

The customizable Comprehensive Exoplanetary Radial Chart illustrates the radii of planets according to colors that represent equilibrium temperatures, eccentricity, and other data relevant to assessing their potential habitability.



TOM HANDS

The winning submission to the Exoplanet Visualization Contest is ExoVis, an interactive website that allows one to visualize, search for, study, and compare all planetary systems in the Open Exoplanet Catalogue.

The success of the open-source movement is phenomenal. Every time you start a computer, open a web browser, or send an email, you are utilizing an open-source program, often in the background. The success story of open source is largely based on the wide adoption of distributed version-control systems.[2] These toolkits allow thousands of people to work and collaborate together on a single project. Every change ever made to any file can be traced back to an individual person. This creates a network of trust, based on human relationships. Initially, the concept of having thousands of people working on the same project may appear chaotic, risky, or plain impossible. However, studies have shown that this kind of large-scale collaboration produces software that is better[3] and more secure than using a traditional approach.

Hanno Rein, Member (2010–13) in the School of Natural Sciences, is studying the formation and evolution of planetary systems. In addition to the Open Exoplanet Catalogue, he has developed a smartphone application called Exoplanet (http://exoplanetapp.com), which has attracted almost ten million users. The application lists all extrasolar planets and features three-dimensional visualizations and an interactive model of the Milky Way. Rein describes it as similar to Google Earth, but for the entire universe. He will be joining the University of Toronto as an Assistant Professor this fall.

Recommended Reading: More information about the Open Exoplanet Catalogue, its workflow, and data format is available online at www.openexoplanetcatalogue.com/. Tom Hand's ExoVis website is hosted at www.tomhands.com/exovis/. High-resolution images of Jorge Zuluaga's Comprehensive Exoplanetary Radial Chart may be found at http://astronomia.udea.edu.co/iCERC/.

Astrophysics lags behind this revolution. While there are some software packages that are open source (and widely used), the idea of applying the same principles to data sets and catalogues is new. Extrasolar planets provide an ideal test case because the data set is generated by many different groups of observers from all around the world. Observations and discoveries are evolving so quickly that a static catalogue is not an option anymore.

To get people excited about the ideas and philosophy behind the Open Exoplanet Catalogue, I started a visualization competition, the "Exoplanet Visualization Contest," with the goal of coming up with stunning and creative ways to visualize exoplanet data. We set no restrictions to the kind of submission. The only requirement was that each submission had to use real data from the Open Exoplanet Catalogue. This led to an extremely diverse set of submissions. For example, we received publication-grade scientific plots, artistic drawings of potentially habitable exomoons, and an interactive website. One participant went so far as to design a wearable vest with built-in microcontrollers and displays that show exoplanet data. Thanks to a generous outreach grant from the Royal Astronomical Society in London, we were able to give out prizes to the best submissions. With the help of Scott Tremaine (Richard Black Professor in the School), Dave Spiegel (Member in the School), and Dan Fabrycky (Assistant Professor at the University of Chicago), two winners were chosen.

Second prize went to Jorge Zuluaga from Antioquia, Colombia. He designed a new way to present exoplanet data, such as planetary sizes and equilibrium temperatures. Those are of particular interest when it comes to determining whether a planet is potentially habitable or not. His submission, the Comprehensive Exoplanetary Radial Chart, illustrates the radii of exoplanets according to colors that represent their approximate equilibrium temperatures. The chart also shows information on planetary orbit properties, size of host stars, and potentially any other variable of interest.

The winner of the contest was Tom Hands, a Ph.D. student from Leicester. He wrote an interactive website, ExoVis, that visualizes all discovered planetary systems. The project makes use of HTML5, Javascript, jQuery, and PHP. One can search for planets, study their orbital parameters, and compare them to other systems, all within a web browser.

The Open Exoplanet Catalogue is a very new project. The crucial issue is to reach a large number of regular contributors; then, the quality of the data set will outperform all "closed" competitors in the long run in the same way Wikipedia is now much more widely used than the *Encyclopædia Britannica*. I am optimistic about the future. ■

1 Pluto was originally classified as the ninth planet in the solar system. In 2005, the International Astronomical Union decided to call Pluto a dwarf planet.

2 The most popular of those tools is Git, used by people who write the Linux kernel and many other major open-source projects.

3 In the software world, "better" is measured in units of bugs per line of code.

Studying the Shape of Data Using Topology

BY MICHAEL LESNICK

The story of the "data explosion" is by now a familiar one: throughout science, engineering, commerce, and government, we are collecting and storing data at an ever-increasing rate. We can hardly read the news or turn on a computer without encountering reminders of the ubiquity of big data sets in the many corners of our modern world and the important implications of this for our lives and society.

Our data often encodes extremely valuable information, but is typically large, noisy, and complex, so that extracting useful information from the data can be a real challenge. I am one of several researchers who worked at the Institute this year in a relatively new and still developing branch of statistics called topological data analysis (TDA), which seeks to address aspects of this challenge.

In the last fifteen years, there has been a surge of interest and activity in TDA, yielding not only practical new tools for studying data, but also some pleasant mathematical surprises. There have been applications of TDA to several areas of science and engineering, including oncology, astronomy, neuroscience, image processing, and biophyics.

The basic goal of TDA is to apply topology, one of the major branches of mathematics, to develop tools for studying *geometric features of data*. In what follows, I'll make clear what we mean by "geometric features of data," explain what topology is, and discuss how we use topology to study geometric features of data. To finish, I'll describe one application of TDA to oncology, where insight into the geometric features of data offered by TDA led researchers to the discovery of a new subtype of breast cancer.

In this article, by "data" I simply mean a finite set of points in space. In general, the space in which our points lie can have many dimensions, but for now the reader may think of the points as sitting in two or three dimensions. For a concrete example, each point in a data set in 3-D space might correspond to a tumor in a cancer study, and the x, y, and z coordinates of the point might each correspond to the level of expression of a different gene in a tissue sample of the tumor.

What, then, do I mean by "geometric features of data?" Rather than offer a formal definition, I'll give three representative examples of the sorts of geometric features of data we study in TDA. I'll take the data in each of the examples to lie in 2-D space.

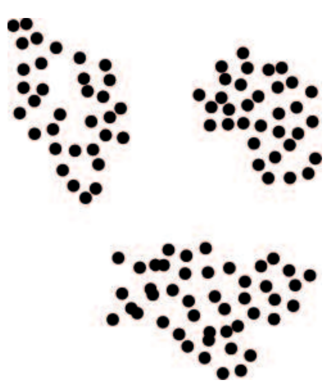


Figure 1: A data set with three clusters

As a first example, consider the data set in Figure 1. We see that the data breaks up into three distinct clusters. Clusters like these are a first type of geometric feature of data we study in TDA. We'd like to count the number of distinct clusters in the data and partition the data into its clusters. We'd like to be able to do this even when the cluster structure of the data is corrupted by noise, as in Figure 2.

The problem of detecting clusters in data is in fact an old and well-studied problem in statistics and computer science, but TDA has recently introduced some new ideas and tools to the problem.[1]

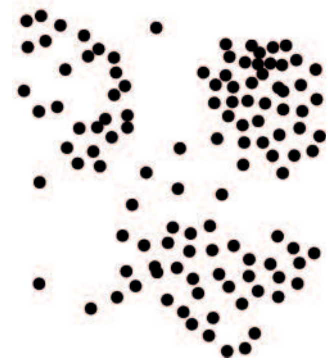


Figure 2: A data set with three noisy clusters

A second kind of geometric feature of data we study in topological data analysis is a "loop." Figure 3 gives an example of a loop in a data set. Again, we'd like to be able to detect a loop in a data set even when it is corrupted by noise, as in Figure 4.

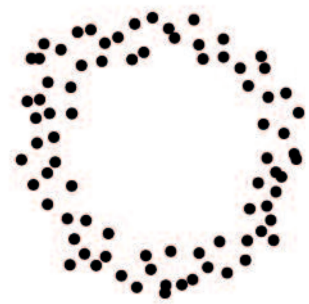


Figure 3: A data set with a loop

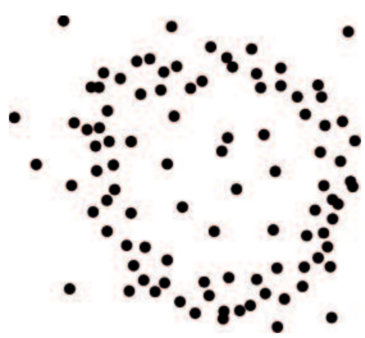


Figure 4: A data set with a noisy loop

A third kind of geometric feature we study in TDA is a "tendril." Figure 5 depicts a data set with three tendrils emanating from a central core. In a data set with this sort of structure, we'd like to detect the presence of the tendrils, count the tendrils, and partition the data into its different tendrils.

The objective of research in TDA is to develop tools to detect and visualize these kinds of geometric features, and to develop methodology for quantifying the statistical significance of such features in randomly sampled data. Because much of the data arising in scientific applications lives in high-dimensional spaces, the focus is on developing tools suitable for studying geometric features in high-dimensional data.

Figure 5: A data set with three tendrils emanating from a central core

Why, though, should we be interested in studying such features of data in the first place? The key premise behind this line of research is that *insight into the shape of scientifically relevant data has a good chance of giving insight into the science itself*.

Experience has shown that this premise is a reasonable one. Cluster analysis is used as a matter of course throughout the experimental sciences to extract scientific information from data;[2] the study of loops and their higher-dimensional analogues has recently offered insight into questions in biophysics[3] and natural-scene statistics;[4] and, as I will describe in the last section of this article, the study of tendrils has recently offered insight into oncology.[5]

As noted above, TDA studies the geometric features of data using topology. Topology is the study of the properties of a geometric object that are preserved when we bend, twist, stretch, and otherwise deform the object without tearing it. The primary example of such a property is the presence of *holes* in the object; as such, topology is concerned largely with the formal study of holes. (Homotopy theory, discussed in the article about the Institute's univalent foundations program on page 1, is a central part of topology. However, homotopy theory also admits an axiomatic formulation that abstracts away from the topological setting and provides a framework for the adaption of topological ideas to settings outside of topology.)

To anyone who's ever eaten a slice of swiss cheese or a doughnut, the notion of a hole in a geometric object is a familiar and intuitive one; the idea that the number of holes in a geometric object doesn't change when we bend, twist, and stretch the object is similarly intuitive.

In topology, we distinguish between several different kinds of holes. A hole at the center of a donut is an example of a first kind of hole; the hollow space inside an inflated, tied ballon is an example of a second kind of hole. In geometric objects in more than three dimensions, we may also encounter other kinds of holes that cannot appear in objects in our three-dimensional world.

As intuitive as the notion of a hole is, there is quite a lot to say about holes, mathematically speaking. In the last century, topologists have put great effort into the study of holes, and have developed a rich theory with fundamental connections to most other areas of modern mathematics. One feature of this theory is a well-developed set of formal tools for computing the number of holes of different kinds in a geometric object. TDA aims to put this set of tools to use in the study of data. Computations of the number of holes in a geometric object can be done automatically on a computer, even when the object lives in a high-dimensional space and cannot be visualized directly.

Besides the number of holes in an object, another (very simple) property of a geometric object that is preserved under bending, twisting, and stretching is the number of components (i.e. separate pieces) making up the object. For example, a plus sign + is made up of one component, an equals sign = is made up of two components, and a division sign ÷ is made up of three components. Deforming any of these symbols without tearing does not change the number of components in the symbol. We regard the problem of computing the number of components that make up a geometric object as part of topology. In fact, in a formal sense, this problem turns out to be closely related to the problem of computing the number of holes in a geometric object, and topologists think of these two problems as two sides of the same coin.

