SFI Bulletin

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Harold Morowitz on Mayonnaise, Biochemical Pathways, and the Origin of Life

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Patrisia Brunello at 984-8800, Ext. 269 or pdb@santafe.edu

EDITORIAL STAFF:
Ginger Richardson
Lesley S. King
Andi Sutherland

CONTRIBUTORS:
Suzanne Dulle
Lesley S. King
Marsha McEuen
Thomas Patrick O'Connor
Cosma Rohilla Shalizi
Timothy Kohler
Sander van der Leeuw
Henry Wright

DESIGN & PRODUCTION:
Patrick McFarlin

COVER ILLUSTRATION:
Patrick McKelvey

CORRECTION

The identification of the image on page 4 of the Fall 1999 issue of the SFI Bulletin is incorrect in two regards. Captioned as "Giorgio Basarim (1511-1573) 'View of Florence' fresco," the image is actually a later painting by an unknown artist who was drawing from a 16th-century woodcut. Our thanks to Dale K. Haworth for his guidance in this matter.

2000 COMMUNITY LECTURES JAMES A. LITTLE THEATER, SANTA FE

June 14

Evolutionary Innovations: How Ecology and Development Combine to Change the World

Douglas Erwin, *Research Paleobiologist and Curator of Paleozoic Mollusks, The Smithsonian Institution*

SPONSORED BY THE W. M. KECK FOUNDATION

Why are major evolutionary innovations clustered in time, rather than distributed randomly in time? The first appearance of animals during evolution's "Big Bang" 530 million years ago, the emergence of early land plants, and the proliferation of mammals all follow a similar pattern. Erwin explores how in each case the appearances of new groups were tied to the creation of new ecological relationships. Similar patterns seem to occur in the aftermath of mass extinctions, and the evolutionary events during such innovations appear to be distinct from those during other intervals.

July 12

Harnessing Complexity: Organizational Implications of a Scientific Frontier

Michael Cohen, *Professor, Information and Public Policy, University of Michigan*

SPONSORED BY THE PETERS COMPANY AND CENTURY BANK

Michael Cohen and co-author Robert Axelrod's new book *Harnessing Complexity: Organizational Implications of a Scientific Frontier* examines the lessons that managers and policy makers can extract from complexity research. Cohen presents an overview of complex adaptive social systems, examines some examples in detail, and sets out an approach to acting constructively in complex settings, even when the future may be very difficult to foresee.

August 16

Hepatitis C Virus, A Y2K Health Threat Alert: A Silent Epidemic with Rapid Viral Dynamics.

Avidan Neumann, *Senior Lecturer, Mathematical Biology, Bar-Ilan University*

SPONSORED BY JANE ANN AND JASPER WELCH AND BY JACKALOPE

Chronic infection with Hepatitis C virus—called "the silent epidemic" because of the low public awareness—is on the rise throughout the world. Unfortunately treatment with Interferon and Ribavirin is successful only in a third or less of cases, and the way the therapy works is unknown. Mathematical modeling by Neumann and others embodies a new approach to better understanding the effect of treatment and the reasons for non-response. As a result of this research, new treatment strategies, based on individualizing the therapy for each patient as a function of viral dynamics, are now being developed.

September 19, 20, 21

Annual Stanislaw Ulam Lectures

The Brain as a Complex System

Charles Stevens, *Professor, The Salk Institute for Biological Studies*

The brain is one of the most complex of complex adaptive systems. These lectures review what features make a system complex, summarize facts about the brain's development and function, and survey insights about the brain offered by approaching it as a complex system.

The essence of complex systems is that they possess emergent properties, often quite complicated ones, which arise from the cooperative interactions between much simpler constituent components. The brain is, in many regards, a perfect example of this scheme. When the brain develops in a baby, each of the billions of neurons must find its right place in the brain and make just the right connections to thousands of others neurons. The enormously complicated structure of the brain must emerge through simple interactions between its billions of components, the nerve cells.

After the basic structure of the brain is formed, it must modify this structure by experience, and here, too, the final result must emerge from the interactions of individual neurons following their own simple rules. Finally, as the brain functions, the complicated patterns of neuronal activity that constitute thought must arise from simple functional interactions between individual neurons.

Stevens gives examples of the simple rules neurons follow and explains how the complex properties that characterize the human brain emerge from them.

October 18

Flights and Resting Places: Discovering Complementarity in Scientific Collaboration

Vera John-Steiner, *Presidential Professor, Linguistics and Education, University of New Mexico*

SPONSORED BY ALPHAGRAPHICS, SANTA FE

What is the meaning of collaboration within the scientific community? Some of the most significant contributions to 20th-century science have been the result of long-term partnerships. Collaborations take form in diverse patterns. Some build on the complementarity of the participants' disciplinary knowledge; others are driven by the tensions between competing positions. When "communities of thought" emerge, they contribute to perspective shifts within their domains. Most of these collaborations develop a shared vision and achieve jointly negotiated outcomes. John-Steiner examines such collaborations as those between Richard Feynman and Freeman Dyson and Niels Bohr and his collaborators. She also looks at Albert Einstein's generative friendship with Marcel Grossman, and two generations of partnership among the Curies.

November 15

"Delight Makers" and "Delight Takers" in the Archaeology of Bandelier National Monument

Timothy Kohler, *Professor, Anthropology, Washington State University*

Human organizations are extremely complex systems that have the disquieting ability to change rapidly in structure. Kohler proposes that between A.D. 1150 and the arrival of the Spanish, the Puebloan societies in Bandelier underwent one minor and one major organizational transformation that archaeologists would be delighted to explain. Oral tradition, along with recent survey and excavation in Bandelier discussed by Kohler, contribute greatly to this goal.

Talks begin at 7:30 p.m. All talks are held at the James A. Little Theater on the campus of the New Mexico School for the Deaf, 1060 Cerrillos Road, Santa Fe. There is no admission charge and no reservations are necessary, but seating is limited.

Please contact the Santa Fe Institute to arrange for sign-language interpretation, if necessary.

HAROLD MOROWITZ TACKLES LIFE—WITH THE HELP OF A FEW FRIENDS

by Thomas Patrick O'Connor

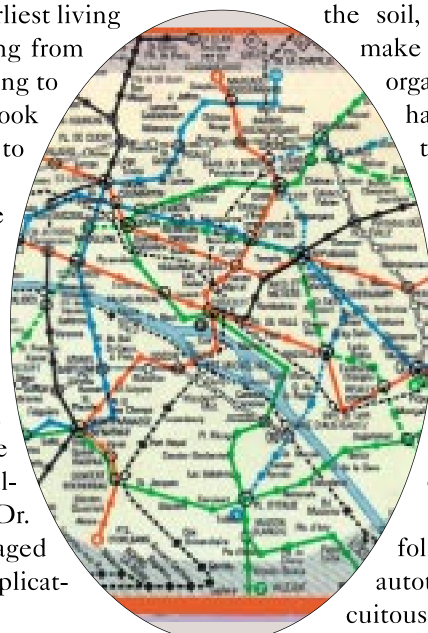
ILLUSTRATION: PATRICK MCKELVEY

profile

The Chart of Intermediary Metabolism hanging on the wall of Harold Morowitz's tidy office in the Krasnow Institute for Advanced Study at George Mason University looks like the subway map of Paris. The three- by four-foot chart connects all the chemical reactions that occur in living organisms. If you eat a banana, for instance, the chart can tell you what chemical transformations take place to make it into amino acids, vitamins, and sugars. In turn, these chemical transformations show how they connect up with all the other elements on the chart.

"What I'm trying to do," Morowitz says without pretense, "is to trace the origins of life using that chart." I look at the chart and at Morowitz. He's a reserved, bespectacled man, with a glowing countenance and a gnome-like expression that suggests he might actually know the secret of life's origins, a question that has baffled mankind for millenniums. As he moves closer to the chart, his smallish movements belie large ideas.

"There is only one chart of intermediary metabolism because all living organisms have parts of that same chart," he says. "That means you're looking at four-billion-year-old biochemistry—a fossil older than any rock we have." This fossil is the clue that began his present investigations, which attempt to empirically prove an extraordinary postulate: that the core of this chart, the citric acid cycle, was present in the earliest living cells. That means Morowitz is starting from the chart and working backwards, trying to trace the chemical reactions that took place on the earth all the way back to some four billion years ago.



As he traces lines on the maze-like chart with his index finger and explains their connecting points, I'm reminded of a detective following clues—say, Popeye Doyle (Gene Hackman in *French Connection II*) studying the map of Marseilles in order to track down the leader of the French drug cartel. Although physically Morowitz is more reminiscent of Dr. Watson than Popeye Doyle, he's engaged in detective work infinitely more complicated than either.

The metabolic chart is the result of hundreds of thousands of work hours by scientists since the mid-1800s, though the chart itself was not printed until the 1940s. Morowitz's complex theory that the citric acid cycle was present in the earliest living cells is elementary to him. "It's simple chemistry; all pathways come off of this central set of reactions to make anything. You make amino acids by reacting components from the citric acid cycle. You back up another pathway and you make sugar. You go in another direction, you make fats, but it all comes from this central core. There's a real logic: it's that universal grand design—the unity within diversity." Professor Morowitz argues that the Chart of Intermediary Metabolism is to biology what the periodic chart of elements is to chemistry.

Morowitz, a biophysicist and author of some 17 books and nearly 150 articles, is a modest, congenial man with wide ranging interests. Those interests are revealed in a few of his book titles: *Foundations of Bioenergetics*, *The Thermodynamics of Pizza*, *Theoretical and Mathematical Biology*, and *Entropy and the Magic Flute*. Moreover, his books have drawn praise from a broad and varied readership. *The Kindly Doctor Guillotine*, a book of essays, features a book-jacket quote from SFI's Murray Gell-Mann, but also one from Peg Bracken, author of *The Complete I Hate to Cook Book*. Ms. Bracken captures his work (and his person) in a comment that reads: "In his work a good measure of humor and humanity underlies the breadth of his scholarship."

As I puzzle over the chart, Morowitz smiles and points to another of its features—organisms called autotrophs. Autotrophs make all their own compounds starting with carbon dioxide, ammonia, and water. Plants are autotrophs; they get CO^2 out of air and nitrate from the soil, but all intermediate chemicals they make themselves. "I contend that the earliest organisms had the entire chart. People don't have the entire chart because they eat things that have those intermediate chemicals necessary for life. Autotrophs have the entire chemistry, and some are microorganisms that can carry out all the reactions. My guess is that the original ancestor was this kind of cell. It could make every carbon compound that you need for life starting with CO^2. What I'm trying to do is to trace how that chart came to be in the chemistry that preceded human life."

Morowitz's detective work has meant following clues as obscure as the first autotroph and traipsing down paths as circuitous as the Paris subway map. His investigations began 12 years ago when his first connection with the Santa Fe Institute coincided with his appointment as the Clarence J. Robinson Professor of Biology and Natural Philosophy at George Mason University in Virginia.

The Robinson Professors at George Mason, distinguished researchers at the top of their fields, are asked to teach introductory courses—courses taught by graduate students at many universities. Morowitz taught Biochemistry 101, rudimentary material he hadn't taught in 30 years, and he realized that the introductory courses are the only place where a discipline is looked at in its entirety.

The metabolic chart, something every introductory course in biochemistry uses, got him thinking about the core of the chart—the citric acid cycle. "Suppose I look at all the kinds of simple compounds—carbon, hydrogen and oxygen—contained in the citric acid cycle," he mused, "to see how they could have come to be in the Intermediary Metabolic Chart." The reference librarian at George Mason downloaded those compounds from the Dictionary of Organic Compounds. It turned out to be only a few thousand, but the list contained all 11 compounds of the citric acid cycle.

In 1992, he took the list with him on sabbatical at SFI. "I asked, 'Can I find the logic of why these 11 compounds of the citric acid cycle are used out of a collection of thousands? Was it a frozen accident or could it be derived from more general laws?'" At SFI he spent time with Walter Fontana and Leo Buss, who were working on a more abstract approach to general biochemistry. Fontana directed him to Daylight Inc., a company in Santa Fe that maintains SMILES, an extensive on-line database of the directories of organic compounds. SMILES enables researchers to find formulas of organic compounds in a direct and simple way and download them. Daylight's data enabled Morowitz to go from general ideas to hard data. For example, using their database and computational methods, he was able to get the water-oil partition coefficients.

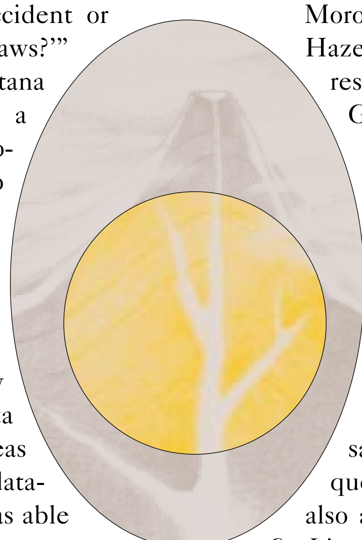


ILLUSTRATION: CATHERINE KIRKWOOD

The laws of chemistry tell us that oil and water don't mix, yet Morowitz theorizes that the first living cell was surrounded by a membrane composed of oil and water. In his book, *Mayonnaise and the Origins of Life,* Morowitz compares this membrane to mayonnaise. In mayonnaise as well as in that first membrane, oil and water do mix. His explanation of why they do is complex enough to fill a book; suffice it to say it's another clue in his search for the key to life's origins.

Thinking about these issues brought him to another question: "How do you use the laws of chemistry to go from the periodic table [of chemistry] to the core of the metabolic chart?" Part of Morowitz's sabbatical was spent at NASA Ames Research Center in California working with the organic chemist Sherwood Chang and the biochemist Larry Hochstein. Chang helped Morowitz find a way to make amino acids from keto acids, while Hochstein introduced him to the reductive citric acid cycle. After his sabbatical, Morowitz returned to George Mason and became the founding director of the Krasnow Institute for Advanced Studies. His research went on the back burner for the time being.

At about this time Morowitz began to rethink the research done by his friend, Jack Corliss. Five years earlier, Corliss had been doing research on early life in the deep trenches of the ocean near the Galapagos Islands. He postulated that life could have originated at the bottom of rift zones where lava hits the water. This theory suggested to Morowitz that perhaps he was looking at the wrong chemistry, because the chemistry at high pressures and high temperatures is totally different from those at more standard pressures and temperatures. The physical properties of water change, and it acts more like an organic solvent. This had been known by measurements of physics, but no one had thought about its significance for biology or organic chemistry.

Morowitz talked about this problem with Bob Hazen and George Cody, who are on the research staff for the Carnegie Institute of Geophysics in Washington, DC. Hazen and Cody let Morowitz use their equipment to do experiments on organic reactions under deep-sea conditions. "This was very special. There are only a few places in the world where you can do such high-pressure experiments, and Carnegie is located in Washington—only 15 minutes away from George Mason."

In 1998, Morowitz went on another sabbatical at Yale, where he took up his quest again to find the origins of life. It was also at Yale that Morowitz discovered *Beilstein On-Line,* a much more extensive compendium than the *Dictionary of Organic Chemistry. Beilstein On-Line* has a database of 3,500,000 compounds. Before Beilstein went online, it was 515 thick volumes of thin paper and small type in dense German, dating back to 1797. It was virtually inaccessible because of the magnitude of the information. Jennifer Kostelnik, an informatics librarian at Yale, helped him access Beilstein. In an effort to narrow the information, they asked, "How could we develop a set of chemical rules from a theory of what went on in this early chemistry to find compounds of reductive citric acid cycle by normative organic chemistry?"

They came up with a set of six physically based pruning rules to narrow the search for the citric acid cycle. Using the six rules, they were able to get through all of Beilstein and arrive at a subset of the 142 compounds that contain all the compounds of the citric acid cycle. "In looking at networks of compounds, the surprise was that you get a small subset of compounds that contain all the citric acid cycle intermediates.

"We're not finished yet," he cautioned. "Now we're searching for the kind of reaction networks that could give you the citric acid cycle. I'm not looking at the whole chart, rather at the core of the chart to see how this first cycle came about." Everything else is future research: how molecules in the chart combine with molecules of ammonia to make amino acids, then the next stage of the chart, and so-on. His ultimate goal? "The postulate is that the chart is not an accident but comes out of physical and chemical properties of the atoms that make up living systems," he says. "What we're trying to do is to reduce the biochemistry to the underlying physical chemistry."

