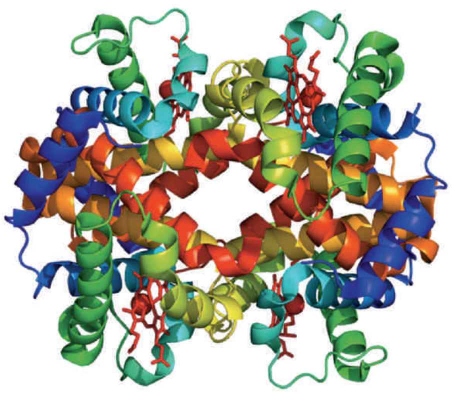
The Institute Letter

Institute for Advanced Study — Spring 2014

Using Protein Sequences to Predict Structure

How do proteins self-assemble into functional molecules?

By Lucy Colwell



LUCY COLWELL/WWW.PYMOL.ORG

Once folded, a protein is described as a monomer, and often different monomers or multiple copies of the same monomer self-assemble into protein complexes that form functional molecules.

Proteins are typically cited as the molecules that enable life; the word protein stems from the Greek *proteois* meaning "primary," "in the lead," or "standing in front." Living systems are made up of a vast array of different proteins. There are around 50,000 different proteins encoded in the human genome, and in a single cell there may be as many as 20,000,000 copies of a single protein.[1]

Each protein provides a fascinating example of a self-organizing system. The molecule is assembled as a chain of amino acid building blocks, which are bonded together by peptide bonds to form a linear polymer. Once synthesized, this polymer spontaneously self-assembles into the correct and highly ordered three-dimensional structure required for function. This ability to self-assemble is remarkable—each linear polypeptide chain is highly disorganized, and has the potential to adopt an array of conformations so vast that we cannot enumerate them, yet within less than a second a typical protein spontaneously assumes the correct, highly ordered three-dimensional structure

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History, Evolution, and Social Networks

Do actors make relations or do relations make actors?

By John Padgett

The encounter of historical and evolutionary perspectives within the intermediate trading zone of social science often has been unsatisfactory. Biological metaphors of social evolution were common among the original founders of the social sciences—in sociology and anthropology especially—but collectivist functionalism[1] now is thoroughly discredited. Horrific misuses of biological and evolutionary "scientific theories" by nineteenth- and twentieth-century racist social movements need no recounting. More recently, sociobiology—the analysis of discrete social behaviors and cultural "memes" as if these were genes in evolutionary competition—has gained an enthusiastic following as a sect, but sociobiology is viewed as simplistic and naive by most contemporary social scientists.

Less well known among social scientists, the reverse reception of historicist arguments in evolutionary biology also has been rocky. Stephen Jay Gould is widely known and praised outside of his own subfield, but his arguments are held at arm's length if not in disdain by his evolutionist peers. Celebrating "historical contingencies" to them seems tantamount to giving up on scientific explanation altogether. Postmodernists in the social sciences and the humanities are willing to take that step, but contemporary evolutionary biologists (including the late Gould himself)

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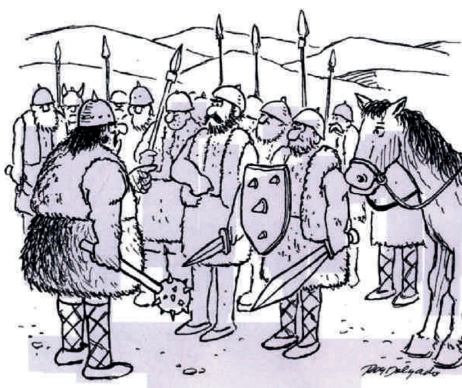
Climate Change and the Rise of an Empire

Did an unusually favorable climate create conditions for a new political order under Chinggis Khan?

By Nicola Di Cosmo



ROY DELGADO

" Pillage and plunder, yes ... but ***don't harm the environment !*** "

In his recent book *Global Crisis: War, Climate Change & Catastrophe in the Seventeenth Century*, Geoffrey Parker states: "although climate change can and does produce human catastrophe, few historians include the weather in their analyses." This is generally true, and the distance between historians and the weather may not have improved (indeed, may have been underscored) by the evolution of environmental history as a separate branch of historical research. Moreover, while the collection of historical climate data has never been more robust, instances of collaboration between scientists and historians are still very few and far between. In 2006, the National Science Foundation launched a program for research on Coupled Natural and Human Systems, capturing the need to model the interaction between societies and environments. Few of the projects funded so far, however, involve a long-term historical perspective or engage actual historical questions. One of these, funded last year, is titled "Pluvials, Droughts, Energetics, and the Mongol Empire" and is led by Neil Pederson, Amy Hessl, Nachin Baatarbileg, Kevin Anchukaitis, and myself.

Based on data collected in Mongolia over several years by climate scientists, the project aims to study climate change in relation to a particular set of circumstances, namely, the rise to power of Chinggis (or Genghis) Khan and the beginning of one of the most remarkable events in world history. Everyone knows Chinggis Khan but no one has so far been able to clearly explain the process through which the Mongols became so powerful nor why they would feel compelled to move out of Mongolia and conquer most of the Eurasian landmass. All countries from China to the Black Sea, including Central Asia, Russia, Iran, and parts of the Middle East, came to be under Mongol rule for the best part of the thirteenth and a good portion of the fourteenth centuries. The legacy of Mongol rule, however, continued to be felt in all of these regions well into the modern age. Mongol armies reached even beyond these lands: they invaded Poland, Hungary, and central Europe, riding as far as Vienna. Although the memories they left were not altogether pleasant (the Apocalypse was often invoked as a fitting metaphor), Europeans were intrigued and eventually found grounds to look at the Mongols in a more positive light and try to learn more about them.

The first exploratory contacts were established by Franciscan and Dominican missionaries. They were not necessarily sympathetic to the Mongols, but looked at them in more realistic terms: not as agents of divine wrath, but as a people who were seriously different, and even a little barbaric, but nonetheless human. Ever since their first appearance on the world scene, people wondered about where they came from and how they got there, but academic curiosity about their appearance was soon replaced by more contingent questions about their system of government, religion, habits, and especially the opportunities that their conquest opened to priests and merchants. Popes and European kings were intrigued by the blows dealt by the

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News of the Institute Community

The Association of American Publishers has awarded the 2013 PROSE Award in Education to *Education, Justice, and Democracy* (University of Chicago Press, 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 Visiting Professor (2009–10) in the School. Judged by peer publishers, librarians, and medical professionals since 1976, the PROSE Awards annually recognize the very best in professional and scholarly publishing in over forty categories. Allen also will receive an honorary doctorate from the University of Miami in May and will deliver the commencement address.

ANGELOS CHANIOTIS, Professor in the School of Historical Studies, has been decorated as Commander of the Order of the Phoenix by the President of the Republic of Greece in recognition of his contribution to scholarship. Chaniotis has also been elected Corresponding Member of the Academy of Athens.

Three works by DIDIER FASSIN, James D. Wolfensohn Professor in the School of Social Science, have recently been published: *Enforcing Order: An Ethnography of Urban Policing* (Polity Press, 2013), an inquiry into the activity of law enforcement in poor neighborhoods; *Moral Anthropology: A Critical Reader* (with Samuel Lézé, Routledge, 2013), the first anthology of texts in the domain of the anthropology of morality and ethics; and *Juger, Réprimer, Accompagner: Essai sur la Morale de l'État* (with Yasmine Bouagga et al., Seuil, 2013), the result of a collective five-year research project on the ethnography of the French state. All three publications are the outcome of a project funded by the European Research Council.

PETER SARNAK, Professor in the School of Mathematics, has been awarded the Wolf Foundation's 2014 Wolf Prize in Mathematics for his outstanding contributions to number theory, analysis, geometry, combinatorics, and computer science.

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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.

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The American Mathematical Society and the Conference Board of Mathematical Sciences have co-published *Hodge Theory, Complex Geometry, and Representation Theory* (2013) by PHILLIP GRIFFITHS, Professor Emeritus in the School of Mathematics, Mark Green, and Matt Kerr. This monograph uses complex geometry to understand Hodge theory and representation theory, as well as their relationships to one another. Additionally, Springer New York has published the second edition of *Rational Homotopy Theory and Differential Forms* (2013) by Griffiths and John Morgan.

HERBERT SPOHN, Member in the School of Mathematics, has been awarded the Cantor Medal, the highest distinction of the German Mathematical Society, for his decisive impact on the development of stochastic analysis, the theory of kinetic equations, and mathematical physics.

YITANG ZHANG, Member in the School of Mathematics, has been awarded the 2014 Rolf Schock Prize in Mathematics by the Royal Swedish Academy of Sciences for his spectacular breakthrough concerning the possibility of an infinite number of twin primes.

MARIBEL FIERRO, former Member (1994–95) in the School of Historical Studies, has been awarded the Alexander von Humboldt Foundation's Anneliese Maier Research Award to work on Islamic intellectual history with SABINE SCHMIDTKE, Member in the School, at the Freie Universität Berlin.

CHRISTOPHER HIRATA, former Member (2005–07) in the School of Natural Sciences, has been awarded the Helen B. Warner Prize for Astronomy from the American Astronomical Society for his observational and theoretical work on weak gravitational lensing, one of the most important tools for assessing the distribution of mass in the universe, as well as his work on cosmological recombination, structure formation, and dark energy and cosmic acceleration. Hirata is Professor of Physics and Astronomy at the Ohio State University.

EPHRAIM ISAAC, former Visitor (1979–80) in the School of Historical Studies, has been decorated as Knight of the Order of the Polar Star, First Class, by King Carl Gustaf of Sweden. Isaac is Director of the Institute of Semitic Studies in Princeton and Chair of the Peace and Development Center in Addis Ababa.

YOSEF KAPLAN, former Member (2007–08) in the School of Historical Studies, has been awarded the 2013 Israel Prize from the Hebrew University of Jerusalem for his research on the history of the Jewish people and his contributions to understanding the key processes in the development of modern Jewish society. Kaplan is Bernard Cherrick Emeritus Professor of the History of the Jewish People at the Hebrew University of Jerusalem.

BRUCE McKELLAR, former Member (1966–68) and Visitor (1999) in the School of Natural Sciences, has been proclaimed Companion in the General Division of the Order of Australia (AC), the country's highest civilian honor, for eminent service to science, particularly the study of theoretical physics, as an academic, educator, and researcher. McKellar is Professor and Chair of Theoretical Physics at the University of Melbourne.

RAMAMURTI RAJARAMAN, former Member (1967–69, 1973–75) in the School of Natural Sciences, has been awarded the 2014 Leo Szilard Lectureship Award by the American Physical Society for contributions to global security and efforts to promote peace and nuclear security in South Asia. Rajaraman is Professor Emeritus of Physics at Jawaharlal Nehru University.

YAKOV G. SINAI, former Member (1991) in the School of Mathematics, has been awarded the 2014 Abel Prize from the Norwegian Academy of Science and Letters for his fundamental contributions to dynamical systems, ergodic theory, and mathematical physics. Sinai is Professor at Princeton University.

STEVEN VANDERPUTTEN, former Member (2005) in the School of Historical Studies, has been proclaimed the 2013 Laureate in Humanities by the Royal Flemish Academy of Belgium for Science and the Arts. Vanderputten is Professor at Ghent University.

NADIA ZAKAMSKA, former Member (2005–10) in the School of Natural Sciences, has been awarded the American Astronomical Society's 2014 Newton Lacy Pierce Prize for observational research by a young astronomer. Zakamska is cited for her multi-wavelength work on Type II quasars and for her work in finding direct evidence for outflows driven by active galactic nuclei, regarded as an essential ingredient in galaxy-formation models for regulating star formation. Zakamska is Assistant Professor at Johns Hopkins University.

ROBBERT DIJKGRAAF

Strings 2014

Strings 2014 will take place at Princeton University and the Institute for Advanced Study from June 23–27. For decades, meetings in the Strings series have been focal points of the field, with experts from around the world presenting new work and reviewing recent developments. Strings 2014 will follow in this tradition, aiming for a unified presentation of the many strands of modern string theory. In addition to plenary talks, this year the program will include parallel sessions, a poster session, a gong show, and vision talks.

The Institute's 2014 Prospects in Theoretical Physics program, which will focus on string theory, will precede the Strings 2014 conference on June 16–20; see https://pitp2014.ias.edu for more information.

For more information about Strings 2014, visit http://physics.princeton.edu/strings2014/.

Fred Van Sickle Appointed Chief Development Officer

JILL LEVINE

Fred Van Sickle

The Institute has appointed Fred Van Sickle as its new Chief Development Officer. Van Sickle most recently served as Executive Vice President for University Development and Alumni Relations at Columbia University, where he led the team that completed the $6.1 billion Columbia Campaign. He is an accomplished and versatile leader in fundraising, alumni affairs, and constituent relations with extensive and wide-ranging experience in higher education. Van Sickle replaces Michael Gehret, who retired from the Institute on March 31 after eight years of dedicated leadership and service.

As the Institute's Chief Development Officer and Associate Director for Development and Public Affairs, Van Sickle will lead the development and public affairs program, ensuring the Institute's continued independence and commitment to curiosity-driven research and broadening its visibility. Van Sickle, who will begin his appointment at the Institute in May, will oversee the Institute's fundraising strategies, working directly with Robbert Dijkgraaf, Director and Leon Levy Professor at the Institute.

"We are thrilled that Fred Van Sickle will be joining the Institute," stated Robbert Dijkgraaf. "Fred's extensive experience and knowledge in fundraising at the very highest level will be an incredible asset as we complete our current $200 million capital campaign and widen and deepen our circle of supporters. These important actions will dovetail with our efforts to strategically build the Institute's public profile, and I am eager to collaborate closely with Fred on these and other activities to secure the future success of the Institute."

Regarding his appointment, Van Sickle said, "I have long admired the Institute and its singular role in the worlds of scholarship and inquiry. It will be my privilege to work with distinguished colleagues to engage a wider circle who share a commitment to that inspiring mission."

Reporting to Columbia University President Lee Bollinger, Van Sickle has overseen all development initiatives and outreach to Columbia's alumni worldwide. He played a key role in the planning, implementation, and completion of the $6.1 billion Columbia Campaign, which concluded in 2013. Before joining Columbia, Van Sickle held leadership positions in alumni relations and development at several institutions of higher education, including the University of Michigan, where he was the Associate Vice President for Development and Assistant Dean for Development for the College of Literature, Science, and the Arts. He also served as Vice President for Alumni and Development and Secretary of the College at Lake Forest College, and he is the former Director of Principal Gifts at Princeton University.

Van Sickle earned his undergraduate degree from Lake Forest (1983), a master's degree in education from Harvard University (1989), and a doctorate in education from the University of Pennsylvania (1996). He is a trustee of International House–New York and is Chair of the Board for the Crisis Ministry of Mercer County. Van Sickle resides in Princeton with his wife Susan. ■

Mark Baumgartner Appointed Chief Investment Officer

Mark Baumgartner

Mark Baumgartner, an investment management executive, has been appointed Chief Investment Officer at the Institute. Baumgartner joined the Institute in January 2014 and works closely with the Investment Committee of the Institute's Board of Trustees to manage the Institute's endowment. He succeeds Ashvin Chhabra, who served as Chief Investment Officer from 2007–13.

Baumgartner comes to the Institute from the Ford Foundation, where he was the Director of Asset Allocation and Risk and was responsible for providing strategic direction for the endowment of the $11 billion private foundation. Prior to joining the Ford Foundation, Baumgartner was Managing Director, Senior Portfolio Strategist, and Head of the Portfolio Architecture team for Morgan Stanley Investment Management's Global Portfolio Solutions group. Additionally, Baumgartner has held positions as Portfolio Manager at both Quantal Asset Management and Strategy Capital.

Of Baumgartner's appointment, Robbert Dijkgraaf, Director and Leon Levy Professor, stated, "We are honored to have someone with Mark's combination of strong investment experience and understanding of the Institute's needs to guide our strategic growth."

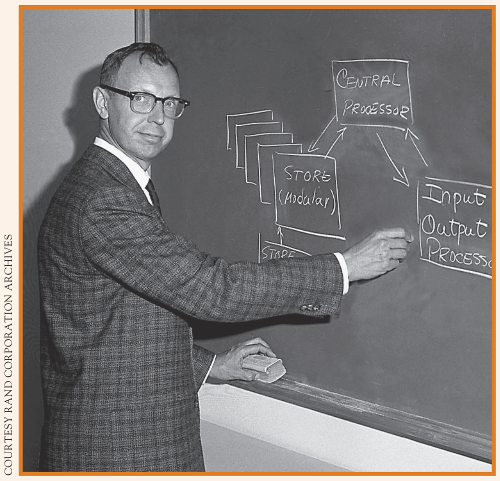
Baumgartner received a Ph.D. in aerospace engineering and a certificate in public policy from Princeton University, and a B.S.E. in aerospace engineering from the University of Florida. He also holds the Chartered Financial Analyst certification. ■

Willis Ware: Last of the Original ECP Engineers

Ware's contributions helped create the working architecture of the modern digital computer.

BY GEORGE DYSON

Willis Ware accepted a position with the Institute for Advanced Study's Electronic Computer Project (ECP) on May 13, 1946, and began work on June 1. He was the fourth engineer hired to work on the project—and, at his death on November 22, 2013, was the last survivor of the original engineering team. The working architecture of the modern digital computer—gates, timers, shift registers, all the elements we take entirely for granted including how to implement an adder, not to mention random-access memory and the registers that keep track of it—has Willis Ware's fingerprints all over it.



COURTESY RAND CORPORATION ARCHIVES

Willis Ware

He and his friend and colleague James Pomerene were hired by chief engineer Julian Bigelow from Hazeltine Electronics in Little Neck, Long Island, where they had worked on IFF (Identification Friend or Foe) radar systems during World War II. IFF was an implementation, using analogue components, of high-speed digital coding, and was the opposite of encryption. Instead of trying to encode a message that was as difficult as possible to understand when intercepted, the goal of IFF was to transmit a code that would be as difficult as possible to *mis*understand. The ability to reliably manipulate high-speed pulses of electrons that Ware and colleagues had developed for IFF was perhaps the greatest technical contribution that anyone brought to the problem of physically realizing, at megacycle speed, what John von Neumann had set out to do, in theory, in late 1945 and early 1946.

Ware was there from the very beginning—starting with the construction of workbenches in the Fuld Hall basement—using "firewood" since wartime rationing of lumber was still in effect. Even scarcer than lumber were apartments, and Ware and Pomerene solved this problem by trading their New York apartments with a couple of Princeton residents who were commuting to work at the United Nations. Ware became the project's official technical photographer, and his superb documentation of every stage in the construction of the new machine, included in the widely disseminated series of "Interim Progress Report[s] on the Physical Realization of an Electronic Computing Instrument" (starting in January 1947) were instrumental to the immediate and worldwide replication of the IAS design (including its commercial implementation as the IBM 701). Ware and his fellow engineers were well aware that they were forgoing any patents on the inventions they were making right and left, but, continuing in the spirit of wartime cooperation they had started with, they did not object.

About von Neumann, and the origins of stored-program computing, Ware made the now immortal statement that "he was in the right place at the right time with the right connections with the right idea, setting aside the hassle that will probably never be resolved as to whose ideas they really were."

Ware was there at the creation. "I and Akrevoe [Kondopria Emmanouilides, the project secretary, who came to IAS from the ENIAC project at Penn] are the only ones left of the Princeton tribe," he wrote to me this past year. "If there is any last thing that you need about ECP, now's the time to ask about it. The hourglass has only a few hundred grains of sand remaining."