How do we use topology to study the geometric features of data? Without pretending to give a full answer to this question, I'll mention some of the basic ideas. To begin,

(Continued on page 11)

 (Continued from page 10)

I'll describe a primitive strategy for studying data using topology that, while unsatisfactory for most applications, is the starting point for what is done in practice.

As mentioned above, topology offers tools for computing numbers of holes and components in a geometric object; we would like to apply these tools to our study of data. However, a data set X of n points in space has n components and no holes at all, so directly computing the numbers of holes and components of X will not tell us anything interesting about the geometric features of X.

To study X using topology then, we will consider not the topological properties of X directly, but rather the topological properties of a "thickening" of X.

I'll explain this in detail. Assume that X is a finite set of points in the plane (2-D space). Let δ be a positive number, and let $T(X, \delta)$ be the set of all points in the plane within distance δ from some point in X; we think of $T(X, \delta)$ as a "thickening" of the data set X.

For example, let X_1 be the data set of Figure 1. Figure 6 shows $T(X_1, \delta_1)$ in red for some choice of positive number δ_1, together with the original data X_1 in black. For a second example, let X_2 be the data set of Figure 3. Figure 7 shows $T(X_2, \delta_2)$ in red, for some choice of positive number δ_2, together with X_2 in black. For especially nice data sets X and good choices of δ, the clusters in X will correspond to components of $T(X, \delta)$ and the loops in X will correspond to holes in $T(X, \delta)$. For instance, in Figure 6 the clusters in X_1 correspond to the components of $T(X_1, \delta_1)$, and in Figure 7 the loop in X_2 corresponds to the hole in $T(X_2, \delta_2)$.

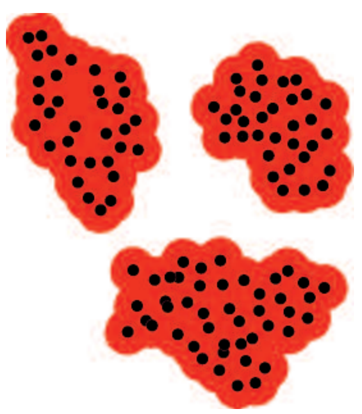


Figure 6: $T(X_1,\delta_1)$, for some choice of δ_1, is shown in red; X_1 is shown in black.

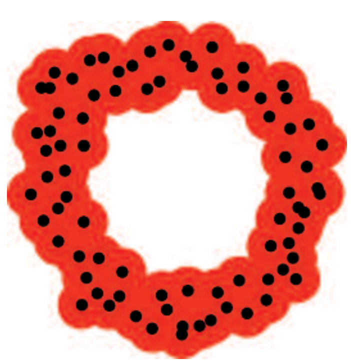


Figure 7: $T(X_2,\delta_2)$, for some choice of δ_2, is shown in red; X_2 is shown in black.

Thus, for nice data sets X, we can get insight into the geometric features of X by studying the topological properties of $T(X, \delta)$. The same strategy also works for studying the geometric features of a data set sitting in a high-dimensional space, in which case the data cannot be visualized directly.

Most data sets we encounter in practice are not as nice as those of Figures 1 and 3, and though the primitive TDA strategy we have described does extend to data in high-dimensional spaces, for typical data sets X in any dimension, the strategy has several critical shortcomings. For one, the topological properties of $T(X, \delta)$ can depend in a very sensitive way on the choice of δ, and a priori it is not clear what the correct choice of δ should be, or if a correct choice of δ exists at all, in any sense. Also, the topological properties of $T(X, \delta)$ are not at all robust to noise in X, so that this strategy will not work for studying the geometric features of noisy data sets, such as those in Figures 2 and 4. Moreover, this approach to TDA is not good at distinguishing small geometric features in the data from large ones.

Thus, for dealing with most data one encounters in practice, more sophisticated variants of this basic strategy are required. Much of the recent research in TDA has been focused on developing such variants. One central idea in this direction is that it is much better to consider at once the topological properties of the entire family of objects $T(X, \delta)$ as δ varies than it is to consider the topological properties of $T(X, \delta)$ for a single choice of δ. This is the idea behind *persistent homology*, a key technical tool in TDA.

The problem of studying tendrils in data is closely related to the problem of studying clusters. To see this, consider Figure 8, where the points in the central core of the data in Figure 5 are shown in green. If we were to have a principled way of identifying the central core of the data, then by removing that central core, we would obtain a data set with three distinct clusters, as in Figure 9, where each cluster corresponds to a tendril in the original data set. It is natural to expect, then, that some of the topological tools that are useful for studying clusters can be extended to the study[5] of tendrils, and in fact this is the case.

Figure 8: The central core of the data set of Figure 5

Figure 9: When we remove the central core of the data set of Figure 5, we get a data set with three clusters.

In work published in 2011 by Monica Nicolau, Gunnar Carlsson, and Arnold Levine (Professor Emeritus in the School of Natural Sciences),[5] insight offered by TDA into the geometric features of data led the authors to the discovery of a new subtype of breast cancer.

The authors studied a data set describing the gene expression profiles of 295 breast cancer tumors, each from a unique patient. The data set consists of 295 points sitting in a 24,479-dimensional space: each point corresponds to one tumor and, roughly speaking, each of the 24,479 coordinates of the point specifies the level of expression of one gene in a tissue sample of the corresponding tumor.

To begin their analysis of the data, the researchers mapped the data from the 24,479-dimensional space into a 262-dimensional space in a way that preserved aspects of the geometric structure of the data relevant to cancer, while eliminating aspects of that structure not relevant to cancer.

The work of Michael Lesnick, Member (2012–13) in the School of Mathematics, focuses on the theoretical foundations of topological data analysis.

The researchers then studied the geometric features of the data in 262-dimensional space using a TDA tool called Mapper.[6] They discovered a three-tendril structure in the data loosely analogous to that in the data of Figure 5. In addition, they found that one of these tendrils decomposes further, in a sense, into three clusters. One of these three clusters, they observed, corresponds to a distinct subtype of breast cancer tumor that had hitherto not been identified. This subtype, which the authors named *c-MYB*$^{+}$, comprises 7.5 percent of the data set (22 tumors). Tumors belonging to the *c-MYB*$^{+}$ subtype are genetically quite different than normal tissue, yet patients whose tumors belonged to this subtype had excellent outcomes: their cancers never metastasized, and their survival rate was 100 percent.

A standard approach to the classification of breast cancers, based on clustering, divides breast cancers into five groups. The *c-MYB*$^{+}$ subtype does not fit neatly into this classification scheme: the *c-MYB*$^{+}$ tumors divide among three of the five groups. The results of Nicolau, Carlsson, and Levine thus suggest a nuance to the taxonomy of breast cancer not accounted for in the standard classification model.

These results illustrate how the tools of TDA can be useful in helping researchers tease out some of the scientific information encoded in their high-dimensional data. They are just one of a growing number of examples where TDA has facilitated the discovery of interesting scientific information from data. Still, in spite of good progress in the field over the last several years, there's still much to be done in terms of fleshing out the mathematical and statistical foundations of TDA, and in terms of algorithm and software development. The shared hope among researchers in the field is that by advancing the theory and tools of TDA, we can lay the groundwork for the discovery of new applications of TDA to the sciences.

For further details about TDA, see any of the several surveys available on TDA,[7-9] or the book.[10] ■

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2 Anil K. Jain, M. Narasimha Murty, and Patrick J. Flynn, "Data Clustering: A Review," *ACM Computing Surveys (CSUR)* 31, no. 3 (1999): 264–323.

3 Marcio Gameiro, Yasuaki Hiraoka, Shunsuke Izumi, Miroslav Kramar, Konstantin Mischaikow, and Vidit Nanda, "Topological Measurement of Protein Compressibility via Persistence Diagrams," MI Preprint Series 2012-6, Faculty of Mathematics, Kyushu University, 2012.

4 Gunnar Carlsson, Tigran Ishkhanov, Vin De Silva, and Afra Zomorodian, "On the Local Behavior of Spaces of Natural Images," *International Journal of Computer Vision* 76, no. 1 (2008): 1–12.

5 Monica Nicolau, Arnold J. Levine, and Gunnar Carlsson, "Topology-Based Data Analysis Identifies a Subgroup of Breast Cancers with a Unique Mutational Profile and Excellent Survival," *Proceedings of the National Academy of Sciences* 108, no. 17 (2011): 7265–70.

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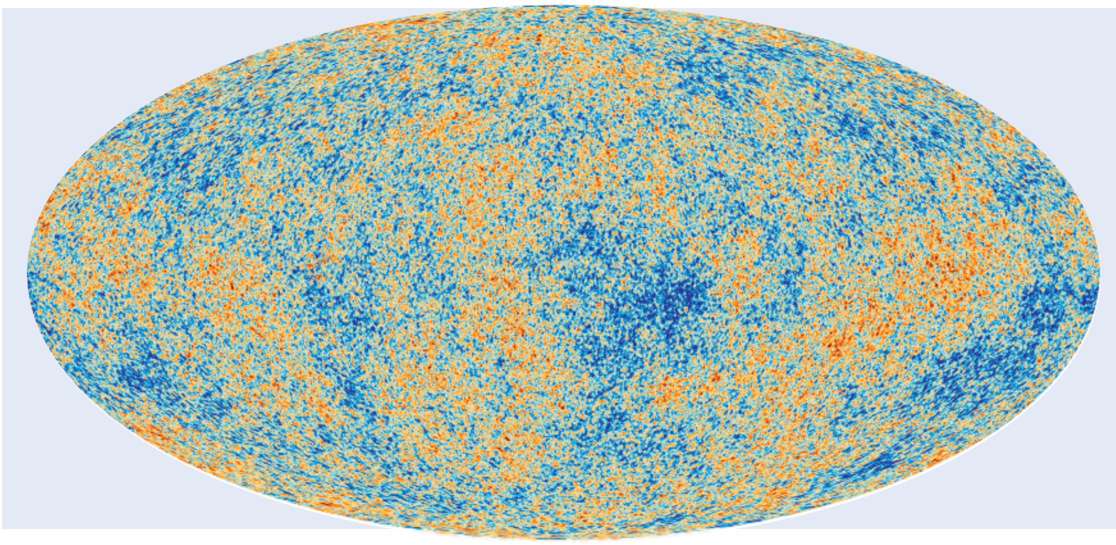
Most Detailed Map of Infant Universe Shows Conditions for Structure Formation

The most detailed map of the infant universe to date was publicly released in March, showing relic radiation from the Big Bang, imprinted when the universe was just 380,000 years old. This was the first release of cosmological data from the Planck satellite, a mission of the European Space Agency that was initiated in 1996 and involved hundreds of scientists in over thirteen countries. In a lecture in May, Matias Zaldarriaga, Professor in the School of Natural Sciences, explained how theoretical models allowed the Planck team to determine the composition of the universe, map the seeds for the formation of structure, and confirm our broad understanding of the beginnings and evolution of the universe.

Our current understanding of the history of the universe began to take shape around the 1930s, after Edwin Hubble discovered that the universe was expanding. Since then, there have been great advances in understanding the composition of the universe and how it has evolved through cosmic history. According to the standard cosmology model, in the current phase in the history of the Big Bang, the universe began about fourteen billion years ago. Initially the universe was hot and dense with interacting particles. It has been conjectured that prior to this phase, the universe underwent a brief period of accelerated expansion known as inflation when quantum fluctuations, stretched to cosmologically large scales, became the seeds of the universe's stars and galaxies.