He adds that this project has been atypical of most scientific research because it hasn't been him alone working in a lab on a narrow experiment. "It is asking broad philosophical questions about the origins of life and involves a broad coalition of people. I'm talking about a network of people that's as complicated as the metabolic chart. Most of these people are in some way associated with the Santa Fe Institute; SFI has been the connecting point."

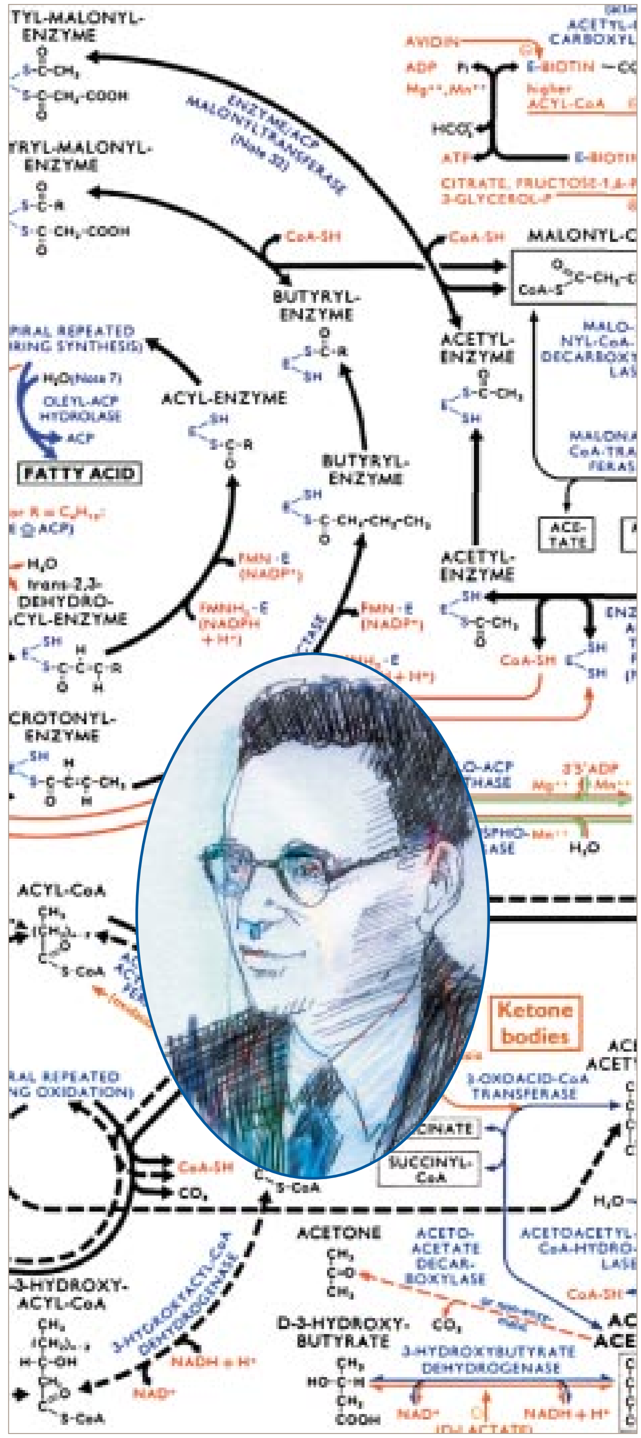
Asking philosophical questions comes naturally to Morowitz. He majored in philosophy and physics as an undergraduate at Yale in the '40s, and many of his books deal with philosophical questions. *Cosmic Joy and Local Pain* is a book about why the world works much better than we have a right to expect. Morowitz says he is one of the few biologists he knows who admires the philosophy of the Jesuit theologian and scientist Pierre Teilhard de Chardin.

Matter, Teilhard argued, has always obeyed "that great law of biology . . . complexification." With the emergence of Man, Teilhard said, evolutionary development entered a new dimension. From the biosphere (the layer of living things covering the earth) has emerged the noosphere (a mind layer surrounding the earth). This mind layer, human consciousness, generates increasingly complex social arrangements that in turn give rise to a higher consciousness.

"I'm a great fan of Teilhard. In my view the Worldwide Web is the noosphere," says Morowitz. "As a result of high-speed digital computers, we are getting whole new ways of looking at things." While Morowitz is deeply concerned with philosophical questions, he is at heart an empirical scientist. "I believe it [research] must be reduced to experiments done in the laboratory. I'm not going off in never-never land of theory. It always has to come back to experiments in the lab."

Thomas Patrick O'Connor is an Associate Professor of Media Arts at James Madison Univeristy and a freelance writer.

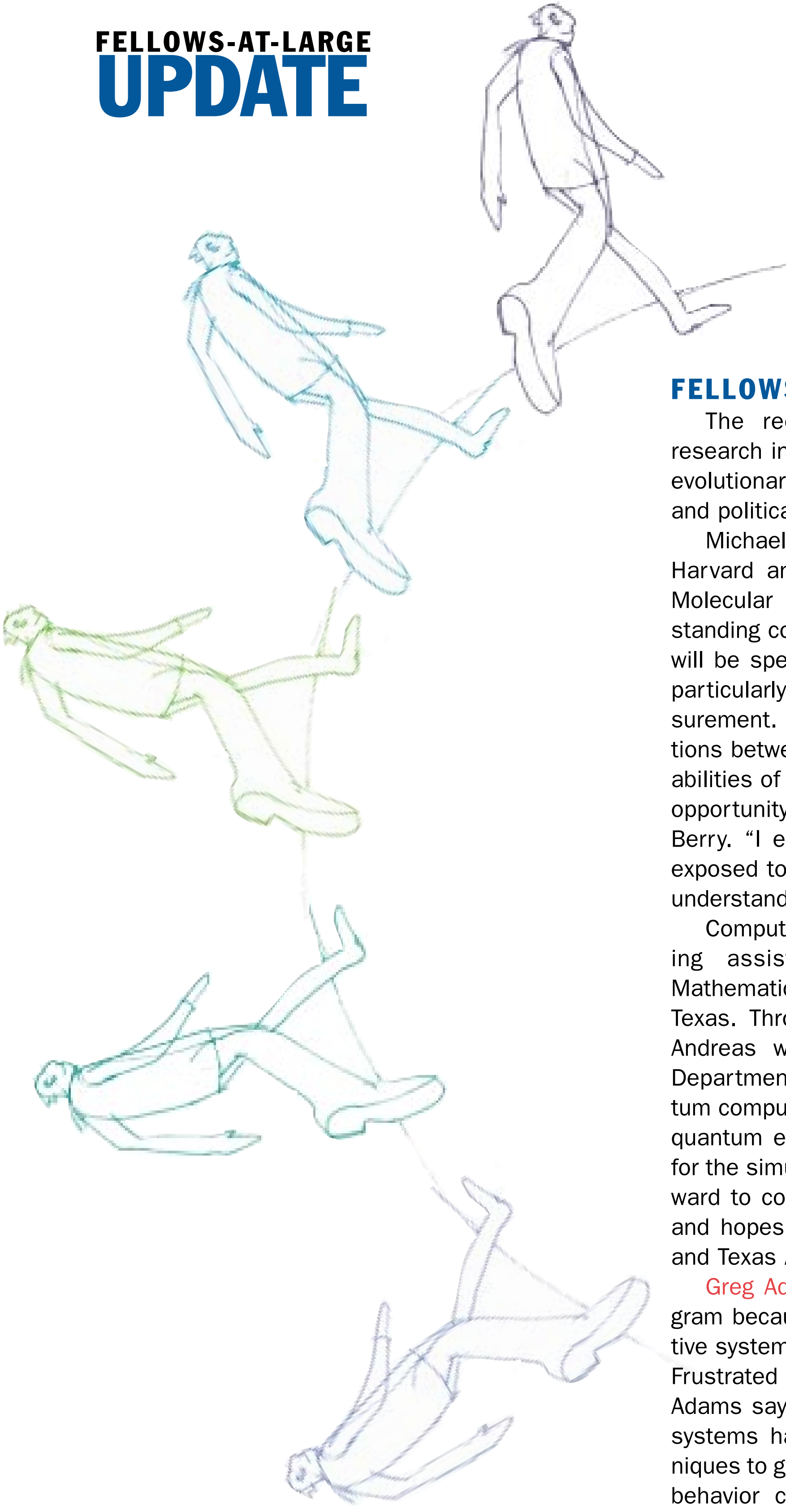
ILLUSTRATION: PATRICK MCFARLIN



Hans Krebs, professor of biochemistry at the University of Sheffield, 1945-54, won the Nobel Price for Medicine/Physiology in 1953. He discovered the mechanism by which energy is released in living cells through the oxidation of foodstuffs, a cycle of reactions which became known as the "Krebs Cycle" or the citric acid cycle.

The metabolic pathways chart was first sketched by microbiologist Donald Nicholson at the University of Leeds to help students make biological sense of biochemical pathways and enzymes. Krebs used the chart to illustrate his own textbook.

FELLOWS-AT-LARGE
UPDATE



The SFI Fellows-at-Large program supports the research efforts of young scholars in the area of complex systems and promotes setting up relevant research agendas in the individuals' home institutions. Among other activities, the program funds SFI-affiliated researchers to visit the Fellows' home campuses for research talks and collaborations.

FELLOWS-AT-LARGE SELECTED

The recently selected 2000 Fellows represent research in the areas of molecular biology, ecology and evolutionary biology, mathematics, computer science, and political science.

Michael Berry, who holds a Ph.D. in Physics from Harvard and is an assistant professor in Princeton's Molecular Biology Department, is interested in understanding computations performed by neural circuits. He will be specifically studying the retina, a circuit that is particularly accessible to experimental control and measurement. More generally, he wants to make connections between the properties of single neurons and the abilities of systems of neurons. "I am excited about the opportunity to come to the Santa Fe Institute," says Berry. "I expect that many of the ideas that I will be exposed to there will prove fruitful for my goal of better understanding the human brain."

Computer Scientist Andreas Klappenecker is a visiting assistant professor in the Department of Mathematics at Texas A&M University in College Station, Texas. Through A&M's Information Sciences Seminar, Andreas will introduce students and faculty of the Department of Mathematics to the main ideas of quantum computing, focusing on quantum signal processing, quantum error control codes, and quantum algorithms for the simulation of complex systems. He is looking forward to collaborating with Santa Fe Institute members and hopes for a lively exchange of ideas between SFI and Texas A&M.

Greg Adams was drawn to the Fellows-at-Large program because of his growing interest in complex adaptive systems and the development of predictive models. Frustrated by the limitations of traditional approaches, Adams says that the methodology of complex adaptive systems has enabled him to use computational techniques to generate predictions about how individual-level behavior can produce macro-level outcomes. Adams holds an assistant professorship in the Department of Social and Decision Sciences at Carnegie Mellon University and has recently been a Robert Wood Johnson Foundation Fellow at the University of Michigan.

An alumna of SFI's 1995 Complex Systems Summer School, mathematician Kellie Evans is fascinated with the rich dynamics and complex self-organization exhibited by the "Larger than Life" (LtL) family of two-state, two-dimensional cellular automaton rules. In addition to her current research at California State University, Northridge, Kellie is interested in moving in a new direction and will be using complex adaptive systems and other approaches to model problems in fields such as chemistry, mathematical biology, and population ecology.

Attendance at two SFI workshops on spatial modeling in ecology and biology piqued Douglas Deutschman's interest sufficiently to cause him to apply to the 2000 Fellows-at-Large program. Hired as a quantitative ecologist at San Diego State University, Deutschman's research program is aimed at understanding and managing the complex dynamics of biological populations, communities, and ecosystems. He is currently participating in an NSF-sponsored international collaborative research project aimed at understanding the importance of biodiversity in ecosystem function.

The rapid explosion of scale and tighter coupling among protocol elements on the Internet are the impetus behind the research of Kihong Park. Park is another alumnus of SFI's Complex Systems Summer School and is now an assistant professor of computer science at Purdue University. Park explains how the emergence of complicated, sometimes surprising, collective behavior from interacting, constituent components is a trademark of complex systems; and its study, in the context of the Internet, is the theme of his research activities. His hope is that his appointment as an SFI Fellow-at-Large will facilitate interaction between SFI-affiliated researchers and himself and will culminate in a workshop at Purdue on the "Internet and Complex Systems."

ILLUSTRATION BASED ON PAUL KLEE'S THE TWITTERING MACHINE: PATRICK MCFARLIN

1999 FELLOWS-AT-LARGE ACTIVITIES

DEBATES IN DYNAMICS

Last August, Fellow Dagmar Sternad, of the Kinesiology Department at Pennsylvania State University, hosted a three-day meeting entitled "Debates in Dynamics" during which a small group of researchers discussed recent developments and challenges for a dynamics systems account of motor control. The meeting was held in conjunction with the Second International Conference on Progress in Motor Control: Structure and Function of Voluntary Movements. The themes in movement coordination of this ongoing work range from the relation between spinal reflexes and cortico-motoneuronal pathways to the nature of control schemes in postural control. Other themes include the perception of metric structure in music, the role of attention to temporal regularities in speech utterances as the result of peripheral and central processes, and the interrelation of elements in complex behavioral sequences to multi-joint coordination. Some related theoretical issues are the link between phenomenological models and biomechanical structures, the integration of fast and slow scale processes, and the multi-level nature of a control system assuming networks on a central and peripheral level.

Meeting participants explored several very recent advances from a dynamic systems perspective focusing on both convergent assumptions and themes and their divergent routes. They talked about understanding the variability of rhythmic movements through dynamical systems modeling, the temporal structure of rhythms and the dynamics of attending, and the central and peripheral processes in speech production.

[continued]

FELLOWS-AT-LARGE
UPDATE [continued]

BUSINESS APPLICATIONS

"Complex Adaptive Systems and their Business Applications" was the theme for last fall's seminar series organized on campus by 1999 Fellow Filippo Menczer in the Management Sciences Department at the University of Iowa. SFI and the NCS Corporate Lecture Series provided support for the program.

Three pairs of speakers—Blake LeBaron (Brandeis) and Dave DeMers (Prediction Company); Winslow Farrell (PricewaterhouseCoopers) and Leigh Tesfatsion (Iowa State); Paul Weller and Tom Rietz (both University of Iowa)—discussed agent-based models of financial markets, behavioral finance, and economic dynamics. Another set of seminars addressed evolutionary algorithms and their applications for scheduling, data mining, and portfolio management. These talks featured Bill Fulkerson (John Deere), David Davis (Tica Associates), Charles Elkan (UC San Diego), and Nick Street (Iowa). A day on bioinformatics included seminars by William Hart (Sandia National Laboratories) and Jim Golden (Pioneer Hi-Bred International). Rob Axtell (Brookings) and Scott E. Page (Michigan) discussed agent-based models of social systems and organizations. The series' final speakers—Steve Lawrence (NEC Research), Dave Eichmann, Andrew Williams, and Menczer (all Iowa)—focused on intelligent and adaptive information agents for taming the complexity of the Web.

Students from several graduate programs in the College of Business were able to register for the seminars as a special topic course offered by the Management Sciences Department. NCS support allowed for the production of multimedia presentations of some of the talks and these will eventually be available at the seminar series web site at http://www.biz.uiowa.edu/class/6K299_menczer/.

TO APPLY

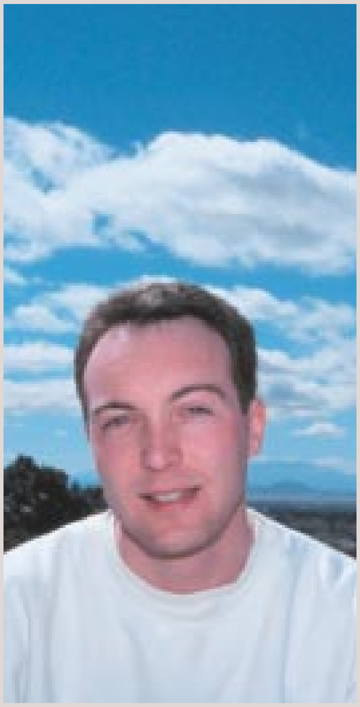
Applications for the 2001 Fellows-at-Large program may be submitted anytime up through January 15, 2001. At the time of proposal, applicants should be no more than five years beyond their Ph.D. Unusually well-qualified advanced graduate students are also eligible. Submissions should include a CV, a letter of recommendation from an individual familiar with the candidate's research, a two-page statement outlining the applicant's current research efforts in the area of complex systems, and a letter of support from the candidate's department head outlining both the candidate's qualifications and the department's commitment to the activities involved in the Fellowship. Send complete packages to FAL Program, Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, New Mexico 87501.