He gave all of us so much. ■

George Dyson, Director's Visitor (2002–03), is the author of Turing's Cathedral: The Origins of the Digital Universe *(Pantheon Books, 2012).*

Revolutionary Ideas: An Intellectual History of the French Revolution

How freedom of the theater promised to be a major extension of liberty

By Jonathan Israel

Early on in the French Revolution, in his memoir on press freedom submitted to the Estates-General in June 1789, Jean-Pierre Brissot (1754–93), later a prominent revolutionary leader, proclaimed liberty of the press "un droit naturel à l'homme." Loathed by Maximilien Robespierre, Brissot, together with his political allies, was later guillotined in October 1793 by the Montagne, the political faction that organized the Terror of 1793–94. During 1789 and throughout the period down to the coup that brought the Montagne to power in June 1793, no one publicized the demand for full freedom of expression more vigorously than Brissot. He also raised the issue of liberty from theater censorship, something which at that time existed nowhere in Europe, or indeed anywhere else, and never had. Theater freedom mattered more for renewing "liberty" than people think, he explained, since the theater exerts a great influence "sur l'esprit public," a point he would develop further, he adds, were not a writer of talent—the playwright Marie-Joseph Chénier (1762–1811)—already doing so. Among the Revolution's principal champions of free expression, this literary ally of Brissot's was the brother of the poet André Chénier who was guillotined by the Montagne in July 1794.

UNKNOWN ITALIAN ARTIST FOR POPE GREGORY XIII, SALA REGIA, VATICAN

A sixteenth-century painting of Charles IX in front of the Parliament of Paris on August 26,1572, attempting to justify the Saint Bartholomew's Day massacre.

By July 1789, the month of the storming of the Bastille, the question was no longer whether revolutionary France should possess freedom of expression and of the press—all the revolutionaries then agreed that it should—but rather whether this freedom required limits. Should there be "liberté illimité de la presse" without legal responsibility for calumny or inciting violence? This posed a dilemma for the national legislature, for aside from the principle itself, there was much uncertainty and anxiety about the unpredictable consequences. Many believed the campaign to bring "philosophy" and Enlightenment to the people would fail. Press freedom and the other new rights were justified in the people's name, and yet, not one-hundredth part of the people actually read, warned the veteran republican writer and future deputy, Louis-Sébastien Mercier (1740–1814), while only one-thousandth part read with sufficient discernment and knowledge to separate truth from falsehood. The "ordinary man, being ignorant," he admonished, judges politicians' reputations by popular reputation rather than talent or knowledge—with predictably disastrous results.

The ensuing debate rapidly revealed the complexity of full freedom of expression. It was highly dangerous, insisted some, to permit unlimited freedom. For this enabled ill-wishers to continually denounce the best, most knowledgeable, and virtuous political candidates, journalists, and orators as "scoundrels" and "traitors" allegedly conspiring with *aristocratisme* and monarchism. Unrestricted press freedom was desirable, admonished Camille Desmoulins (who later with Georges Danton, in 1793–94, tried to curb the Terror), but came at a cost: for it fomented a new species of political deceiver, *le calomniateur* despot who systematically reviles and defames rivals using the press, forging a new kind of tyranny—*le despotisme populacier*—built on organized ignorance. The "whole art of the vile rascals" who, according to Brissot, Mercier, and Chénier, later on, in 1792–93, blighted and wrecked the Revolution and eventually imposed the Terror, lay according to them, in discrediting men of principle by systematic vilification in the popular press and by mimicking and mobilizing popular phrases and expressions that the ignorant applauded while actually disseminating views intended to silence dissent, impose their despotism, and cheat the multitude.

Five days after the storming of the Bastille, the Paris theater world erupted with its own revolutionary drama. Chénier, a democratic republican and fervent champion of free expression (detested by Robespierre), appealed to the Comédie-Française's actors to stage his newly completed antimonarchical play *Charles IX*. Designed to inspire hatred of "prejudice, fanaticism, and tyranny," it represented a new kind of political drama recounting a "national tragedy," the Saint Bartholomew's Day massacre of 1572. The Revolution demanded a new kind of play, but most actors, more accustomed to aristocratic audiences and censorship than deferring to dissident playwrights, refused to represent a French monarch onstage as a despot, criminal, and perjurer. Chénier countered with a publicity campaign demanding *Charles IX* be performed for the public good, even loudly interrupting an evening performance of another play at the Paris Théâtre-Français.

As the furor escalated, the actors found themselves severely hemmed in because the republican papers, including Brissot's *Patriote français*, unstintingly backed Chénier. Chénier sought the complete liquidation of the *ancien régime* censorship by eliminating its last effective strand—theater censorship. It was the *philosophes* who taught him and his generation "to think," he explained in his best-known pamphlet *De la Liberté du théâtre en France* (Paris, 1789) (already written but not released until late August 1789), leading them, as if by the hand, toward the truth: "they alone have prepared the Revolution now commencing." In this pamphlet, he lists philosophy's principal heroes as "Voltaire, Montesquieu, Rousseau, d'Alembert, Diderot, Mably, Raynal and Helvétius." These *philosophes* had served society during their lives and now "from the tomb" inspired the Revolution, including the upheaval transforming the theater. How did "la philosophie moderne" evolve before 1789 from the writings of the *philosophes* into a formidable force reordering all of society? Via their writings, their example, and society's mounting persecution of them. Chénier particularly stressed the unwitting contribution of the bishops who for years fought from the pulpit, issuing pastoral circulars denouncing *la philosophie* and its "doctrine abominable" as the source of all misfortune. If "philosophy" had pervaded France in recent decades, entered the royal council, and entrenched itself in aristocratic homes, and men had finally become "reasonable" in many respects, revolutionary France owed it all to those enlightened writers and thinkers banned and hounded before 1788, not just by the Crown but by the judiciary and religious authority.

The 1789–90 *Charles IX* uproar was a major cultural revolutionary episode with implications extending far beyond freedom of expression. At stake was the social function of culture itself. During the summer of 1789, those resisting the staging of *Charles IX* often embraced even full freedom of the press. What they disputed was not freedom of expression as such but rather any right to stage material that was not just topical but politically, religiously, and socially divisive. Freedom of the theater existed nowhere, and never had, and promised to be a major extension of liberty, opening up a vast new thought-world to innumerable city-dwellers who were not fully literate. In eighteenth-century England, the press was (partially) free, assuredly, but the theater remained rigidly controlled, and more tightly than ever since Horace Walpole's time. Theater culture stands apart from the world of print by being experienced collectively in an atmosphere of heightened emotion in which the semiliterate fully participate. The "antitheatricalism" of Chénier's opponents played on the evidently acute danger of unchaining previously restrained popular emotion. No true freedom of expression can exist, retorted Chénier and Brissot, where theater aligns with conventional thinking. This is why, subsequently, stringent control of the theater was one of the most vital aspects of Robespierre's dictatorship during the months from June 1793 to July 1794.

Theater reflects the people's will only where free from control and the conventions to which, historically, it has been subjected. Potentially, the stage, held Chénier and other republican stalwarts of the 1789 theater controversy, was a more potent agent of change than even books and reading. In July 1789, the newly reformed Paris city government had to intervene. Both sides to the dispute accepted society had entered a new era of freedom, and that the theater represented a potent agent of reeducation. In terms of the much-discussed but not-yet-proclaimed Declaration of the Rights of Man, Chénier and Brissot might appear fully justified. But in fact the anti-republican conservative and moderate opposition arguably held the more logical position. After all, France was a monarchy, they pointed out, that had always proclaimed Catholicism the state church: any play purposely depicting monarchy and Catholicism as odious was therefore contrary to the existing constitution, public order, and the public interest. *Charles IX* not only dramatized the reprehensibility of "tyranny" and "fanaticism," but by declaring the Saint Bartholomew's Day massacre a monstrous crime committed by king and Church directly equated monarchy with "tyranny" and Catholicism with "fanaticism."

The new, enlightened mayor of Paris, the astronomer Jean-Sylvain Bailly, opposing the staging of *Charles IX*, sharply distinguished, like British ministers, between liberty of the press and freedom of theater, because in the theater people experience

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Recommended Reading: This article is excerpted from Jonathan Israel's *Revolutionary Ideas: An Intellectual History of the French Revolution from the Rights of Man to Robespierre* (Princeton University Press, 2014).

spectacles collectively and, as he put it, "s'électrisent" (mutually electrify each other), becoming all too readily disruptive of public order and good morals. Several commentators agreed that the multitude was unpredictable and easily steered in the wrong direction by "unpatriotic" writers. Backed by the mayor, the actors briefly gained the initiative. But the republicans mobilized support in the Paris sections against Bailly, in part by buying up large quantities of tickets and packing performances with their supporters. On August 19, 1789, demonstrators disrupted a performance at the Comédie-Française, calling out from the pit for *Charles IX*. There was no official permission for this, retorted the actors, to which the demonstrators replied: "no more permissions!"

As Brissot, Nicolas de Condorcet, and the democratic republicans gained ground in Paris municipal politics, so did Chénier and the other republican publicists embroiled in the capital's theater wars. Finally, on November 4, 1789, with the theater's name officially changed from Comédie-Française to Théâtre de la Nation, the play was staged contrary to the actors' wishes. On opening night, both Danton, who had attended some rehearsals, and Mirabeau figured among the audience, their presence endorsing the play's message. As the curtain rose, Danton, despite his huge girth, leaped onto the stage to direct the applause. Staged for several months over the winter of 1789–90, *Charles IX* was indeed a landmark in theater history, inaugurating an era characterized (until Robespierre's coup) by an entirely new close alignment of the stage with "philosophy."

The "moderates" succeeded in dampening down Paris's theater wars somewhat during early 1790, but the furor resumed with undiminished intensity as the first anniversary of the storming of the Bastille approached. The July 14, 1790, first anniversary precipitated a wave of emotion not only across France but also across the entire pro-Revolution intelligentsia in Britain, Holland, Belgium, the United States, and Germany as well. At Hamburg, Georg Heinrich Sieveking organized a grand all-day festival and banquet for eighty guests on his property at nearby Harvestehude. Those present included numerous noted intellectuals and literary figures, among them the son of the great philologist Reimarus, Johann Albert Heinrich Reimarus (1729–1814); his famous unmarried sister, Elise Reimarus (1735–1805), a friend of Gotthold Ephraim Lessing and Moses Mendelssohn; the former leader of the Illuminati in Protestant Germany, Adolph Freiherr von Knigge (1752–96), among the foremost supporters of the French Revolution outside France; and the celebrated German poet Friedrich Gottlieb Klopstock (1724–1803). The banquet, accompanied by live music, a women's choir, discharge of ceremonial cannon, and two revolutionary odes by Klopstock, lasted all day, the participants successively toasting the "happiness of France," the glorious July 14, the French National Assembly, Bailly, Lafayette, Mirabeau, and Klopstock. The men, sporting tricolor cockades, and the women, wearing white dresses with tricolor sashes and hats with tricolor cockades, ate, listened to speeches, and sang, raising their glasses to numerous ideologically charged toasts, including to "prompt consequences" and an end to princely *Despotismus* in Germany.

Predictably, the fraught Paris theater world powerfully added to the tide of pro-Revolution emotion of July 1790. As the first anniversary of the Bastille approached, the actors were besieged with demands for performances of Voltaire's *Brutus* (1731) and *The Death of Caesar* (1735); Antoine-Marin Lemierre's *Guillaume Tell* (1766), a play revived with success, earlier, in 1786; *Barnevelt*, also by Lemierre; and, of course, Chénier's *Charles IX*. In recent months, all such requests had been routinely rejected by royal ministers and theater directorates owing to the overtly republican slant one could expect Paris's indoctrinated, expectant, and unruly audiences to place on their content. Boycotting all those plays, the former Comédie-Française, since November 1789 renamed the Théâtre de la Nation, performed what pro-Revolution theater critics called "the most insignificant pieces" they could find, all breathing the spirit of "servitude" and "adulation." Comédie-Française actors, who despite the change in the name of the theater still styled themselves "comediens français ordinaires du roi," reportedly mostly backed the *parti anti-révolutionnaire*. With their blatantly biased choice of plays, ministers, actors, and theater directors were accused of inculcating into the people, or at least into the most unaware and least sophisticated, adulation of kings and nobles "nothing being easier than to mislead ordinary folk and seduce their minds" by manipulating emotions in ways they fail to understand. However, the resistance of the actors and theaters simply collapsed amid the growing furor and commotion in the French theater world during July.

Pressure to stage republican material eventually proved irresistible. The Théâtre de la Nation agreed to stage its first ever performance of *Barnevelt*, a drama about Johan van Oldenbarnevelt's downfall in 1618. The premiere took place on June 30, 1790, its more obviously republican moments eliciting embarrassingly furious applause from the audience. A spectator, defiantly expressing monarchical indignation by hissing loudly, was hounded from the theater. Predictably, *Charles IX*, performed thirty-four times in the autumn of 1789, was insistently demanded but was resisted stubbornly. Like the rest of society, the actors were deeply split, most vigorously opposing the pressure to stage the play. A minority, led by the radical François-Joseph Talma (1763–1826), the most renowned tragic actor of the revolutionary era, and his leading lady, Mme. Vestris, did wish to perform it.

Requests flowed especially from volunteer soldiers (*fédérés*) from the provinces who had been sent to Paris to participate in the July 14 marches and celebrations. Those from Marseille demanded the play with particular ardor and enlisted Mirabeau to help secure it. A disturbance calling for the play, openly encouraged by Talma, occurred at the theater on July 22. Opposing efforts to enlist Bailly to ban the play and arrest Talma as an *incendiaire* failed, Chénier mobilizing additional support in the most militantly radical district of Paris, the notorious Cordeliers section. Noting Mirabeau's intervention, Danton's interest, and the fédérés' enthusiasm, Bailly wisely permitted performance to go ahead but took care to post armed guards around the theater. The play was finally staged on July 23, with Danton present. Trouble ensued afterward when Talma, now publicly allied to Brissot, Mirabeau, Danton, and Chénier, so antagonized fellow actors that they ejected him from the theater and permanently boycotted him.

The French theater world was plunged into ferment, one side adhering to a "moderate" course, the other proclaiming the theater "the modern school of liberty." When Voltaire's *Brutus* was repeated on November 17, the audience, relating events onstage to events in the country, immediately split into opposed factions, one side yelling "Vive le roi!," the other "Vive le roi, vive la Nation!" During a performance of *La Liberté conquise* at the Théâtre de la Nation, at the moment the Bastille's assailants proclaim their oath to "conquer or die," the audience rose to their feet as one, the men lifting their hats on the ends of their canes and shaking them in the air, the women holding aloft their hands and throwing up handkerchiefs, thoroughly stirring all present. During another performance of this same play, "the brave Arné"—the grenadier who overpowered the Bastille's governor and then clambered up the Bastille's highest turret to raise his hat high into the air on his bayonet—was spotted. The audience spontaneously demanded he be crowned with a liberty cap. As Arné was "crowned," enthusiastic market women rousingly sang an uplifting chorus in the hero's honor.

The Paris Opera became equally polarized. *Iphigénie en Aulide* by Christoph Willibald Gluck, first performed at the Paris Opera in 1774, produced an unruly incident in December 1790, with *patriotes* occupying the parterre in force and monarchists predominating higher up, in the more expensive seats. When the aria "let us celebrate our queen" was sung, aristocrats in the boxes thunderously applauded while the parterre stamped, hissed, and jeered. In response, Antoinettistes hurled down cartons and apples, provoking *patriotes* to try to climb up to the boxes with little "martinets" for whipping fine ladies sporting the white (royalist) cockade, only to be repelled by the National Guard posted by the mayor to keep order.

At a meeting on September 27, 1790, Théâtre de la Nation actors expressed resentment at being yelled at by revolutionaries and called "réfractaires" and "authors of counterrevolution" by hostile audiences. Unable either to secure court permission to perform *Charles IX* or persuade audiences that the play was banned, the actors requested a Paris civic directive requiring performances of *Charles IX* on specified days as a way of evading blame and recrimination for staging "republican plays." When the autumn season of *Charles IX* eventually opened, Mirabeau was spotted among the audience and given a rousing ovation. On December 18, 1790, by which time there was tension in Paris not just between "moderates" and republicans, but now also between the increasingly anticlerical Revolution and the Church, the Théâtre de la Nation premiered *Jean Calas*, based on Voltaire's most famous public campaign against bigotry, a piece written by the man who subsequently emerged the most daring democratic, free speech, and anti-Robespierre playwright of the revolutionary years, the Left republican playwright Jean-Louis Laya (1761–1833). His play in which not only the political old regime but also the judges' "fanaticism," religious authority, and ecclesiastical intolerance were all unremittingly pilloried, according to the pro-Revolution papers was "applauded universally."

Yes, indeed, the noisy Parisian democratic republican element applauding Jean-Louis Laya and Chénier had become a powerful force. For a time they took over the theaters. But not for long. The applause could not hide the fact that most people in France either supported the ultra-royalist Right, or the constitutional monarchists like Bailly, wanting some limitation of freedom of expression, or else, and much worse, followed Marat and Robespierre in their ruthless drive for dictatorship, suppression of press freedom, and the elimination of all dissent. From June 1793, Chénier was silenced, Brissot imprisoned and his paper suppressed, Laya forced into hiding, and the theaters not just of Paris but of all France's cities were as thoroughly terrorized and subjected to the dictatorship of popular counter-Enlightenment and the "ordinary" as any part of French culture. ■

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What Can We Do with a Quantum Computer?

The study of quantum information could lead to a better understanding of the principles common to all quantum systems.

By Andris Ambainis

When I was in middle school, I read a popular book about programming in BASIC (which was the most popular programming language for beginners at that time). But it was 1986, and we did not have computers at home or school yet. So, I could only write computer programs on paper, without being able to try them on an actual computer.

Surprisingly, I am now doing something similar—I am studying how to solve problems on a quantum computer. We do not yet have a fully functional quantum computer. But I am trying to figure out what quantum computers will be able to do when we build them.

SCOTT ADAMS/DILBERT

The story of quantum computers begins in 1981 with Richard Feynman, probably the most famous physicist of his time. At a conference on physics and computation at the Massachusetts Institute of Technology, Feynman asked the question: "Can we simulate physics on a computer?"

The answer was—not exactly. Or, more precisely—not all of physics. One of the branches of physics is quantum mechanics, which studies the laws of nature on the scale of individual atoms and particles. If we try to simulate quantum mechanics on a computer, we run into a fundamental problem. The full description of quantum physics has so many variables that we cannot keep track of all of them on a computer.

If one particle can be described by two variables, then to describe the most general state of n particles, we need 2^n variables. If we have 100 particles, we need 2^{100} variables, which is roughly 1 with 30 zeros. This number is so big that computers will never have so much memory.

By itself, this problem was nothing new—many physicists already knew that. But Feynman took it one step further. He asked whether we could turn this problem into something positive: If we cannot simulate quantum physics on a computer, maybe we can build a quantum mechanical computer—which would be better than the ordinary computers?

This question was asked by the most famous physicist of the time. Yet, over the next few years, almost nothing happened. The idea of quantum computers was so new and so unusual that nobody knew how to start thinking about it.

But Feynman kept telling his ideas to others, again and again. He managed to inspire a small number of people who started thinking: what would a quantum computer look like? And what would it be able to do?

Quantum mechanics, the basis for quantum computers, emerged from attempts to understand the nature of matter and light. At the end of the nineteenth century, one of the big puzzles of physics was color.

The color of an object is determined by the color of the light that it absorbs and the color of the light that it reflects. On an atomic level, we have electrons rotating around the nucleus of an atom. An electron can absorb a particle of light (photon), and this causes the electron to jump to a different orbit around the nucleus.

In the nineteenth century, experiments with heated gasses showed that each type of atom only absorbs and emits light of some specific frequencies. For example, visible light emitted by hydrogen atoms only consists of four specific colors. The big question was: how can we explain that?

Physicists spent decades looking for formulas that would predict the color of the light emitted by various atoms and models that would explain it. Eventually, this puzzle was solved by Danish physicist Niels Bohr in 1913 when he postulated that atoms and particles behave according to physical laws that are quite different from what we see on a macroscopic scale. (In 1922, Bohr, who would become a frequent Member at the Institute, was awarded a Nobel Prize for this discovery.)