ESA AND THE PLANCK COLLABORATION

Planck's map of the cosmic microwave background, which depicts temperature variations of the light left over from the very early universe

The Planck map—a composite made from nine maps of the sky in nine different frequencies by the Planck satellite—captures the early light from the cosmic microwave background radiation that is remnant from the Big Bang. The cosmic microwave background was first detected in 1964 and since then space, ground, and balloon-based experiments have mapped temperature variations of this light left over from the very early universe, allowing cosmologists to see if theoretical models can reproduce the formation of objects that can be seen through cosmic history. The Planck satellite is three times more sensitive than the previous satellite, the Wilkinson Microwave Anistropy Probe (WMAP), and its unprecedentedly precise map depicts "how the universe was before its structure had time to develop," said Zaldarriaga. "We are seeing the initial conditions for this process of structure formation."

According to the standard cosmology model and the latest Planck data, the universe is made up of ordinary visible matter (less than 5 percent), dark matter (about 27 percent), and dark energy (about 68 percent). Dark matter, which emits no light but exerts a gravitational pull, is believed to be a particle that was left over from the Big Bang. It has not yet been produced in a laboratory, such as the Large Hadron Collider, nor have detectors on Earth detected it, even though it is believed to pass through the planet. Even less is known about the mysterious dark energy, a uniform background field that is credited with accelerating the expansion of the universe.

Through the effect of gravitational lensing (the bending of light due to the presence of matter curving spacetime), a method first proposed by Zaldarriaga and Uros Seljak in 1999, Planck was able to map the distribution of dark matter in the universe. Through the Sunyaev-Zeldovich effect (named in part for Rashid Sunyaev, Maureen and John Hendricks Visiting Professor in the School of Natural Sciences, it identifies hot-gas regions through distortions in the cosmic microwave background radiation), Planck mapped the distribution of hot gas in the universe and discovered new clusters of galaxies.

Recommended Viewing: A video of "The Latest News from the Cosmos," a lecture by Matias Zaldarriaga, may be viewed at http://video.ias.edu/zaldarriaga-lecture-5-13/.

In the 1980s, cosmologists developed inflation models of the very early universe that incorporated our current understanding of the laws of physics—the law of general relativity to understand how gravity works, and quantum mechanics to understand how matter behaves. To explain the universe's longevity and homogeneity, theorists introduced a period of inflation before the Big Bang. Without it, a universe, behaving according to the laws of general relativity, would collapse into a black hole or become completely empty within a period of a few fractions of a second. Inflation had a surprise bonus: due to the uncertainty principles of quantum mechanics, inflation had to last longer in different regions. These tiny differences could then act as the seeds for structure.

According to inflation theory, as the universe expands exponentially fast, its geometry becomes flat—this geometry was confirmed experimentally around 2000. Theorists then had to use the laws of physics to solve the "graceful exit" problem of how to make the inflation stop so that the universe cools and structure starts to form. "In a sense, the material that filled the universe at the time of inflation had to act like a clock," said Zaldarriaga. "The universe was expanding and at some point it had to stop this inflationary period to start something new." Quantum mechanics then provides a source for fluctuations.

While Planck and WMAP have confirmed major details of inflation theory, in the coming months and years, cosmologists will try to explain some small anomalies in the Planck data, zero in on the correct prediction for identifying the physical system that stops the inflationary period, and develop better methods for detecting signatures of gravitational waves, which are believed to have been produced during inflation and could have shown up in the Planck data but haven't yet.

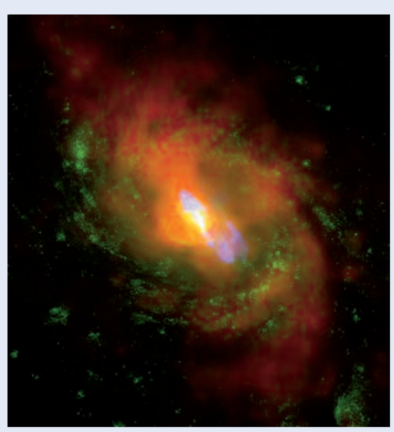
Only more data, more observations, and more thinking will help cosmologists resolve what Zaldarriaga described as cosmology's chicken (universe) and egg (inflation) problem, which leads to a range of possible solutions including the existence and collision of multiple chickens (and eggs) within the larger structure of a multiverse. "We have beautiful pictures of this chicken as it grows up," said Zaldarriaga. "Of course the first question everybody asks is 'Where does the chicken come from?' Our theory friends in the '80s came up with the idea that the chicken comes from an egg. If we say the chicken comes from an egg, where does the egg come from? It comes from a chicken. . . . Of course, we don't know exactly what eggs should look like. The obvious thing to do is to try to get better pictures of the early universe, of some property of this egg that we can compute, and then see if it matches what we are now saying an egg might look like. This is how we can make progress, and this is what we are trying to do."

—Kelly Devine Thomas, Senior Publications Officer, kdthomas@ias.edu

Black Holes and the Birth of Galaxies

Galaxies are the visible building blocks of the universe, astrophysical laboratories that have profoundly informed our knowledge of cosmology and nature. Black holes—once a bizarre mathematical consequence of Einstein's relativity theory—are now mainstream astronomy, thanks to studies of the centers of nearby galaxies where these exotic objects are routinely found. In May, Nadia Zakamska, former John N. Bahcall Fellow and Member (2005–10) in the School of Natural Sciences and Assistant Professor at Johns Hopkins University, described the basic theory of galaxy formation and shared insight into the complex interrelationship between supermassive black holes and their host galaxies.

According to basic galaxy formation theory, the universe consists of galaxies composed of billions to trillions of stars that form around a filamentary network of mysterious yet powerful dark matter that dominates gravity. It appears that almost every massive galaxy has a supermassive black hole in its center, which can be detected by its gravitational pull on surrounding stars in our own galaxy and by a characteristic stellar velocity pattern toward the center of other galaxies. The first galaxies formed from small quantum fluctuations that grew into gas that cooled and condensed into stars due to gravitational attraction; the first stellar black holes, which increase their size by consuming nearby stars and gas, were produced from explosions of massive stars (supernovae).



NASA/CXC/MIT/C. CANIZARES, D. EVANS, ET AL/STSCI/NSF/NRAO/VLA

A composite image showing wind from a supermassive black hole in the center of NGC 1068, a nearby galaxy

Aside from wanting to determine the composition of dark matter, cosmologists are also trying to understand why the current theory predicts the wrong number of galaxies. A possible explanation, which cosmologists are trying to match with observation, is that supermassive black hole winds, created when too much matter falls into the black hole, clear off the gas from its host galaxy and halt star formation. "This is a self-regulation process," said Zakamska. "If the galaxy tries to feed too much mass into the black hole, the black hole produces a powerful wind, shuts off the star formation, and stops its own feeding." A video of Zakamska's lecture "Gone with the Wind: Black Holes and their Gusty Influence on the Birth of Galaxies," sponsored by the Association of Members of the Institute for Advanced Study (AMIAS), may be viewed at http://video.ias.edu/zakamska-lecture-5-13/.

were very important to astrologers, they had no lasting effect on astronomical thinking at the time. Tycho, however, realized that such an event was revolutionary. By accurately and repeatedly measuring the position of the "nova," Tycho showed that it was much further than the moon. In one night, Tycho managed to scientifically falsify the millennia-old Aristotelian belief that anything beyond the sphere of the moon cannot change. This convinced Tycho that the "known" cosmology was wrong and motivated him to devote his life to performing measurements of stars and planets to study the "true" cosmology. His hard, lifelong work paid off. His careful measurements of the positions of the planets enabled the discovery of the law of gravity by Johannes Kepler and Isaac Newton. Kepler would later say that if Tycho's star did nothing else, it produced a great astronomer. Yet, even Tycho and Kepler could not have appreciated that what seemed like a new star was actually an explosion of unimaginable power and that such explosions are crucial for our existence.

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Tycho Brahe described his observations of a new star in the constellation Cassiopeia in his book De Nova Stella *(1573). This engraving appeared in a 1632 English translation of the book.*

Tycho's "nova" faded from sight about eighteen months after its discovery. However, modern instruments reveal a spectacular sight at the position recorded by Tycho. Observations of the same spot in the sky by NASA's Chandra X-ray observatory, nearly five centuries later, show material expanding with velocities of thousands of kilometers per second with a mass of a few billion billion billion tons, comparable to that of the Sun. Tycho had evidenced a powerful explosion, which we now term "supernova." The huge amount of energy released in a few months is equivalent to the output of a few billion billion billion H-bombs. At the current rate of emission, it would take our Sun several billion years, of order of its lifetime, to release the same amount of energy. This phenomenon turned out to be very rare, occurring roughly once per century within a galaxy like our own. While supernovae have not been detected in the Milky Way during the last three centuries, modern technology has allowed thousands of supernovae to be detected in other galaxies. Supernovae are not just beautiful cosmic fireworks—many of the elements that are essential for life, such as calcium and iron, are believed to have been produced by supernovae.

But what causes these explosions? There are currently two explanations involving theoretical mechanisms that are related to the two ways in which stars die. Stars cannot shine forever for the simple reason that their energy supply—nuclear burning—is finite. What happens to stars once they exhaust their nuclear fuel (mainly hydrogen) is believed to depend crucially on their mass. One of the most important theoretical discoveries in astrophysics is that a critical mass exists above which stars cannot sustain themselves against their own gravitational pull without a continuous supply of energy. The two types of star endings depend on whether their mass is above or below this critical mass, which is called the Chandrasekhar mass limit, named after Subrahmanyan Chandrasekhar (Member, 1941, 1976), one of its discoverers. If, by the time a star exhausts its fuel, it has a mass greater than this limit, the core of the star cannot sustain itself and collapses. A huge amount of energy is released when the core collapses to the tiny size of a few kilometers, becoming a black hole or a neutron star. While most of this energy is emitted in invisible neutrinos, a small fraction of this energy ejects the outer parts of the star, creating an explosion sufficient to produce a supernova. Such a theoretical event is called a core-collapse supernova.

Astrophysical objects with known intrinsic luminosity are rare and precious, and type Ia supernovae are one of the few such "standard candles" that can be seen from cosmological distances.

Stars that are less massive than the Chandrasekhar mass limit, or lose enough mass during their life to become so, are able to resist gravity once their nuclear fuel is exhausted. Gravity does manage to shrink them considerably, however, and they settle at a radius of a few thousand kilometers. Such dense stars, with a mass comparable to that of the Sun (one million times the mass of Earth) and a size comparable to that of Earth, are called white dwarfs. These stars are abundant and have been extensively studied observationally and theoretically. Without their previous nuclear energy supply, white dwarfs slowly become dimmer and eventually become unobservable. While white dwarfs are stable, their exceptional high density make them very powerful thermonuclear bombs. If properly ignited, white dwarfs are capable of powerful thermonuclear explosions with a sufficient energy release to account for a supernova. Such theoretical events are called thermonuclear supernovae. An appealing aspect of theories involving nuclear energy is that they naturally explain why the energy-per-unit mass released by supernovae is comparable to that of H-bombs and our Sun. Yet neither core collapse in massive stars nor thermonuclear explosions of white dwarfs have been theoretically established to account for the supernovae that we see. While core collapse is likely inevitable, it has not been shown that the outer parts can be ejected successfully. While white dwarfs can explode if ignited, a robust ignition mechanism has not been identified. Yet the two explosion mechanisms are widely believed to occur, based on several successes for explaining supernovae observations and given that we simply do not have better ideas.