Fellowships are awarded annually, with Fellows' terms beginning in July of each year. Awardees are named approximately three months prior to the formal beginning of each term to provide the new class planning time for program activities.

If you have further questions regarding the application procedures, contact Catherine Griebel at 505-984-8800 Ext. 235 or cate@santafe.edu.

Recognitions

Erik van Nimwegen



Wim Hordijk

PHOTOS: JULIE GRABER

TWO SFI GRADUATE FELLOWS EARN PH.D.S

Two SFI graduate fellows, both from The Netherlands, completed their doctoral research in the fall of 1999.

In September 1999, Erik van Nimwegen was awarded a doctorate (with honors) in Bioinformatics from the University of Utrecht. Erik has been in residence at the Institute since October 1995 working with Research Professor Jim Crutchfield and External Faculty member Melanie Mitchell within the Evolving Cellular Automata project.

Van Nimwegen's main research interest is the mathematical theory of (very) simple evolutionary processes. He contends that, although this topic has long been the subject of mathematical population genetics, understanding of the dynamics of simple evolutionary processes can be developed much further using concepts and techniques from dynamical systems theory and statistical mechanics. A particularly important tool is the use of maximum entropy methods in non-equilibrium situations.

His thesis is entitled "The Statistical Dynamics of Epochal Evolution." It can be accessed at van Nimwegen's web page on the Santa Fe Institute site at www.santafe.edu/~erik/. Currently, van Nimwegen is continuing his research at the Institute as a postdoctoral researcher.

Fellow countryman Wim Hordijk earned his doctorate in Computer Science from the University of New Mexico in December 1999. Like van Nimwegen, Hordijk has been in residence at the Institute since 1995 working on his dissertation with Crutchfield and Mitchell as well as Stephanie Forrest (at UNM and SFI). His thesis, which investigates relations among dynamics, emergent computation, and evolution in decentralized spatially extended systems, can be found at www.santafe.edu/~wim/. Hordijk now holds a postdoctoral researcher appointment jointly between the Department of Ecology and Evolutionary Biology at Yale University and the Institute. He is working with Günter Wagner (at Yale) and the Evolving Cellular Automata group (at SFI) on questions concerning epistasis, canalization, and (the evolution of) mutational robustness.

GEANAKOPLOS AND CO-AUTHORS AWARDED FOR PATH-BREAKING STUDY ON SOCIAL SECURITY REFORM

SFI External Faculty member John Geanakoplos of Yale University—along with co-authors Olivia S. Mitchell and Stephen P. Zeldes—are the 1999 winners of TIAA-CREF's fourth annual Paul A. Samuelson Award for Outstanding Scholarly Writing on Lifelong Financial Security.

The three won the award for "Social Security Money's Worth," an article first published in *Prospects for Social Security Reform* (University of Pennsylvania Press, 1999). Some of the key findings reported in the piece are:

•Any reform must deal with accrued benefits promised to individuals for past contributions, and estimates of what these benefits are can differ by as much as $800 billion.

•Privatization has benefits, but proposals to privatize Social Security do not properly account for the immense costs of transition, the impact of transition costs, and the risks involved.

•The benefits of investing in the stock market have been exaggerated. Contrary to an earlier official study, the present-value gain of investing a dollar of Social Security funds in equities instead of bonds would be 59 cents, not $2.85, when properly adjusted for risk factors.

The Paul Samuelson Award is administered by the TIAA-CREF Institute, an educational and research arm of TIAA-CREF, which is the largest pension system in the world. The award was named after Nobel Laureate Paul Samuelson in honor of his achievements in economics, as well as for his service as a CREF trustee.

GERARD PRIZE RECOGNIZES STEVENS

SFI Science Board member Charles Stevens, from the Salk Institute, is the 1999 recipient of the prestigious Ralph W. Gerard Prize in Neuroscience. The Society for Neuroscience endows this prize to honor outstanding contributions to neuroscience. The prize—a plaque and an honorarium—is named after Ralph W. Gerard, who was instrumental in founding the Society and who served as Honorary President from 1970 until his death in 1974.

BROWDER AND KADANOFF ARE AMONG 1999 NATIONAL MEDAL OF SCIENCE WINNERS

Two members of the SFI research community—Felix Browder and Leo Kadanoff—are among the dozen recipients of the 1999 National Medal of Science. The new medalists are the last to be named in the 20th century. They received their medals at the White House in March 2000.

In 1959, Congress established the Medal of Science, which the National Science Foundation (NSF) administers. Counting 1999's recipients, there have been 374 medals bestowed on leading U.S. scientists and engineers. Rita Colwell, former director of the NSF, notes, "The contributions of these scientists are so profound, so connected to our everyday lives, and so lasting that these medals go only a short way to express the gratitude the nation owes them."

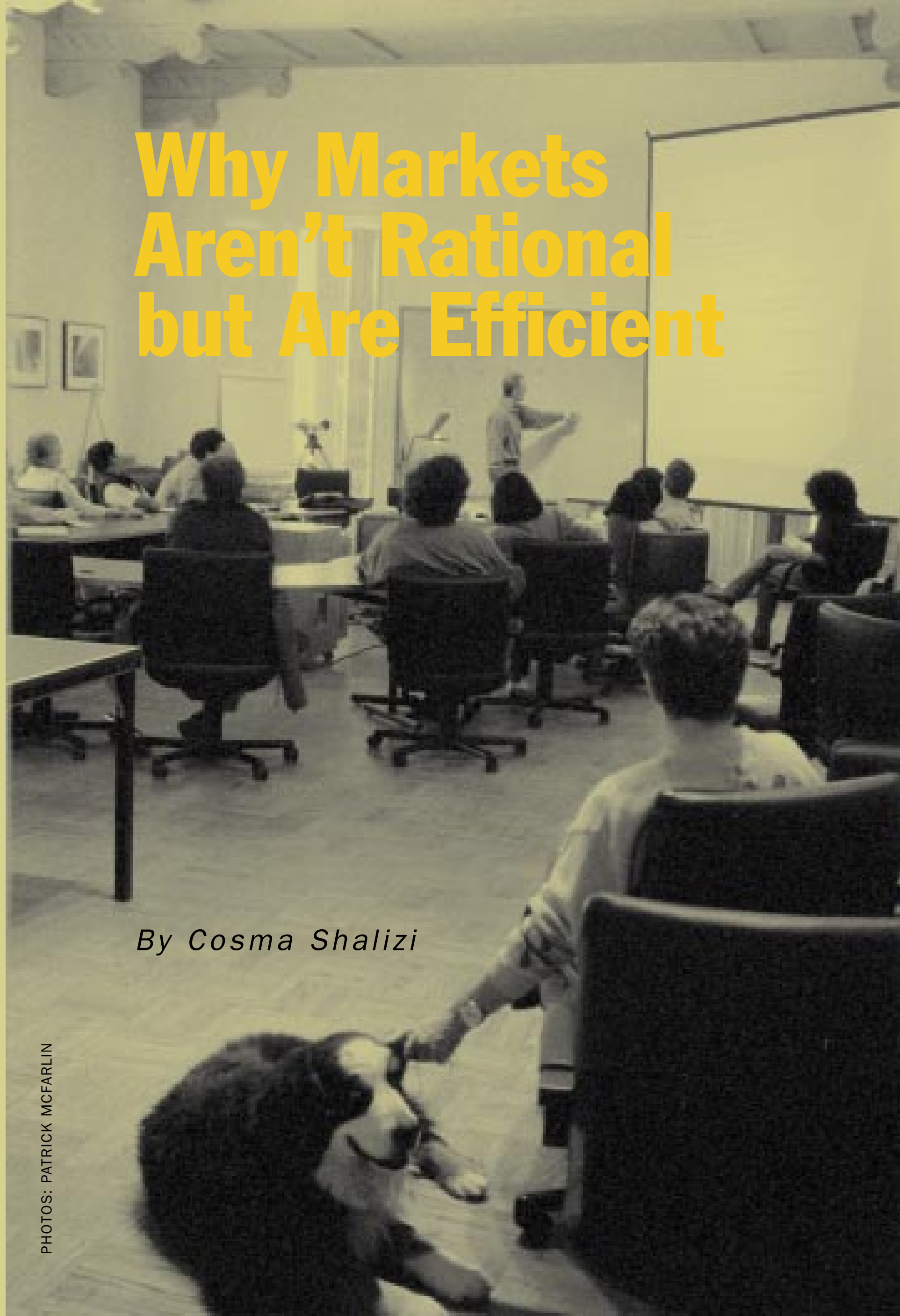
SFI Science Board member Felix E. Browder, a professor at Rutgers University, was recognized for pioneering mathematical work in the creation of nonlinear functional analysis that opened up new avenues in nonlinear problems, and for leadership in the scientific community that broadened the range of interactions among disciplines.

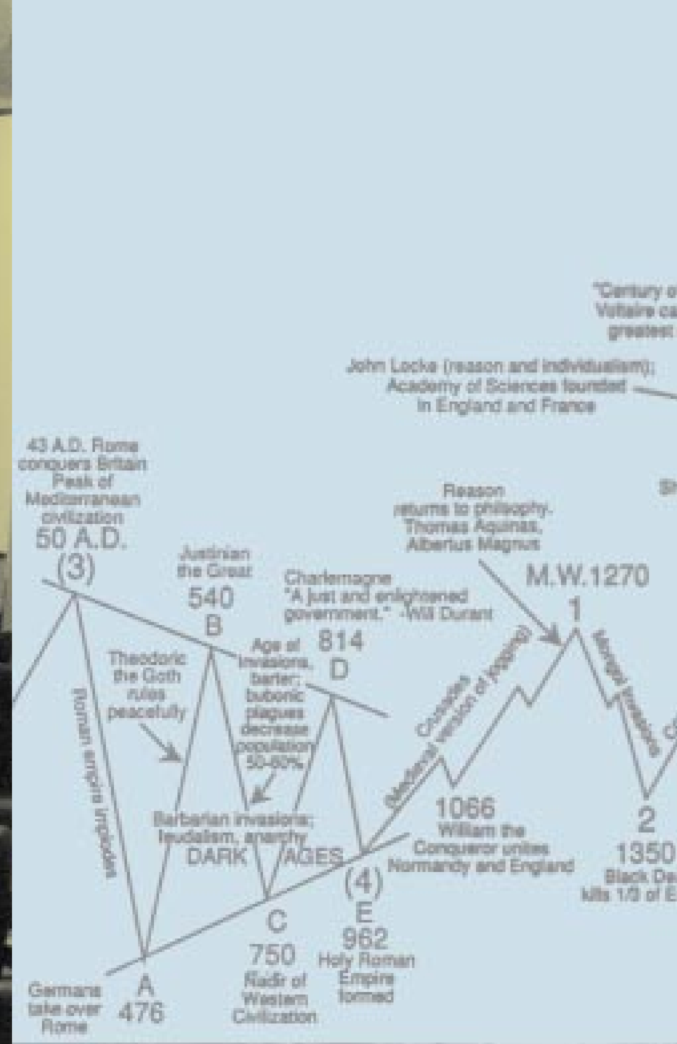
The University of Chicago's Leo Kadanoff, a member of the Advisory Board for the Institute's W.M. Keck Foundation Program in Evolutionary Dynamics, receives his award for his contributions to statistical, solid state, and nonlinear physics.

Charles Stevens

Why Markets Aren't Rational but Are Efficient

By Cosma Shalizi





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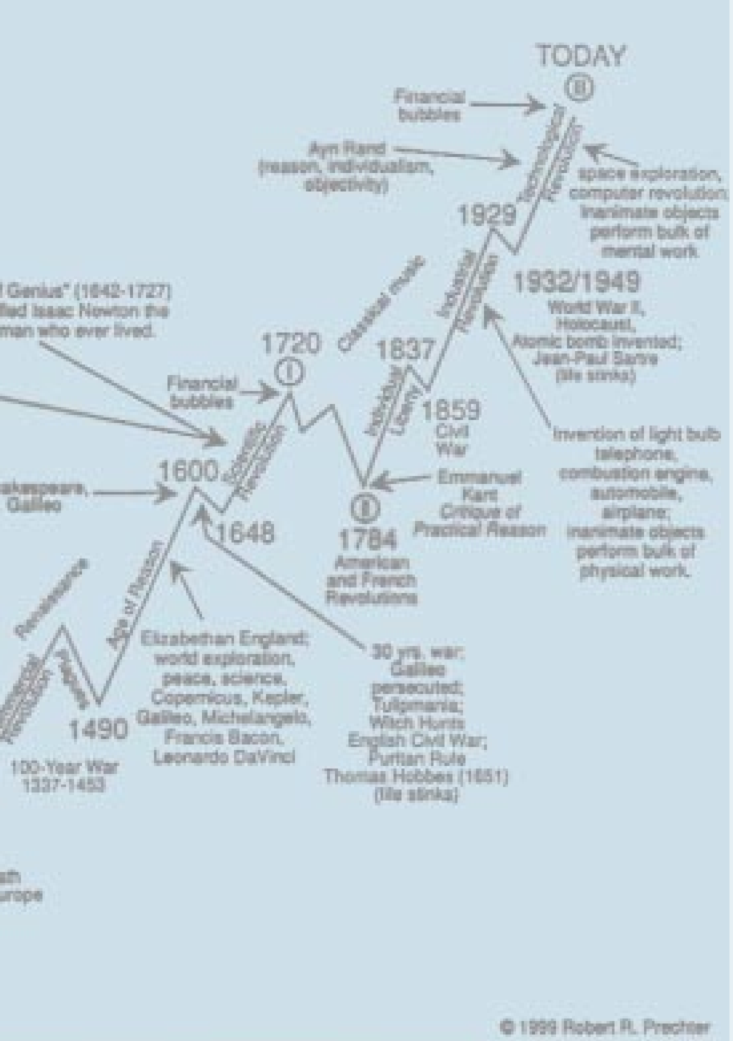


The great paradox of financial markets is this: trade is largely driven by experienced guesswork and simple rules, when not driven by confusion, error, and nonsense, supplemented by (as one financial journalist puts it) "testosterone and cocaine." One could hardly imagine a process less likely to deliver a reasonable evaluation of what something is worth, yet it's exceedingly hard to beat the market over any substantial length of time. How can this be?

This is the puzzle addressed by SFI resident faculty member J. Doyne Farmer in his recent research, summarized in his paper "Market Force, Ecology, and Evolution" and in an informal short course this March. The latter was part of a new NSF-funded program for which the Institute is a pilot, designed to expose physics graduate students to interdisciplinary research. During the presentation, John Geanakoplos, a professor of economics at Yale and a collaborator of Farmer's, played the role of devil's advocate.

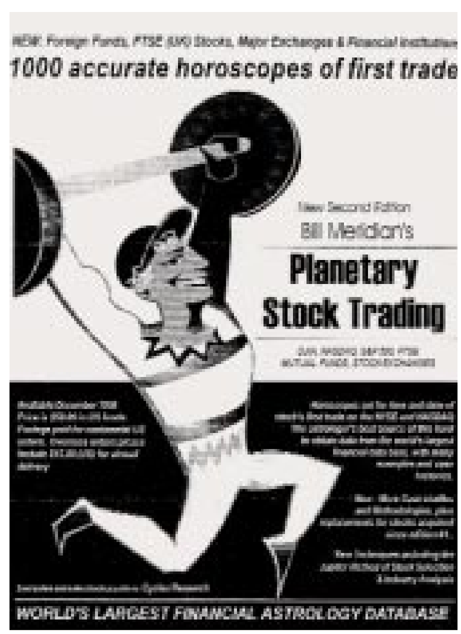
Farmer comes to this work from a background in nonlinear dynamics (he was a member of the "Dynamical Systems Collective" at UC Santa Cruz in the late 1970s), a long association with the Institute (he participated in the well-known conference on "The Economy as an Evolving Complex System" in 1987), and a number of years at the Prediction Company, which uses time-series analysis techniques on very large volumes of data to predict market movements. Farmer's current research has moved into yet new realms; he's working to understand how markets function, which probably won't help anyone make a killing, but might give us a better handle on these beasts which play such an important role in the world.