To understand the difference, we can contrast Earth (which is orbiting around the Sun) and an electron (which is rotating around the nucleus of an atom). Earth can be at any distance from the Sun. Physical laws do not prohibit the orbit of Earth to be a hundred meters closer to the Sun or a hundred meters further. In contrast, Bohr's model only allows electrons to be in certain orbits and not between those orbits. Because of this, electrons can only absorb the light of colors that correspond to a difference between two valid orbits.

Around the same time, other puzzles about matter and light were solved by postulating that atoms and particles behave differently from macroscopic objects. Eventually, this led to the theory of quantum mechanics, which explains all of those differences, using a small number of basic principles.

Quantum mechanics has been an object of much debate. Bohr himself said, "Anyone not shocked by quantum mechanics has not yet understood it." Albert Einstein believed that quantum mechanics should not be correct. And, even today, popular lectures on quantum mechanics often emphasize the strangeness of quantum mechanics as one of the main points.

But I have a different opinion. The path of how quantum mechanics was discovered was very twisted and complicated. But the end result of this path, the basic principles of quantum mechanics, is quite simple. There are a few things that are different from classical physics and one has to accept those. But, once you accept them, quantum mechanics is simple and natural. Essentially, one can think of quantum mechanics as a generalization of probability theory in which probabilities can be negative.

In the last decades, research in quantum mechanics has been moving into a new stage. Earlier, the goal of researchers was to understand the laws of nature according to how quantum systems function. In many situations, this has been successfully achieved. The new goal is to manipulate and control quantum systems so that they behave in a prescribed way.

This brings the spirit of research closer to computer science. Alan Key, a distinguished computer scientist, once characterized the difference between natural sciences and computer science in the following way. In natural sciences, Nature has given us the world, and we just discovered its laws. In computers, we can stuff the laws into it and create the world. Experiments in quantum physics are now creating artificial physical systems that obey the laws of quantum mechanics but do not exist in nature under normal conditions.

An example of such an artificial quantum system is a quantum computer. A quantum computer encodes information into quantum states and computes by performing quantum operations on it.

There are several tasks for which a quantum computer will be useful. The one that is mentioned most frequently is that quantum computers will be able to read secret messages communicated over the internet using the current technologies (such as RSA, Diffie-Hellman, and other cryptographic protocols that are based on the hardness of number-theoretic problems like factoring and discrete logarithm). But there are many other fascinating applications.

First of all, if we have a quantum computer, it will be useful for scientists for conducting virtual experiments. Quantum computing started with Feynman's observation that quantum systems are hard to model on a conventional computer. If we had a quantum computer, we could use it to model quantum systems. (This is known as "quantum simulation.") For example, we could model the behavior of atoms and particles at unusual conditions (for example, very high energies that can be only created in the Large Hadron Collider) without actually creating those unusual conditions. Or we could model chemical reactions—because interactions among atoms in a chemical reaction is a quantum process.

Another use of quantum computers is searching huge amounts of data. Let's say that we have a large phone book, ordered alphabetically by individual names (and not by phone numbers). If we wanted to find the person who has the phone number 6097348000, we would have to go through the whole phone book and look at every entry. For a phone book with one million phone numbers, it could take one million steps. In 1996, Lov Grover from Bell Labs discovered that a quantum computer would be able to do the same task with one thousand steps instead of one million.

More generally, quantum computers would be useful whenever we have to find something in a large amount of data: "a needle in a haystack"—whether this is the right phone number or something completely different.

Another example of that is if we want to find two equal numbers in a large amount of data. Again, if we have one million numbers, a classical computer might have to look at all of them and take one million steps. We discovered that a quantum computer could do it in a substantially smaller amount of time.

All of these achievements of quantum computing are based on the same effects of quantum mechanics. On a high level, these are known as quantum parallelism and quantum interference.

A conventional computer processes information by encoding it into 0s and 1s. If we have a sequence of thirty 0s and 1s, it has about one billion of possible values. However, a classical computer can only be in one of these one billion states at the same time. A quantum computer can be in a quantum combination of all of those states, called superposition. This allows it to perform one billion or more copies of a computation at the same time. In a way, this is similar to a parallel computer with

(Continued on page 7)

What's Next?

New physics suggests a profound conceptual revolution that will change our view of the world.

The following excerpts are drawn from Professor Nathan Seiberg's public lecture "What's Next?" available online at https://video.ias.edu/seiberg-2013/.

I do not know what the future will bring. I guess nobody knows; and we do not know what will be discovered, either experimentally or theoretically, and that's actually one of the reasons we perform experiments. If we knew for sure what the outcomes of the experiment would be, there would be no reason to perform the experiment. This is also the reason scientific research is exciting. It's exciting because we're constantly surprised either because an experiment has an unexpected outcome or theoretically someone comes up with a new insight. . . .

We are in an unusual and unprecedented situation in physics. We have two Standard Models. The Standard Model of particle physics describes the shortest distances and the Standard Model of cosmology describes the longest distances in the universe. These models work extremely well over the range of distances for which they were designed to work. However, there are excellent arguments that this story is not complete, and there must be new physics beyond these models. . . .

We have something that works almost perfectly, there are only a few details that don't work and these details really should be interpreted as the first sign of the next revolution. . . . One should focus on these little discrepancies, these little things that are not fully understood, because these are the things that will guide us. . . .

Often research progresses in steps. We collect data. We find a pattern, explaining a lot of data using fewer numbers (parameters). And then we ask why is the pattern right? What is the underlying principle that controls this pattern? Once we find the underlying principle behind the pattern, we try to understand the remaining parameters and then we go back to the beginning. . . . Sometimes we try to explain a number that is not fundamental, and the art is to figure out what is it that we need to explain. . . .

In many cases, we understand the laws only in principle. What most physicists do is try to understand the consequences of the laws we understand. All of chemistry follows from these laws. All of biology follows from these laws, and there is a lot of interesting and exciting science trying to work out the consequences of these laws. But, at least in principle, we know what the fundamental laws are. . . .

"Take a look at this everyone - it just could be the signature we've been looking for!"

CHRIS MADDEN

The model of particle physics uses two of the revolutions of the twentieth century: quantum mechanics and special relativity. The cosmology model uses the third revolution of twentieth-century physics: general relativity. We need to combine the principles of one model with the principles of the other model. In other words, we need to combine quantum mechanics and general relativity. . . .

We would like to explain all of the parameters in these two models. Some of these parameters are unstable. If we make small changes at short distances, they make a huge difference at long distances. An ongoing experiment, the Large Hadron Collider (LHC), is going to give us input into this question. If there is a stabilizing mechanism for this instability, it will be discovered at the LHC. . . .

The experiments will find a new stabilizing mechanism or, alternatively, that there is no stabilizing mechanism. If there is no stabilizing mechanism, we may have to go to a multiverse arena where there are lots of universes and we are just in one random universe, where these parameters are environmental; and we will have to start learning how to think about physics in such a setup. Clearly these are very interesting issues. I asked at the beginning of the talk, "What is next?" The answer is we do not know, but it's guaranteed to be exciting. ■

QUANTUM COMPUTER *(Continued from page 6)*

one billion processors performing different computations at the same time—with one crucial difference. For a parallel computer, we need to have one billion different processors. In a quantum computer, all one billion computations will be running on the same hardware. This is known as quantum parallelism.

The result of this process is a quantum state that encodes the results of one billion computations. The challenge for a person who designs algorithms for a quantum computer (such as myself) is: how do we access these billion results? If we measured this quantum state, we would get just one of the results. All of the other 999,999,999 results would disappear.

To solve this problem, one uses the second effect, quantum interference. Consider a process that can arrive at the same outcome in several different ways. In the non-quantum world, if there are two possible paths toward one result and each path is taken with a probability ¼, the overall probability of obtaining this result is ¼+¼= ½. Quantumly, the two paths can interfere, increasing the probability of success to 1.

Quantum algorithms combine these two effects. Quantum parallelism is used to perform a large number of computations at the same time, and quantum interference is used to combine their results into something that is both meaningful and can be measured according to the laws of quantum mechanics.

The biggest challenge is building a large-scale quantum computer. There are several ways one could do it. So far, the best results have been achieved using trapped ions. An ion is an atom that has lost one or more of its electrons. An ion trap is a system consisting of electric and magnetic fields, which can capture ions and keep them at locations. Using an ion trap, one can arrange several ions in a line, at regular intervals.

One can encode 0 into the lowest energy state of an ion and 1 into a higher energy state. Then, the computation is performed using light to manipulate the states of ions. In an experiment by Rainer Blatt's group at the University of Innsbruck, Austria, this has been successfully performed for up to fourteen ions. The next step is to scale the technology up to a bigger number of trapped ions.

There are many other paths toward building a quantum computer. Instead of trapped ions, one can use electrons or particles of light—photons. One can even use more complicated objects, for example, the electric current in a superconductor. A very recent experiment by a group led by John Martinis of the University of California, Santa Barbara, has shown how to perform quantum operations on one or two quantum bits with very high precision from 99.4% to 99.92% using the superconductor technology.

The fascinating thing is that all of these physical systems, from atoms to electric current in a superconductor, behave according to the same physical laws. And they all can perform quantum computation. Moving forward with any of these technologies relates to a fundamental problem in experimental physics: isolating quantum systems from environment and controlling them with high precision. This is a very difficult and, at the same time, a very fundamental task and being able to control quantum systems will be useful for many other purposes.

EXPERIMENTS IN QUANTUM PHYSICS ARE NOW CREATING ARTIFICIAL PHYSICAL SYSTEMS THAT OBEY THE LAWS OF QUANTUM MECHANICS BUT DO NOT EXIST IN NATURE UNDER NORMAL CONDITIONS.

Besides building quantum computers, we can use the ideas of information to think about physical laws in terms of information, in terms of 0s and 1s. This is the way I learned quantum mechanics—I started as a computer scientist, and I learned quantum mechanics by learning quantum computing first. And I think this is the best way to learn quantum mechanics.

Quantum mechanics can be used to describe many physical systems, and in each case, there are many technical details that are specific to the particular physical system. At the same time, there is a common set of core principles that all of those physical systems obey.

Quantum information abstracts away from the details that are specific to a particular physical system and focuses on the principles that are common to all quantum systems. Because of that, studying quantum information illuminates the basic concepts of quantum mechanics better than anything else. And, one day, this could become the standard way of learning quantum mechanics.

For myself, the main question still is: how will quantum computers be useful? We know that they will be faster for many computational tasks, from modeling nature to searching large amounts of data. I think there are many more applications and, perhaps, the most important ones are still waiting to be discovered. ■

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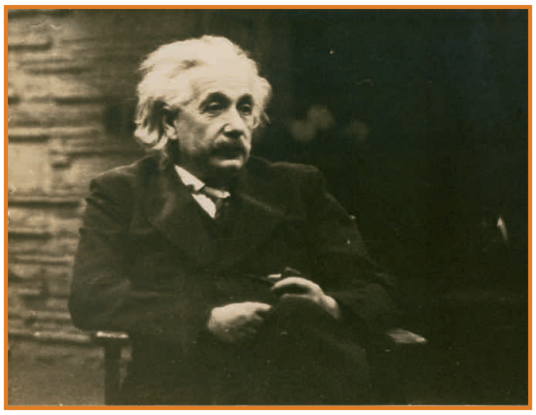
Albert Einstein, Frank Lloyd Wright, Le Corbusier, and the Future of the American City

Einstein's reputation gained him a following among architects who were out to transform American architecture and design.

BY MILTON CAMERON

When Albert Einstein first met Frank Lloyd Wright, he mistook the architect for a musician. Leaping from his chair, Einstein announced that he was returning home to fetch his violin and would be back shortly to perform a duet. Only upon his return did he learn that Wright was not a pianist. It was early 1931, and the two men were guests of Alice Millard, a rare book and antique dealer. The setting, ironically, was the dining room of La Miniatura, the house that Wright had designed for Millard at 645 Prospect Crescent, Pasadena. But if the architect was taken aback by Einstein's gaffe, he did not show it. Wright had just met the most famous person in the world, and was determined to exploit the opportunity for all it was worth.

Wright liked to groom important public figures to complement his social circle and support his campaigns. The latest of these, which would obsess him for the remainder of his life, was to replace congested, disease-ridden cities and their skyscrapers with a dispersed, horizontal form of development that would spread across the countryside and capitalize upon the increasing availability of automobiles. Wright knew he would need all the help he could get to achieve such a radical transformation of the fabric of American society. Einstein's name and reputation was just what he required.



Albert Einstein in living room, Fallingwater, 1939

Le Corbusier and Albert Einstein in Princeton, New Jersey, 1946

Both men were away from home. Einstein, who was employed by the Prussian Academy of Sciences in Berlin, was a visiting scholar at the California Institute of Technology. Wright lived at Taliesin, his country retreat in Spring Green, Wisconsin, and was in Pasadena to discuss the garage addition to La Miniatura with his client. The physicist and the architect only managed to exchange a few words that evening. Wright told Einstein about the school of architecture he was establishing at Taliesin, where, in addition to architecture and construction, his apprentices were engaged in farming, gardening, cooking, music, and dance. Like Wright, Einstein preferred quiet places, far away from the hustle and bustle of large cities, which he believed were not conducive to deep thought. Although he had an apartment in Berlin, Einstein spent most of his time just outside the city at Caputh, in a small weekend house designed for him by German architect Konrad Wachsmann.

As Einstein sat with Wright in La Miniatura, a tiny, romantic, Mayan-temple of a house with dappled light filtering through perforated block screens and a view over a pond bridged with stepping-stones, he was charmed by the architect's enthusiasm and creative imagination. Wright asked if he would like to visit Taliesin. Einstein said he would try to come in the fall.

In February 1931, Wright sent a telegram to Einstein confirming his invitation. He offered to meet the Einsteins in Chicago, drive them to Taliesin, and return them to Chicago two days later, in time for their New York train. Elsa Einstein replied that their itinerary was full, and suggested that they spend a few hours together at the Chicago railway station instead. Wright obliged, and on March 3, he and his wife, Olgivanna Lloyd Wright, sat and talked with the Einsteins in their Pullman car while they waited for their 20th Century Limited express.

When Wright's new book, *Modern Architecture* (based on his 1930 Princeton University Kahn Lectures), was published, he inscribed a copy: "To the Supreme Scientist Albert Einstein from Frank Lloyd Wright in remembrance of an hour together," and mailed it to the physicist. In *Modern Architecture*, Wright critiqued historical eclecticism, commercial skyscrapers, and urban planning, and distinguished his own organic architecture from the sleek, machine-age aesthetic advocated by the Bauhaus School and European modernists such as the Swiss architect Le Corbusier. Wright's reasons for distrusting these "evil crusaders" were personal: at the age of sixty-four, he saw them as rivals and a threat to his legacy. Einstein's view of European modernism was more nuanced. While he provided intellectual and moral support to the Bauhaus through his positions on the Governing Board and the Circle of Friends, he did this because he valued artistic freedom, not because he endorsed Bauhaus design. When Wachsmann had presented his preliminary sketches for the weekend house, Einstein declared: "I don't want a house that looks like a carton with giant display windows." Instead, he specified walls of brown stained wood, white window frames, white wooden shutters, and a dark red tiled roof. And when Wachsmann produced interior sketches by Marcel Breuer, Einstein added: "I do not want to sit on furniture that reminds me of a machine shop or an operating room."

When Wright had not received a response from Einstein by October 1933, he wrote again, reminding the physicist of his promise to visit Taliesin, and pledging congenial company amidst the forty young architects of the Taliesin Fellowship. Elsa replied from the Peacock Inn: they could not make the trip because they had just arrived in Princeton, where her husband was "fully occupied with his problems" at the Institute for Advanced Study. They hoped, however, that Wright might be able to visit them in Princeton.

Wright had a better idea: if Einstein could not come to Taliesin, perhaps the scientist could attend one of his lectures in New York? What a publicity coup it would be to have Einstein in the audience, and in his entourage for dinner afterwards! "I am to lecture at Columbia University on 'creative America' on November 20th," Wright announced, "and I hope I may see you then." Wright even organized tickets for the Einsteins, and another for Millard, who was visiting New York. Einstein replied that he was very happy that Wright was to give an important lecture in New York, and that there was to be a dinner afterwards to which he was invited. He regretted, however, that he could not attend because it would be too difficult for him to return to Princeton at night. Einstein invited Wright to pay an informal visit to their house, then at 2 Library Place, Princeton, instead. Wright put the letter—and Einstein—aside for the time being.

Two weeks later, the *New York Times Magazine* published "A Noted Architect Dissects our Cities," an article in which Le Corbusier savaged the planning and architecture of New York and Chicago. Wright had no problem with that, but was outraged by Le Corbusier's proposed alternative. Wright believed that Le Corbusier's "Radiant City," a high-density arrangement of sleek, modern skyscrapers in a park, was simply a new version of the old industrial city that he detested. The American was invited to respond, and his riposte—"Broadacre City: An Architect's Vision"—set out details of the decentralized concept that he had been formulating. In Broadacre, cities and towns would be "eliminated," government reduced to no more than a county architect who would allocate land and construct basic community facilities, and every family would be allocated a minimum of one acre of land upon which to build a house. The houses, and almost everything else, would be privately owned. There would be no trains; everyone would drive a car or pilot an autogyro. Broadacre City would be a continuous, rectilinear grid of private enterprise development extending from coast to coast across the entire country.

Meanwhile, Einstein was considering his own solutions to America's housing problem. Based on observations he made during a 1923 visit to Rishon LeZion, the first modern Zionist settlement in Palestine, and Moshav Nahalal, a collective settlement designed by German architect Richard Kaufmann, Einstein became interested in the idea of cooperative communities. In 1933, he lent his support to a project instigated by Benjamin Brown, a Ukrainian-Jewish immigrant. Einstein, Brown, and four other advocates petitioned the United States government for funding to relocate two hundred skilled Jewish needleworkers from the slums and sweatshops of Manhattan to the country. There, the workers were to be provided with housing, a cooperative garment factory, retail store, and community farm from which they could become self-sustaining. The government contributed a stretch of New Jersey flatland near Hightstown; German-born, Philadelphia architect Alfred Kastner and his young assistant, Louis Kahn, designed the project.

As he worked on the design, Kahn sat at his drafting table with a book by Le Corbusier propped up in front of him. The thirty-five small, white houses with flat roofs and large garment factory (comprising the first stage of the project) that Einstein officially opened in June 1936 were closer in spirit to Le Corbusier and the Bauhaus than they were to Wright's organic architecture. That year, the Jersey Homesteads, as they became known, were included in an "Exhibition of Architecture in Government Housing" at the Museum of Modern Art, while an article in the *Architectural Forum* claimed they were "the most remarkable houses standing in the U.S. last month," "the most modern, functional houses ever erected by the U.S. government."

Einstein had not heard from Wright since he received the invitation to the Columbia University lecture in 1933, but the architect's influence and legacy were becoming increasingly difficult to avoid. In 1937, Frank Aydelotte, President of Swarthmore College who served on the Institute's Board of Trustees and would

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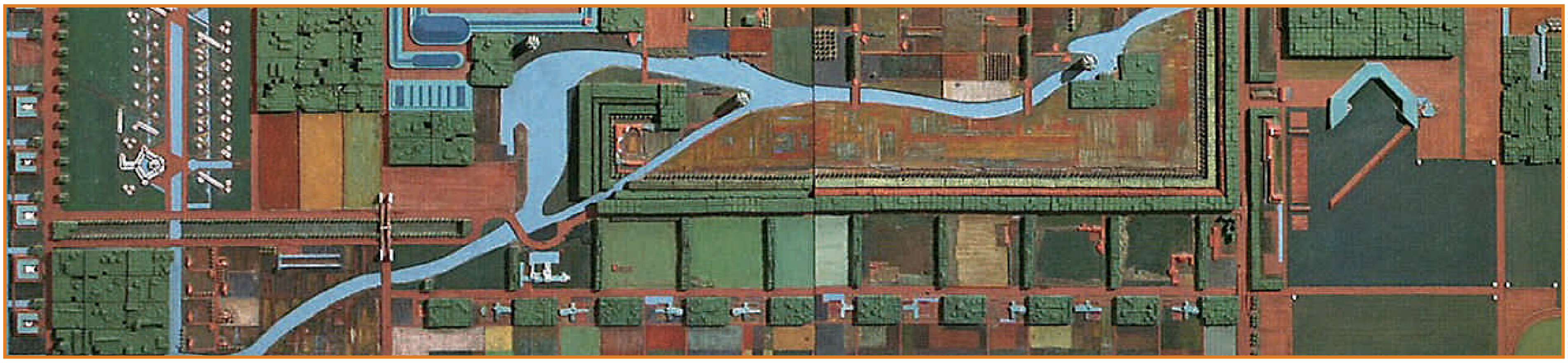


A portion of Frank Lloyd Wright's model of Broadacre City, 1934–35

become Director of the Institute in 1939, began searching for a suitable architect to design the new Institute buildings. One of the first people he contacted was the social historian Lewis Mumford. Mumford happened to be a friend and partisan of Wright, and through his writing was attempting to establish the American as the rightful father of the modern movement. Writing to Aydelotte, Mumford was effusive in his praise: Wright was "in a class by himself," he said, the "outstanding architect in the world today: more fertile and vigorous at sixty-five [sic] than in his youth. A very positive personality: hence at his best only with a completely cooperative client." Wary of the implications of Mumford's last phrase, and because he wanted a conservative Colonial or Georgian style building, Aydelotte did not include Wright on his shortlist.