Perhaps the best clues for identifying an explosion mechanism have come from a few nearby supernovae where a star, located in pre-explosion images at the precise position of the supernovae, had disappeared in images taken after the supernova had faded away. In all of these cases, the exploding star was massive and at a late stage of its life in accordance with the core-collapse theory. This scenario was confirmed for the famous supernova that exploded in the Large Magellanic Cloud galaxy in 1987—the closest among these supernovae—in which the predicted neutrino burst was detected.

However, core collapse of massive stars cannot account for all of the supernovae. A significant fraction of supernovae occur in elliptical galaxies where massive stars simply do not exist. These massive stars have lifetimes of only millions of years and have long died in elliptical galaxies where stars have ceased forming for billions of years. Interestingly, it turns out that all supernovae that occur in such old stellar environments seem to share many distinctive emission properties, belonging to a separable class called type Ia. These supernovae are distinct by not showing any trace of hydrogen and helium, the most abundant elements in the universe, but exhibiting significant abundance of much heavier elements such as silicon, nickel, and iron. These features are naturally explained if these supernovae are the thermonuclear explosions of white dwarfs, which are abundant in all stellar environments, including elliptical galaxies, and are predominantly made of carbon and oxygen rather than hydrogen and helium. Perhaps the strongest piece of evidence in this direction is the huge amount—a considerable fraction of the ejected materials—of the unstable isotope Ni^{56} detected in these supernovae, which is an expected outcome of a thermonuclear explosion. In fact, given the short lifetime of a few days, this isotope must have formed in the explosion itself, favoring a nuclear origin. While type Ia are the only supernovae known to occur in elliptical galaxies, they are observed to occur in all stellar environments, including spiral galaxies like our own. In particular, the supernova observed by Tycho, which occurred in our own galaxy, was a type Ia supernova. Although observations of type Ia supernovae are compatible with explosions of white dwarfs, they do not provide any hint as to why some white dwarfs suddenly explode.

Before we address the mystery behind the sudden explosion of white dwarfs, it is worth mentioning the importance of the resulting type Ia supernovae. The large amounts of Ni^{56} that are observed in these supernovae decay to Co^{56} and then to iron. Type Ia supernovae are the most efficient known production sites of iron. A significant amount of the iron in the universe, including a large fraction of Earth's mass and the iron in your blood, was produced in such supernovae. In addition, type Ia supernovae have turned out to be very useful tools for measuring fundamental properties of the observable universe. Among the wide variety of supernovae, type Ia are the brightest and comprise a relatively homogeneous group. Their high brightness allows them to be detected clearly across the observable universe. Their homogeneity allows a calibration of their intrinsic luminosity, which enables their distance to be measured. An object with a given intrinsic luminosity appears dimmer when it is more distant and brighter when it is closer, allowing a determination of its distance based on the measurement of its apparent brightness. Astrophysical objects with known intrinsic luminosity are rare and precious, and type Ia supernovae are one of the few such "standard candles" that can be seen from cosmological distances. In recent years, distances across the observable universe that were measured using type Ia supernovae led to the surprising conclusion that the expansion of the universe is accelerating, prompting fundamental modifications to the Big Bang cosmological model. The 2011 Nobel Prize in Physics was awarded to three astronomers due to this application of type Ia supernovae. The growing importance of the use of type Ia as accurate rulers for cosmological distance has strengthened the need for a firm theoretical understanding of these explosions.

This brings us back to the pressing issue of why some white dwarfs explode (about 1 percent of white dwarfs account for type Ia supernovae). During the last several decades, the standard lore has centered on increasing the mass of these white dwarfs toward the unstable Chandrasekhar limit where an explosion is assumed to occur. In the most popular scenarios, the mass of some white dwarfs grows with time, due to material deposited by a nearby companion. Despite its popularity, this scenario has never been convincingly shown to lead to an explosion, and there is observational evidence that there are not enough relevant systems to account for the rate of type Ia supernovae even if they were to explode. Also lacking an explanation is the amount of Ni^{56}, which varies by about an order of magnitude between the faintest and brightest type Ia supernovae. While the shortcomings of this Chandrasekhar model have been presented in many recent papers and reviews, it remained popular mostly due to the fact that there were no other good alternative suggestions.

We now believe we have found the solution to this problem: type Ia supernovae occur when two white dwarfs directly collide with each other. The explosion is trig-

(Continued on page 15)

Derek Bermel on Tangents, Leaps, Rigor, and Creativity

Derek Bermel, the Institute's Artist-in-Residence since 2009, organized the Edward T. Cone Concert Series and conversations with poets, writers, composers, and musicians during his appointment, which ended in June. These included performances in Wolfensohn Hall by violinist Midori, pianist Jeremy Denk, inventive groups like eighth blackbird and the Borromeo String Quartet, as well as a reading by Broadway actors of his musical Golden Motors. *He created a new series of Writers Conversations that probed the nature of creativity and collaboration with artists, poets, directors, and writers, including Steve Bodow, producer and writer for the* Daily Show, *poet Tracy K. Smith shortly before she won the Pulitzer Prize, and composer Stephen Sondheim who called art "a kind of puzzle." While at the Institute, Bermel collaborated with Helmut Hofer, Professor in the School of Mathematics, on a musical piece inspired by symplectic dynamics, a mathematical theory of dynamical systems. In February, the JACK Quartet performed Derek's clarinet quintet "A Short History of the Universe (as related by Nima Arkani-Hamed)," inspired by lectures he attended by Arkani-Hamed, Professor in the School of Natural Sciences.*

What was your approach when you first started as the Institute's Artist-in-Residence?

I'd say my approach has been fairly consistent. I've always been interested to make contact with people here. I only wish that I could have gone to more lectures, seen more presentations, participated even more. The Institute is a very rich place. There's quite a bit below the surface, and it was clear to me right from the beginning that the Faculty and Members here were all working on fascinating projects; some of them I could only grasp skeletally, nonetheless it was well worth the effort.

One of the really special things about the Institute is the abstract quality of the work being realized here. It's one thing to be at a place where everybody is working on a cure for cancer—and, in fact, folks here are working on cures for cancer!—but the majority are working on projects that can be hard to quantify, hard to articulate and make clear to those who are not specialists in their field.

The public and those who support the Institute have to embrace the central premise that this is theoretical work whose implications may be profound and wide-ranging, that there may be potent ramifications, but that the work itself may not easily be made understandable to the general population, or even to others here.

There are many overlaps between my artistic process and that of scientists, mathematicians, and scholars. I tend to look for points of intersection, and sometimes that requires following what appear to be tangents. Some might prefer the term leaps of faith, but I would just call them leaps, because points of intersection between things that don't seem obviously connected may turn out to be places where something quite startling or unusual occurs. It's true in the arts as well as in scholarly work and in the sciences.

BENTLEY DREZNER

KATE ABLUTZ

BENTLEY DREZNER

BENTLEY DREZNER

During his four years as Artist-in-Residence, Derek Bermel organized dozens of concerts and conversations with poets, writers, composers, and musicians, including (from top to bottom) the JACK Quartet (Eclectic/Electric), Bernard Woma (Mallet Madness), Christopher Taylor (Across the Continent), and Stephen Sondheim (at left with Bermel).

The late Marston Morse, Professor in the School of Mathematics, wrote an essay about mathematics and the arts and the common role of intuition. He suggested a psychological and spiritual affinity between the types of explorations pursued by the lone 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."

Yes, and then one must work backwards and try to tie that intuition to something solid. Sometimes I have the intuition, and then I work toward trying to make it real, but often I make a discovery through action, through doing. I encounter a stumbling block, a dead end that keeps giving me a disappointing result. Then I decide, "Well, if I keep ending up here, my initial premise—the way that I've begun this composition or this piece—must be wrong." Then I have to start from the disappointing place and ask, "Now, how can I reimagine it in a way that allows that truth to be manifest?" Looking for truths, which are not always convenient truths, not necessarily the truth I had been seeking, is what writing music is about for me.

There are glimpses of truths that don't immediately make sense, that are puzzles, that we see only vaguely from a distance, or that we can see just one facet of, and they may remain puzzles for our lifetimes and several more after; we may only catch a dim impression, a shadow of what they imply.

Will you talk a little bit about the piece that was inspired by Nima?

I went to a number of Nima's lectures on modified gravity. Gravity is something at once so mundane and so abstract. We feel it in our bones, yet its nature still remains elusive, like music. My piece is a musical illustration of various manifestations of gravity. I constructed the melodic/harmonic material based on notes being pulled in a particular direction, relative to other notes. One of the many things I enjoyed about Nima's lectures is that he linked so many different aspects of the universe, from the vast to the miniscule, painting a coherent picture.

I went to many lectures by other professors while I was here. Even when I didn't fully comprehend a given topic, I encountered a familiar seesaw way of thinking, sometimes methodical and sometimes intuitive. It's very similar to the way I work, veering between the two approaches. I often begin with a system of pitch, of rhythm, of timbre—or something else—and then, at some point I find that I need to abandon, or at the very least change, the system to accommodate what feels intuitively correct. That's always a very dangerous moment, simultaneously frustrating and exciting, because the implications are large. Ripples are formed that reverberate throughout the piece, throughout the world that I'm creating and defining.

The actual experience of writing is, for me, quite rigorous, and I don't think rigor by definition excludes spontaneity or creativity—on the contrary, it needs to incorporate them. For me, a piece of music must have a coherent logic to it, and it must ultimately feel inevitable, like it could not have evolved any other way. All the music I love has that quality of inevitability, and I strive for that in my own work. In other words, even though I might have encountered a crossroads while writing a work, a place where it was possible to move in one of several different directions, it should never be evident to the listener where that crossroads occurred.

How did you arrive at your program of concerts and writers conversations?

Well, I have to thank Peter Goddard for helping to engender them, and Robbert Dijkgraaf for continuing to support them. In fact, the theme of the talks was: "Artists Derek knows." The only commonality was that they were all good. Artists offer their work, and what the audience takes away is up to them. That's a precious thing about making art, and it's one of the things that I think scientists or mathematicians or scholars instinctively understand. I tried to find artists who present their work with a sense of openness, who don't ascribe to it an exact meaning; I enjoy hearing from artists who like to ask questions, not provide answers. There are so many ways in which one's work can be interpreted, and as an artist you don't have control over that. Just like as a scientist or scholar, you can't dictate what people do with the information you put out there. It really has its own life, for better or worse.

For you, what is the purpose of knowledge?

I don't know that knowledge as such exists, because knowledge is relative for every user. What's considered knowledge? What's considered to be in the canon of knowledge? What's considered "true"? If the canon of knowledge is the set of all things that we consider to be true, then I suppose the purpose of knowledge is to ask more and better questions.

But for you personally, what is its purpose?

It's fun. Knowledge is a game. It helps me make sense of life and offers me different perspectives on what is happening around me. I'd say there's nothing more stimulating than gaining a new perspective on something familiar, or at least getting a window into that different perspective, then incorporating that new slice into my understanding of the universe.

What is the question that you most want answered?