First some background to help understand the context for the talks: Neo-classical economics has very definite ideas about what traders and markets should look like. Economic agents have beliefs about the world and desires about how the world (or at least their part of it) should be. Their guesses about what will happen are the best that can be formed on the basis of what they believe, which some call "rational expectations," and their actions are the ones most likely to satisfy their desires, again given their beliefs. If all their desires are purely self-interested, and they are allowed to trade everything they have initially, and a few more technical conditions are met, then after one round of trading, markets will be at equilibrium, meaning that everyone will have made all the trades they want to, and nobody will want to make any more trades. Markets at equilibrium are said to allocate efficiently, since goods wind up with those for whom they have the highest utility, i.e., those who are willing and able to pay the most to have them. The good allocated in financial markets is, essentially, capital.

Equilibrium markets are not necessarily static; in fact, generally they change, and do so unpredictably. After all, agents are rational people; the price they are willing to pay for a good reflects all the available information that has any bearing on the good's value. Suppose new relevant information appears. Either this could have been predicted from the old data, in which case, because of rational expectations, it would have been, and prices adjusted accordingly, or it could not, in which case the movement of prices is unpredictable and random. This property—the unpredictability of prices—is also called "efficiency," and in equilibrium, with rational agents, prices are efficient if and only if allocation is efficient.

There are several reasons why ideas about markets in general tend to be tested by examining *financial* markets. First, lots of reliable, fine-grained data is available for these markets over long stretches of time. Second, agents interact only in tightly constrained, almost ritualized, ways. Similarly, financial markets themselves have only limited and constrained interactions with other parts of the economy (no suppliers, no customers, etc.), so quite crude representations of the real economy may suffice for financial modeling. Finally, determining the value of securities is in some ways actually easier than determining the value of, say, machine parts, haircuts, or software, since securities have no intrinsic utility. For instance, the price you should pay for a share of stock is how much you would get in exchange for your money, that is, the value of the dividends the stock will pay, discounted for risk and the fact that we generally prefer money now rather than later—the "net present value"—of the dividend stream. Other kinds of securities can be priced similarly.

How well do standard economic ideas hold up? At first sight, surprisingly, pretty well. After removing trends which reflect the long-term growth of the real economy, securities prices do indeed appear to be random—more exactly the logarithms of prices fit very closely to the stochastic process physicists call a "random walk." (In fact, much of the mathematics of random walks was first developed to model market movements, and only subsequently applied to physical problems.) So prices are very nearly efficient, which means that it's extremely hard to do better than the market average in the long run, and why nobody now remembers investment

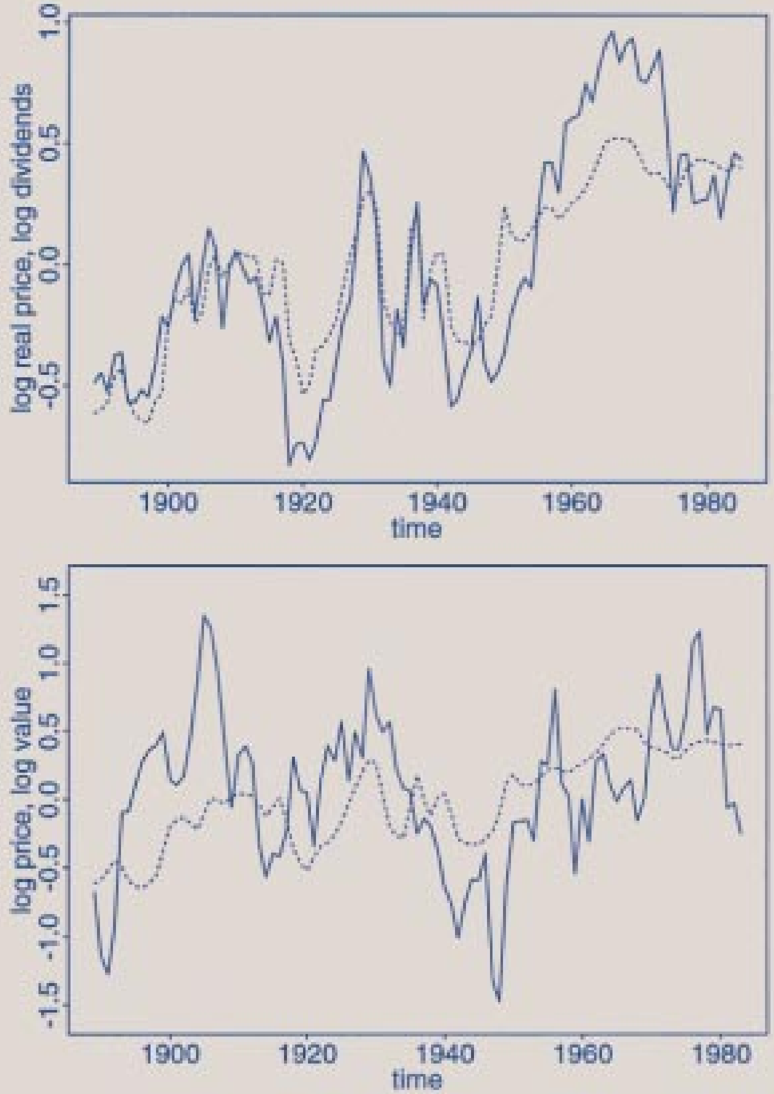


gurus from 10 years ago, and why nobody will remember today's gurus in 2010.

On the other hand, if financial markets really were in equilibrium, they would be immensely less active than they are. Agents would trade only when they received genuinely new data, or their desires changed—otherwise their existing positions would be sub-optimal. But the volume of trading, at least in modern markets, is orders of magnitude too large to be due to new information or new wants; the volume of daily currency trading, for instance, is (roughly) 50 times the daily output of the world economy (and most of that output doesn't involve international trade anyway). Similarly, large price movements often display no real connection to any sort of news which might rationally influence prices. (The inhabitants of Korea, Indonesia, etc., recently had an all-too-convincing demonstration of this phenomenon.) So evidently traders do not rationally evaluate all available evidence, with potentially very important effects.

This is consistent with empirical observations of the way traders actually make decisions, with which we began. Their procedures run from trying to value securities according to fundamental information, through attempting to find patterns in the movements of prices, what's called "technical trading," to using such tools as numerology and astrology.

So now we can be a bit more precise about the puzzle. Traders in the markets aren't rational, but prices in the markets are efficient. A good theory of markets should explain how this trick is turned. It should also explain why prices aren't completely efficient—why traders who crunch enough data can out-perform the market. And it should explain two very robust statistical features of securities prices: The first is the existence of "fat tails," which is a situation where there are more very large changes in prices than a simple random walk can account for; the other is "clustered volatility." In this instance the amounts by which the price of a security changes on different days are correlated, and the correlation decays only slowly, as a power-law (but we've seen that, according to rational expectations, there should be no correlations in



The top panel shows the logarithm of the inflation-adjusted price of the S&P index (solid line) over roughly a 100-year period. The dashed line is an estimate of the "value" of these stocks based on their dividends. The difference between value and price can be quite large: The market can be persistently undervalued or overvalued for decades. Similar behavior is observed using different measures of value. The bottom panel shows a simulation of prices based on the same set of values. The simulation assumes that the investors in the market consist of value investors (fundamentalists) and trend followers (momentum traders). The value investors hold stocks when they are undervalued, and short stocks when they are overvalued. The trend followers hold stocks when the price movement over the most recent 1-100 days is up, and short them when the price movement is down. While the two price series do not agree in detail (no effort has been made to match parameters or initial states), they are qualitatively similar in that prices oscillate around values, and there are long periods where the market is either overvalued or undervalued.

price changes at all). Farmer is attempting to come up with a simple theory that can accommodate all these facts—the near-efficiency of markets, the irrationality of traders, fat tails, and clustered volatility, among others.

Farmer's model works as follows: There are two assets, one of which is riskless but pays no dividends, which we can think of as cash; the other fluctuates in price, and can be thought of as a stock that pays no dividends. There are a number of agents engaged in trading. In a rational-expectations model, we would need to specify the utility function of each agent, and from that we could deduce what position it wants to hold—how many shares of stock it wants to own—in any given state of the world. Here instead we specify for each agent a behavioral rule, which computes a position as a function of certain data about the world. There is no particular reason for this rule to be optimal. Behavioral rules have to be stated in terms of positions and not orders, simply because no sane agent wants to take an unbounded position in any given security. (Neoclassical models would represent this as a risk-aversion term in the agent's utility function; Farmer has to put it in by hand, as it were.)

At each time-step, every agent computes what it wants its position to be, and then calculates the order it wants to place as the difference between what it wants and what it has. Orders are then submitted to a special agent, the market maker. In Farmer's models, the market marker has two roles: it matches supply and demand, and it determines the new price of securities. Many real markets, such as the Chicago Board of Trade, feature people who take on this job; we'll see why they might presently; for now, let's look a little closer at each role.

Markets are said to "clear" when supply equals demand, in this case, when the sum of the buy orders equals the sum of the sell orders. Equilibrium markets always clear; and a common assumption in modeling is that no trades happen until a market-clearing price is found. This is not how markets work nowadays (though it was how some financial markets worked in the late 19th century, when the foundations of modern economics were laid). One of the jobs of the market maker is to ensure clearing, by either buying up shares when there is an excess of supply, or by selling off shares when there is an excess of demand. (The latter can force the market maker to take a negative or "short" position.) The other function the market maker performs is to adjust the price at which the stock changes hands. This is, again, modeled as just a behavioral rule (rather than a reasoned consideration of what would benefit the market maker). That rule determines the "market-impact" or "price-impact" function, which says how the new price depends on the current price and the net demand for the stock. Even if the rule isn't optimal for the market maker, it's still plausible that the price should rise when demand exceeds supply, and fall under the opposite circumstances. A convenient, but not particularly realistic, price-impact function is that the logarithm of the ratio of the new price to the old price should be proportional to the size of the net demand. This is called the "log-linear pricing rule."

Once we have a price-impact function, and once we assign a strategy function to every trader, we've essentially specified the model, and can watch its dynamics unfold. Three kinds of strategies have been studied in depth so far. The first and simplest are "users": they buy the stock at one time and sell it at a fixed later time, regardless of price. (Think of people saving for future expenses.) Next are "value investors": they have some estimate of what the stock is really worth, and want to hold a positive position in it when it is under-priced, and a short position when it is overpriced. The simplest such strategy tells them to take a position proportional to the value minus the price; surprisingly, in a market consisting of value investors of this type, price does not track value. There are value strategies which do so, especially ones where only changes in the mis-pricing above some threshold lead to changes in position. These strategies also lead to fat tails, and to clustered volatility (though the correlations in price movements are not of the form seen in real markets). The third class of strategies are trend-based rules or "technical trading" strategies, which set their position based on the recent history of price changes.

A market containing a plausible mix of value and trend investors, fed realistic value data, produces mis-pricing reminiscent of what's seen in actual markets, and the main statistical features—the fat tails and the clustered volatility—are also in at least qualitative agreement with reality. This model is, however, much too crude to be used for forecasting, or for further efforts at parameter estimation; the point is not to predict what the Nasdaq will do next week, but to gain at least some insight into how markets work in general.

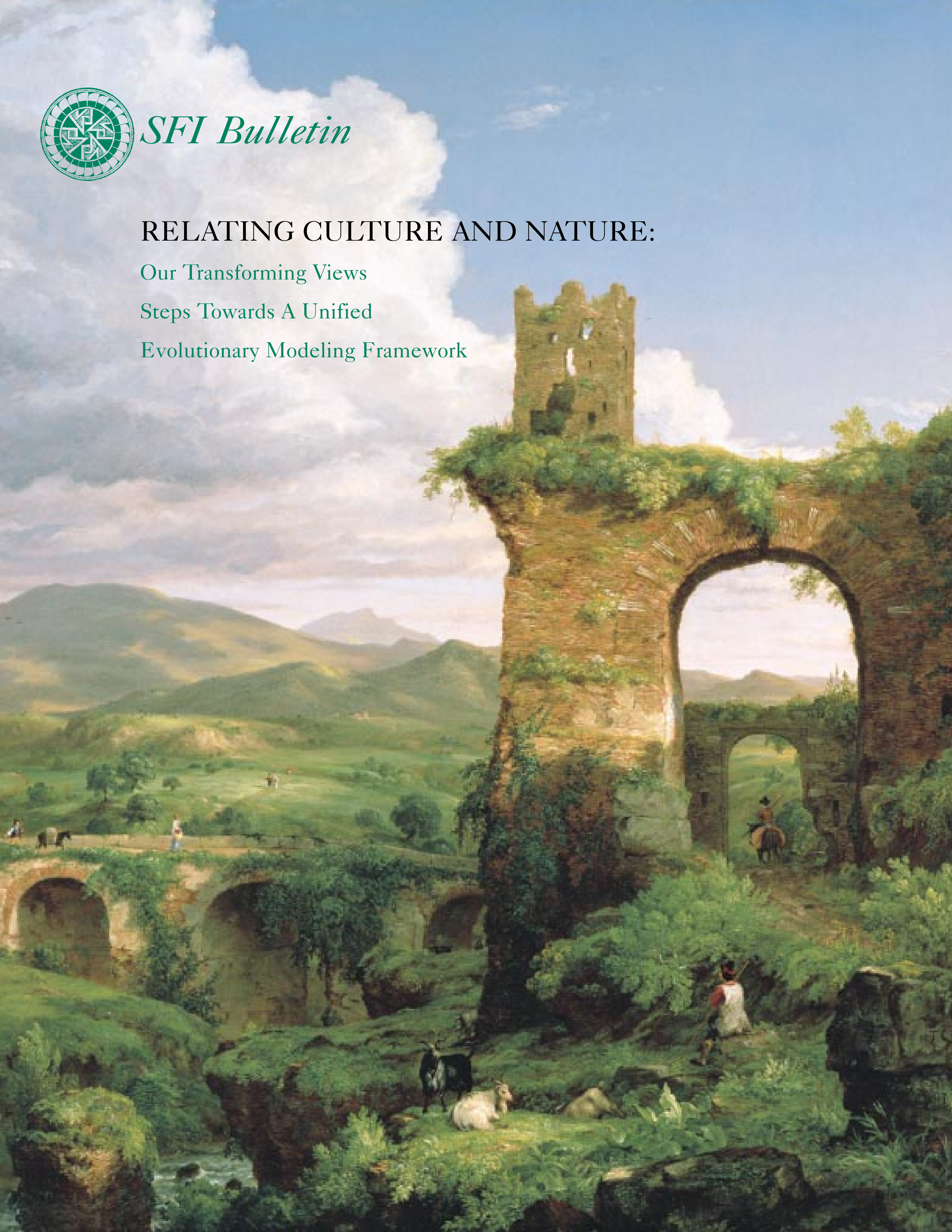
Now that we have several kinds of strategy in the model, it's natural to wonder how well they do relative to one another. It turns out that, given log-linear pricing, the (average) profits of each strategy can have a "pairwise decomposition," meaning they can be found from calculating how much money the strategy makes from all the other strategies in the market (including itself), and adding. That is, if there are three strategies,

SFI Bulletin

RELATING CULTURE AND NATURE:

Our Transforming Views

Steps Towards A Unified Evolutionary Modeling Framework



RELATING CULTURE AND NATURE:

Our Transforming Views
Steps Towards A Unified Evolutionary Modeling Framework

There was at one time in Europe a view of human culture as good and safe, but also fragile; this was juxtaposed against a view of nature as dangerous and potentially evil. Following the industrial revolution, however, many in the West came to see human society as a corrupting force and nature as pristine. This new perspective remained substantially intact throughout much of the 20th century even as Western worldviews slowly took in Darwin's notions, removing humans from our self-accorded pedestal of special creation. However, today another shift is occurring, one that sees the relationship between culture and nature as intertwined, each affecting the other.