In January 1938, a confident looking Wright appeared on the cover of *Time* magazine, a dramatic sketch of one of his houses looming over his right shoulder. Later that year, the Museum of Modern Art devoted an entire exhibition to the same house. Edgar J. Kaufmann's weekend house in rural Pennsylvania, better known as Fallingwater, was Wright's most accomplished residential work. Einstein visited Fallingwater on June 13, 1939, while attending a conference convened by Kaufmann to discuss the protection of Jews trapped inside Nazi Germany. Set deep within a forest, and comprising a dynamic composition of overlapping, projecting volumes cantilevered from a high rock ledge over a waterfall, Fallingwater confirmed Wright's extraordinary ability to imagine space. Perhaps the outrageous cantilevers, which stretched reinforced concrete technology to its limits (and sometimes beyond), caused Einstein to reflect momentarily upon what might have been. As a boy, he had planned on becoming an engineer.

Einstein was now familiar with three of Wright's most iconic buildings; before meeting Wright in La Miniatura in 1931, he had stayed in the Imperial Hotel in Tokyo during the 1922 Tokyo Chrysanthemum Festival and had admired Wright's entrance lobbies and geometrically carved Oya stone panels. But the vital question remained: was Wright's unquestionable genius as a manipulator of space and surface sufficient to convince Einstein of the architect's broader credentials in regard to urban planning?

The irrepressible Wright believed that it was. In January 1943, anticipating the shortage of housing and infrastructure that would exist after World War II, he stepped up his campaign for Broadacre City. Writing again to Einstein, Wright enclosed details of his proposal, plus a petition for which he hoped to receive the famous physicist's support. "A Citizen's Petition" urged the Roosevelt administration to declare Broadacre City a "worthy national objective," and to grant Wright carte blanche to produce sufficient plans, models, and drawings to explain the proposal to the American people. Einstein's reply (translated by the architect Erich Mendelsohn), stated:

> I have read with great interest the proposal of Mr. Frank Lloyd Wright whose creative imagination I always have admired. However, I do not believe in the possibility of a decentralized production at least if it is based on private enterprise. In spite of my sympathy and great esteem for Frank Lloyd Wright, I am terribly sorry to say that in all conscience I cannot support his plan.

Wright wrote back immediately. Surely there must be a mistake, he said. Perhaps the great man had misunderstood his proposal? Or perhaps Mendelsohn had not explained it clearly? After lecturing Einstein about the benefits of decentralized private enterprise, Wright tried another technique: "Thoughtful people," he said, who did not agree with all of his principles, might sign his petition anyway, because allowing him to develop Broadacre would be valuable to democracy. Hoping that it might help his cause, Wright signed off with a gentle reminder: "I remember with pleasure a little dinner with Mrs. Einstein present at Alice Millard's in Pasadena. Do you? Perhaps you will come to Taliesin—someday?"

Einstein did not reply, but it made no difference: Wright went ahead and included the scientist's name on the petition anyway. Despite Wright's constant badgering, Einstein never did make it to Taliesin.

When Le Corbusier visited the United States, Wright did not invite him to Taliesin—in fact the American refused to meet Le Corbusier on three occasions, claiming: "Corbu's influence in this country is just terrible, and he has no business here. I don't want to have to shake his hand."

Paradoxically, it was Le Corbusier, not Wright, who visited Einstein in Princeton, showing up on his doorstep one day in May 1946. Le Corbusier had not traveled to Princeton to discuss Broadacre City, nor the Radiant City. He wanted to talk to Einstein about another project that was just as ambitious. Le Corbusier wanted Einstein's endorsement of Le Modulor, a system of idealized proportions that he was developing, to which he wanted all prefabricated components for architecture and industry to conform. Le Corbusier was confident: "full of great hope that his hour had come—the time at last to do great things in this big country." He had already arranged to meet Henry Kaiser, the American industrialist and shipbuilder, and was hoping to collaborate with him on the design of prefabricated houses based on Le Modulor. Kaiser had claimed he could produce up to 10,000 houses per day (three million in a year). All Le Corbusier needed was Einstein's blessing. But the architect, who lacked confidence in mathematics, was uncharacteristically nervous in the presence of the world famous physicist. He became confused when trying to explain his grid. Einstein picked up a pencil and began to calculate. An agitated Le Corbusier kept interrupting him. Einstein eventually replaced the pencil, the calculation was lost, and the conversation turned to other things. Le Corbusier was devastated. He thought he had missed his opportunity. The physicist, however, was generous. "It is a new language of proportions," he said, as Le Corbusier was about to leave, "which expresses the good easily and the bad only with complications." Le Corbusier beamed at this, and asked Einstein to write it down. He obliged, and they posed in the rear garden at 112 Mercer Street for Le Corbusier's colleague to capture a photograph.

Le Corbusier proudly included Einstein's quotation in *Le Modulor* (1948) and *Modulor 2* (1955). Wright, naturally, was not impressed, claiming that he had always used a similar tool: "We called it a grid," he said. "Now a Swiss gentleman has written a book on it and called it the Modulor system … I sat at the kindergarten table with it." Le Modulor was not widely adopted by the construction industry. Kaiser changed his mind and decided to build cars instead of houses. Wright's utopian metropolis of Broadacre City was never realized, but the architect and his apprentices kept on tinkering with a twelve-foot-square model of the project, removing buildings and structures and replacing them with newer ones as Wright developed them.

By contrast, Jersey Homesteads, the housing project that Einstein had advocated, was conceived and built amidst controversy and economic hardship. While it failed as a cooperative venture, the residents managed to build a strong community. Renamed Roosevelt in 1945 in honor of the late president, the town gained a reputation as an artists' colony, and in 1983 was named to the National Register of Historic Places.

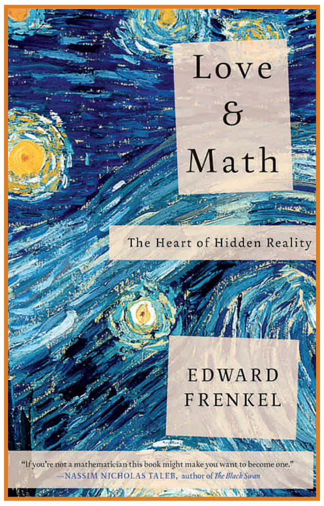
In 1955, the year that Einstein died, Wright (who was twelve years Einstein's senior), was still working on grand projects. His latest was a Mile High Tower to accommodate 100,000 employees of the State of Illinois in Chicago. A tower this high could be justified, Wright argued, if it was spaced sufficiently apart from other structures and, more importantly, if he designed it. Fortunately for Chicago, the Mile High Tower remained a figment of Wright's boundless imagination, and testament to the maverick architect's ability to reinvent himself. This was the same architect who, in 1931, had mailed Einstein a copy of his book *Modern Architecture*, which included a chapter titled "The Tyranny of the Skyscraper." ■

Milton Cameron, Visitor (2013–14) in the School of Social Science, is researching ways in which modern architects and architectural historians sought to associate themselves with Albert Einstein to gain intellectual credibility for their own work, or attempted to use aspects of Einstein's theories as metaphors for their own thought processes or as catalysts for paradigm shift within architectural design.

Recommended Viewing: "Frank Lloyd Wright and the City: Density vs. Dispersal," on view at the Museum of Modern Art in New York through June 1, includes a twelve-foot by twelve-foot model of Wright's Broadacre City plan.

Love and Math: The Heart of Hidden Reality

How a conference at IAS began a new theory bridging the Langlands program in mathematics to quantum physics



BY EDWARD FRENKEL

The Institute for Advanced Study has played an important role in my academic life. I have fond memories of my first visit in 1992, when, a starstruck kid, I was invited by Gerd Faltings and Pierre Deligne to talk about my Ph.D. thesis, which I had just completed. In 1997, I spent a whole semester at the IAS during a special year on quantum field theory for mathematicians. I returned to the IAS on multiple occasions in 2007 to collaborate with Edward Witten, and then in 2008–09 to work with Robert Langlands and Ngô Bao Châu.

Perhaps one of the most memorable visits was the one that happened exactly ten years ago, in March of 2004. It is described below in the (slightly abridged) excerpt from my book Love and Math*. A few months earlier, Kari Vilonen, Mark Goresky, Dennis Gaitsgory, and I were chosen to receive a multimillion dollar grant from the Defense Advanced Research Projects Agency (DARPA) to work on a project aimed at establishing links between the Langlands program and dualities in quantum field theory. We felt like we were in uncharted territory: no mathematicians we knew had ever received grants of this magnitude before. Normally, mathematicians receive relatively small individual grants from the National Science Foundation. Here we were given a lot of resources to coordinate the work of dozens of mathematicians with the goal of making a concerted effort in a vast area of research. This sounded a bit scary, but the idea of surpassing the traditional, conservative scheme of funding mathematical research with a large injection of funds into a promising area was really exciting, so we could not say no. We turned to the Institute for Advanced Study as the place to foster innovation. As they say, the rest is history.*

In a stroke of luck, Peter Goddard, one of the physicists who discovered the electromagnetic duality in non-abelian gauge theories, was about to become the Director of the Institute for Advanced Study in Princeton. His more recent research was on things related to representation theory of Kac–Moody algebras, and because of this, I had met Peter at various conferences.

In my email to Peter, I told him about our DARPA grant and suggested that we organize a meeting at the Institute for Advanced Study to bring together both physicists and mathematicians to talk about the Langlands program and dualities in physics, to try to find common ground, so that we could solve the riddle together.

Peter's response was the best we could hope for. He offered his full support in organizing the meeting.

The Institute was a perfect venue for such a meeting. Created in 1930 as an independent center of research and thinking, it has been home to Albert Einstein (who spent the last twenty years of his life there), Andrè Weil, John von Neumann, Kurt Gödel, and other prominent scientists. The current faculty is equally impressive: it includes Robert Langlands himself, who has been a professor there since 1972 (now emeritus), and Edward Witten. Two other physicists on the faculty, Nathan Seiberg and Juan Maldacena, work in closely related areas of quantum physics, and several mathematicians, such as Pierre Deligne and Robert MacPherson, conduct research on topics linked to the Langlands program.

My email exchange with Goddard resulted in plans for an exploratory meeting in early December 2003. [DARPA Program Director] Ben Mann, Kari Vilonen, and I were coming to Princeton, and Goddard promised to participate. We invited Witten, Seiberg, and MacPherson; another Princeton mathematician, Mark Goresky, who was co-managing the DARPA project with Kari and myself, was to join us as well (we also invited Langlands, Maldacena, and Deligne, but they were traveling and could not attend).

The meeting was set to start at 11 a.m. in the conference room next to the Institute cafeteria. Ben, Kari, and I arrived early, about fifteen minutes before the meeting. There was no one else there. As I was pacing nervously around the room, I couldn't stop thinking: "Is Witten coming?" He was the only one of the invitees who had not confirmed his participation.

Five minutes before the meeting, the door opened. It was Witten! That was the moment when I knew that something good would come out of all this.

A few minutes later, the other participants arrived. We all sat around a big table. After the usual greetings and small talk, there was silence.

"Thank you all for coming," I began. "It has been known for some time that the Langlands program and electromagnetic duality share something in common. But the exact understanding of what's going on has eluded us, despite numerous attempts. I think the time has come to unravel this mystery. And now we have the necessary resources because we have received a generous grant from DARPA to support research in this area."

People at the table were nodding their heads. Peter Goddard asked, "How do you propose we go about it?"

Prior to the meeting, Kari, Ben, and I played out different scenarios, so I was well prepared. "I suggest that we organize a meeting here at the Institute. We will invite physicists working in related areas and we will organize lectures by mathematicians to present our current state of knowledge in the Langlands program. We will then discuss together possible links to quantum physics."

Now all eyes turned to Witten, the dean of quantum physicists. His reaction was crucial. Tall and physically imposing, Witten projects great intellectual power, to the point where some feel intimidated by him. When he speaks, his statements are precise and clear to a fault; they seem to be made of unbreakable logic. He never hesitates to take a pause, contemplating his answer. At such times, he often closes his eyes and leans his head forward. That's what he did at that moment.

All of us were waiting patiently. Less than a minute must have passed by, but to me it felt like eternity. Finally, Witten said, "This sounds like a good idea. What dates do you have in mind for the meeting?"

Ben, Kari, and I couldn't help but look at each other. Witten was on board, and this was a big victory for us.

After a brief discussion, we found the dates that were suitable for everyone: March 8–10, 2004. Then someone asked who would be the participants and the speakers. We mentioned a few names and agreed to finalize the list over email and send the invitations shortly. At this, the meeting adjourned. It took no more than fifteen minutes.

Needless to say, Ben, Kari, and I were very pleased. Witten promised to help organize the meeting (which would of course be a big draw for the invitees) and to actively participate in it as well. We also expected that Langlands would take part, as well as other physicists and mathematicians on the Institute faculty who were interested in the subject. Our first goal was accomplished.

In the course of the next few days we finalized the list of participants, and a week later invitations went out. Normally, conferences like this have fifty to a hundred participants. What often happens is that speakers give their talks while everyone listens politely. A couple of participants might ask questions at the end of the talk, and a few more may engage the speaker afterward. We envisioned something completely different: a dynamic event that was more a brainstorming session than a typical conference. Therefore we wanted to have a small meeting, about twenty people. We hoped that this format would encourage more interaction and free-wheeling conversation between participants.

Just about an hour by train from New York City, Princeton looks like a typical Northeastern suburban town. The Institute for Advanced Study, known in the scientific community simply as "The Institute," is on the outskirts of Princeton, literally in the woods. The area around it is quiet and picturesque: ducks swimming in small ponds, trees reflected in still water. The Institute, a cluster of two- and three-story brick buildings with the feel of the 1950s, radiates intellectual power. One can't help but savor its rich history wandering in the hushed corridors and the main library, which was used by Einstein and other giants.

This is where we had our meeting in March 2004. Despite the short notice, the response to the invitations we sent in December was overwhelmingly positive. There were about twenty participants—so when I opened the meeting, I asked those present to take turns and introduce themselves. I felt like pinching myself: Witten and Langlands were there, sitting close by, as was Peter Goddard—and several of their colleagues from both the School of Mathematics and the School of Natural Sciences. David Olive, of the Montonen–Olive and Goddard–Nuyts–Olive papers, was also present. And of course Ben Mann was with us as well.

Everything went according to plan. We were essentially recounting the story that you have been reading in this book: the origins of the Langlands program in number theory and harmonic analysis, the passage to curves over finite fields and then to the Riemann surfaces. We also spent quite a bit of time explaining the Beilinson–Drinfeld construction and my work with Feigin on Kac–Moody algebras, as well as its links to the two-dimensional quantum field theories.

Unlike a typical conference, there was a lot of give and take between the speakers and the audience. It was an intense meeting with discussions continuing from seminar room to cafeteria and back.

Throughout, Witten was in high gear. He was sitting in the front row, listening intently and asking questions, constantly engaging the speakers. On the morning of the third day, he said to me, "I'd like to speak in the afternoon; I think I have an idea what's going on."

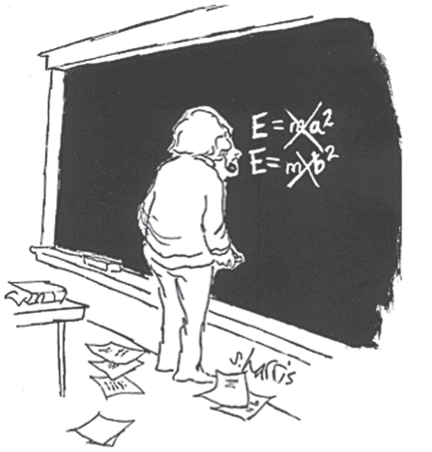
After lunch, he gave an outline of a possible connection between the two subjects. This was the beginning of a new theory bridging math and physics, which he and his collaborators, and then many others, have been pursuing ever since. ■

Edward Frenkel, Member (1997) in the School of Mathematics and Professor of Mathematics at the University of California, Berkeley, is the author of Love and Math: The Heart of Hidden Reality *(Basic Books, 2013), which has been named one of the Best Books of 2013 by both Amazon and iBooks. You may learn more about Frenkel and his work at www.edwardfrenkel.com.*

Truth or Beauty: What Can Mathematical Language Do for You?

To be fully grasped, mathematical ideas have to be rediscovered or reimagined, much like in the translation of poetry.

By Ralph Kaufmann



Mathematical language is becoming more and more pervasive. This phenomenon ranges from the mundane (imprints on T-shirts or mugs) to the more scientific (its use in reporting or in disciplines outside of mathematics) and even includes art in its span. This begs the question, why and how does it work? Or more poignantly: *What is the form and function of mathematical language inside and outside its community of speakers?*

Mathematical text itself is highly stylized. Apart from its most abstract form of symbols and equations, the language contains diagrams (pictures) and stylized natural text, such as the standard composition structure: *definition, lemma, theorem.*

In the field of mathematics itself, the situation is not as homogenous as one might think. How much truth is contained in a proof by pictures is quite different in algebra versus geometry, and, historically, there is great variation in what is considered a proof—mainly how stylized the language should be. Being too relaxed can lead to foundational crises and questions like those Helmut Hofer is working out in symplectic geometry. An extreme position, which I call Frege's dream, is also alive today with Vladimir Voevodsky and his colleagues through their endeavors to formalize language as much as possible to maximize verifiability. Some might argue that Bourbaki represented a golden age for striking a balance between the formal, the communal, and the communicable.

Wherever one falls on the spectrum of style and formality, the aim of mathematical language is to convey truth. Following Keats and the motto of the IAS, "Truth and Beauty" always appear conjointly. Where does beauty in mathematical language reside? Certainly, there is an aesthetic point of view from inside mathematics. Everybody has their own view of what beauty is, although there is certainly agreement on many singular items. One commonly accepted criterion for "elegant proofs" is simplicity. There is a bit more to it though for mathematicians. As Yuri Manin once put it, "Good proofs are proofs that make us wiser." Yet simplicity as opposed to convoluted byzantine arguments acts as a beacon that is easily perceived, even by a more general audience. For example, $E=mc^2$ is a famous formula with high recognition value and beauty in its simplicity. It is also an instance of physics using mathematical language. A venerable precedent is the Pythagorean theorem $x^2+y^2=z^2$.

Both examples exhibit an almost universal appeal that takes hold well beyond the world of mathematics. They carry meaning beyond the community of people who know their exact context. There is something that remains, even if there is not a complete translation or transportation of content. The humorous illustrations of the discovery of these formulas play exactly on these aspects. So, what happens if you take mathematical language out of its community? I have used mathematical language inside different fields of mathematics (mostly about dialect), in research and conversations with physicists and chemical and materials engineers (requiring translation), but also with philosophers, the poet Oswald Egger, and, of course, just as a member of society.