What was around before the Big Bang, if anything? I'm wary of "why" questions. I think "what" and "how" are really good questions, but the answers to "why" tend to be unsatisfying. If they're approached in a simplistic or sloppy way, they can lead to bad places. Human beings make things up to satisfy that continual urge, the desire to feel that we know why, just in order to keep going. The rush to answer why is like the rush to tell someone what something means as opposed to letting them figure out what it means. There's a difference between art and dogma. Dogma dictates exactly what everything's purpose is; it is designed to influence our minds in this or that direction. But art by its very nature is elusive and cannot be explained. It's meant to stimulate the brain to come up with its own adventure. ■

An Immediate and More Visceral Commonality

On May 8, Derek Bermel organized an IAS community concert featuring performances by scholars and family. The concert was followed by a farewell reception in the Common Room of Fuld Hall that celebrated Bermel's many contributions to Institute life and wished him well in his future endeavors as he was concluding his four-year term as Artist-in-Residence. Following are the remarks given by Nima Arkani-Hamed, Professor in the School of Natural Sciences and a member of the Faculty Music Committee, who spoke about Bermel as a grand unifier, a fellow wanderer, and a continued inspiration.

I have known Derek for a number of years now, and came to recognize him as, first and foremost, a brilliant and sensitive composer and musician. Being in the presence of stellar talent in so many different fields, even and especially fields far removed from one's own areas of interest, is one of the privileges and joys of life at the Institute, and we are all very grateful to Derek for spending part of his meteoric musical trajectory in our little neck of the woods.

Derek's contributions and importance to our intellectual life at the Institute extend far beyond this. Most obviously, to borrow a favorite physicist's term, Derek has been a grand unifier of our activities here. We all think about a huge number of disparate things, and there are wide gulfs between the ideas and methods we use in our work. But music is famously a universal language and brings us all together. (Not least because many of us, including those brave enough to perform earlier today, have had or continue to have musical aspirations!) Derek took this raw material, our natural enthusiasm for music, and not only engaged it through his wonderful concerts, but used it to push many of us into listening to and coming to appreciate exciting new music, in a way that has permanently affected our musical lives. I am likely more of a musical philistine than most of you, but I must say, if it wasn't for Derek, I would never have fallen in love with the music of György Ligeti. Nor would I have ever heard of Nico Muhly.

Of course, continuing to speak a little more personally, if it wasn't for Derek, there wouldn't be a wonderful piece of music with my name associated with it, and I wouldn't be able to show off to my friends. Even more importantly, there wouldn't be a frantic movement for strings and clarinet with the simply awesome title of "twistor scattering." The only people more thrilled by that than me were the disciples of Roger Penrose, inventor of twistor theory. So, thanks, Derek, for taking the pedestrian struggles of a physicist to convey something about what we know of the world to a general audience and using the power of music to turn it into something a little more transcendent.

BENTLEY DREZNER

Nima Arkani-Hamed (left), Professor in the School of Natural Sciences, with Derek Bermel, Artist-in-Residence

This brings me to what I feel is the most important quality Derek brought to the Institute. While all of us here work on totally different subjects, we are all united by a common, fundamental experience. I'm not talking about what one normally refers to as the commonality of academic discourse, involving abstract things like "creative research pushing back the frontiers of knowledge" or similarly earnest endeavors. I am talking about something more immediate and more visceral. Almost every day, day after day, we all get up in the morning, start working very hard, sometimes through to the wee hours of the next morning, and our strenuous efforts are rewarded with failure. Again and again, we fail. What makes the failure all the more brutal, and what keeps us banging our heads against the wall again and again, is that we have some idea of what success looks like, and it is very hard to fool yourself when you aren't there. Whether in physics and mathematics or in the humanities, when something finally really works, it has a certain perfection to it, a feeling of inevitability, like it was so completely obvious all along, and it couldn't be any other way. Artists, musicians, and especially composers (and also novelists of a certain variety) are familiar, as are academics, with the feeling of continually falling short of that perfect something that they know is there. I recently stumbled across a fantastic series of YouTube videos of lectures given by Leonard Bernstein, where he explained precisely this process in the context of the first movement of Beethoven's Fifth Symphony. He found all sorts of alternative passages that Beethoven had conceived, put them back in the symphony, and they were simply terrible. Bernstein referred over and over to the sort of perfection, inevitability, and complete harmony with an inner logical structure that Beethoven finally achieved, not by a flash of inspired genius, but by struggling through darkness and noise and confusion, not resting until he got it completely right.

So while we do completely different things, we are mostly wandering around in a distraught state of coping with yet another failure. We may not all be Einsteins or Beethovens, but they are our heros, and their example is never far from our minds. In this state, it is a deep and genuine pleasure to run into a fellow traveler on the same path in a totally different realm. Like Derek. We meet up at lunch or over cookies and tea, and talk about how things are going. Of course, we are rarely so explicit about these things—"You failing today?" "Yup!" "Same here!" But the sort of casual conversations we have in all settings, over all topics, are all touched by this important common experience in an essential way. We are energized by each other's rare successes (which are more common for Derek than for me!). It takes someone experiencing fundamentally the same struggles to deeply understand our own, and through conversations and interactions, short and long, to be a continued source of inspiration to keep going. For that too, Derek, I am sure that all of us are deeply grateful for the time you spent with us.

We are going to miss you immensely, but at the same time, we're all extremely excited to see and hear the spectacular things you are certain to do in the coming years. Please come back and visit us every chance you get. You will forever be welcome here, not just by great admirers, but also by good friends.

—Nima Arkani-Hamed, Professor, School of Natural Sciences

SUPERNOVAE *(Continued from page 13)*

gered by the shock waves that result from the collision, which occurs at velocities of thousands of kilometers per second due to the gravitational pull of the white dwarfs. Such collisions lead to successful explosions over a wide range of white dwarf masses and produce the right range of Ni^{56} masses seen in type Ia supernovae. They have nothing to do with the Chandrasekhar mass. While it was known that such collisions could lead to explosions, it was never regarded as a possible explanation for type Ia supernovae since it was believed that such collisions were very rare. A very small rate was thought to occur in dense stellar systems, with less than 1 percent of all type Ia supernovae possibly resulting from such collisions.

In a paper published last year by Members Boaz Katz and Subo Dong (http://arxiv.org/pdf/1211.4584v2.pdf), it was argued that the rate of collisions actually may be as high as the total rate of type Ia supernovae. The argument was based on the fact that most stars are observed to start their life in small groups of three or more. It was shown that collisions are likely in triple systems, consisting of two white dwarfs orbited by a third star, due to the three-body gravitational interaction between them. The rate of such collisions can reach the rate of Ia supernovae if a few tens of percent of stars remain in triple systems when they become white dwarfs, a quite reasonable assumption. That type Ia supernovae are the result of common collisions in triple systems seems like a highly unlikely explanation at first thought. Given the small size of white dwarfs, the chance of a collision at any given passage is roughly one in a million. But numerical calculations by Katz and Dong showed that a few percent of these systems lead to a collision. The key is that the systems have billions of years to spare, during which the white dwarfs experience millions of passages. Due to the subtle yet persistent pulls from the distant third star, each passage of the two white dwarfs occurs at a slightly different configuration and, after a million passages, the chance for a collision becomes significant.

In a combined effort led by Member Doron Kushnir with Katz, Dong, Member Rodrigo Fernandez, and Eli Livne of Hebrew University, the detailed process of white dwarf collisions was calculated and shown to reproduce several features of the broad distribution of type Ia supernovae. For the first time since their discovery by Tycho more than four centuries ago, a detailed scenario for a significant fraction of supernovae was studied in which the explosions could be numerically calculated from first principles based on the physically well understood processes of Newtonian dynamics, hydrodynamics, and thermonuclear burning. In a paper published by our group (http://arxiv.org/pdf/1303.1180v1.pdf), the model was shown to successfully pass three independent and robust observational tests, including the successful recovery of the wide distribution of Ni^{56} masses. It is thus very likely that what Tycho thought was the sudden birth of a new star was actually the violent death of two. He might have been gratified to learn that the two stars collided due to the application of the same law of gravity that would later be deduced based on his dedicated observations. ■

Boaz Katz, John N. Bahcall Fellow and Member (2012–13) in the School of Natural Sciences, works on various problems in high-energy astrophysics and few-body dynamics. Subo Dong, Ralph E. and Doris M. Hansmann Member (2012–13) in the School, works on extrasolar planets, dynamics, microlensing, and time-domain astronomy. Member (2012–13) Doron Kushnir works on various problems in high-energy astrophysics, in particular, type Ia supernova explosions.

Marriage Market Imbalances and the Position of Women

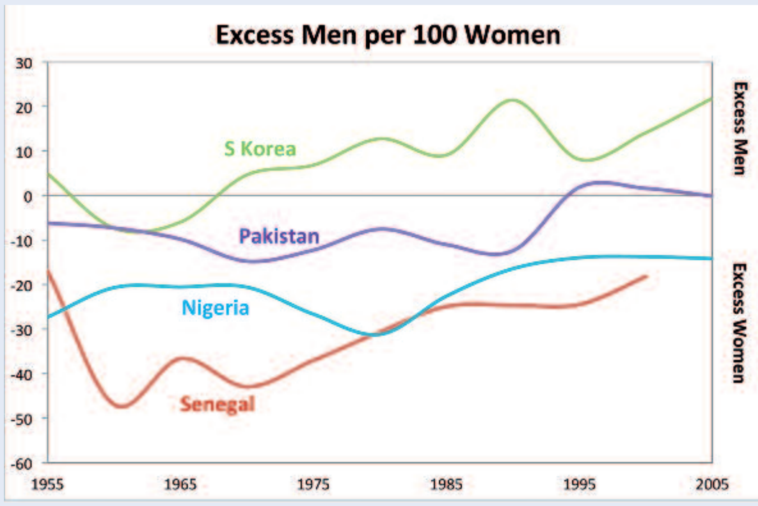
BY VENKATARAMAN BHASKAR

Every day I meet someone better. I am waiting for the best.

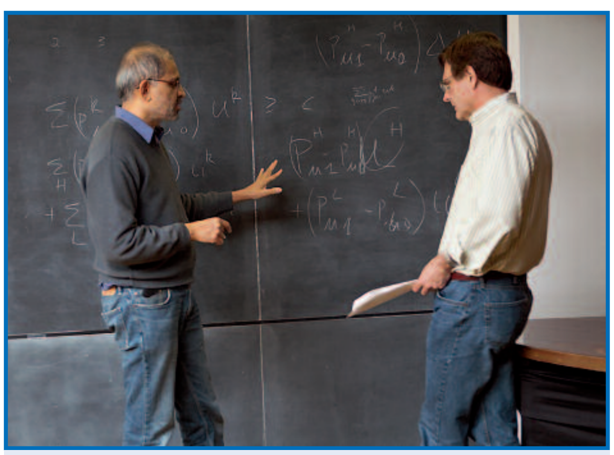
—female Moroccan immigrant to the United States on her local marriage prospects

Women's rights have come a long way since the beginning of the twentieth century. Before that, if a European or American woman were married, her husband owned the wages she might earn and controlled any property or inheritance she might bring. Women have also made major strides in developing countries. In India or China today, their position is a far cry from the past, when they may have been confined to the house or have their feet bound. Nonetheless, there are some puzzling steps backward. In India, the practice of dowry—payments made by the parents of the bride to the groom—has spread to parts of the country where it was earlier unknown. Dowry payments have also increased, despite laws banning the practice. In sub-Saharan Africa, polygyny persists and is socially acceptable despite modernization—Jacob Zuma's four wives did not hinder his ascent to the Presidency of South Africa. Why has the forward march of women been interrupted in these developing countries? Is this trend likely to persist, or will it be reversed?