How have our perceptions of our place in nature affected the way we inhabit the world—and conversely, how have the results of the industrial revolution, including dense populations of stable size, increased prosperity, and global consumerism, affected our perception of our place in nature? The Santa Fe Institute has agreed to a proposal by Sander van der Leeuw, professor of archaeology at the Université de Paris I (Panthéon-Sorbonne), Timothy A. Kohler, archaeologist in the Department of Anthropology, Washington State University, and Henry T. Wright, curator of archaeology at the Museum of Anthropology, University of Michigan, to host the first of two conferences in which they plan to explore the intersections between complex adaptive systems, world views, and the environment.

The conferences will bring a new perspective to the ways we view the natural and cultural worlds. More specifically, they will examine the consequences of considering natural and cultural worlds to be inseparable, and the past and the present to be continuous manifestations of a dynamic that can be studied from a unified perspective. Particular attention will be paid to how tools developed to study generalized complex adaptive systems (e.g., the Swarm simulation system developed at SFI under the leadership of Chris Langton) can support theories of how culture changes, how human perceptions are created, and how they affect behavior.

These workshops are in part a reaction to current practice in a number of areas. The relatively independent development of the social and natural sciences has led us to divorce these two realms, or at best to see them as separate subsystems in a socio-environmental system. The workshops will explore the idea that although the dynamics may be different, they nevertheless interact so directly that they are indivisible. "There is no 'social system,' neither is there a 'natural system,' there are only socio-natural interactions."[1]

The workshops will also address the usual firm separation between the past and the present. The natural sciences, for example, have projected back their understanding of the present using evolutionary theory, conceiving of a past operating in the same basic way as the present. At the same time, the social and historical sciences typically have tended to do the inverse, constructing their perspective of the present based on their understanding of the past. (Archaeologists seem obsessed with understanding the origins of practices, which only makes sense if origins provide a superior perspective from which to understand current practice!) A theme of the workshops is that the sciences of the past must abolish the implicit taboo of relating past and present. At the same time, the environmental sciences, by basing their conception of socio-natural dynamics mainly on data from the last few centuries (at best) do themselves injustice because they look at a very short section of the total trajectory. This excludes the consideration of a wide range of states of the socio-natural dynamics involved, and worse, biases their perspective toward dynamics that are heavily influenced by human impact. The workshops will, of necessity, bring together both social and natural scientists.

An underlying belief of the conference organizers is that a "complexity perspective" offers a way to study systems that have not been separated into natural versus cultural, or past versus present. In fact, these separations perhaps derived from an inability to think productively about, or model, the coupled systems in the absence of complexity approaches. What, concretely, do such approaches offer? Agent-based modeling, born of and contributing to complexity theory, makes it possible to investigate differences among the "actors" in the system. Some social theory suggests that societies change as a result of ongoing "negotiations" among factions whose differing interests emerge from their differing circumstances. Before the advent of modern transportation and communication, spatial context was a critical factor in conditioning densities and types of interactions among people, and between people and the landscapes they inhabited. Agent-based modeling makes it possible to study systems strongly resembling those in which people really lived, where the various actors co-evolve with the landscapes they inhabit. Moreover, these models also honor many of the other characteristics we hold to be true for the real world, such as the irreversibility of time, and the importance of what came before in providing a context for what happens next ("path dependence").

The meetings are also a reaction to increasing differences in the approach to theory and method for studying human-environment interaction on different sides of the Atlantic. In Europe it seems that more attention has been paid to problem conceptualization, emphasizing the primacy of human perception, while in North America steps have been taken towards solving the many technical difficulties met on the way towards implementing computer simulation tools such as those provided by the Swarm simulation system. These two communities of practice will confront each other in the workshops in hopes of achieving a productive synthesis.

Kohler, van der Leeuw, and Wright have several specific themes and questions in mind.

RELATING NATURE AND CULTURE ON THE LANDSCAPE

Between 1980 and today, the debate on environmental matters has changed, first in the scientific arena, but increasingly also on the political front, and in the eyes of the general public. The role of human beings in socio-environmental relations has gone from re-active, through pro-active, to inter-active. For example, for a long time many considered desertification as a natural phenomenon. Then the focus of attention shifted to the (presumably negative) human impact on the landscape (land degradation). More recently, though, such phenomena are viewed as complex phenomena in which many processes, both natural and social, participate. Some other dimensions of this relatively recent shift in perspective are summarized below, in tabular form, just to point to some of its manifestations.

In the emergence of this new perspective, the socio-natural evolution of the landscape plays a special role. It is in landscapes that there is a direct confrontation between the social and the natural sciences—the former contributing ideas concerning the evolution and dynamics of societies through time, and the latter proposing explanations for the natural dynamics governing the biosphere in which such societies are embedded. The collaborators hope to define the main dimensions of this confrontation in an attempt to improve the understanding of the relationship between scientific approaches and perspectives on landscapes.

Table 1: Dimensions of the shift towards an interactive approach of the nature/culture opposition.

PRE 1980s	1980s	PRESENT
Culture is natural	Nature is cultural	Nature and culture have a reciprocal relationship
Humans are re-active to the environment	Humans are pro-active in the environment	Humans are inter-active with the environment
Environment is dangerous to humans	Humans are dangerous for the environment	Neither is dangerous if handled carefully; both if that is not the case
Environmental crises hit humans	Environmental crises are caused by humans	Environmental crises are caused by socio-natural interaction
Adaptation	Sustainability	Resilience
Apply technofixes	No new technology	Minimalist, balanced use of technology
'Milieu' perspective dominates	'Environment' perspective dominates	Attempts to balance perspectives

RELATING PAST AND PRESENT

Different disciplines, of course, approach the question of time in very different ways. Such disciplines as ethnography and geography, for example, typically consider recent time (short time scales) only, while historians have not gone back much beyond 3000 years BC in the best of cases. Most of the natural sciences have either dealt only with the present and the recent past, or have used a uniform perspective to comprehend the distant past (viewing processes as though they've always functioned the way they do today), as in the case of paleontology and evolutionary theory. In evolutionary theory, for example, "mutation" and "natural selection" are seen this way. Other differences are summarized in Table 2. Here, again, the challenge is to find a perspective that will encourage the integration of both perspectives.

Table 2: Differences Between the "Culture-Historical" and the "Natural History" Approaches

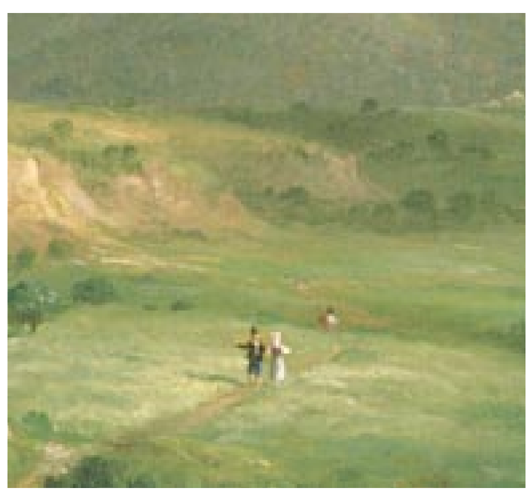
CULTURE-HISTORICAL APPROACH	NATURAL HISTORY APPROACH
Interest in past	Interest in present
Understanding of the present based on the past	Understanding of the past based on the present
Time and process irreversible	Time and process reversible, cyclical or reproducible
Accentuates differences	Accentuates similarities
Case studies	Generalizations
No coherence between events	Coherence between events
Focus on inter-scale interaction	Focus on intra-scale interaction

Both archaeology and geology are exceptional. Both view the present from the perspective of the past, and the past from that of the present. They also deal with short-term events as well as long-term processes, and other time scales in between. Moreover, both are concerned with a multitude of spatial scales. Their potential contribution lies in the way they may help develop a tool kit to analyze and understand the long-term evolution of societies. Van der Leeuw, for example, has experimented over the last decade with the design and application of such a tool kit as coordinator of a multi-disciplinary team focused on problems of desertification, land degradation, and land abandonment in southern Europe. Kohler has designed and used more detailed but smaller scale models, focusing on agriculture in an arid environment, showing how the behaviors of different individuals influence each other and, together, are responsible for the conditions and the dynamics which one observes at the collective level. The meetings and resulting publication will carry this approach to other cases and types of problems.

WHAT DOES A "COMPLEXITY PERSPECTIVE" PROVIDE?

Complexity science may have the potential to bring the concerned disciplines together in a useful way[2]. The approach is capable of conceptualizing problems in both natural and social dynamics in languages independent of specific disciplines. For instance, descriptive languages used for studying genetic networks may be equally appropriate to networks of economic exchange in small-scale societies[3]. It is also capable of conceptualizing the interaction between phenomena at different spatio-temporal scales by viewing large, stable phenomena as the result of unstable interactions between smaller entities. It can reformulate natural dynamics from an irreversible temporal perspective by introducing the notion that similar causes can have different results, and different causes, similar results.

More generally, the complexity perspective invites a rethinking of the issues of cause and effect in the social sciences. Causal language has been central in those sciences, and a common research tactic has been to evaluate causal hypotheses using statistical analysis on system behavior. However, in the nonlinear dynamics that are apparently so pervasive in nature, the effect of a change in a state variable depends to a very great extent on the state of the entire system at that moment, for example, in a landscape (such as landslides) or in a society (such as revolutions). Finally, a complex systems approach captures both continuity and change, tradition and innovation, by relating the one to the other. An example is its emphasis on the study of the historical trajectories of systems, arguing that sudden transformations are due to an interplay between process (continuity) and events (innovation).



With these integrative themes in mind, the meeting organizers hope to address a number of specific topics:

- How do we relate spatial and temporal scales over the long term? In the distant past, the individual impact of people and societies was spatially limited, and change was very slow; in the present, change is very rapid, and spatial impact is vast. How do we establish scale(s) of measurement against which we can project not only change, but also the change of change?

- How do environmental and social dynamics interact, if we accept that participating species and individuals have a self-referential dynamic of change, whether genetic or through learning? What is the resonance between species and individuals, or between them and their contexts?

- What is the role of the landscape as the experimental dynamic context within which individuals and species interact?

- What is the role of techniques (technology) in mediating between nature and culture? Could one approach socio-natural co-evolution through the study of techniques?

- What is the role of human perception and cognition in identifying resources in that landscape? How do other species identify new resources?

- Is there directionality in change ("tendency" in the terms of Leroi-Gourhan[4]) in human societies (anticipation) and in non-human species? If so, could it be modeled/imagined as a potential in time (part of a "temporal flow structure" analogous to a spatial one) at either the individual or species level?

- Is it productive to view social organization as an adaptive technique or as a collective "flow structure" around information processing? If so, what is the interaction between such dynamic knowledge structures and individual instances of change (innovation)?

- How do the different flow structures in a society interact? Suppose each is related to the exploitation (in whatever sense) of one or more resources (natural or social), how do these exploitation flow-structures interact at different points in space/time? What is the role of resource-use competition in structuring the communities of species on landscapes?

- How do we model the intimate interaction between tradition and innovation, between stability and change in ways which are both useful and applicable to the natural and the social realm and to its interactions? What are "crises"? How do they come about? Do they favor or hamper innovation?

The conference organizers hope that by raising questions that have relevance both for the present and the past, for natural dynamics and social processes, they will be able to foster the growth of concepts generally useful in the social and natural sciences.

A second, later meeting will focus on actual case studies of socio-natural co-evolution from different parts of the world and different periods and will expand on the approaches developed in the first conference. These case studies will address socio-natural co-evolution under varying conditions.

The hope is that these case studies will lead directly to further proposals for new theoretically grounded models of key transformations in socio-natural systems. Indeed, Kohler, van der Leeuw, and Wright think that both of these conferences, and the follow-up work, have immediate relevance to important modern-day issues. Growth of population, and the mosaic of different cultures, will inevitably cause an increase in the frequency and scope of differences of opinion about land use. Knowledge about the underlying differences in attitude towards similar landscapes may help policy makers anticipate and in some cases defuse such conflicts.

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A, B, and C, A's profits are a sum of how it would do playing against itself alone, how it would do playing against B alone, and how it would do playing against C alone. For other pricing rules, pairwise decomposition is in general not possible, though it may still be a good approximation. (That is, the effects of interactions of three or more strategies may be small.) Within each pair, A will profit from B if it disagrees with B, or anticipates what B will do, or, preferably, both. (More exactly, the profits are proportional to the correlation between A's position now and B's position at the next time-step, minus the correlation between A's position now and B's position now.) It is not enough to be contrarian; you must also be right. This means that a strategy will not make money playing against itself; rather the market maker will. (In these models, the market maker almost always turns a profit in the long run.) Notice that all this has to do with the profits or losses of a strategy; an agent following that strategy will take a share of that profit proportional to the size of its position, its capital.

Given the pairwise decomposition, we can write down equations for how the capital of different strategies will change over time. Remarkably, these equations have exactly the same form as the Lotka-Volterra equations of ecology, which describe how the populations of interacting species will change. The flow of money from one strategy to another corresponds to that of energy and resources in ecology, and one can arrange strategies in a trophic web, showing which ones "feed" on which others as one can do with species. "User" strategies, not surprisingly, tend to be at the bottom of the food chain.

One of the features of the Lotka-Volterra dynamics is what biologists call density-dependence, and economists call non-constant returns to scale. For any strategy, there comes a point where the extra profit made from scaling up one's position is more than offset by the reduction in profit due to one's own order's effect on prices, what's called "market friction." That is, profit increases with capital up to a certain point (analogous to the carrying capacity in ecology), after which it declines towards zero (i.e., returns to scale are diminishing). Blindly reinvesting your profits actually diminishes them in the long run; ideally, agents would limit the size of their position to that which gave maximum profit and would try to hold themselves just at carrying capacity. As Farmer notes, "In my experience as a practitioner, understanding market impact well enough to accurately limit capital is a difficult statistical estimation problem that even the best traders have a tough time solving." And it's extremely implausible that real traders do maximize their profits, much as they might like to. If several agents follow the same strategy, total profits would be maximized by holding the total capital invested at the carrying capacity, but this is not to be expected either in Farmer's models or in a rational-expectations equilibrium.