Drawing on my personal experience, I posit that there is a certain scale for effectively communicating mathematical language and its associated truth and beauty. This type of communication is somewhat broken, however, in the sense that we can transmit ideas, but in order for them to be grasped, they have to be rediscovered or reimagined, much like in the translation of poetry. Here, beauty takes the lead as it is more facile to convey. Once beheld by the other party, it acts as a major indicator of truth and hence as a motivator for the regaining of the underlying truth through reconstruction. As Irving Lavin correctly pointed out, the positive result is the tree of knowledge growing between truth and beauty.

A good example, which contains all previously mentioned ingredients, is given in a cartoon by Robbert Dijkgraaf, IAS Director and Leon Levy Professor, which appeared on the cover of *Quantum Fields and Strings: A Course for Mathematicians* (American Mathematical Society, 1999), drawn from a special year-long program held at the Institute. It depicts the ongoing interdisciplinary conversations between physicists and mathematicians through an exchange of text and language. In both cases, it is necessary to reunderstand what is meant.

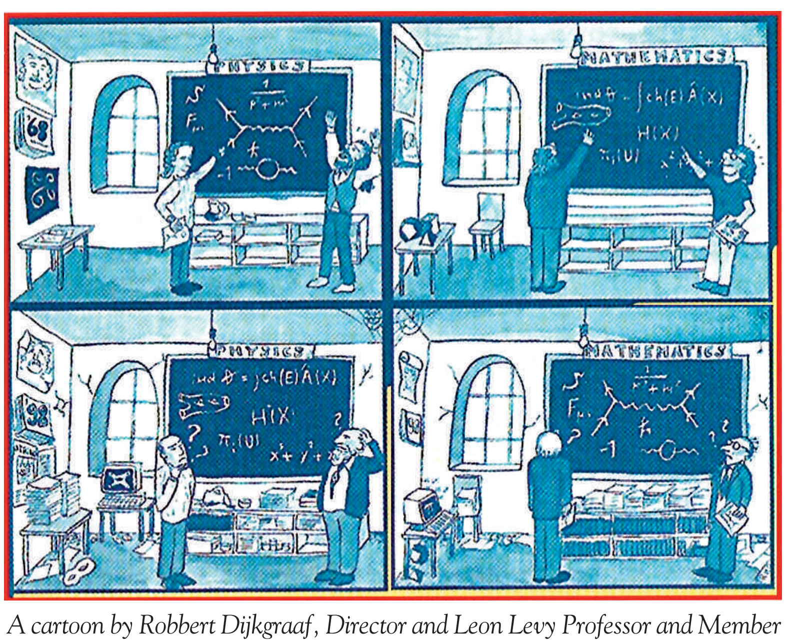
There is a strong gradient for peoples' willingness to listen to abstract mathematics and their tolerance for it. Depending on their degree of familiarity with mathematical abstraction and symbols, this final step of decoding is what makes the task of communicating mathematical concepts or modes of thinking arduous. It also presents a hard problem for mathematicians, as we usually want to tell the full truth and this can be lengthy. The self-proclaimed aim of a mathematical text is to be universally understandable, although this requires a very strong commitment on the part of the reader.

THE SELF-PROCLAIMED AIM OF A MATHEMATICAL TEXT IS TO BE UNIVERSALLY UNDERSTANDABLE, ALTHOUGH THIS REQUIRES A VERY STRONG COMMITMENT ON THE PART OF THE READER.

It stands to reason that more pictures and natural language would be beneficial, but this bears some risk. Consider what happens when mathematical language is entirely removed from mathematics, such as in recent artworks by Bernar Venet, involving commutative diagrams. Without context and depending on the state of the diagram's alteration by the artist, some of the truth is hard to extract, but it nevertheless illuminates the art. There are other artworks that exhibit a similar underlying beauty, such as sculptures of ruled surfaces, the Klein bottle, the gyroid surface, or neon art by Mario Merz based on the Fibonacci sequence, to name only a few.

One interesting aspect of some of these examples is that they incorporate more modern mathematics. For example, Oswald Egger was intrigued by the picture "a hole through a hole in a hole" and the Alexander horned sphere, which both deal with topology. He translated the beauty of these and other concepts into poetry. To make sure that truth remained a "golden thread," Egger engaged me in discussions and took great efforts to understand the topological background.

The end product of mathematical activity is stark naked and condensed like a gem; it can be easy to forget that this is inherently a human activity and, although intentionally pushed to the background, it takes place within an individual's thoughts and language. The thought-provoking titles above exemplify this, and in this light, it is not surprising that many of the technical terms of mathematics are shared with other disciplines, such as category, connection, and topos.



A cartoon by Robbert Dijkgraaf, Director and Leon Levy Professor and Member (1991–92, 2002–03) in the School of Natural Sciences, showing the interplay between mathematicians and physicists at the Institute, from the cover of volume 1 of Quantum Fields and Strings: A Course for Mathematicians *(American Mathematical Society, 1999). The publication, edited by Professor Pierre Deligne and others, was the outcome of a year-long program in quantum field theory that took place at the Institute in 1996–97 when Institute mathematicians and physicists worked together to create and convey an understanding, in terms of some fundamental notions of physics.*

This is not a totally moot point; it provides a common ground from which to start a conversation. Historically, this is deeply rooted from Plato to Kant to Hegel to Cassirer, etc. Well-known examples are furnished by the Platonic solids and their role in Timaeus and the solution of a cubic equation in the form of a poem by Tartaglia in 1539. The poem is hardly readable today, and for us formulas would be easier. At the time, it was intended for a much greater audience of the learned society or even for the general public at market day contests. It is interesting to note that the full standard model Lagrangian is roughly the same length as the poem.

The following points may serve as a short summary. Mathematics strives toward truth, for which its language is designed. It can be made use of by exporting it to other disciplines or contexts. Reciprocally, mathematicians and mathematics gain a greater context. The language itself is complex and requires considerable effort, and direct application is difficult. But beauty, carefully communicated through illustrations, can help intuition and be a guide. This endeavor is, however, a worthy investment in truth and beauty. It will be great to see what modern mathematics can do and what the impact of its language will be on future society. ■

Ralph Kaufmann, Member (2013) in the School of Mathematics and Professor of Mathematics at Purdue University, works in geometry and topology using algebraic and geometric methods.

Pineapples in Petersburg, Cabbage Soup on the Equator

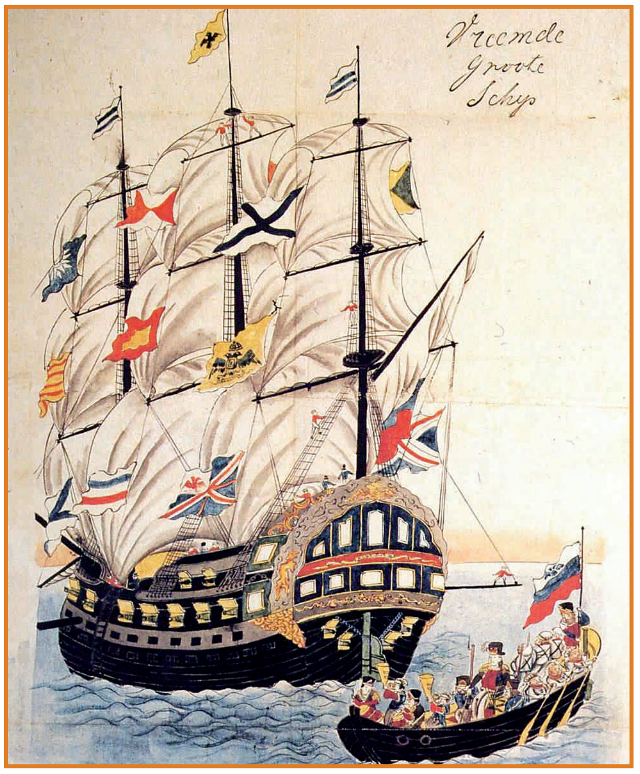
A Russian Writer Tours the Colonial World.

By Edyta Bojanowska

Multiethnic empire? Colonialism? These aren't topics that we associate with Russian literature. And yet, a sprawling, expansionist, multiethnic empire was a determining factor of Russian history since at least the mid-sixteenth century. Hundreds of ethnic groups found themselves within Russia's borders, making ethnic Russians, in the census of 1897, a minority in their own empire. Among modern times, the Russian empire rivaled the British one in size, and at various points included Finland, the Baltics, Poland, Belarus, Ukraine, the Caucasus region, Central Asia, Siberia, the Far East, and Alaska. To this day, as a result of this process, the Russian Federation remains territorially the largest country on earth.

In recent decades, the history of Russia's imperial expansion and management has come into greater focus. But this empire's cultural self-image remains elusive. What were the cultural echoes of this process? With what images and ideas did Russian literary classics dress up (or dress down) the empire? What are the Russian equivalents of E. M. Forster's *A Passage to India* or Joseph Conrad's *The Heart of Darkness*?

Contrary to its popular image, Russian literature has long grappled with questions of multiethnicity, colonization, and imperial expansion. Such issues predominated not only in Russian popular culture, but also evoked diverse engagements from all major Russian writers of the tsarist era, running the full gamut from propagandistic to anti-colonial. These writers include such major figures as Pushkin, Lermontov, Dostoevsky, Leskov, Chekhov, and Tolstoy. Sometimes, the imperial themes of their well-known works have been ignored. At other times, the texts that engage these themes, though popular in their own time, have been sidelined in the process of canonization—especially as commandeered by the Soviet authorities, which by and large sought to minimize both tsarist and Soviet imperialisms or to portray them as strictly benevolent.



Writer Ivan Goncharov published a detailed account of his travels on the Pallada (depicted here in an 1854 Nagasaki print) in a two-volume literary travelogue, The Frigate Pallada *(1855–57). The goal of the government-funded Pallada expedition was to establish trade relations with Japan. Goncharov's cultural documentation of the expedition reflects a particular imperial mentality that found broad resonance among contemporary Russian readers.*

The case of Ivan Goncharov (1812–91), on whom this article will focus, is of the second variety: a writer whose fabulously popular imperially themed classic has since been sidelined. Today, Goncharov is best known for his novel *Oblomov* (1859), about a paradigmatic Russian couch potato, a man so sedentary in his ways that he renounces the woman he loves because marriage would entail the hassle of moving to a bigger apartment. How surprising that this author, who often chastised his own sloth as Oblomov-like, undertook a daring and arduous circumnavigation of Africa and Asia in the years 1852–55, returning to St. Petersburg over land through Siberia! The sheer scope of the voyage, which allowed Goncharov to see firsthand so much of the world, makes him unique among major Russian writers, who tended to confine their international itineraries to Europe. Goncharov published a detailed account of his travels in a two-volume literary travelogue named after the ship on which he sailed, *The Frigate Pallada* (1855–57); "Pallada" means "Pallas" in Russian).

The goal of the government-funded Pallada expedition was to establish trade relations with Japan, which then observed a strict policy of isolation. Goncharov served as a secretary to the expedition's commander, Vice-Admiral Evfimy Putiatin. The mission was conceived as Russia's response to increased British, French, and American imperial activity in East Asia. Indeed, Putiatin's American rival Commodore Perry outraced the Russians by three weeks and is now credited with "opening" Japan. Russia's diplomatic mission was further complicated by the outbreak of the Crimean War, in 1855, which was a clash of European empires over control of the Black Sea. The Pallada had to duck attacks by British and French ships. Yet Putiatin eventually negotiated a better deal for Russia through the 1855 Treaty of Shimoda.

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The Frigate Pallada is a fascinating cultural document that reflects a particular imperial mentality that found broad resonance among contemporary Russian readers. Read by few nonspecialists today, in the nineteenth century, *The Frigate Pallada* was in fact a greater bestseller than *Oblomov*. It offered Russian readers a synthetic portrait of a global imperial world order based on colonial expansion and competition, in which the Russian empire increasingly asserts itself. Goncharov takes Russian readers on a grand tour of the colonial world and acquaints them with the maritime colonizing empires—British, Portuguese, Spanish, and Dutch—that have transformed the life of much of the globe. *The Frigate Pallada* surveys these competitors' practices, ponders how the Russian empire fits in, and what it can learn.

Above all, the travelogue argues that Russia must catch up to its colonial rivals, especially the ever-energetic British. Including the Russians emphatically in the European civilizational community (he kept his doubts private), Goncharov impresses upon his readers a confident civilizing mission, in Russia's own Siberian Orient and Asia more generally, as their birthright and supreme duty. The book is a densely textured primer of imperial ideology. In its descriptions of colonial sites and peoples, it richly partakes of classic rhetorical tropes of European colonialism.

Goncharov opens his travelogue with images of a rapidly interlocking world: Chinamen clothed in Irish linen, French hotels on the Hawaii Islands, Russian cabbage soup available on the equator. The Pallada encounters commercial vessels filled to the brim with European migrants headed for Australia, or with Chinese coolies headed for San Francisco. Manila's European street life appears to him the same as in Moscow, Petersburg, Berlin, and Paris. Goncharov's visits to Asian ports, opened to European trade after Britain's Opium Wars, cement this vision of a globalized world born of modern imperialism. He presciently diagnoses globalization in terms recognizable to us today: labor integrated with commodity, global capital, and vibrant trade, all moving the world closer to uniformity.

Considering comfort and civilization nearly synonymous, Goncharov writes: "In the north, a pineapple costs five to ten rubles, while here—a mere kopeck. The goal of civilization is to quickly ship it to the north and drive down the price to five kopecks, so that you and I can treat ourselves to our heart's content." This is a juicy metaphor indeed. It joins in a memorable nexus modern bourgeois comfort, a mercantilist ethos, and the civilizing prerogatives of those who direct this traffic—Europeans. This is also a vision that fits remarkably well with our own contemporary world. Today, Goncharov's paean to a globally traded pineapple would fit quite well in a press release by any price-cutting CEO of corporations such as Walmart.

Before reaching Asia's global marketplace, Goncharov visited the Cape Colony in South Africa. There, he focused on the pacification of resistant populations, which he related to Russia's own concurrent war in the Caucasus. Seeking instructive lessons for Russia's own colonization projects, he also compared the Dutch subsistence colonization to Britain's profit-oriented model, equating the latter with head-spinning material and civilizational progress. Goncharov's account of his trip into the colony's interior unfolds as a procession of idyllic spaces created by the industrious white settler. He impresses his Russian readers with the economic benefits of colonization by reporting on the income of Dutch farmers, which would have been a rough equivalent of a ministerial salary in Russia.

In Japan, Goncharov mingles descriptions of Japanese lands and manners with muscular realpolitik that shows him to be more gung-ho about militaristic imperialism than the average Russian bureaucrat. An arsenal of classic colonial tropes, such as the discursive emptying of Japanese lands of people, or these people's infantilization, or manipulative recasting of conquest as a benevolent humanitarian action, assist Goncharov's bold assertion of Russia's civilizing mission in Japan and in Asia. He presents cannons as blandishments of civilization. He also presciently identifies Korea as a future arena of imperial rivalry and recommends that Russia should quickly snatch it. The Russians make themselves quite at home in Korea, barging into Korean homes and conducting land surveys (as Koreans shower them with rocks). Just as Commodore Perry graced the Edo (Tokyo) Bay with names such as Perry Island or Mississippi Bay, the Russian crew chose Russian eponyms for Korean landmarks, one of them becoming the Island Goncharov.

(Continued on page 13)

The Legacy of Mandela's Life: A Political and Moral Hero

Mandela reinstated the rights of those who were oppressed and restored their dignity without perpetuating resentment or inciting retaliation.

By Didier Fassin

On the eve of South Africa's first democratic elections in 1994, few observers thought that the day would pass without bloodshed. A smooth transition toward democracy seemed very unlikely. Having been in a state of emergency from 1985 to 1990, the country had suffered from years of civil war–like conditions. In the early 1990s, the police force of the apartheid regime, white supremacists, and secessionist Zulus had massacred members of the African National Congress. The charismatic General Secretary of the Communist Party, Chris Hani, had been the recent victim of an assassination ordered by a member of the Conservative Party. And during ANC meetings the crowd would sing the combative chant "Kill the Boer." Thus, it was an unlikely transition, even more so because South African President Frederik de Klerk was accused of supporting the Inkatha Freedom Party of Mangosuthu Buthelezi, which was implicated in the violent outbreaks.

STEVEN SIEWERT

Nelson Mandela, the first democratically elected president of South Africa

The elections were marked by the enthusiasm surrounding the universal right to vote for the first time and there were no major incidents that would have marred the momentous event. The ANC won with 62 percent of the votes, and Nelson Mandela, freed four years before after twenty-seven years of imprisonment, became the first president of a democratic South Africa while his former enemies, Frederik de Klerk and Mangosuthu Buthelezi, were appointed Vice President and Minister of the Interior, respectively. This unlikely display of national unity was the result of tough negotiations conducted by the president of the ANC with the whites who had been in power, sought to preserve their privileges, and feared revenge from the black majority, as well as with his own party, which was hardly inclined to compromise with those who had enforced the racist policy of segregation and oppression for decades.

EVEN IF MANDELA WAS UNABLE TO REDUCE THE SOCIOECONOMIC INEQUALITIES AND DELAYED TAKING MEASURES AGAINST THE AIDS EPIDEMIC, THE FORMER SOUTH AFRICAN PRESIDENT STILL ACCOMPLISHED AN IMPRESSIVE TASK BY BUILDING THIS "RAINBOW NATION" AS ARCHBISHOP DESMOND TUTU CALLED IT.

A determined militant fighting against apartheid (he refused to be freed under conditions) as well as a pragmatic planner of democratization (he accepted that white civil servants would keep their current positions), Nelson Mandela thought that "courageous people do not fear forgiving, for the sake of peace." When the South African Springboks won the Rugby World Cup in 1995, he wore the team's jersey, an execrated symbol of white racism, when he handed the trophy to the captain—a very powerful gesture of national reconciliation.

It is this two-sided image of political and moral hero that South Africans will remember of this man who transformed their country from an object of international ostracism into a model nation. Due to this image, he also became a consensual figure for the entire world because his actions reinstated the rights of those who had been oppressed and restored their dignity without perpetuating resentment or inciting retaliation. The establishment of the Truth and Reconciliation Commission from 1996 to 1998, which allowed the government to grant amnesty to those who were guilty of major violations of human rights provided that they confessed their actions, has become an obligatory point of reference for countries transitioning from periods of dictatorship or conflict, even if many in South Africa have regretted an overly lenient justice toward the perpetrators and only modest reparations for the victims.

Unlike his successor, Thabo Mbeki, a vindictive politician, Nelson Mandela was not what Nietzsche calls a "man of *ressentiment*." Tirelessly engaged in the present and resolutely facing the future, he never dwelled on the past, but did not try either to erase its trace like many wished to do after apartheid in order to absolve those who had instituted or simply tolerated the regime of their responsibility. For him, forgiving did not mean forgetting. And he was critical of white people who, after having exploited the natural and human resources of the country, left it under a pretext of fear that they had actually contributed to fuel in spite of the benevolence shown by the government toward them.

Indeed, as head of state, Nelson Mandela tried to reassure the white minority in order to undermine the position of extremists who would most likely resort to violence as well as to prevent companies and capital from fleeing the country. Despite the Restitution of Land Rights Act for the reparation of damages due to the 1913 Natives Land Act, which had allowed the dispossession of the majority of black people, land reform remained very modest. And although an ambitious economic plan of equal opportunity was put in place, fewer than ten percent of all companies quoted on the stock exchange were owned or managed by blacks at the end of his first and only presidential term. Insofar as the nationalization of large companies and the plan for the creation of jobs under the Reconstruction and Development Program were concerned, they were abandoned in exchange for a liberal policy in line with the requirements of the World Bank and the International Monetary Fund.