I argue that demographic trends, in interaction with the gap in the ages between men and their wives, provide an explanation. Men usually marry younger women—this is true in every country for which data is available, with an average gap ranging from two to seven years. For most of human history, the age gap has not mattered, since human populations have been stationary. However, as countries develop, birth cohorts start growing in size, at 2 percent or 3 percent a year. If the age gap at marriage is four years, the cohort of men born in a given year will be matched with the cohort of women born four years later and the latter cohort will be approximately 8–12 percent larger (assuming that the sex ratio within each cohort is balanced). This implies a very large excess of women on the marriage market, and one can expect adverse consequences for them, at marriage and later within the household, since their bargaining position is considerably reduced. This was the case in India in the second half of the twentieth century, and men were able to demand larger dowries. Parents came to perceive their daughters as a burden, especially given social norms that deemed it essential that they be married. The observed preference for boys in some parts of India may be attributable to these demographic trends, rather than innate son preference (although son preference is no doubt strong in northwest India). Similarly, in many sub-Saharan African countries, such as Senegal, birth cohorts are increasing at 2 percent per year, and this growth shows no signs of tapering off. Since these countries have a large gap at marriage, this magnifies the imbalance and provides ample opportunities for many men to indulge in polygyny.



This chart illustrates trends in marriage-market imbalances in selected countries. It graphs the excess of men per one hundred women in the birth cohort every five years, between 1955 and 2005, taking into account the actual sex ratio in the age group 0–4 and the required sex ratio implied by cohort growth and the age gap at marriage. It also takes into account differential mortality between the sexes. The zero line on the vertical axis corresponds to marriage market balance; below the line, we have an excess of women, while above it there is an excess of men. We see that South Korea has rapidly become a country with an excess of men, mainly due to a sharp decline in cohort growth, while Nigeria and Senegal continue to have a large excess of women.



ANDREA KANE

Venkataraman Bhaskar (left), Roger W. Ferguson, Jr., and Annette L. Nazareth Member (2012–13) in the School of Social Science, is Professor of Economics at University College London. His research interests focus on microeconomic theory, industrial organization, game theory and contract theory, and economics of marriage and the family.

But there is good news for women. These demographic trends have now been reversed in many countries. As women have become more educated and fertility has declined, cohorts have now started shrinking. This effect is most pronounced in East Asia, with cohort sizes in South Korea declining at 2–4 percent per year. Each cohort of men is now matched with a smaller cohort of women, giving rise to a shortage of women. One should expect to see a significant improvement in the position of women, as their bargaining position improves. Trends in East Asia are indicators for the rest of the developing world. Cohort-size growth has now declined in other Asian countries and is turning negative. This is also true in the countries of the Arab Spring, such as Tunisia. The reversal of trend has major social consequences. As fertility declines further, and cohort sizes fall, not only can a woman paraphrase the Moroccan immigrant quoted at the start of this article and say to a man, "I am waiting for someone better," but her improved options will improve her bargaining position and say within marriage.

An additional cause of gender imbalances is sex-selective abortions. Technological developments allow parents to ascertain the gender of the fetus. In countries where abortion is freely available, such as India and China, and where parents prefer boys, they are able to selectively abort female fetuses, giving rise to an unbalanced sex ratio at birth. In China, the 2010 census figures show 119 boy births per 100 girls, with some regions having 130–135 boys per 100 girls (as compared to the normal ratio of 105–106 boys per 100 girls). In India, while the overall figure is less unbalanced (109 in the 2011 census), some states in the northwest have ratios of 120.

The consequences for Chinese men are severe, if not catastrophic. As a consequence of the one-child policy, Chinese birth cohorts are falling at 5 percent per year, so that the excess of men due to sex-selective abortions is exacerbated. The cumulative imbalance is so large that one in five Chinese men born between the years 2000 and 2010 likely will not be able to find a partner. This is already causing major social changes in Chinese social life. For instance, Chinese couples are increasingly transferring more resources to the woman's parents rather than the man's. Chinese women can be choosier, and parents with a son are saving money to buy apartments, in order to improve his marriage prospects. Indeed, some economists suggest that marriage-market competition arising from the unbalanced sex ratio may be partially responsible for the enormous savings rate of Chinese households.

Why are Chinese parents so shortsighted that they continue to prefer boys even as this significantly reduces the likelihood that their sons will be able to marry? Chinese parents may prefer sons, but surely evolution has also imbued them with a desire for grandchildren? It turns out that the imbalance is not necessarily due to a lack of foresight but may well be an equilibrium consequence of son preference. Just as each commuter finds it optimal to take his car during rush hour, even though this clogs up the traffic and delays everyone else, so too Chinese parents clog up the marriage market with their excess of sons. Of course, even parents with gender-biased preferences would be better off if they had fewer sons, just as our commuters would be better off if they reduced their reliance on the automobile even slightly. But self-interest coupled with gender bias precludes such a rational solution. Governments can ban sex-selective abortions, but there remain formidable barriers to effective enforcement of such laws—since both ultrasound and abortions are legal, it is difficult to prevent sex-selective abortions.

I have argued here that a shortage of women, arising from demographic trends or sex-selective abortions, improves their bargaining position, just as an abundance of women has hurt them in the recent past. Some activists and social scientists argue differently—that a shortage of women will worsen their position, as they will be increasingly subject to trafficking, violence, and exploitation. These divergent views boil down to a more general question: does the owner of a resource become better off or worse off when the resource becomes scarce? If the owner of the resource is secure in his or her ownership, then she must be better off—she is no worse off if she keeps the resource for herself and will get better terms if she chooses to trade it. On the other hand, if property rights are not secure, then she may lose the resource when it becomes more valuable, since other parties have a greater incentive to grab it. For example, the indigenous people of the Amazon were harmed by the discovery of gold, since their lands became attractive to settlers. The question therefore turns on the security of women's self-ownership. In societies where women have self-ownership—the right to make decisions about themselves and their bodies—increased scarcity will give them greater choice and make them better off. On the other hand, in a society such as Kyrgyzstan—where wife kidnapping is rife—scarcity could well make them worse off. The empirical evidence from many developing countries, including China and India, suggests that women have been harmed by their relative abundance. It also suggests that their position improves with scarcity. Nonetheless, this makes all the more compelling the case for legal protection guaranteeing women control over their bodies and their future and their right to make life choices without coercion. ■

Civic Identity at Ostia, Rome's Harbor Town

BY CHRISTER BRUUN

Besides Rome itself, there are principally two cities in Roman Italy that vie for the attention of both scholars and the public at large: Ostia and Pompeii. The latter is known for its tragic end in the volcanic eruption of 79 C.E., for fascinating wall paintings, and for millions of tourists who every year trample its sunbaked streets. Ostia suffers from relative neglect. Situated too close to the attractions of eternal Rome, the town draws many fewer visitors than its monuments and its overall importance would deserve, even though its green pine trees and the lush vegetation help make it into a peaceful historical oasis at the very mouth of the Tiber River.

From a historical perspective, Ostia was a more important settlement than Pompeii. With a population of perhaps as many as fifty thousand inhabitants, the town was much larger than its "rival." More significantly, while Pompeii's history was cut short when Rome's imperial period was only in its infancy, Ostia, which was first settled in the fourth century B.C.E., still thrived during the third century C.E., and we have historical sources that allow us to follow its development well into the 400s.

At Ostia, the written sources, the lifeblood of historians, mostly consist of inscriptions that Roman stonecutters and manufacturers inscribed on funerary monuments, public buildings, everyday objects, and even lead water pipes. This creates a particular challenge for scholars like myself who want to understand the mentality of the Ostians, how they felt about their place in the world and about their hometown. Was there a particular ideology that informed their actions and decisions, or, more likely, a welter of convictions and beliefs about what it meant to be an Ostian? There are no letters, no diaries, and of course, no interviews that could shed light on these questions. The city archive, the minutes of the council meetings and of the local citizen assembly are long lost.

Some scholars think that in Roman times, as today, Ostia lived in the shadow of the capital (distant less than twenty miles), and that the harbor town was no more than a suburb of Rome, lacking an identity of its own. For various reasons, this argument fails to convince. I have been studying various aspects of Ostia for two decades or more: the infrastructure (the supply and distribution of water), the local government, the influence and control of the emperors, the city's slaves and freed slaves, the immigration to the city, its character as one of the major ports in all of the Mediterranean Sea and a key to supplying the capital Rome, to name a few issues. At the Institute, I had a much-appreciated opportunity to tackle these issues and many more within the framework of investigating the civic identity of the Ostians. The issue of "identity" is rightly a popular topic these days in many sectors of historical (and other kinds of) research, but nobody has attempted to study Rome's harbor town from this perspective. It may be that teasing out the relevant information from the almost six thousand surviving inscriptions from Roman Ostia has seemed too daunting a task.

In my work at the Institute, I focused on inscriptions that alert us to the presence of historical memory at Ostia. Here is a modern example of what I mean: a bronze plaque affixed to the southern façade of City Hall in Philadelphia reminds the townspeople that the first Europeans on the site were settlers from Sweden and Finland, who in the early 1600s attempted to build up New Sweden. (Some early leaders of this immigrant community are named; one was called John Rambo.) In fact, bronze plaques with historical information can be found all over North America. Nothing this programmatic and organized existed at Ostia, but we find public statues and memorials of great Ostians with extensive information on their deeds and benefactions to their community. For example, there is the local magnate Lucilius Gamala the Elder (active in the 50s–30s B.C.E.), who was honored in public because of the many gifts he bestowed upon his fellow citizens, among which was a public feast for which 217 sets of dining couches were prepared, thus accommodating almost 2,000 guests. What is this if not a demonstration of "Ostianness" (combined, as always, with a wish for personal glory and renown)? To this comes the fact that the inscription that recounts Gamala's benefactions was recut in the middle of the second century C.E. The occasion was a series of similar good deeds in favor of the Ostians by a much later descendant, Lucilius Gamala the Younger. This set of texts illustrates both the existence of Ostian patriotism and the importance of local historic memory.

MUSEI VATICANI, GALLERIA DELLE CARTE GEOGRAFICHE/A. DANTI/O. TESTAGUZZA

Ostia's port after its completion under the emperor Trajan (98–117 C.E.)

Ostia's claim to being the first settlement (*colonia*) of Roman citizens outside Rome is celebrated in a text that praises the legendary founder, Rome's fourth king, Ancus Martius. Then there is the public chronicle (the *Fasti Ostienses*), annually inscribed on great marble slabs, as far as we know a unique feature among Roman towns, which records Roman consuls and Ostia's local magistrates, combined with important events often related to the imperial family and thus demonstrating imperial loyalty, year by year for centuries. Here one reads about how the Ostians solemnly received the body of the emperor Augustus's adopted son Lucius Caesar in 2 C.E. and accompanied it onwards on the journey from Massilia in southern France to Rome. More happily, in 140 C.E. a statue of the future emperor Marcus Aurelius was erected, while in 152, a private citizen dedicated a public building, a basilica, for which he had paid. On this occasion, he also offered the townspeople a gladiatorial spectacle and a wild beast hunt, and dedicated two statues representing the Genius and the Fortuna of the people of Ostia. It becomes clear that Ostia was much more than a suburban satellite of Rome, as modern scholars often suggest. As far as we can judge, its inhabitants were proud of their close relationship with the capital but certainly stressed their own achievements.