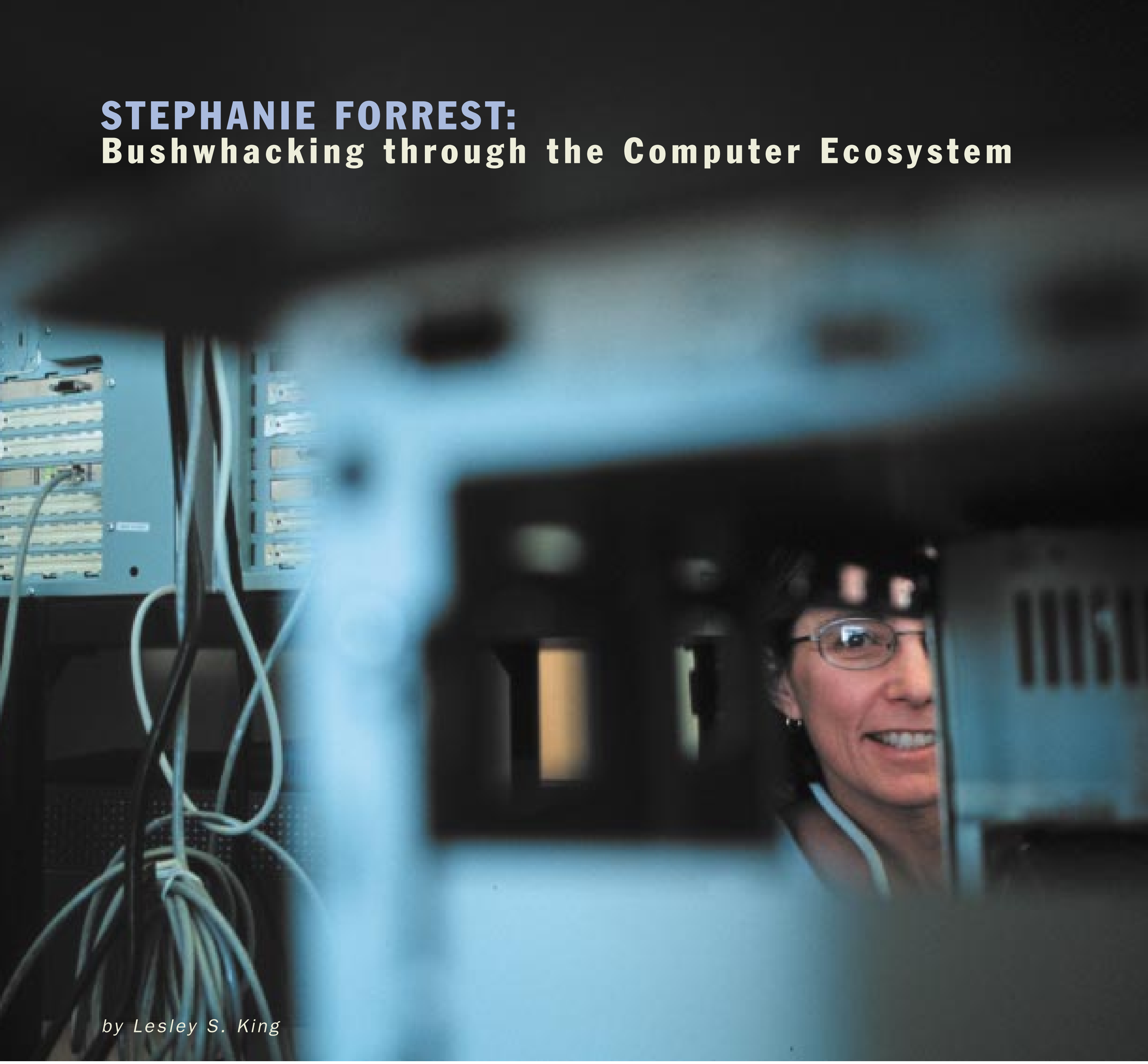
In a rational-expectations model, any pattern in prices will be noticed by the agents, and if they can make money by exploiting it, they will, tending to eliminate the pattern in the process; this is part of what leads to efficient pricing. In Farmer's models, it's perfectly possible for a pattern to persist indefinitely, just because none of the agents has a strategy which can detect that pattern. If there are strategies that are sensitive to it, then whether or not it will be exploited away depends on how many agents have the right strategies, and how much capital they devote to trading. A single profit-maximizing agent will generally cut the size of the pattern in half, but not eliminate it; only if the number of agents is large will the pattern disappear.

The idea that market economies resemble ecosystems has been around for a long time, but Farmer's work is one of the first to make the analogy detailed and concrete. One current direction of his research is to add evolution on top of this ecology, to allow the strategies followed by agents in the market to change over time, connecting this work to the extensive traditions of research on evolutionary game theory and evolutionary economics. Farmer is also intent on modeling more realistic strategies, looking at the effects of including more detailed "real" economy as a determinant of value and cash flow (currently the real value is simply another random walk). And he'd like to consider questions of efficiency; Farmer estimates that the real time-scale for efficiency in allocation (as opposed to pricing) is on the order of several years.

Since we've given financial markets a great deal of power over our lives, it would be comforting to think them incapable of erring, or at least of making large errors which persist for a long time. But once we give up the belief in rational expectations and equilibrium, we loose any reason to think that markets are "optimal," that they do their jobs perfectly, or even close to perfectly. What the research of Farmer and others shows is that the actual facts about markets can be explained by the far-from-equilibrium behavior agents "of very little brain." Work like this promises an improved understanding of the real causes both of market success and of market failure. Whether the new knowledge will offer ways to eliminate causes of failure is unclear, but this research should give us a better idea of how these vitally important creations work.

Shalizi is a SFI Graduate Fellow

STEPHANIE FORREST:
Bushwhacking through the Computer Ecosystem



by Lesley S. King

PHOTO: JULIE GRABER

In her Santa Fe Institute office, Stephanie Forrest moves adeptly from conversation to computer. One moment we're discussing how her work has evolved over the years and the next moment she's pulling up a quote illustrating a point on her screen. Forrest appears to be completely intertwined with computers, and yet this scientist who is receiving broad attention for her work with them is not at all convinced that they function well. In fact, she and a handful of other scientists are bent on reconceiving the whole notion of computing.

It's no small task. Fortunately this University of New Mexico professor, long-time member of the SFI community, and interim SFI vice president, is imbued with the strength and determination of an athlete. The former world-class ski racer is indeed succeeding, and her ideas are receiving national attention, with recent articles appearing in *Science News, Business Week*, and the *Economist*. Meanwhile, she balances her research and teaching commitments at UNM and her responsibilities guiding science at SFI with raising, along with her husaband, her 8-year-old daughter, Madeleine. Behind the balancing act is an intellect that invests much of its energy in not only reinventing the computer world, but also integrating that world with other fields, making discoveries that may well save time and money, and even human lives.

INSPIRED BY BIOLOGY

Forrest and her colleague at University of New Mexico, David Ackley, have a revolutionary view of the world of computers. They see it as a living system. "This ecosystem of computers, with people, software, data, and programs has many of the properties of a living system," says Forrest. She and Ackley spend a great deal of time exploring those similarities and figuring out how to draw from that analogy in order to produce stronger systems.

Her innovative views of computer science were encouraged early on during days at University of Michigan working with her thesis advisor, John Holland, who helped her look at computer science from an interdisciplinary standpoint. An SFI External Faculty member, Holland has been integral to the evolution of modeling. He is the inventor of genetic algorithms and the original developer of the simulation tool ECHO. It was through working with Holland that Forrest began combining ideas from evolution with ideas from computer science.

Later, she returned to New Mexico (where she had received a B.A. at St. John's College) and began carpooling from Santa Fe to Los Alamos with Alan Perelson, who is now leader of the Theoretical Biology and Biophysics Group at Los Angeles National Laboratory and director of SFI's Theoretical Immunology Program. As they traveled back and forth on US 285, they got to talking about immunology. "He convinced me that the immune system was interesting," says Forrest.

At the time Perelson was working with developing models of the immune system. In particular, he was exploring how immune systems recognize foreign agents, trying to understand the algorithms that the immune system uses. "Stephanie picked up on this," says Perelson. "She was curious, very interested in learning the biology of this system and integrating that within the context of her own field; she took seriously the idea of using biology as an inspiration and improving the field of computer science in that way."

From their conversations, Forrest took the notion of pattern recognition. She thought she could build the equivalent in the computer, translating those biological algorithms into computer algorithms. Her success in doing so is gaining widespread recognition from the computer science community.

But what's equally impressive is the way this initial carpooling collaboration has led to biological insight. Forrest and Perelson began asking, can we use those algorithms to build interesting models of immunological phenomena? That question led to their most recent collaboration, along with Derek Smith at UNM and SFI. They're working with immune response with influenza and the role of vaccination. The findings could help design strategies of yearly vaccination in order to improve vaccine design. "The findings evolved from abstract notions," says Perelson. "And now they're affecting serious immunological problems."

LIVING SYSTEMS

The innovative viewpoint Forrest gained through these kinds of collaborations ranges far beyond traditional computer science, particularly her theories about design. "If we look at these machines from the perspective of biology, we're likely to be more successful than with traditional engineering methods," she says. The views also have implications for software engineering, a term that she believes is misnamed. "The idea that you can engineer software—well you're barking up the wrong tree," she says. The reason?

"The problem with the phrase "engineering software" is that it implies that we know what we are trying to build ahead of time, when often, the software specification changes throughout development," she says. "It also implies that we know how to design systems that can be built correctly, and it implies certain ways of thinking about design and implementation that are more appropriate for static structures, like bridges and buildings, than for dynamic entities, like software."

So, instead, Forrest chooses to view computer systems and their software as living systems. "There are a lot of ways computer programs act like living things," says David Ackley. "They reproduce themselves, make copies, move around, evolve, consume energy when they run. They even have reproduction with variation and selection; every time your hard drive fills up and you delete information, that's natural selection. Now these programs are moving all over the place–you receive greeting cards from friends that are actually little programs—that's this little beast that's trying to make a go of it in this world using 'cute' to survive. If you forward it to two other friends, it's doing well. And the system is getting pretty big; simple tools we used to use are really breaking down, because of viruses, macro viruses—you name it."

FIGHTING INTRUSIONS

They've found the perfect proving ground to test their theories: the area of computer security. Clearly, with what's happening on the world computer scene, computer security methods have proven largely unsuccessful. Some people remember 1999 for the attack of Melissa, a virus which caused, some believe, as much as $400 million in damages in America alone. Almost daily, newspapers report new infringements on security. It's clear that current "engineering" methods just aren't working.

However, Forrest's biological methods are. Her computer security work has involved creating within the computers, or "organisms," powerful and versatile "immune systems" that can fight intrusions. Her software, developed in conjunction with several of her UNM students, uses what they call "computer antibodies," whose job is to identify what is and is not foreign.

The process is based on the performance of lymphocytes in the immune system. These principal cells in the immune system go through a negative selection process which works as follows: Created randomly, the lymphocytes first must undergo checks to be sure they don't react with naturally occurring molecules within the body. Those that do react are destroyed, but those that don't are released into the blood to search for intruders.

In one system, developed by UNM Postdoctoral Fellow Steven Hofmeyr, a pool of randomly selected strings (like lymphocytes) is automatically compared to binary strings (like the body's molecules) sent across a network. Those that prove compatible become detectors, which will identify invader strings much the way lymphocytes do in the immune system. When such a string is identified, an alarm is sounded so that a human can intervene. A detector that does its job well is made immortal; it can, in the future, detect similar disturbances. This process is comparable to the way the body builds the immune system through "memory B-cells."

Forrest's design has proven effective. In tests it was able to detect all the common security breaches it tested against, while sounding fewer false alarms than competing systems. Her success is also illustrated through organizations interested in the work. In her battle against viruses, she's received both government and corporate funding.

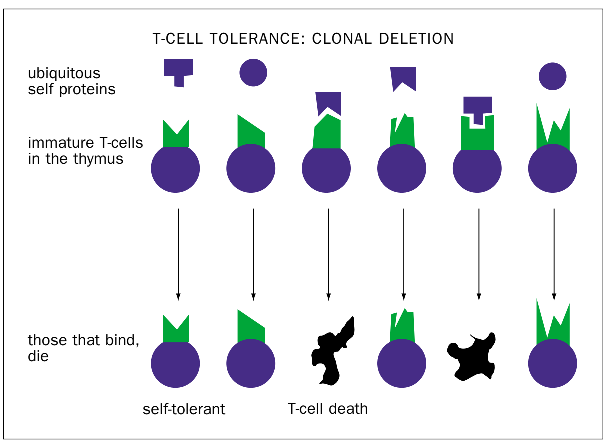
EVOLVING ECOSYSTEMS

But her vision is much larger. She hopes to expand the whole charter of computer science to include many alternative forms of information processing. In a 1998 statement she writes: "This work has the goal of both building better electronic computers, by importing strategies used in other devices, and of furthering our scientific understanding of natural processes, by using information-processing principles to explain their behavior."

Certainly through her work on immunology with Perelson and Smith she is achieving this goal. And it's coming to fruition in other areas as well, in particular, the area of cancer research. Forrest and Brian Reid of the Fred Hutchinson Cancer Research Center, as well as UNM Postdoctoral Fellow Carlo Maley, are looking at cancer as an evolving ecosystem.

Their view is that patients with cancer can be seen as microcosms of evolution for a few reasons. First, mutant cells in each individual compete for limited resources, both within a tumor and with the rest of the body, and second, different cell lines and different cell types interact with one another in nontrivial ways. "Cancer gives us an almost unprecedented opportunity for observation and control over simple evolving ecosystems with many replicates (each patient being a replicant)," says Maley.

This research falls right in line with Forrest's quest to better understand the workings of systems. One renegade statement she has been known to say to her students at UNM is "correctness is highly overrated." This follows from her notion that current software has lots of flaws and is badly broken. "That's the natural state," she adds. "We can't afford and it's not feasible to develop correct programs. So you evolve it—help each component of a software system to be more robust."



T-CELL TOLERANCE: CLONAL DELETION
Tolerance is implemented by a class of lymphocytes, called helper T-cells, because they mature in the thymus, and "help" B-cells. The thymus is an organ located just behind the breast bone. Most self proteins are circulated through the thymus, so any T-cells maturing in the thymus are exposed to most self proteins. If a maturing T-cell binds to any of these proteins, it will be censored, or removed, in a process that is called clonal deletion. T-cells that survive the maturing process and leave the thymus will be tolerant of most self proteins. This is essentially centralized tolerance, because the immature T-cells are tolerized in a single location.

UNM Ph.D. student Anil Somayaji is working with Forrest to do just that. Their project sets out to make computer operating systems more homeostatic—more self-maintaining and self-regulating. In biology, evolution has discovered many ways of keeping systems going under adverse circumstances. There's a homeostatic mechanism within cells and at the global level, which regulates them.

When applied to computer science, this involves monitoring every executing process on a computer, at the system-call level, and when anomalous sequences of system calls are observed, the computer begins delaying execution of subsequent system calls for that process. "If you take this view seriously, it has implications at all levels of computer design," Forrest says. If you look at computer security, for instance, this notion could mean computers being able to protect themselves from bugs, faults, and malicious attacks.

Together, Forrest and Ackley have come up with a set of principles—inspired from looking at biological systems—upon which systems should be built. These include robustness, diversity, autonomy, disposability, and adaptation. But while Ackley believes success will be found in building correctly from the bottom up, creating a whole new system, Forrest chooses to work within the present computer ecosystem and sees the process like evolutionary innovation. "We have to live with Unix or Microsoft systems and assumptions we have about their correctness," she says.

DESIGNING DIVERSITY

One problem she's addressing within this present system is that it's a monoculture. "Collectively the system is so vulnerable because most people are using the same mailing program, for instance," she says. In contrast, if people were using programs that behaved a little differently from each other we would have more diversity and more robustness.

If you look at humans you might get a sense of how this works. If we were all alike, a virus, for instance, could conceivably wipe out the entire population. But since our immune systems each have unique strengths and weaknesses, individuals get sick, even groups do, but the population as a whole survives.

The key lies in the notion of diversity. But how much diversity do these new computers need in order to not only survive but to thrive? It's a big question, one many of us grapple with daily as we watch the growing human population encroach upon most other populations. To explore the question, Forrest is collaborating with James H. Brown, Regents' Professor of Biology at UNM and SFI External Faculty member. Brown has collected 22 years worth of data on biodiversity in southeastern Arizona.

"You do want to have considerable diversity," he says. But when looking at an ecosystem the situation isn't simply a matter of preserving what's there; it's more complex than that. "At any given time an ecosystem or ecological community has a certain set of species present, so there is some standing level of diversity," says Brown. "When environmental conditions change, these species which have different requirements for resources and environmental conditions and do different 'jobs,' can adjust by changing their individual interactions with the environment."

They might shift diet to use new or more abundant resources, for example. Or they might shift their abundances—some species might increase while others decrease in number. But there can also be another level of response if the ecosystem is "open" and there are other species in the surrounding area that can potentially colonize, or immigrate, to exploit the altered conditions. This is why when the environment changes, species composition also changes, but the local diversity (number of species) often remains relatively constant.

"There is this phenomenon—even though at any given time, a relatively small number of species may be doing the job, once you put in change you get maximum performance if you have access to quite a bit of diversity," he says.

"The problem we have in ecology is the diversity to which we have access is limited, as it would be in a computer, because you have to deliberately design it. A lot of questions have to do with variation in the environmental and performance conditions; the more variable those are the more you may want to access diversity. Some understanding of the scaling of that variation is probably really crucial."

Such considerations led Forrest and Ackley to write a paper entitled "Diverse Computer Systems." In it they look at computer programs' many arbitrary features, what Forrest calls "implementation dependencies." These are aspects of a computer program that are arbitrary, but fixed. Examples include: names and locations of variables, arbitrary program constants, and the order in which variables are passed into functions. "We have to decide how memory will be laid out, how information is loaded into memory, and what is stored where," she says. "Those decisions are arbitrary. Each computer could have a different way of doing it."

They're suggesting that computers would be more robust if each one had its own way of talking and its own means of translating what other computers are saying. "If you take these consequences seriously, you really change the way we think about developing, debugging, distributing, and maintaining software," says Forrest.