Within the ANC, critics certainly pointed out this apparent renunciation of the principles of social justice promoted by the party. However, the considerable achievements that were accomplished in a difficult environment should not be underestimated. During the five years that Nelson Mandela was in power, all administrations, which had been segregated according to four racial groups under apartheid on a local as well as national level, were unified, allowing the same services for everyone; various grants for the retired, the disabled, and poor or orphaned children were allocated equitably to all social categories; free health care became available to pregnant women and children under six years; poor rural and suburban areas benefited from a network of roads and infrastructure; and numerous low-income houses were built. Thus, even if he was unable to reduce the socioeconomic inequalities and delayed taking measures against the AIDS epidemic, the former South African president still accomplished an impressive task by building this "rainbow nation" as archbishop Desmond Tutu called it.

The political and moral lesson to be drawn from Nelson Mandela is thus his determination to fight against oppression and injustice, his refusal to renounce his principles and values, and his unfailing courage to make difficult decisions and to speak the truth—a valuable lesson for the contemporary world. ■

This text is a slightly modified version of an obituary for Nelson Mandela published in Le Monde *on December 7, 2013.*

Didier Fassin, James D. Wolfensohn Professor in the School of Social Science since 2009, is an anthropologist and sociologist and the author of When Bodies Remember: Experiences and Politics of AIDS in South Africa *(University of California Press, 2007).*

PINEAPPLES IN PETERSBURG *(Continued from page 12)*

The tenor of Goncharov's Siberian chapters changes significantly. Siberia emerges as a showcase of Russia's colonizing prowess, and hence of its European credentials. It is presented as a superior counter-model to British colonialism, which Goncharov now portrays as ruthless and greedy. Suddenly, profit is bad and Russia's activities in the region are claimed to be benevolent and selfless. The vocabulary of colonialism, freely used in reference to Western European possessions, vanishes in Goncharov's descriptions of Siberia, which was Russia's most classic colony. Conquered in 1582, it was exploited for natural resources that enriched the Russian metropole, its indigenous inhabitants decimated by smallpox, a rapacious tribute system, or explicitly genocidal wars. Though his private writings show that he knew otherwise, Goncharov sanitizes Siberia's image in *The Frigate Pallada*, hiding uncomfortable truths about the Russians' conduct toward the aborigines, or the probity and effectiveness of Russian administrators. Instead, he promotes a boosterist propaganda to encourage further Russian colonization (calling it "resettlement"). Most importantly, *The Frigate Pallada* Russifies Siberia's cultural image, presenting its land, consistent with Russia's version of Manifest Destiny, as *eo ipso* Russian, a vast arena in which Russian national destiny was unfolding.

The cultural heritage of works such as *The Frigate Pallada* influenced Russian imperial history by shaping attitudes and aspirations that survive to this day. The widely publicized Russian alphabet video, issued as part of the opening ceremony for the 2014 Sochi Olympics, proudly displayed "Empire" for the Russian letter "I" with which the word's Russian equivalent begins ("Imperiia"). At the time of writing, the world is anxiously watching Russia's reaction to the political changes in Ukraine. To this day, whether in state pageantry, politics, or contemporary culture, nineteenth-century Russia continues to supply Russians with revered national icons that inform their vision of the larger world and their own place in it. ■

Britain's Moment in Palestine

How the first Arab-Israeli war became inevitable

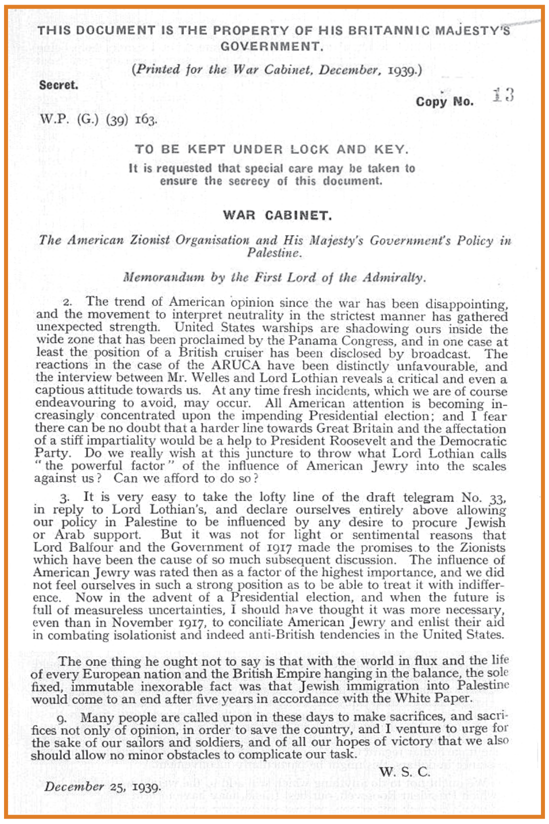
By Michael J. Cohen

The British Mandate in Palestine may be divided roughly into four distinct periods.

1. 1915–1920: In February 1915, a small Turkish force, led by German officers, managed to cross the Sinai desert and reach the Suez Canal, the imperial artery to the "jewel in the (British) Crown"—India. This shattered Britain's previous strategic conception that no modern army could attack the canal from the North, and led her to move her defense line north, to Palestine. In November 1917, the British issued the Balfour Declaration, which offered to help the Zionists establish a Jewish national home in Palestine—provided that nothing was done to "prejudice the civil and religious rights of existing non-Jewish communities in Palestine."

At one of the most critical junctures of the war, the Declaration served many purposes, not the least of which was as a propaganda tool: it harnessed for Britain the alleged, all-powerful influence of international Jewry (the cabinet feared that the Germans were about to preempt them with a Declaration of their own). It also served British military and strategic interests. Britain's Zionist proxies enabled the government to demand Palestine solely for itself (thereby finessing the French out of Palestine, as had been agreed in the Sykes-Picot share-out of May 1916). President Wilson was persuaded by prominent American Zionists to agree to the Declaration, in effect, to a British occupation of Palestine, even if still under Turkish rule.

These interests prevailed over the objections of the Anglo-Jewish establishment, and of a senior cabinet Jewish Minister, who opposed Zionism. There is no little irony in the fact that the culture and public discourse of the country that issued the Declaration was permeated with anti-Semitism—not only the working classes, who resented the intrusion of Jewish immigrants from Czarist Russia, but also the press and the British Parliament.


THIS DOCUMENT IS THE PROPERTY OF HIS BRITANNIC MAJESTY'S GOVERNMENT.

(*Printed for the War Cabinet, December*, 1939.)

Secret.

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W.P. (G.) (39) 163.

TO BE KEPT UNDER LOCK AND KEY.

It is requested that special care may be taken to ensure the secrecy of this document.

WAR CABINET.

The American Zionist Organisation and His Majesty's Government's Policy in Palestine.

Memorandum by the First Lord of the Admiralty.

2. The trend of American opinion since the war has been disappointing, and the movement to interpret neutrality in the strictest manner has gathered unexpected strength. United States warships are shadowing ours inside the wide zone that has been proclaimed by the Panama Congress, and in one case at least the position of a British cruiser has been disclosed by broadcast. The reactions in the case of the ARUCA have been distinctly unfavourable, and the interview between Mr. Welles and Lord Lothian reveals a critical and even a captious attitude towards us. At any time fresh incidents, which we are of course endeavouring to avoid, may occur. All American attention is becoming increasingly concentrated upon the impending Presidential election; and I fear there can be no doubt that a harder line towards Great Britain and the affectation of a stiff impartiality would be a help to President Roosevelt and the Democratic Party. Do we really wish at this juncture to throw what Lord Lothian calls "the powerful factor" of the influence of American Jewry into the scales against us? Can we afford to do so?

3. It is very easy to take the lofty line of the draft telegram No. 33, in reply to Lord Lothian's, and declare ourselves entirely above allowing our policy in Palestine to be influenced by any desire to procure Jewish or Arab support. But it was not for light or sentimental reasons that Lord Balfour and the Government of 1917 made the promises to the Zionists which have been the cause of so much subsequent discussion. The influence of American Jewry was rated then as a factor of the highest importance, and we did not feel ourselves in such a strong position as to be able to treat it with indifference. Now in the advent of a Presidential election, and when the future is full of measureless uncertainties, I should have thought it was more necessary, even than in November 1917, to conciliate American Jewry and enlist their aid in combating isolationist and indeed anti-British tendencies in the United States.

The one thing he ought not to say is that with the world in flux and the life of every European nation and the British Empire hanging in the balance, the sole fixed, immutable inexorable fact was that Jewish immigration into Palestine would come to an end after five years in accordance with the White Paper.

9. Many people are called upon in these days to make sacrifices, and sacrifices not only of opinion, in order to save the country, and I venture to urge for the sake of our sailors and soldiers, and of all our hopes of victory that we also should allow no minor obstacles to complicate our task.

W. S. C.

December 25, 1939.

NATIONAL ARCHIVES, LONDON

Extracts from Churchill's Cabinet memo, warning against implementing the Land clauses of the 1939 White Paper. Christmas Day, 1939.

2. 1920–1936: After the war, the government's support for the Zionists encountered fierce criticism, both by Palestinian Arabs, and at home, by the Conservative right-wing and its press, dominated by the press barons, Lords Northcliffe (whose empire included *The Times*) and Beaverbrook. They complained that the Declaration had been a wartime exigency, but should not be allowed now to embroil Britain with the entire Arab and Muslim worlds. During a debate on Palestine in July 1922, William Ormsby-Gore, Conservative M.P., and a future Colonial Secretary (1936–38), referred to the "anti-Semitic party" in the House:

> … those who are convinced that the Jews are at the bottom of all the trouble all over the world. Whether they are attacking an anti-Zionist… or Zionists, or rich Jews, or poor Jews …"

In October 1922, the Lloyd George coalition government was replaced by a Conservative administration. In view of the latter's condemnation of the Balfour Declaration, there was a general expectation that the Conservatives would abrogate it. In June 1923, Prime Minister Stanley Baldwin set up a cabinet committee to study the problem. The committee, headed by the Colonial Secretary, but dominated by Lord Curzon, concluded that Britain must continue to support Zionism if it wished to retain Palestine. The committee's report, endorsed by the full cabinet, recommended: 1. Britain must remain in Palestine, if only to prevent any rival power from getting too close to the Suez Canal; 2. Britain could not afford to lose international face by reneging on the Balfour promise, now enshrined in the League of Nations mandate; 3. Britain had become dependent upon the import of Jewish capital for administering the country, at a minimal cost to the British taxpayer.

At no time was this financial dependence on Zionists more pronounced than in 1930, when the minority Labor government issued a new White Paper on Palestine. This would effectively have halted all further development of the Jewish national home—no more land sales to Jews, and no further Jewish immigration. The new policy represented the consensus of the Colonial Office establishment, both in London and in Jerusalem, following the so-called "Wailing Wall Disturbances" of August 1929.

But one year after the Wall Street crash, with the British economy sinking into deep recession, no British government dared to offend "international Jewry" who, it was feared, were able to turn the White House against Britain. Further, the Conservative Opposition, and the Liberal rump led by Lloyd George (upon whose votes Labor depended) took the opportunity to vilify the government. In the parliamentary debate on the White Paper, the Opposition humiliated the government, accusing it of anti-Semitism and of betraying an international pledge. The White Paper was not even put to the vote and never became law.

Following secret negotiations between a Zionist delegation and a cabinet committee, in February 1931, the Prime Minister read into the protocols of the House of Commons a letter from himself to Dr. Chaim Weizmann, the Zionist leader. His letter "re-interpreted" (in effect rebutted) the 1930 White Paper and remained the law of the land in Palestine until 1937. This hiatus provided a window of opportunity for the Zionists. From 1931–1935, while Nazism and anti-Semitism reared their heads in Germany and in Eastern Europe, nearly 200,000 new Jewish immigrants arrived in Palestine, doubling the size of the Jewish community.

3. 1936–1939: But in the mid-1930s, all other policy considerations were swept aside, when the resurgence of Fascist Italy and Nazi Germany threatened a new world conflict. Britain's need of the strategic assets of the Arab states (oil and strategic bases) became paramount. Between 1935–36, Britain's international standing suffered a series of critical reverses; her failure to stop the Italian conquest of Abyssinia, and, in March 1936, taking advantage of Britain's pre-occupation with the Italian threat to Egypt, Nazi Germany re-occupied the Rhineland, in clear violation of the Treaty of Versailles. Both developments were regarded by the Arab world as indications of British weakness, in the face of the dynamic Central Powers.

In 1936, the Arabs reacted with a series of demands for greater independence. In January, Syria's Arabs declared a general strike, demanding the end of the French mandate; in August, the Egyptians secured a new treaty that included a reduction of the British garrison and its removal to the Canal Zone base, and the promise of full independence by 1956. In Palestine, the Arabs declared a general strike in April 1936, which turned into a full-scale rebellion, which lasted intermittently until early 1939. At the rebellion's peak, in the summer of 1938, the British all but lost control of Jerusalem and extensive areas of southern Palestine. The crisis in Palestine coincided with the Munich crisis.

In May 1939, on the eve of World War II, the British enacted a new White Paper on Palestine, designed to appease the Arab states. It asserted that Britain had fulfilled its pledge to facilitate the establishment of a Jewish national home in Palestine, and promised to set up an independent Palestine state within ten years. A further 75,000 Jewish immigrants would be allowed into Palestine over the next five years, after which all further immigration would be conditional upon Arab assent. This figure was calculated to ensure that the Jewish population of Palestine did not rise above its current one-third minority.

4. 1939–1948: During World War II, two major developments transformed the Arab–Zionist conflict in Palestine into an intractable imbroglio. The first was the Holocaust, the extermination of six million of Europe's Jews by Hitler's "Final Solution." This created an irresistible demand for permitting the entry of the survivors into Palestine, over and above the White Paper's 75,000. The second development was the adoption by the Arab League in late 1944 of the Palestinian Arabs' cause. This meant that any British move in Palestine that displeased the Arabs would risk the denial to the West of Arabian oil and strategic bases.

After the war, the British Foreign Office, and the U.S. State Department both favored a Palestine settlement that would be approved by the Arab world, i.e., *no* Jewish state. President Truman agreed—especially when the Cold War held the potential for turning at any moment into World War III. But Truman was forced by his political advisers to lean toward a pro-Zionist solution, i.e., a Jewish state in a part of Palestine (partition). Truman's subservience to the Zionist lobby (the Jewish vote and Jewish contributions to the Democratic Party) persuaded the British to throw in their hand. In February 1947, they referred the Palestine Mandate back to the United Nations, with no recommendations. On November 29,1947, the U.N. voted to partition Palestine into Arab and Jewish states. The first Arab-Israeli war had become inevitable. ■

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Mongols to their bitter enemy, the Saracens. Marco Polo and other travelers rendered an otherworldly Catay and the Mongols who ruled it familiar to a wide European public. Trade followed the scriptures and eventually a copy of Marco Polo's book, still preserved, was attentively read, glossed, and annotated by Christopher Columbus prior to his fateful journey.

The reason why the rise of the Mongols, and their appetite for conquest, has never been explained is simple on the surface: there are no sources that can tell us what happened. Every history book repeats, with greater or lesser accuracy, what we learn from a special Mongol source, the epic saga, orally composed and transmitted sometime in the mid-thirteenth century, known as the *Secret History of the Mongols*. This marvelous composition retells the story of the rise of Temüjin, raised to be the khan of the Mongols with the title of Chinggis Khan in 1206. Episodes of the life of the Mongol conqueror, from foreordained birth to mysterious death, are narrated in beautiful prose and poetry. The trials and tribulations of Temüjin make it clear that he lived in a time of conflicts and violence. Skills, sagacity, fortune, and perseverance yield their rewards when he is able to unify all the Mongols under a single rule, an accomplishment followed in short succession by the decision to invade first northern China and then central Asia.

The historicity of the epic rise of Chinggis Khan and the credibility of this account have long been doubted, but even if we were to take the *Secret History* as fully reliable, actual historical questions would be left unanswered. It has been so far impossible to explain how Chinggis Khan mustered the strength to extend his military operations and his rule so far outside his power base, originally located in northern Mongolia. It is also difficult to argue in favor of any compelling reason why, once peace had been restored among the various warring Mongol clans, more campaigns, as far-flung as Samarkand, the Caspian Sea, and the Himalayas, should be undertaken. Should we pin it on pure hubris, or say that Chinggis went on pillaging and conquering "because he could"? The Mongols did not keep historical records of any kind, and no Chinese or any other written sources provide clues that would allow historians to answer more specific questions: how was a central government and a large army supported? What was the economy of Mongolia after thirty years of civil war? How could the Mongol warriors be so successful in mounting large military operations given that the economy and society were supposedly in shambles?

In 1950, Owen Lattimore, the renowned historian of Inner Asia, wrote: "As is now generally known, the Mongol eruption, and others of the same kind, were due to political causes, not to desiccation in Mongolia as was once assumed. Within historic times there have been no climatic changes that permanently reduced the amount of grazing necessary to support the population that seems to have lived in Outer Mongolia up to the present day. At times, sudden droughts, or a series of droughts, must have brought about small migrations from the poorer pastures bordering the desert, but with the return to normal conditions the desiccated areas appear to have soon received a fresh population."[1] Lattimore's reactions to environmental determinism were credible and justified. The notion that Mongol warriors may have poured out of the steppes because worsening climate, marked by extensive droughts and frosts, might have pushed them to seek, literally, greener pastures, was not endorsed by him. Yet the idea that a climate-induced environmental crisis played some role in the general unfolding of events continued to linger. In a short note published in 1974, Gareth Jenkins presented climate data showing that "a steady and steep decline in the mean temperature in Mongolia in the years 1175–1260" could have had sufficient explanatory power to be included together with other factors, since a decline of such magnitude would have certainly had a "profound impact on a pastoral nomadic economy like in twelfth- and thirteenth-century Mongolia." Jenkins thus argued that "a major climatic overturn did much to encourage the end to the infighting and vendettas among the Mongol clans and make possible their reorganization under Chinggis's military authority," and that "their enthusiasm for the task of conquest may well have been fueled by a climatic defeat at their backs." Jenkins does seem to imply that the end of the civil wars among Mongols as well as their appetite for conquest could have been reactions to a prolonged worsening of the climate and environmental conditions. Still, climatic causes did not get much traction among scholars of Mongolian history, and historical works have remained essentially agnostic on this point, preferring to stick closely to the story presented in the few written sources, and thus privileging, like Lattimore, a political reading.

Pastoral nomadic societies are extremely sensitive to climate changes. Extreme events, such as heavy snowfalls, frosts in winter, or droughts in summer, can, in a very short time span, affect severely the delicate balance between humans, animals, and land. Even in recent times, especially harsh winters have caused the loss of a large portion of the Mongolian livestock. But how should one relate such potential disasters to historical events? Moreover, what happens when the climate becomes unusually favorable to the production of pastoral resources? Historians have overwhelmingly focused on downturns rather than upswings. Based on tree-ring analysis, climate scientists involved in the project in which I am participating have reconstructed the climate of the Orkhon Valley, located in east-central Mongolia, for more than a thousand years.[2] This is the locale where the future capital of the Mongol empire, Karakorum, was going to be built, and an important political site for several nomadic empires such as the Turks (sixth to eighth centuries) and the Uighurs (eighth to ninth centuries).

The data gathered from the tree rings shows an anomaly that caught the eyes of scientists. While the end of the twelfth century (especially the 1180s decade) was marked by prolonged droughts, the period from 1211 to 1225 was instead marked by persistently wet conditions, which would have increased the available pasturage, thus allowing for an increase in livestock. The anomalous sudden transition from a prolonged dry period to a prolonged wet period should indeed create conditions that might have affected the formation of a new political order in Mongolia.

Several studies have attempted, with different degrees of analytical rigor, to link climate change with the emergence of violent conflict. Although such studies are typically based on more-or-less strong correlations, it stands to reason that a reduction of resources may force nomadic groups to move in search of sufficient pasture to feed their animals, thus clashing with other groups over access to grassland. The *Secret History of the Mongols* describes a bleak world rife with tensions, violence, wars, and poverty. Of course, this could just be a standard literary device to describe a society in disarray, whose salvation would come as it was brought under a novel order by the new leader. This messianic element is necessary to ensure the legitimacy of a new type of sovereignty (supratribal) claimed and constructed by Chinggis Khan. However, surely one cannot exclude that such wars and feuds actually happened. The concomitance between deteriorating climate conditions, tales of violence, and a vast body of literature that tends to link climate and conflict, makes it plausible that Mongolia at the end of the twelfth century was indeed perturbed by winds of war and fierce intertribal conflicts.