A very particular view of Roman history is manifested in the recently restored inscriptions that decorated the main city gate, used by travelers between Ostia and Rome. It dates to shortly before 100 C.E. and recalls the contribution of both the consul Cicero and of the tribune of the people Publius Clodius towards building the city wall and the gate in the 50s B.C.E., or a century and a half earlier. Those familiar with Roman history know that the two men were mortal enemies, one defending the establishment and the other opposing it either out of demagoguery or perhaps conviction. Clodius's memory is permanently denigrated thanks to Cicero's many surviving writings, and no other source from antiquity shows a similarly inclusive view of Roman history as this Ostian text. It is as if the Ostians were thinking: "Well, these men of the past were both great Romans. They had their quarrels back then, but that's over. Instead of dwelling on that, let us remember fondly that two men who play conspicuous roles in the glorious annals of our nation's history also looked out for Ostia. Our Ostia was important already then, as everyone can see."

For the Ostians to celebrate Cicero and Clodius in the same public inscription is, perhaps, a bit like if in the United States today we were to find a town or perhaps a hotel owner somewhere proudly announcing (knowing that it would attract general benevolence) that both President Lincoln and President Jefferson Davis had been patrons of the locality in the early 1860s. For all I know, such public inscriptions may exist, but I have a feeling they are rare.

As for the inscription on the gate of Ostia, it is unique in its inclusive view of history. On the other hand, it can also be said to be typically Roman. A general strength of Roman civilization was its ability to overcome deep social schisms that from time to time threatened to rend asunder the state. ■

Christer Bruun, Gladys Krieble Delmas Foundation Member (2012) in the School of Historical Studies, is Professor and Chair of the Department of Classics at the University of Toronto where he teaches Roman history and Latin language and literature.

Gladys Krieble Delmas Foundation: Advancing the Reaches of Human Knowledge

"Times change…and I do not wish to predict or define future priorities. The only guide I would leave you is this: Western societies produced a flowering of human values and enduring beauty; I hope they will not be entirely lost in the new society whose shape we cannot know. Let us try to preserve the best and encourage the shoots of the new to grow in a direction that will not entirely distort the old."

—Gladys Krieble Delmas

Gladys Krieble Delmas (1913–91) was a most generous donor and friend of the Institute for Advanced Study during her lifetime and is a continuing presence today through the endowment she established for the Institute and her foundation's ongoing support of the School of Historical Studies.

Delmas, a broadcaster, journalist, editor, and heir of the family's Loctite Corporation, became an Institute Trustee in 1978, serving until her death in 1991. At the time, her $10 million bequest was the largest gift the Institute had received since its founding. The bequest established an unrestricted endowment that was recently valued at $23.1 million. Delmas gave an additional $6 million to the Institute during her lifetime.

In addition, the Gladys Krieble Delmas Foundation has supported several programs in the Schools of Historical Studies and Social Science, for a total given to date of almost $1.3 million. These programs include annual support since 2004 for scholars of Renaissance studies (see article, this page), an endowment fund established in 2002 to support scholars of East Asian studies, and a gift in 1995 to help establish the Kennan Professorship in the School of Historical Studies. The crucial support that the Institute has received from Delmas and her foundation underscores Delmas's primary goal: "In the case of research or educational institutions, I wish my funds to be used for the support of the best scholars in any field whose work is likely to advance the reaches of human knowledge."

Pierre Deligne, the Abel Prize, and Curiosity-Driven Research

On May 21, King Harald V of Norway presented the Abel Prize of the Norwegian Academy of Science and Letters to Pierre Deligne, Professor Emeritus in the School of Mathematics. In his acceptance speech, published here, Deligne articulated the essential role of freedom and curiosity in research—as the source of most of the important applications of sciences and as a powerful incentive to do the best work possible. The Institute is deeply grateful to Deligne, who has donated a portion of his monetary prize to support fundamental research in the Institute's School of Mathematics.

HEIKO JUNGE/NTB SCANPIX

Deligne received the Abel Prize for seminal contributions to algebraic geometry and for their transformative impact on number theory, representation theory, and related fields.

Your Majesty, Minister, Excellencies, colleagues, family, friends, and guests,

I am very honored that this Abel Prize associates me with the luminaries who received it before me, amongst whom are my teachers and mentors Jacques Tits and Jean-Pierre Serre.

The past century has been a golden century for mathematics. When I look back, I am amazed at all the questions that in my youth seemed inaccessible, but which have now been solved. The last half-century has also been a golden time for mathematicians, but I worry that the prospects for young people are now far from being as good.

Throughout my life, I have received crucial help from many people and institutions. This for me is an occasion to give thanks.

My first debt of gratitude is to Mr. Jeff Nijs. Mr. Nijs was a high school teacher. I first met him at age twelve as the father of a friend. He noted my interest in mathematics, protected it, nourished it by giving me my first serious mathematical books (a risky and felicitous choice: Bourbaki's set theory), and by arranging the possibility for me to borrow books from the Bibliothèque Royale de Belgique. Later, he introduced me to Jacques Tits.

It was fortunate for me that, up to 1964, Tits was a professor at the Free University of Brussels. I learned much from him, and when I was twenty, he told me to go to Paris, where I benefited from Serre's deep and luminous lectures at Collège de France and from [Alexander] Grothendieck's seminar at IHÉS [Institut des Hautes Études Scientifiques]. In due time, Serre also offered me suggestions that proved crucial. One was to look at the work of [Martin] Eichler and [Goro] Shimura relating classical automorphic forms to cohomology. Another was to pay attention to estimates proved by [Robert] Rankin.

My main debt of gratitude is to Alexander Grothendieck. He did not mind my ignorance. He taught me my trade as well as ℓ-adic cohomology by asking me to write up, from his rough notes, the talks seventeen and eighteen of SGA 4 [Séminaire de Géometrie Algébrique 4]. He convinced his colleagues at IHÉS to offer me a position. He exposed me to his philosophy, and especially to his idea of "motives," which for me has been a guiding light.

I would also like to give thanks to the two extraordinary institutions at which I have spent my career: the IHÉS (Institut des Hautes Études Scientifiques) and the IAS (Institute for Advanced Study).

Established in 1930, the IAS was made possible by the generosity of Louis Bamberger and his sister Caroline Fuld and guided by the ideals of its first Director, Abraham Flexner.

As an aside, please allow me to mention that in a letter to the Trustees of 1930, the founders insisted: "It is fundamental in our purpose, and our express desire, that, in the appointments to the staff and faculty as well as in the admission of workers and students, no account shall be taken, directly or indirectly, of race, religion, or sex." This was far from common in the U.S. of the 1930s, and I much prefer such a statement of principles to the creeping quotas that clumsily attempt to enforce a similar ideal at present.

The founding principle of the IAS is expounded in Flexner's article of 1939, "The Usefulness of Useless Knowledge," which remains as relevant now as it was then. It explains that the current tendency of funding agencies to try to direct research is misguided, and that it is even worse to try to direct it toward directly applicable goals. Flexner explains, by examples, that at the source of most of the important applications of sciences are discoveries guided not by applications, but by curiosity.

When applying for a visit to IAS, visitors usually explain what they intend to do. One of the first things they are told upon arrival is that no matter what they said they were going to do, they are free to ignore it and follow their curiosity. That indeed is how it should be.

This freedom is a powerful incentive to do the best we can. As I can attest from examples in my own work, it sometimes leads to dead ends, but that is a small price to pay.

The IHÉS was founded in 1958 by Léon Motchane in deliberate imitation of the IAS but without the security of an endowment and at a time when private support for mathematics or physics was unheard of in France. This made the accomplishment of Motchane in creating the IHÉS—wisely selecting the first permanent members and persuading them to accept, and then keeping the IHÉS alive—a truly extraordinary accomplishment.

I am grateful to both the IHÉS and the IAS for their defense and illustration of curiosity-driven research, and for enabling me to try to do my best. I am glad that the Abel committee is guided by the same principles, and I hope this Abel Prize will enable me to help young mathematicians.

—Pierre Deligne, Professor Emeritus, School of Mathematics

Recommended Reading: "The Usefulness of Useless Knowledge," *Harper's Magazine*, October 1939, available at library.ias.edu/files/UsefulnessHarpers.pdf and "Pierre Deligne Awarded 2013 Abel Prize" at www.ias.edu/news/press-releases/2013/03/20/abel/.

RODRIK *(Continued from page 1)*

"Dani Rodrik's engagement with challenging issues in global economics and his ability to address them with clarity and imagination are unmatched in the field," added Robbert Dijkgraaf, Director and Leon Levy Professor at the Institute. "I am extremely pleased that Dani is joining the Faculty at the Institute, where he will help to sustain and enhance the School of Social Science's intensely active, comparative, and international approach to research across the field."

Joseph E. Stiglitz, University Professor at Columbia University and recipient of the Nobel Prize in Economic Sciences in 2001, has described Rodrik as having "broken the mold of a conventional economist," and has noted that "the economics field has progressively subscribed to the ideas and modes of analysis that he helped pioneer." One of the most widely published and cited economists of his generation, Rodrik's current research centers on the future of economic growth and the role of ideas in political economy. Rodrik's interests are diverse, spanning international development, the consequences of globalization, the role of national institutions, the challenges of inequality, and the tensions between the market and the state, and are in active dialogue with the research pursued by the Faculty and Members in the School of Social Science.

"I cannot imagine a greater honor than being a Professor at the Institute and holding a chair bearing Albert Hirschman's name," said Rodrik. "I am tremendously excited by the prospect of joining the Institute's Faculty and contributing to its life."

Rodrik's books *The Globalization Paradox: Democracy and the Future of the World Economy* (2011), *One Economics, Many Recipes: Globalization, Institutions, and Economic Growth* (2007), and *Has Globalization Gone Too Far?* (1997) have challenged orthodoxy and yet have become standard texts in the field. His arguments, which explore the boundaries between economic theory and policy, have endured, moving debates forward and influencing courses of action. The euro zone crisis has highlighted the relevance of the "trilemma" theory that Rodrik conceived of in the early 2000s, which states that any given country can achieve at most only two of the following: national sovereignty, democracy, and global integration. In contrast to a set of ideas developed in the 1970s and early 1980s known as the Washington Consensus—which adopted a comprehensive and broad approach to development policy—Rodrik maintains that successful institutional design policies take into account preexisting local conditions, market arrangements, distortions, and constraints. Rodrik argues for customizable development strategies underpinned by effective basic principles—property rights; macroeconomic and political stability; processes for innovation, diversification, and regulation; and social cohesion—but implemented through nonstandard policies, which recognize, in Rodrik's words, that "binding constraints on growth differ across countries and over time."

Born in Istanbul in 1957, Rodrik attended Harvard University, where he earned his A.B. in 1979. He received his M.P.A. in 1981 from the Woodrow Wilson School of Public and International Affairs at Princeton University, and his Ph.D. in economics from Princeton in 1985. His early research centered on examining the ways that rural political mobilization in Egypt and Turkey in the 1950s led to entirely different consequences in each country—a revolution in the first case, and a conservative government in the second. In 1980 and in 1981–82, he served as Assistant Economic Affairs Officer at the United Nations Conference on Trade and Development, where he analyzed trade problems confronting developing countries. Rodrik's Ph.D. dissertation three years later

(Continued on page 19)

The Campaign for the Institute

The current $200 million Campaign is helping to strengthen the Institute's financial independence and its ability to provide scholars with the freedom to pursue fundamental research in the sciences and humanities. The $100 million unrestricted challenge grant from the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences, announced in 2011, serves as the basis for the Campaign and must be matched by funds from donors within four years. As of June 30, 2013, more than $64 million has been raised thanks to generous gifts from Faculty, including Professor Emeritus Pierre Deligne (see article, page 18); Trustees, including Robert Fernholz (see article, this page); Friends (see article, this page); foundations, including the Gladys Krieble Delmas Foundation (see article, page 17); former Members and Visitors; and other supporters of the Institute's work. All irrevocable gifts and grants of endowment or operating support are counted toward the Campaign goal and the Simons and Simonyi challenge.