Computers today are exposed to more and more foreign code—e-mail attachments, applets, and computer viruses, to name only a few. "There will be more of that, not less," says Forrest. "So sorting out not just what's foreign and not foreign, but being able to incorporate—to take advantage of—good parts and ignore useless parts, that's the key."

Lesley S. King is a freelancer who also writes for Audubon *and* The New York Times.

the FLU

NEW STRATEGIES AGAINST AN ANCIENT ENEMY

SFI hosts a workshop to explore solutions to one of humankind's most persistent and pervasive problems.

by Marsha McEuen

In 1918, a number of American and European newspapers printed in bold black ink a drawing of a killer: a seductively smiling skeleton swathed in black lace and named "The Spanish Lady." But this frightening agent was not actually a criminal from Spain; it was a common virus—a flu virus—sweeping the globe, so deadly its victims often succombed within a week of their first symptoms. When the pandemic finally ended, 20 million had died—more than were lost on the battlefields of World War I.

Many adults remember another more recent pandemic—the 1968 Hong Kong flu, which was less of a killer but seriously disrupted the world economy. Such scenarios remind us that influenza is a powerful adversary. And it is old; it has been making people sick at least since ancient Greek and Roman days and perhaps since people first began living in large groups. At unpredictable times, a strain within the type A class of flu viruses suddenly mutates so drastically that we have no immunity. This can ignite a pandemic, a situation more serious than an epidemic because pandemics generally cover larger geographic areas and affect an exceptionally high proportion of a population.

"Most influenza experts believe it's not a matter of if we'll have another pandemic, but when," says Nancy Cox, chief of the Influenza Branch of the Centers for Disease Control and Prevention. "We have a large global population that is extremely mobile, so if a new strain of influenza with pandemic potential and the ability to spread from person to person does emerge, we will be in a race against time."

Of course, a new pandemic as lethal as the one in 1918 is unlikely because we have medications to fight the secondary infections such as pneumonia, which actually cause most flu-related deaths. People in the U.S., except for the most susceptible, would probably survive. But people in less-developed countries might not be so fortunate. Even in the U.S., though, influenza is a major health threat; a normal flu year in this country can cause 10 to 40 thousand deaths and cost billions of dollars.

PHOTO: BETTMANN/CORVIS

Photo shows a scene in the Influenza Camp at Lawrence, MA, where patients were given fresh-air treatment. This extreme measure was hit upon as the best way of curbing the epidemic. Patients were required to live in these camps until cured. 10/18/1918

Fortunately, scientists are developing new weapons in the war to first understand, and then conquer this tenacious virus. The Santa Fe Institute played a part in this process, this January, by hosting a workshop sponsored by the W.M. Keck Foundation and the Joseph P. and Jeanne M. Sullivan Foundation. The workshop brought together experimentalists, who work with empirical data, and theoreticians, who develop computer models to help solve complex problems. The result was a new synergy of people who don't often cross paths and a new start to solving this challenging problem.

First, some facts about the flu: There are three main evolutionary groups of flu, types A, B, and C. Of these, the C strains do not cause major public health problems. The A and B viruses are always circulating and are responsible for annual epidemics. Within these categories, new versions of the virus are constantly appearing while others become extinct. The flu has confounded generations of scientists because of its ability to change, mutating constantly to defeat our immunities and thus survive.

The virus can be thought of as looking like a tennis ball with spikes sticking out of it. Inside the ball are eight segmented RNA strands. The spikes are two proteins, hemagglutinin and neuraminidase. Their job is to attach to cells in their host's respiratory tract, then replicate.

Scientists look most seriously at the hemagglutinin because it mutates at a very high rate, giving the virus its ability to circumvent the host's immune defenses. Because new strains with different hemagglutinin are constantly emerging, influenza is like an army of viruses whose soldiers are constantly changing their camouflage.

Add to this another dimension—the evolution of the virus through its hosts. Any time the virus meets a new individual immune system, it can mutate. This is particularly frightening because influenza can jump from one species to another. Aquatic birds are the ultimate influenza reservoirs because the genetic material for every flu virus exists within their population. Periodically, chickens, pigs, horses, and even seals are also infected. This phenomenon acts as a huge mixing bowl, prompting more variants and greatly increasing the chance that a new strain will be produced to which humans have no immunity. It is thought, for example, that the 1918 virus began in birds, spread to pigs, and circulated among humans for several years before it abruptly mutated and became deadly.

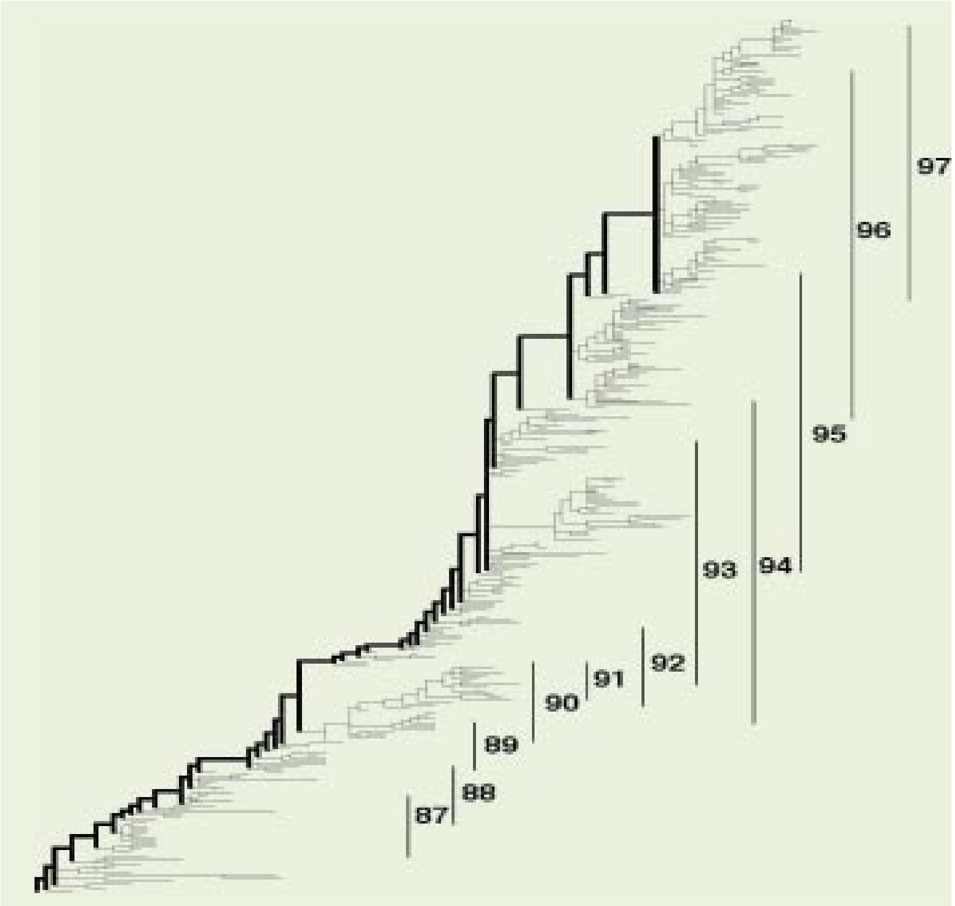
Artist rendering of the influenza virus. Illustration includes the viral membrane with membrane bound protein receptors enclosing the 8 segmented RNA strands.

ILLUSTRATION: PATRICK MCKELVEY

The scientists attending the SFI workshop include an international mix of leading biologists, epidemiologists, virologists, and mathematicians. Their aim is not so much to map a battle plan against influenza, but rather to exchange ideas about new weapons in the arsenal. "Our goal is to bring together people who are looking at various dimensions of the problem so they can inform one another about what the questions and capabilities are," says Simon Levin, professor of biology at Princeton and Cornell, SFI Science Board member, and workshop organizer.

Research biologist Robin Bush works on influenza at the molecular level. She and Walter Fitch are part of a team of researchers at the University of California, Irvine, who are finding clues to one important way the virus evolves—through antigenic drift. This is the accumulation of genetic mutations, particularly in the spiked surface proteins that an influenza virus makes in order to stay ahead of our immunities. Bush and her colleagues constructed family trees for type A viral strains from 11 consecutive flu seasons with each branch representing a new mutant strain. Then they analyzed the number and type of changes in a particular part of the hemagglutinin gene. "In nine out of the eleven cases," Bush explains, "we were able to predict which current strains would be the progenitors of the next strains."

It is an exciting discovery. The studies are theoreti-



Family trees for type A viral strains from 11 consecutive flu seasons with each branch representing a new mutant strain. (Robin Bush)

cal, but if developed, the potential for predicting the capricious ways of the virus could save lives. Scientists might be able to better forecast which strains would cause epidemics or pandemics and tailor the vaccines to be more effective. "Some of this is getting to know your foe," says Alan Perelson, leader of the Theoretical Biology and Biophysics Group at Los Alamos National Laboratory, director of SFI's Theoretical Immunology Program, and workshop co-organizer. "If you want to come up with good treatment strategies, vaccination strategies, and planning strategies, you really have to understand the evolution of the virus."

But how can computer modeling, which was used in the evolutionary study, help scientists who are on the front line of fighting the flu? "When we try to model this system with all these different individuals and different histories, it's immensely complicated," says Levin. The implication is that too detailed a model will produce no insights. "So how do we create reduced-dimensional descriptions that are easier to manipulate and more robust in their predictions?" he asks. "Some differences are important and some are not for understanding a particular question."

He explains that some generalization is necessary to make models work. "Individuals need to be lumped together into groups of individuals with similar epidemiological histories and risks," he says. "Such approaches are standard in dealing with large collections of individuals. Perhaps the best example involves virtually any model to describe evolutionary change. Every individual is unique, yet if [early population geneticists] Fisher, Wright, and Haldane had stopped there, our understanding of evolution would still be in the dark ages. The tools of population genetics focus on very limited numbers of loci, lumping individuals together based on identity at those loci. This approach suppresses variation at unrelated loci, creating classes large enough that robust prediction and generalization can be made.

"Of course, insurers also rely on their ability to create such categories as well, lumping individuals together in ways that may annoy some of those individuals, but allow robust statistical predictions to be made" he adds.

One such agent-based model has been used recently by Derek Smith in collaboration with SFI's Stephanie Forrest, Alan Perelson, and UNM computer scientist David Ackley. It explores the problem of why people who get flu shots every year sometimes get sick anyway, even when the vaccine should protect them. Smith's model showed that more of these people got the flu in years when the epidemic strain was almost identical to the previous year's. "The antibodies stimulated by the vaccine circulate for at least a year," Smith says. "If the strain in the second vaccine is very close, the old antibodies will eliminate it before new immunity can form."

It's a hypothesis, but one that is getting serious attention. Smith and others hope to test it with animal and perhaps human studies in the near future. If the experiments support the theory, the findings could dramatically improve strain selection for the vaccine. "One of the things models can do is inspire clinical trials," Levin says. "If we can get people to believe the model has some merit, then it guides the way to clinical work."

"We as modelers would like to be able to bridge the gap between the genetic data—the sequence data—and someone who needs to know how a specific mutation in the virus might affect the way the immune system sees it," Perelson says. "We can't do that now, but it's a problem we're starting to discuss." Perelson's Los Alamos colleague Catherine Macken has helped to fast-forward this type of research by establishing the Influenza Sequence Database, which incorporates all the influenza sequences in the world, plus tools for working with them, into an easily accessed website.

During the workshop, while participants take informal breaks, discussion centers on such resources. In fact, much of the most important work happens during these breaks when scientists gather in the sunny spaces at SFI. In one group, Neil Ferguson, of Oxford, has prompted discussion with his model, which, though it's in preliminary stages, explores the seasonality of influenza. His findings show that seasons may cause it to mutate very rapidly at specific times. In temperate climates, flu epidemics hit like a wave in winter while remaining at a low ebb in warm months. Ferguson's model, which he hopes to test against epidemiological and genetic data, raises the possibility of genetic bottlenecking due to this wave effect. The findings could help researchers implement better management strategies. Elsewhere, modelers are talking to other modelers with different skills. People who try to understand influenza at its genetic level are exchanging ideas with those who focus on its global spread.

Besides influenza, other diseases such as HIV, measles, malaria, and hepatitis are being discussed because they too evolve in ways that defeat the efforts of the immune system. "This will be a continuing effort and we intend to make some comparisons across systems," Levin says. "The evolutionary tree of influenza doesn't look like other diseases. Why is the evolution of this disease different?"

Answering that question and others will be an ongoing pursuit. "You're going to see a lot of people coming back to SFI to work on these questions," says Levin. Already his group, which focuses on epidemiology, is exploring new directions with Perelson's team, which focuses on immunology. Both scientists hope the effort will eventually include the CDC experts, with whom Perelson's team already has strong interactions, the evolutionary biologists, and others. It's a promising beginning.

Marsha McEuen is a freelance writer who lives in Santa Fe.

HIV OLDER THAN ORIGINALLY THOUGHT

In February, Bette Korber, who is at SFI part time, as well as at Los Alamos National Laboratory, presented work at the 7th Conference on Retroviruses and Opportunistic Infections. Her research indicates that the HIV virus has existed in human populations for at least 70 years—far longer than most researchers had thought.

Korber reached this conclusion by comparing the composition of the genetic material of the many current strains of the virus and extrapolating back to a common origin. The approach she employed is a well-recognized technique that has been used to determine when different species diverged from a common ancestor. Similar studies of human mitochondrial DNA have also identified a common female ancestor of modern humans, called "Eve," who migrated out of Africa sometime between 100,000 and 200,000 years ago. Some researchers are calling Korber's species-leaping HIV a "viral Eve."

The finding that the virus first jumped from the chimpanzees into humans sometime around 1930 could provide epidemiologists strong hints about the future evolution of the epidemic.

PHOTO: JULIE GRABER

ALDERSON PICKED AS 2000 STEINMETZ FELLOW

David Alderson, a doctoral candidate in the Department of Management Science and Engineering at Stanford University, has been awarded the 2000 Steinmetz Fellowship, a prize open to Complex Systems Summer School (CSSS) alumni. The award, which supports a one-month research residency at the Institute, is made to a participant of the school each year to support extended research at SFI in the subsequent year.

Alderson's research interests focus on the dynamic behavior of telecommunication networks and infrastructure protection. His dissertation investigates synchronization behavior in network environments to try to determine the extent to which synchronization may contribute to widespread or "cascading" failures in network systems.

While at SFI Alderson plans to focus on several questions: To what extent does his proposed model for synchronization behavior capture the essential tradeoffs observed in real synchronization environments? What other systems does this model/behavior resemble? How might the model be refined? Might there be such a thing as the "canonical" model for synchronization behavior in networks? To what extent does network topology, specifically a small-world network structure, affect both qualitative and quantitative synchronization behaviors? Does the model for synchronization behavior observe characteristics of self-organized criticality? Do the size and frequency of synchronization events fit a power-law distribution?

"I believe that the Santa Fe Institute is uniquely positioned to be at the heart of some of this ongoing research," comments Alderson. "I look forward to the opportunity to return to SFI."

Dr. Philip R. Steinmetz, a professor emeritus at the University School of Medicine in Connecticut and an alumnus of the 1990 Complex Systems Summer School has generously established this fellowship. Steinmetz is especially interested in complexity in biological systems, including questions of how complex systems develop relatively simple overall behavior and what roles self-organization and entrainment play in these systems.

SWARM VERSION 2.1 RELEASED

Swarm Version 2.1 was recently released at Swarmfest 2000, the fourth annual meeting of the Swarm User Group.

Swarm 2.1 rounds out Java language support. To make Swarm more natural for Java programmers, the Swarm virtual machine can use Java collections interchangeably with Swarm collections. Swarm features that were absent in 2.0.1 for Java users but present for Objective-C users have been added.

For correctness and performance, Swarm 2.1 introduces interfaces for describing language-specific, variable-argument, precisely typed actions as well as interfaces for tagging actions that apply across sets of homogeneous agents. Use of these interfaces gives Swarm the information it needs to accelerate many kinds of common tasks. The Java layer for Swarm has been optimized in a number of ways, and numerous bugs have been fixed.