Contrary to Jenkins's hypothesis, there is no reason to believe that conflict would subside and people would place themselves under someone's rule because of deteriorating climate conditions. The most likely scenario is that during the time of intertribal wars and declining climate, Mongolia experienced vast loss of livestock, displacement of people, and the rise of military commanders vying for scarce resources. The political process common among ancient nomads eventually would remake the political order either by reconstituting territorially based political nuclei (clans and tribes) in a new equilibrium, or fully redefining it by endowing a supreme leader with exceptional powers, leading to a complete overhaul of the political order, one that went from decentralized to centralized, and thus organized in a new hierarchical pyramid-like structure. As we know, the latter is what happened, as all Mongols were brought under a single ruler thanks to the personal skills of Chinggis Khan in forging alliances, isolating his enemies, and introducing new institutions.

Military operations against north China began to take place after Chinggis Khan was raised (literally, on a felt blanket) as the ruler of the people. The climate record for the first ten years of the thirteenth century is variable. The first part of the 1200s decade shows an amelioration of the climate followed by yearly fluctuations and a minor downturn. I would not suggest that Chinggis's military operations were in any way related to climatic changes, but simply note that this period is surely very different from the previous two decades and especially from the very dry 1180s. However, the military operations of Chinggis Khan expanded exponentially from the 1210s until his death in 1227. During his time, the Mongols launched major expeditions in northern China against the Jin dynasty (1115–1234) and in Central Asia against the Muslim kingdom of the Khwarezmshah. The question that a historian needs to ask when climate data is taken into consideration is: what possible effects could a wetter climate have on the type of political structure and on the military operations initiated by Chinggis Khan?

The most reasonable hypothesis toward which our project is working is that a wetter climate, with an increment of the grassland biomass and increasing levels of energy, could have aided the rise of a more powerful state in several ways. Reasoning hypothetically, we need to consider economic, political, and military aspects. On the economic side, we can infer at least two ways in which a moister climate plays a role. First, it assists the rapid economic recovery of the herds and welfare of the people after many years of privation and uncertainty. Secondly, it is possible that in various locations agriculture may have been stimulated, thus contributing to the net increase of available resources. Finding agriculture in Mongolia in this period would be by no means surprising, given the presence of stable settlements and urban sites at different times in the Mongolian steppes through its history. Some evidence of agriculture has been found in Karakorum when it became the Mongol empire's capital, under Ögödei Khan. From a political point of view, the increased productivity of the land would allow greater density of people over a given territory. The Mongol court, especially one that concentrated all the power in a single seat, required thousands of servants, soldiers, animals, and, of course, all the families of the ruling elite and aristocracy to be located in a fairly contained area. Even if additional supplies were brought in from the outside, a highly productive area would have guaranteed

(Continued on page 17)

Nicola Di Cosmo joined the Institute as Luce Foundation Professor in East Asian Studies in the School of Historical Studies in 2003. His main field of research is the history of the relations between China and Inner Asia from prehistory to the modern period. He is currently working on questions of climate change at the time of the Mongol empire, the political thought of the early Manchus, and commercial relations in northeast Asia on the eve of the Qing conquest.

required for function. The identity and order of the amino acids that make up this polypeptide, that is the protein sequence, typically contain all the information necessary to specify the folded functional molecule.[2]

We currently live in a hugely exciting time for the biological sciences, for the simple reason that technological advances have greatly increased our ability to accurately collect large amounts of data. In particular, over the last twenty years our ability to cheaply and precisely determine the sequences of proteins has vastly increased, leading to the assembly of large, freely accessible collections of protein sequences from different species. However, experimentally determining the three-dimensional structure of a protein is expensive and difficult, leading us to ask if we can use the sequence data available for each protein to predict its three-dimensional structure. The crucial point is that the sequence of a particular protein varies between different species. Hemoglobin (figure 1), the protein in our blood that binds and transports oxygen, provides a good example. Versions of hemoglobin from different species are very similar, both in their three-dimensional structure and in the function they carry out. However, there are differences between the hemoglobin amino acid sequences that occur in different species. An exciting current direction of research is to exploit this evolutionary sequence variation and crack the code that relates amino acid sequence to protein structure and function.[3,4]

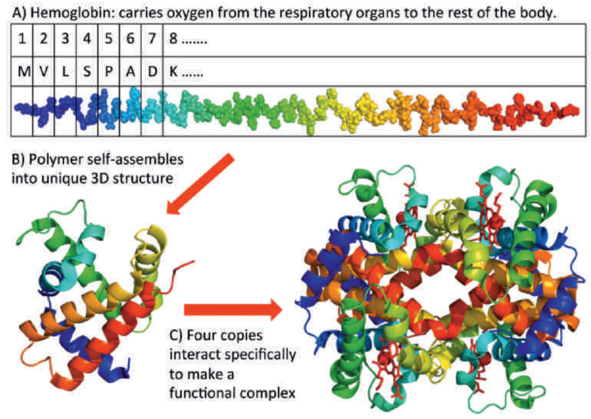

Figure 1: A) The amino acids (letters, second row of table) specified at each sequence position (numbered, top row of table) for a particular protein are synthesized into a polypeptide chain. B) The polymer chain spontaneously self-assembles into the complex three-dimensional structure specific to that protein that is required for the molecular function. C) Once folded, the protein is described as a monomer, and often different monomers or multiple copies of the same monomer self-assemble into protein complexes that form functional molecules.

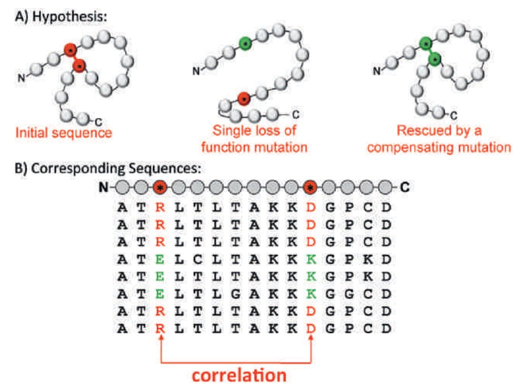

Figure 2: A) The toy model illustrates an example where a mutation at one sequence position results in a protein that no longer folds or functions correctly. This loss of protein function is rescued by a compensatory mutation elsewhere in the sequence, restoring the ability of the molecule to fold and function. B) If this model is correct, it will mean that our sequence database only contains sequences with i) neither of the mutations, or with ii) both of the mutations, and hence the mutation pattern of the two columns that correspond to these two sequence positions will be correlated.

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Model based on sequence data

The basic idea is to use the abundance of protein sequence data that is now available to build a probability model for the amino acid sequence that codes for each protein of interest. The probability distribution for the sequence, $P(A1, A2, \ldots, An)$, describes the probability that each of the twenty amino acids occurs at each of the positions 1,...,n in the sequence of n amino acids that makes up the protein of interest. If we are able to collect enough distinct data samples for a protein of interest, and we make certain assumptions about the mathematical form of the probability distribution, then we can use the data to infer the parameters of the model. For many proteins, upwards of 10,000 sequences are now available, a body of data that constitutes a set of samples from this probability distribution, though the elements of this set are not sampled independently of one another.

What form should the probability model take? The space of models that would generate the data observed for a particular protein is unbounded. However, we can use the knowledge about proteins collected by biologists over the last century to restrict our attention to particular classes of models. A process of selection on standing variation in different populations produces sequences of a particular protein across many species. Through the evolutionary process, mutations (amino acid changes) at different sequence positions within a protein are randomly generated. Some of these mutations lead to an improved version of the protein, increasing the fitness of the organism, and will therefore be selected. There is a high-dimensional space of possible sequences; the sequences corresponding to a protein of interest occupy some subset of this space. Sequences collected in the database that code for a particular protein record the outcomes of millions of evolutionary experiments that probe the boundaries of this subset. The boundaries are imposed by the requirement for a protein to be functional; the idea is to infer the boundaries, or constraints, on which sequences are allowed, and thus learn about the relationship between amino acid sequence and protein function.

A key point is that mutations at different sites do not necessarily have independent effects on the protein. In particular, it is often observed that while a single mutation at one position within a sequence results in a protein that is no longer functional, perhaps because it does not fold correctly, this disability can be rescued by a compensatory mutation that occurs elsewhere in the protein sequence. This suggests that we need to include interactions between different sequence positions in the probability model. Though the number of sequences available for many proteins is large, the space of possible parameters for a model that considers interactions of different orders is much larger, and so we restrict our attention to models that consider pairwise interactions between different sequence positions. We hypothesize that if two amino acids are in close proximity in the three-dimensional protein structure—if they pack against each other, for example, or interact via a hydrogen bond—then their mutation pattern across different species may contain correlations, as in the toy model illustrated in figure 2. If this model is accurate, it suggests that it may be possible to use pairwise interactions to predict the spatial proximity of amino acids in the three-dimensional protein structure from sequence data.

Experimentally determining the three-dimensional structure of a protein of interest is an expensive and time-consuming process, and for many transmembrane proteins (insoluble because they span the hydrophobic lipid bilayer that bounds a cell), it is not yet possible. The question of predicting the three-dimensional structure of a protein from its amino acid sequence has occupied scientists for at least the last fifty years. Part of the reason that this problem is rather intractable is the sheer number of possible conformations that each protein chain could in theory adopt. Each protein chain typically contains hundreds or in some cases thousands of amino acids.

To compute a rough estimate of the order of magnitude of the conformational search space, consider that each amino acid has two independent bond angles that describe its conformation within the context of a polypeptide chain, and add to this at least one extra degree of freedom describing the orientation of the amino acid's side chain. Assuming, conservatively, that each degree of freedom can only take a restricted set of say 10 values, this provides a minimum of 10^3=1000 different structural conformations per amino acid—that is $(10^3)^{150}$ possible configurations for a protein consisting of just 150 amino acids. Even if there is flexibility in the native structure—if amino acid side chains are able to rotate to some extent, for example—the native folded structure of a protein occupies just a tiny fraction of this enormous space, making it computationally intractable for any sort of brute force search approach. If the chain were able to sample conformations at a nanosecond or picosecond rate, it would still take a time longer than the age of the universe to find the correct native conformation (Levinthal's paradox).[5] The fact that proteins manage to fold on biologically relevant timescales suggests that protein sequences are optimized by the evolutionary process to enable fast and reliable folding.

The shape of the energy landscape that enables the protein to spontaneously self-assemble into the correct structure in a matter of seconds is dictated by the physical interactions between different amino acids. Attempts have been made to use approximations of the physical interactions both between atoms of the protein and with atoms of the surrounding solvent to computationally simulate the protein-folding problem. While progress has been made, allowing the structures of some small proteins to be accurately predicted, the problem remains computationally intractable even with the use of coarse-grained approximations. Currently, we are unable to simulate more than a millisecond of protein dynamics, which prevents the simulation of folding trajectories for larger proteins.

The probability model

The question is how we can best use the available sequence data to infer the constraints or bounds on the space of amino acid sequences that result in the particular protein of interest. This is a typical inverse problem; we wish to use the data to infer the model constraints, i.e., to parameterize the probability distribution. This raises the crucial question of what form the probability distribution should have. While we require that the probability model reproduce the statistics of the observed data, there are many models that will do this. We wish to choose a single model from among these, so we choose the maximum entropy model, i.e., the least constrained model that reproduces the observed data. Specifically, we ask for the single site marginals and the marginals for each pair of sites to match the empirical frequency counts for the single sites, and each pairs of sites, in the

(Continued on page 17)

PROTEIN SEQUENCE DATA *(Continued from page 16)*

sequence alignment available for the protein of interest. The resulting Potts model, known from statistical physics, defines a global probability model on the space of protein sequences:

$$P(A_1...,A_n)=\frac{1}{Z}\exp\left\{\sum_{i,j\,i<j} e_{ij}(A_i,A_j)+\sum_i h_i\right\}$$

Where $e_{ij}(a,b)$ are called the *couplings*, and h_i the *fields*. Here $Z=\sum_{A_1,...,A_n}\exp\{-H(A_1,...,A_n)\}$ is the *partition function*, which ensures that the probabilities are properly normalized.

A different model is built from data for each protein, and gives the probability that any sequence of interest will specify the protein for which the model is built. In short, the set of sequences available for a protein of interest is used to infer the parameters for this model.

One prediction is that those pairs of sequence positions that have the highest interaction score will be in close structural proximity in the three-dimensional protein structure. To test the predictive power of our inference procedure, we compare the highest scoring pairs of sequence positions to the experimentally solved crystal structure of an example protein. In figure 3, the match between the model predictions (red stars) and the crystal structure data (grey points) is shown to be excellent.

This is a highly surprising result, which immediately raises the question of whether the information inferred from sequence data is sufficient to predict the three-dimensional protein structure. To test this hypothesis, we start with the unfolded polypeptide chain for the protein of interest, and use an algorithm called distance geometry to enforce that the two amino acids in each high-scoring pair are within 7 angstroms of each other in our structural model. Distance constraints that reflect the secondary structure predicted from protein sequence are also included.

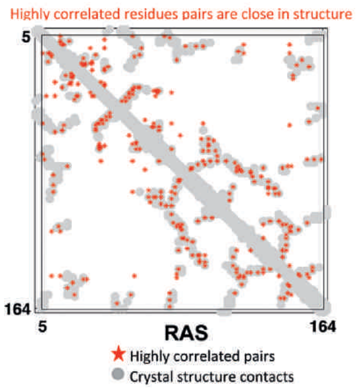

Figure 3: In grey is a two-dimensional map of the three-dimensional crystal structure data—this is a binary matrix where a '1' represents two amino acids between which the distance in the crystal structure is less than 5 angstroms. The highest scoring amino acid pairs from the maximum entropy model inferred from sequence data are plotted in red. The fact that many of the red points coincide with grey points demonstrates that we can predict information about three-dimensional protein structure from sequence data.

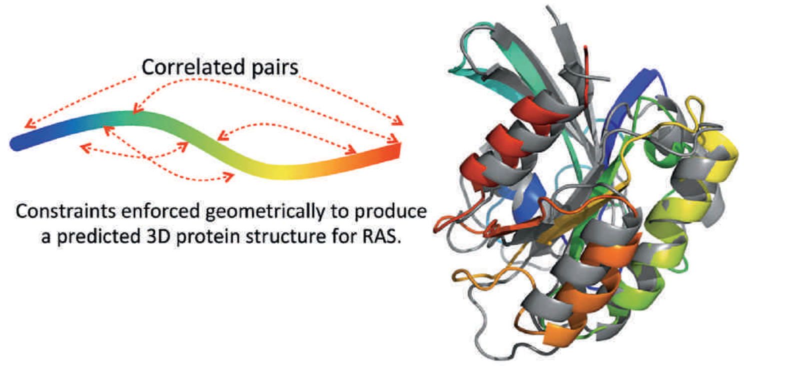

Figure 4: Comparison of our predicted three-dimensional protein structure for the protein RAS with the crystal structure (grey). The root mean square deviation between the Cα-atoms of our predicted structure and the experimentally solved crystal structure is 3.5 angstroms, comparable to a low-resolution crystal structure.

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We find that there is indeed sufficient information in these large sequence alignments to accurately predict protein three-dimensional structure.[6] This statistical method makes progress on the protein-folding problem by predicting, from sets of protein sequences, structures for a range of globular and transmembrane proteins. In addition, three-dimensional structures were predicted using these methods for a set of transmembrane proteins for which no experimental structure had yet been solved. Many of these proteins are important in human diseases, and the existence of predicted structures will allow models of their function to be constructed and potentially validated. While the ability to use evolutionary variation to shed light on protein structure is exciting, the fundamental question of the relationship between amino acid sequence and protein function requires further work. In particular, it will be important to understand how the concerted actions of groups of amino acids within a protein result in different protein phenotypes, and furthermore how these can be predicted from large collections of protein sequences.[3,4] ■

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MONGOL EMPIRE *(Continued from page 15)*

a steady supply of surplus resources. This particular aspect would also be relevant to military operations, since a considerable number of soldiers, including the imperial bodyguard, would be living in close quarters and under the direct command of Chinggis Khan. Even more important, the Mongol army required a large number of mounts—each soldier would have needed on average five horses—which would not have been available in dry conditions, but would have been plentiful as pasture became more lush and nutritious. These considerations show that the wet environment might have had an important supporting role in fueling military operations and political centralization, sustaining the rapid recovery of the Mongol economy, and creating surpluses critical for the creation of "state-like" institutions and a centralized command structure and administration.

Yet, there are a number of problems and questions that need to be addressed. For instance, the climate data comes from the Orkhon valley, rather than from the Onon valley, in northeastern Mongolia, where Chinggis Khan was based in 1206. There are indications that Chinggis moved the center of his operations to the Orkhon in the late 1210s, and availability of better pasture may have been a reason for this, but we cannot say that for sure until we have more data for other parts of Mongolia, and in particular the Onon-Kerlen region. Another important question is whether the hypothesis that favorable climate and increased rangeland productivity may have played a critical role in the politics of pastoral nomads should be tested against other historical cases. In historical research it is impossible to replicate exactly the same conditions, but our hypothesis would be strengthened if we were to observe that a rapid change from a period of temperature decline and dry weather, followed by markedly better conditions, coincided with drastic political transformations. No systematic research has been attempted so far. Some positive, if not fully relevant, indications, however, can be registered. For instance, Gergana Yancheva, et al., find that Chinese dynasties were established during wet periods, which may indicate a correlation between military operations and energy levels.[3] Closer to our time and problem, a study of paleoenvironmental conditions in the territory of the Golden Horde (Russia–Ukraine) finds that "an increase in climatic humidity within this dry region took place in the period of the High Middle Ages, with a peak in the thirteenth–fourteenth centuries" and that "the favorable climatic, vegetation, and soil conditions in the Lower Volga steppes in the thirteenth–fourteenth centuries were factors that affected the local ethnic and socioeconomic conditions: numerous permanent settlements were established in the regions, and some nomads began crop cultivation."[4] The correlation established in these studies between social development and better climate conditions encourages further probing into the role played by a more favorable environment in the history of nomads.

Beyond exploring ways in which climate data can open new avenues to explain otherwise irretrievable historical scenarios, coupling scientific and historical research may also produce models for future projects. This is especially important in the study of the history of people who have not left much in terms of documents or written records. Material culture, archaeological research into settlements and urban sites, palaeobotanical and palynological data, and climate science can provide evidence that, carefully examined in a comprehensive manner, may bring new insights into historical problems that would otherwise remain shrouded in mystery. ■

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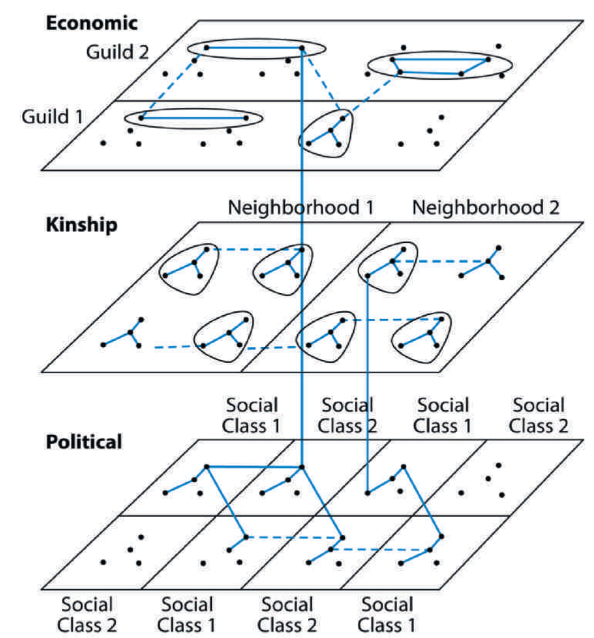
HISTORY AND EVOLUTION *(Continued from page 1)*

have nightmares of creationists and intelligent designers exploiting indeterminacy in evolutionary theory for their own purposes.