Robert and Luisa Fernholz Endow Professorship

Robert and Luisa Fernholz have endowed a Professorship in the Institute's School of Mathematics through the Fernholz Foundation. The first Robert and Luisa Fernholz Professor is Richard Taylor, one of the world's leading number theorists who has been a Professor at the Institute since 2012. A Trustee of the Institute since 2010, Robert Fernholz is Founder and Chairman of the Investment Committee of INTECH Investment Management, and Luisa Fernholz is Professor Emerita of Statistics at Temple University. Luisa currently serves as Director of the Minerva Research Foundation, which the couple founded in 2006.

"We greatly appreciate the generosity and foresight of Bob and Luisa, who clearly value discovery and intellect in its purest form," said Robbert Dijkgraaf, Director and Leon Levy Professor. "Bob and Luisa have made meaningful and vital contributions to our community in so many ways, through their service, engagement, and philanthropy. We are immensely grateful for their support."

An endowed Professorship at the Institute is supported through a contribution of $5 million or more. There are many ways to give to the Institute, including donations of annual support, endowment and program support, and gifts made in conjunction with the estate planning process. For more information or to make a donation, please contact Michael Gehret, Associate Director for Development and Public Affairs, at (609) 734-8218 or mgehret@ias.edu.

The Fernholzes are actively involved with the School of Mathematics Council, and generously support the Institute with gifts of operating support both in the School and as Friends of the Institute. Robert serves on the Friends Executive Committee, overseeing the Friends' goal to provide the Institute with significant discretionary income every year and contributing in many other ways to the sustainability of the Institute's mission.

"Luisa and I are very pleased to support the Institute for Advanced Study with this gift because we value the Institute's mission of supporting curiosity-driven research," said Robert Fernholz. "It is one of the few places in the world where scholars are invited to pursue the kinds of questions that they might never be able to address in traditional academic or professional settings. We are also delighted that Richard Taylor will be the first Robert and Luisa Fernholz Professor." ■

ANDREA KANE

Robbert Dijkgraaf (back row, third from right), IAS Director and Leon Levy Professor, with members of the Friends Executive Committee at the Friends annual meeting and barbecue in May

Record Support from Institute Friends

In 2012–13, gifts from Friends of the Institute for Advanced Study reached an all-time high, with $934,494 raised against a goal of $900,000, providing a critical source of unrestricted operating support for the Institute. Additionally, a record forty-three new Friends were welcomed.

"It has been my privilege to serve as Chair of the Friends this past year and to witness remarkable growth in both membership and fundraising. We surpassed our dollar goal by almost $35,000 this year, a real testament to the overwhelming generosity of our community," said Jack Kerr, who, with his wife Nora, has been a Friend since 1998. "Friends support IAS because they believe deeply in the Institute's mission. At the same time, Friends enjoy access to stimulating programs, intriguing people, and a superb environment. Nora and I derive enormous pleasure from our association with the Institute and, in making financial contributions, feel we are investing in an institution with the potential to change the world."

At the Friends annual meeting and barbecue in May, Robbert Dijkgraaf, Director and Leon Levy Professor, noted, "Friends not only help us to nurture a real sense of family, but also assist with the critically important work of outreach and sharing the Institute's mission of independent scholarship, research, and discovery. They help us to do this by fostering a substantive connection with the surrounding community. The Friends are an integral part of the Institute community, and it is my privilege to be working with them to raise awareness about this great place."

During the meeting, outgoing members of the Friends Executive Committee, Thomas Harvey, Elena Petronio, and Louise Steffens, were honored for their service. Elections were held and the following ten individuals were unanimously chosen to serve on the Executive Committee for three-year terms: Elizabeth Baughan, Helena Bienstock, Martin Chooljian, John Clarke, Victoria Corrodi, Chad Goerner, Sarah Jones, Peter Lighte, Luke Visconti, and John Wellemeyer. ■

Established in 1980, the Friends are partners in the advancement of research and scholarship at the highest level and, as such, are encouraged to participate in the social and intellectual life of the Institute. For more information about the Friends, please visit www.ias.edu/people/friends or contact Pamela Hughes, Senior Development Officer, at (609) 734-8204 or phughes@ias.edu.

(Continued from page 18)

focused on applied trade theory and generated unexpected results using conventional methods. His published articles at the time centered on the efficiency of trade restrictions and the economic rationale for the use of overvalued currencies in developing nations. Rodrik's compelling perspective on the issues challenged generally accepted views and sparked new dialogues in the field.

At the John F. Kennedy School of Government at Harvard, where Rodrik served as Assistant Professor from 1985–89 and then Associate Professor from 1989–92, he worked on the normative and positive economics of trade and development. In his research, he addressed the question of what type of trade policy serves developing countries best, and analyzed the advantages of different trade policies, such as import tariffs, quantitative restrictions, export subsidies, and performance requirements. His interests continued to broaden thematically and internationally, and he published surveys on "real world" problems present in Africa, Eastern Europe, and Asia, where he challenged the dominant views that coalesced around the Washington Consensus. From 1992–96, Rodrik served as Professor of Economics and International Affairs at Columbia University, and focused his work on the reasons why the public sector expanded so rapidly in advanced economies in the decades following World War II. Rodrik's econometric analysis of one hundred countries demonstrated a correlation between the expansion and the openness of international trade. This research led to a broader preoccupation with the consequences of economic globalization, and resulted in his influential book *Has Globalization Gone Too Far?*

Rodrik returned to Harvard in 1996 and centered his research on institutions and economic growth, which was facilitated by the greater availability of large cross-national data sets. In a paper published in the *Quarterly Journal of Economics*, he posited that, despite the fact that cross-national distribution of wages is determined largely by labor productivity, politics play a clear role: in democratic regimes, workers are able to bargain for better wages and obtain these at no cost to overall economic performance. Through this and other research published in the *American Economic Review*, Rodrik demonstrated that democratic regimes worked better than authoritarian ones, even in developing countries, and pointed to the need for governmental reform grounded in local innovation and experimentation. Also at Harvard, Rodrik initiated a research effort concerned with a new general theory of growth using the language of constrained optimization, supplemented by an empirical strategy called "growth diagnostics." His 2007 book, *One Economics, Many Recipes*, synthesizes these ideas, which were soon adopted by the World Bank and the Inter-American Development Bank, as well as several national governments.

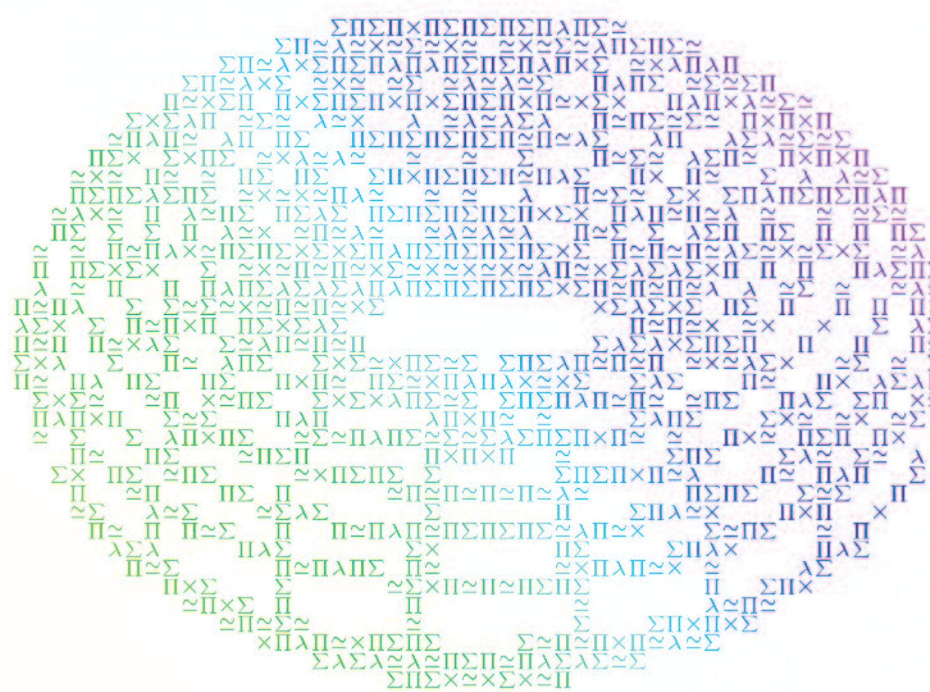
Rodrik and his work have been recognized by major awards, fellowships, lectureships, and honorary doctorates. He was awarded the Social Science Research Council's first annual Albert O. Hirschman Prize in 2007 and the Leontief Prize for Advancing the Frontiers of Economic Thought in 2002 by the Global Development and Environmental Institute at Tufts University. He is a member of the Science Academy of Turkey and serves on the Scientific Council of the Paris School of Economics and the Committee on International Economic Policy Reform. Rodrik also has served as an adviser to many national governments and institutions, including the World Bank. He is coeditor of the *Journal of Globalization and Development*, and is on the editorial and advisory boards of leading economic and policy publications. His monthly columns for *Project Syndicate* (www.project-syndicate.org/contributor/dani-rodrik) appear in many publications worldwide. ■

— Christine Ferrara, Senior Public Affairs Officer, cferrara@ias.edu

The Institute Letter

IAS

Summer 2013



THE HOTT BOOK

The Art of Bridging

In this issue, **Danielle Allen** writes about the art of bridging as an essential tool for linking people who come from different social spaces and as especially powerful for the diffusion of knowledge (page 4). **Catherine Rottenberg** provides a real-world example in the establishment of a school for Arab and Jewish children in Israel (page 5). Depicted above is a mathematical torus (a donut-shaped object that cannot be deformed into a sphere in a continuous way without tearing it) made of logical symbols. It represents homotopy type theory, a new branch of mathematics that connects homotopy theory (the study of continuous deformations) and type theory (a branch of mathematical logic). **Steve Awodey** and **Thierry Coquand** explain how an international team of thirty-two researchers in computer science, logic, and mathematics worked at the Institute during the past year to develop this theory and the related univalent foundations of mathematics, which can be used to verify the correctness of individual mathematical proofs and facilitate the large-scale formalization of mathematics by allowing mathematicians to build shared, searchable libraries of formalized definitions, theorems, and proofs (page 1). **Andrej Bauer** describes the socio-technological aspects of writing the *Homotopy Type Theory* book, six hundred pages by two dozen mathematicians in less than six months, which can be freely downloaded and contributed to as an open-source project on GitHub (page 7). **Hanno Rein** writes about starting an open exoplanet database in order to connect observations and discoveries that are evolving so quickly that a static catalogue is no longer an option (page 9). And **Michael Lesnick** explains how the study of topology (of which homotopy theory is a central part) is being used to study geometric features of data, yielding greater understanding in the areas of oncology, astronomy, neuroscience, image processing, and biophysics (page 10).

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