With this history and context in mind, Walter Fontana, Member (1999–2000) in the School of Natural Sciences, Walter Powell of Stanford University, and I are initiating a new Social Science Research Council Working Group on History and Evolution in order to develop theoretical and empirical bridges between disciplines not usually in close conversation: evolutionary biology, history, and the social sciences. This initiative builds upon previous collaborations and working groups at the Santa Fe Institute and upon discussions this year at IAS. Why reopen this Pandora's box of trying to make evolution and history speak to each other? There are motivational and scientific maturity answers to this question.

On the motivational side, the social sciences seem stuck, as Andrew Abbott has long argued,[2] in ever reproducing fractal polarities. Methodologically, this is quantitative versus qualitative, but theoretically this is more like methodological individualism versus social constructivism. Instead of contradicting each other, I would argue that both sides need the other to proceed. Methodological individualist theories[3] need "actors" to drive their bottom-up deductions about collective behavioral patterns, but "actors" themselves enter from offstage in this approach as axioms, immune to derivation by the theories themselves. Social constructivism strives for the opposite top-down causality—to derive actors and institutions from cultural meaning and interpretation—but "meaning" (or "reflexivity") axiomatically is presumed in this approach without deriving the material and behavioral patterns to which cognition and language point. In our recent book *The Emergence of Organizations and Markets* (Princeton University Press, 2012), Powell and I pose this duality as "in the short run, actors make relations, but in the long run, relations make actors." Instead of juxtaposing the short-run and the long-run sides of this feedback as contradictory, we suggest that their causal interdependence can be seen as a problem of intercalating time scales. The long-run side of this feedback is currently less well understood than is the short-run. Specifically, we suggest that the largest outstanding gap in social science's collective understanding is our weak processual knowledge about the emergence of "actors"—where do new types of people, organizations, social movements, states, and markets in history come from?

Figure 1. Multiple-network ensemble Renaissance Florence



Note: a) Solid lines are constitutive ties. Dotted lines are relational social exchanges. Oblongs are formal organizations (families and firms.)
b) People in multiple roles are vertical lines connecting corresponding dots in the domains of activity in which people are active. (Only two are shown.)

JOHN PADGETT

Where do new types of people, organizations, social movements, states, and markets in history come from? Padgett sketches one way in which coevolution and autocatalysis can be conceptualized in terms of the multiple social networks of Renaissance Florence.

This social-science question about emergent actors is essentially the same as the famous speciation question that Darwin asked about biology long ago in his *The Origin of Species*. Charles Darwin changed the scientific world with his grand theory of natural selection (which operates on phenotypic variation coming from outside the theory), but he did not answer his original question. Quite rightly in my view, social scientists and even more so historians frequently are repelled by the unilinear progress implications of what they perceive to be Darwinist theory, without appreciating how much of that derives from Herbert Spencer's "survival of the fittest" bastardization, rather than Darwin's own "progressive diversification" interpretation.[4] Many social scientists also may not realize that contemporary biochemists have come closer toward answering Darwin's original biological speciation question than did the mid-twentieth-century "Modern Synthesis" of natural selection and genetics into population genetics—that methodologically individualist approach to natural selection based on populations of selfish genes.[5]

Perhaps the most powerful recent advance in evolutionary biochemistry relevant for this proposal is "evo-devo"—an acronym for evolutionary developmental biology. This is not the study of genes as changing bags of different colored balls, but instead is the study of genes as unfolding regulatory (i.e., feedback) networks of interconnected and sequentially expressed genes and proteins in fetal development. The empirical discovery of a surprisingly low number[6] of genes in the human genome has refocused research attention on the combinatorics and sequencing of unfolding gene and protein networks, which actively construct tissues that in turn sequentially interact. Morphological differences among species now seem to be rooted as much in evolving chemical network structures as in evolving genes per se. Evo-devo bridges the gap (or at least tries to) between genotype and phenotype through chemical networks constructing and guiding the interaction of tissues—without denying the competitive selection dynamics of genes-as-inheritance that lie at the heart of all forms of Darwinism.

In a somewhat less momentous way, contemporary evolutionary biology also is being reframed by ecological perspectives, through the concepts of "stigmergy" and "niche construction." These terms refer to evolutionary feedback between critters (and their social interaction) and the resource environments that those critters themselves partly create. That is, critters make physical environments, which in turn may shape their own evolution if their changes are lasting or repetitive enough. These ecological perspectives gain network twists if "environment" is conceptualized not just as physical resource spaces of consumption but as food webs of multiple species eating each other. Microgenetic (and protein) regulatory networks and macroecological networks must interact because they are all chemical transformations in the end, but coupling network dynamics across multiple time scales is the next research frontier for evolutionary biology.

What does this scientific maturity in biochemistry imply for the social sciences? I propose that history likewise might fruitfully be analyzed as interacting sets of dynamically evolving (and tipping) networks—but of people and practices, not of phenotypes and genotypes.

Fatal missteps of past discussions of biology have followed from slavish social-science efforts to imitate biological reasoning—such as by arguing that biological genes (or pseudogenes like "memes") should become logical foundations for the social sciences. We social scientists should recognize, however, that biology itself has moved way beyond those primitive notions of unilineal progress and relative species superiority. Once interacting networks replace methodologically individualist genes (or anything else monadic), then coevolution replaces evolution as the outcome to explain. Fixed mountains of optimality dissolve into locally malleable adaptive landscapes that change with movement upon them. Genes and species don't defeat each other so much as learn (through relative reproduction as well as other mechanisms) how to fit together in mutually consistent (which includes agonistic) ways. Autocatalytic network systems can reproduce themselves through coevolution without being superior or optimal in any global sense.

In our recent book, Powell and I have sketched one way in which coevolution and autocatalysis can be conceptualized in terms of multiple social networks—political, economic, kinship, etc.—in dynamic interaction through time. It is not a complete theory as much it is a proof-of-concept that the social speciation question about the emergence of novel actors can be understood in terms of dynamic interaction and cascading feedback among multiple networks. Network analysis already is booming in the social sciences and hardly needs the SSRC to catalyze it. But this subfield has not been placed into dialogue with macroevolutionary and historical questions at the foundations of social science. (Instead network analysis currently is being pushed along more by its synergies with the internet and computer science.) In between the segregated fields of evolutionary biology, history, and network analysis lies a potentially powerful generative space ("structural hole" in the language of Ronald Burt[7]) where new insights reside, if only mutually respectful conceptual bridges can be built to catalyze them.

What does reframing of evolutionary processes (either biological or social) in terms of networks imply for our understanding of history? Darwin's idea of biological explanation was not the point predictions of physicists. History to him was a branching bush of diversifying path-dependent trajectories, not a teleological optimum toward which all are heading. The goal of science in this image is not the determinate derivation of the structure of the entire bush; it is the discovery of iterative processual mechanisms that induce both trajectories on the one hand and branching on the other. Discovering mechanisms, not predicting outcomes, is the primary objective of science in its biological variant.[8] We now understand better than did Darwin that network features of micromechanisms are responsible for generating nonlinear (and hence hard to predict) macrodynamics. Trajectories ("continuities") and branching ("change") are not distinct logics in history according to this biologically inspired view, they are just different phases of common (albeit yet to be discovered) underlying iterative dynamics.

Is this just a more sophisticated nonlinear way of conceptualizing determinism? No. Even within single-network nonlinear systems, bifurcations leave mathematically indeterminate which route to take. Within socially more realistic multiple-network systems, catalytic feedbacks across systems provide one way of conceptualizing "historical contingencies" as consequential interactions between simultaneous parallel processes, which amplify or dampen each other. Surely, this is not the only way of conceptualizing historical contingency, but it is a way mutually respectful of (indeterminate) history, evolutionary biology, and network analysis. The classic problem of agency versus structure thereby gets reframed away from two

(Continued on page 19)

HISTORY AND EVOLUTION *(Continued from page 18)*

competing and contradictory logics to a focus on understanding dynamic system responsiveness to various perturbations, including agentic ones.[9] Great individuals frequently can be found in exciting case studies, but the science of history resides in understanding how (multiple) networks of others interacted and responded at particular moments in time.[10] More generally, social structures become fluid vortexes, not constraining buildings, in a processual understanding.

The activities of the SSRC Working Group on History and Evolution will be three: (a) to convene an inaugural conference of about twenty-five sympathetic social scientists, historians, and evolutionary biologists in order both to explore these themes and to identify committed future participants, (b) to meet regularly as a ten- to twelve-person working group of junior and senior scholars over two to three years in order to develop theory and empirical applications, and (c) to produce an edited SSRC volume that lays out and exemplifies an agenda for the budding field. The SSRC book models I have in mind are Charles Tilly's *Formation of National States in Western Europe* (Princeton University Press, 1975) and Theda Skocpol's *Bringing the State Back In* (Cambridge University Press, 1985), both landmark examples of SSRC influence on budding social-science agendas. Like these highly successful predecessors, this new SSRC volume will not be a passive summary of existing knowledge and approaches but rather an active intervention, demonstrating how to do interdisciplinary research in an (almost) virgin territory.

Particular sample questions worthy of further exploration, debate, and development by this working group include the following:

1. If genes and memes are insufficient microfoundations for a social-science analogue to contemporary evo-devo, what are the substitutes? Powell and I propose production rules (for production autocatalysis), relational protocols (for biographical autocatalysis), and symbolic addresses (for linguistic autocatalysis). We suggest that interactionally induced assemblages of such practices within people are the disarticulated "under the hood" content of human "agency." Agency thereby becomes socially diverse, not universally homogeneous, as one corollary. Are these three subsets sufficient to operationalize a practice-based social science, or are more microevolutionary components required? "Consciousness" is a notable omission in the above list, but does that comforting human quality have to appear *deus ex machina* in our theories, or can it too become an emergent property?

2. If not simplistic "survival of the fittest," then what is "selection" in a network-based approach? Powell and I propose that "autocatalysis" is the answer, but is that exhaustive of the abstract ways in which practices (of various kinds) differentially reproduce through human interaction? Parasitism and symbiosis, in addition to the usual competition, already are implied within autocatalysis. But mechanisms of multiple-network regulation—where the numerous autocatalyses of overlapping social networks mutually support or undermine each other—remain to be articulated.

3. Both physics and biological natural selection lean heavily on modular architectures[11] of units within units (for example, atoms within molecules within gene/protein macromolecules within tissues within organisms within species, etc.) to work. Yet despite the sometime existence of cliques in single networks, multiple-network ensembles of social networks are rarely modular. The cross-cutting overlap of multiple networks is the topological essence of their mutual regulation and coconstitution.[12] How modular does the social-science analogue to network-based evo-devo have to be? What do evolution, development, and the genesis of novelty look like in more heterarchical architectures?

4. Political science and sociology colleagues in historical institutionalism recently have become interested in processes of institutional change, in addition to their more traditional focus on comparative equilibria. How does their more macro focus on "institutions" articulate with the more mezzo focus on "networks" articulated here? Obviously, this is a matter of levels of analysis, rather than some deep ontological divide. But how neatly can one segregate time scales, especially in times of historical change when interaction between time scales may be precisely the "spillover" that generates those unintended consequences so frequently observed in empirical case studies about the emergence of novelty?

5. One question that Powell and I get a lot: Does this mean that one has to spend twenty years gathering hard-to-find network data from primary sources before one can have anything to say? The widely diverse (in evidentiary ways as well) empirical chapters in our book are meant to alleviate this career-killing concern. But the fact remains that studying networks, either of social systems or of chemical systems, is data intensive. Biologists have solved this problem through pooling resources on seven or eight "model organisms," on which most of their biochemical knowledge is based. In the 1960s, SSRC was central in developing organizational models for collaborative research in survey research. Nowadays, efficient computer-search procedures are leading us toward a new world of "big data"—although perhaps at the cost of narrowing social science to the study of Twitter. If the study of "dynamic social networks" is to be more than just the study of the internet, then how can collaboration between social scientists and historians (and any other empirical researchers interested in the deep study of change over time) proceed?

6. If "model organisms" is identified as one useful organizational precedent for coordinating historically dynamic multiple-network research, then what is the set of proof-of-concept empirical cases that we want collectively to study?

7. Powell and I identify "poisedness" as an important next research frontier in the study of emergence. That is, in historical and biological studies of the emergence of "actors," the macrostudy of the reverberation reaction of networks into which novel actors are inserted is as important as is the microstudy of processual mechanisms of emergence itself. Powell and I describe the emergence of novelty as "innovation"; we call innovation plus network tipping "invention." If invention is a network system property, then the degree to which previous networks are "on the edge" of tipping becomes important to know. Formal models are suggestive for providing conceptual clues about this question, but empirical historical work, in which "the tape is only played once," requires disciplined investigation of narrowly constrained counterfactuals to make any progress.

8. "History" is not just the sequential record of events. "History" is also our narration about that record of events. As all historians know, history in the second sense requires authorial selection from the available record of events. History in the first sense, moreover, required selection by whoever coded events into records in the first place. Many historians (including myself) regard the tasteful and argument-driven selection and arrangement of events from records as itself constituting "explanation."[13] Lightly formalizing narrative histories into "narrative networks" of events is one analogical tool for bringing historiographical discussions about alternative narrative representations of the same record into conversation with evolutionary biologists and chemists who also study alternative ways of representing development and evolution.[14] Computer scientists who study concurrency in parallel-processing computation could be useful partners in this conversation because they investigate how action rules and timing intercalate. Both evolutionary sequencing in evo-devo and concurrency in parallel-processing computation pose challenges to traditional linear notions of causality in the social sciences similar (or at least analogous) to those posed by historiographical debates about narrative. This topic of the representation of history (and the meaning of causality in such representations) is an important methodological corollary to the substantive question of emergence. Methodological underpinnings need to be addressed in any serious empirical application of theories of nonlinear dynamics in highly interactive systems like multiple networks. ■

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1. Jon Elster, *Nuts and Bolts for the Social Sciences* (Cambridge University Press, 1989). In contrast, individualist functionalism, in the form of rational choice, is thriving. The definition of "functionalism" used in these sentences is simply "cause explained by consequence."
2. Andrew Abbott, *Chaos of Disciplines* (University of Chicago Press, 2001).
3. By this I refer not only to neoclassical rational choice, but also to bounded rationality and cognitive-science approaches like that of Herbert Simon.
4. Symbolized by the branching bush in Darwin's notebooks.
5. Population genetics does not even conceptualize, much less analyze, phenotype—relying instead on conceptualizing "species" as population-level gene distributions.
6. Lower than any scientist guessed in a lottery before the announcement.
7. Ronald Burt, *Structural Holes* (Harvard University Press, 1992).
8. This is not to say, however, that short-term prediction does not remain very important in empirical testing.
9. Like in evolutionary biology: Sure, the important historical contingency of the meteor killed the dinosaurs. But meteors have hit the earth many times without similar consequences. Ecosystem responsiveness to shock at that point in evolutionary time is as central to the explanation of dinosaurs' extinction as is the meteor itself.
10. Of course in the long run, great men too are made by (iterations of) relations.
11. In his "The Architecture of Complexity," *Proceedings of the American Philosophical Society* (Dec 1962), Herbert Simon called this "nearly decomposable systems." He further made the powerful argument that this architectural feature of observed structure is a deep consequence of the separation (or quantization) of time scales between the multiple dynamic processes that generated it.
12. This idea, of course, is not foreign to biology—nerve systems, blood systems, immune systems, respiratory and digestive systems also overlap and cross-cut in exquisite mutual interaction as well.
13. The word "interpretation" is more frequently used in this context, but equating the two words without getting too hung up on epistemology leads to more fruitful interdisciplinary dialogue than does rigidly insisting on their distinction.
14. Narrative networks are useful for steering between the Scylla of structural determinism and the Charybdis of radical indeterminacy because they make well defined the question of overlap and divergence of multiple representations. See, for example, the intriguing aggregation of fourteen oral histories by Chinese villagers about the "same" Cultural Revolution in their village in Peter Bearman et. al.'s "Blocking the Future," *Social Science History*, 1999.

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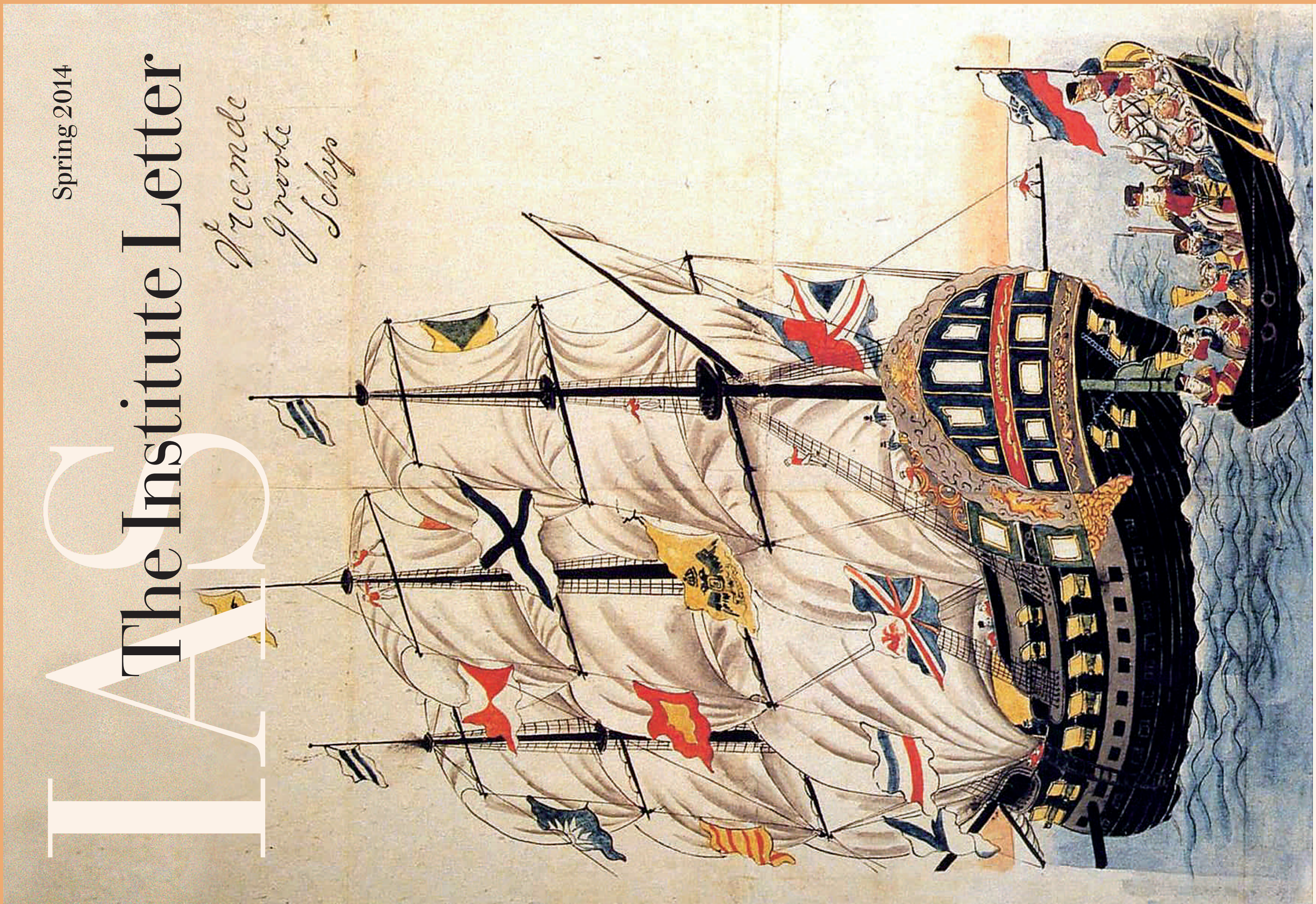

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