The Swarm Development Group (SDG) continues working toward making Swarm easy to install while preserving the open sourceware spirit of the project. For Windows users, the Swarm 2.1 CD-ROM will ship with an InstallShield® package of a self-contained and up-to-date GNU development environment configured for Swarm, and an automated installer for GNU Emacs. Emacs will come preconfigured with JDE (a Java IDE) and multi-lingual editing support. (Kozo Keikaku Engineering has contributed a Japanese translation of the Swarm documentation, but it will likely be superseded. We need help maintaining this information. The multilingual Emacs support combined with a set of binaries on the CD-ROM make it possible to work on documentation in Windows with minimal fuss.)

Finally, Swarm 2.1 will have more binary distributions than ever: Solaris 2.[67] for Sparc, Debian 2.2 for Intel & Sparc, Redhat 6.1 for Intel & Sparc, Suse 6.3 for Intel, and LinuxPPC 1999. Swarm is known to run on many more platforms, but we are limited by time and privileged access to computers for making more. Potential contributors: this is very useful and straightforward work.

The Swarm User Guide has gone from alpha to beta status. It will contain some updated material formerly found in the Reference Guide. This will have the dual advantage of slimming down the rather thick Reference Guide and making the updated material available in a more appropriate context.

PHYSICS STUDENTS SELECTED FOR SFI FELLOWSHIPS

David Albers, from the University of Wisconsin, and Sameer Gupta, from Pennsylvania State University, are the first two Fellows named through the new NSF/SFI Physics Graduate Student Fellowship program. Supported by the Physics Division of the National Science Foundation, these fellowships offer physics graduate students an innovative research and educational experience that introduces them to the application of approaches and concepts from physics to topics outside of the traditional domain of physics. At the same time, the program is a keystone in building new research triads consisting of the graduate fellows, their faculty advisors, and SFI researchers.

David Albers' research interests include the fields of nonlinear dynamics, global analysis, and bifurcation theory. Currently he is focusing his attention on the general study of large, random dynamical systems. Along with his advisors at Wisconsin—including William Brock, W. D. Dechert, and Clint Sprott—Albers is working on an analytic proof and numerical analysis (through the use of neural networks) of the genericity of the Hopf bifurcation in large dynamical systems. They are also concerned with modeling and embedding theory coupled with spurious Lyapunov exponent detection. [continued]

Albers is working with J. Doyne Farmer, McKinsey Professor at SFI. Previous studies of a simple market model developed by Shareen Joshi and Farmer show that prices vary irregularly whenever each agent has multiple strategies, and chooses the most successful strategy based on past performance. This is true even when there are no noisy inputs, leading to the conjecture that the price series is chaotic. The goal of this project will be to investigate this conjecture, by computing the Lyapunov exponents of the market, and to determine the conditions that lead to chaos in prices.

Sameer Gupta is working with his advisor Lee Smolin at Pennsylvania State University on a cluster of topics including aspects of loop quantum gravity and spin networks, particularly the role of self-organized criticality in the classical limit of the theory, and extension of the theory to non-compact spaces. He is also working on a data analysis project evaluating noise filters for the Laser Interferometric Gravitational Wave Observatory (LIGO) project. At SFI, Gupta is working with Visiting Professor Sanjay Jain studying the structure and evolution of biological, ecological, and social networks.

NICHOLAS METROPOLIS, 1915-1999

Nicholas Metropolis, one of the founders of the Santa Fe Institute and Emeritus Science Board member, died in October 1999 in New Mexico. He was 84.

Metropolis served on the SFI's Board of Trustees before moving to the Science Board. He later became the first "emeritus" member of the Science Board. "Nick was closely involved with the planning and start-up phases of the Institute," says SFI's first president, George Cowan. "He initially proposed cognitive science as our central theme. It was, of course, included in the broader theme of complexity. His advice and good judgment contributed enormously to the Institute's success."

As a graduate student at the University of California at Berkeley in the late 1930s and early 1940s, Metropolis interacted with a number of notable scientists including Bethe, Bothe, Compton, Fermi, Lawrence, Millikan, Oppenheimer, Turkevich, and Urey. These contacts led him to Los Alamos in 1943. During World War II, Metropolis and Richard Feynman struggled with the extremely slow electromechanical machines used for the hand calculations needed for weapons design. This experience caused Metropolis to become deeply intrigued by John von Neumann's suggestion that ENIAC, the first electronic calculator, could have a major impact on the future of computation.

Metropolis went on to become the builder of a series of Maniac computers at Los Alamos National Laboratory, an accomplishment that established him as one of the founders of the information age. The Monte Carlo method of calculation emerged during this era through the interactive efforts of Metropolis, Ulam, and von Neumann. This technique, with its seemingly limitless potential for development and applications to all areas of science, is due to the breadth of the original ideas.

Metropolis was a great computer architect, but he also saw clearly the many problems computers raised about the foundations of mathematics. In the second half of his long career, he collaborated on many articles on this topic with mathematician/philosopher Gian Carlo Rota.

Metropolis became a senior fellow at Los Alamos National Laboratory in 1980. In 1987 he was the first laboratory employee honored with the "emeritus" title by the University of California. The editor of numerous scientific volumes, he served on the editorial boards of many journals. In 1992 Metropolis delivered the Los Alamos National Laboratory's annual J. Robert Oppenheimer Lectures. He was awarded the Pioneer Medal by the Institute of Electrical and Electronics Engineers and was a member of the American Academy of Arts and Sciences, the American Mathematics Society, and the American Physical Society.

PUBLICATIONS UPDATE

TWO NEW SFI BOOKS ARE FORTHCOMING FROM OXFORD UNIVERSITY PRESS

Dynamics of Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes, edited by Timothy A. Kohler and George J. Gumerman, presents a series of studies from archaeologists, ethnographers, primatologists, computer scientists, sociologists, and philosophers who use agent-based models to examine social and spatial dynamics. These papers ask and find provisional answers to fundamental questions such as: How do levels of selection and spatial configuration of resources interact in the evolution of cooperation? How can we explain the evolution of inference? And what is the role of warfare in the emergence of state-level societies? Other papers are concerned with understanding how settlement patterns are generated among groups such as Mesolithic foragers in the Southern Hebrides and small-scale Neolithic societies in the North American Southwest.

Scaling in Biology, edited by James H. Brown and Geoffrey B. West, explores the diversity, promise, and excitement of current research on scaling. In recent years, with the well-publicized advances in many subdisciplines of molecular biology, there has been less attention paid to higher levels of biological organization. It is becoming increasingly clear, however, that molecular approaches and techniques are inadequate to answer many of the most challenging questions about life. Many of these questions concern the complexities of biological systems at levels of organization from organisms to ecosystems. It is at these levels that research on scaling has made major contributions in the past and has the potential to lead to even greater advances in the future.

THE SANTA FE INSTITUTE ANNOUNCES A FREE SUMMER WORKSHOP FOR SANTA FE HIGH SCHOOL STUDENTS

"Exploring the World through Computer Models"

JULY 24-AUGUST 4 CONTINUING THROUGH THE 2000-2001 SCHOOL YEAR

Selected Santa Fe's public and private high school students are invited to spend ten days at the Santa Fe Institute using Starlogo software to develop computer models of decentralized systems such as traffic jams, ecosystems, and ant colonies.

The workshop features Starlogo instruction, tutorials on complex systems, informal project discussions, and plenty of one-on-one project time with staff. A fully equipped computer lab will be available.

This is an introduction to an in-depth academic year program for Santa Fe high school students that will begin in September 2000. Students enrolling in the summer session must make a commitment to continue involvement during the school year 2000-2001. ***Enrollment is limited and by application.***

For more information call 984-8800 Ext. 268 or see
http://www.santafe.edu/sfi/education/sssc/summer00/description00.html

SANTA FE INSTITUTE PHYSICS GRADUATE STUDENT FELLOWSHIPS

Supported by Physics Division of the National Science Foundation

These fellowships offer an opportunity for physics graduate students to pursue an innovative research and educational experience that introduces them to the application of approaches and concepts from physics to topics outside of the traditional domain of physics. The emphasis is on building new research triads consisting of a Graduate Fellow, his/her faculty advisor, and an SFI-affiliated mentor.

The program offers support for up to six months' residency of the Graduate Fellow at the Santa Fe Institute to pursue work drawn from a wide range of topics including:

- LANDSCAPE DYNAMICS FOR BIOLOGICAL EVOLUTION
- INFORMATION-PROCESSING IN LARGE-SCALE NETWORKS
- MODELING OF THE IMMUNE SYSTEM
- ALLOMETRIC SCALING LAWS IN ECOSYSTEMS, AND
- MODELING OF ECONOMIC INTERACTIONS.

The program also offers the opportunity to participate in the full range of SFI workshop, seminar, and educational events including monthly short courses designed specifically for Graduate Fellows.

Tuition support is provided.

TO APPLY

Individuals interested in applying for the Fellowship program should consult the web site http://www.santafe.edu/sfi/education/indexPhysGrad.html. Included on that web site are descriptions of current possible research projects to be supervised by SFI faculty mentors.

The Physics Graduate Student Fellowship pilot program is open to individuals enrolled as Ph.D. candidates in physics departments at accredited U.S. universities. An important application requirement is evidence of the applicant advisor's own interest in active program participation during the period of the fellowship.

Women and minority students are especially encouraged to apply.

Applications are accepted twice annually. Application deadline for the Spring 2001 semester is October 2, 2000. Applications should be sent by postal mail to NSF Physics Graduate Fellowship Program, 1399 Hyde Park Road, Santa Fe, New Mexico 87501.

INTERNATIONAL OUTREACH PROGRAM:

SFI EXPANDS ITS GLOBAL INFLUENCE

by Suzanne Dulle

While SFI has always drawn scientists from all over the world into collaboration, the new International Outreach Program will stretch the Institute's influence across the globe allowing for further expansion of its cross-generational, transdisciplinary research community.

Resulting from a generous grant from a private supporter, Bill Melton, the program will provide research professors, postdoctoral fellows, and advanced graduate students from targeted emerging countries greater opportunities to expand their research agendas to include interdisciplinary research and enhanced theoretical and experimental programs. Grant funds will be used to ensure expanded international participation in SFI's educational and visitors programs, to extend SFI workshops to international sites, and to implement a new fellows program. Special attention will be given to awarding fellowships in countries where funding is not readily available for interdisciplinary research activities, and/or where restrictions on the availability of financial resources might preclude extensive travel opportunities for educational purposes.

The first year of the project targets researchers in China, India, and Russia. Year two will be focused on expanding to Eastern Europe and some of the Southern Hemisphere countries in South America and Africa. The long-term goal is to extend the program to the entire international community.

A major part of the program is the implementation of the International Fellows Program. A model for this program is SFI's "Fellows-at-Large" (FAL) program. Begun in 1998, the U.S.-based FAL program supports the research efforts of advanced graduate students, postdoctoral fellows, and junior faculty in the area of complex systems. This year-old program has proven to be a successful outreach effort. It provides funds for the fellows to invite SFI-affiliated scientists to visit the fellows' home institutions for research talks and short-term collaborations. Funds are also used to support workshops and/or meetings at fellows' home institutions. Additionally, the fellows attend two meetings at SFI to interact with each other, with incoming fellows, and with SFI research visitors and staff.

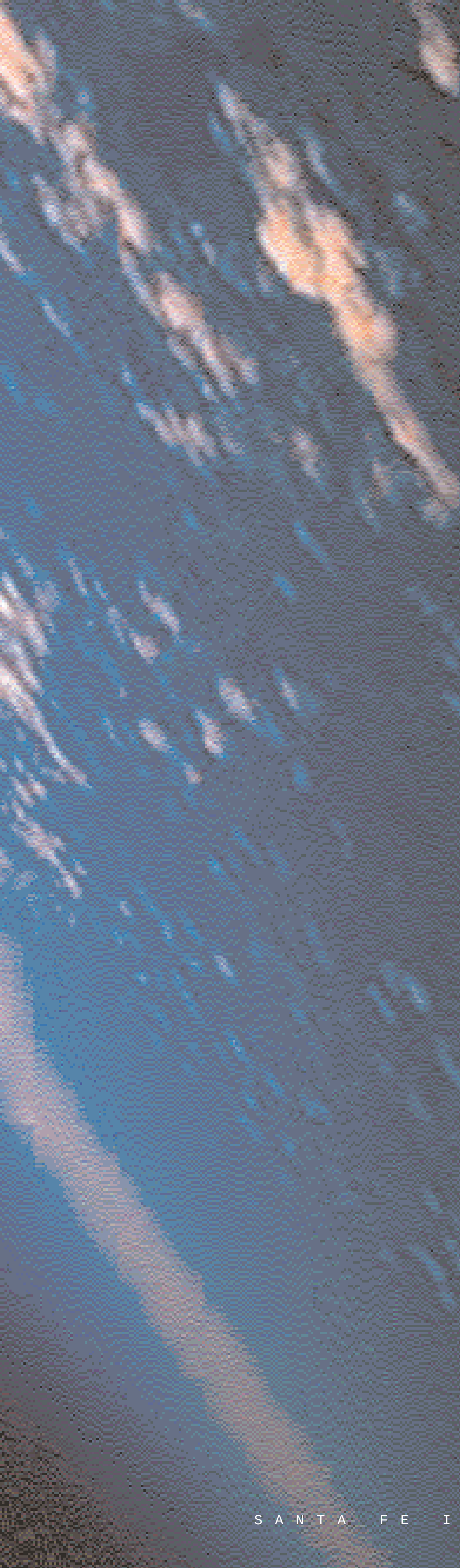


ILLUSTRATION: PETE TURNER, IMAGE BANK

Now, this new phase of the project extends this model to the international research and academic community. SFI has a large network of faculty (over 200 research visitors per year) from around the world, and it is from this international pool that project leaders are soliciting assistance to develop and coordinate the Fellows Program and to identify an expanded international group of researchers. This extended network will be used to disseminate information about the International Fellows Program throughout their country, and it will be used for ensuring that recruitment efforts are extended to a broad group of applicants. International alumni of the Complex Systems Summer School and the Computational Economics Graduate Workshop who are affiliated with institutions within the group of targeted countries will be especially encouraged to apply.

An important component of the program is the networking opportunities, not only to and from the Institute, but also among the various country participants of the International Fellows Program. Individuals will be encouraged to share their research ideas, any papers that are produced, workshop themes, and other aspects of their work with the entire group of fellow participants. Such sharing will take place through the use of the International Fellows Web site. Through the Internet, linkages among the fellows and research collaborators at SFI will be maintained, and the flow of information among the participants encouraged.

SFI will update its web videostreaming capability and purchase needed Internet access equipment at some of the international sites, changes which will allow the international community to view SFI's weekly colloquia series. Joint workshops and meetings at SFI, within participating countries, and among the research community in the various countries, will be encouraged. In these ways, the building of a truly international outreach community will be facilitated.

An initial workshop for a group of Chinese researchers is currently being planned. Targeted for August 2000, the workshop will bring a group of 10 to 12 scholars from Chinese institutions to Santa Fe where they will explore possible research programs and collaborative arrangements with SFI scholars. This founding workshop for the China segment is a result of preliminary discussions with Professor Jiang Zhenghua, vice chairman of the Standing Committee of the National People's Congress and a long-time collaborator with SFI Science Board member and Trustee Marcus Feldman. Other participants for the workshop will be recruited from contacts being made through SFI's External Faculty members, faculty at Renmin People's University of China in Beijing, and professors from the Institute for Theoretical Physics, Academia Sinica.

Inceptive planning for the International Outreach Program in India is occurring with the assistance of SFI Visiting Professor Sanjay Jain, from the Indian Institute of Science in Bangalore. Intentions are to invite selected Indian researchers to make two-week visits to SFI over an eight-month period. We hope this process will result in the formation of a core network of Indian researchers knowledgeable about SFI and SFI's interdisciplinary approach to research. The group will be the basis of a founding workshop to identify additional potential visitors and fellows applicants, anticipated to be held in India during early 2001.

SFI Trustee Esther Dyson, as well as the SFI Science Board, and SFI-affiliated faculty and friends, are in the process of identifying Russian-based scholars with whom SFI project managers can interact for the purpose of developing the Russian component of the program.

Program funds will be available for use in a variety of ways. Because many societies around the globe are currently undergoing rapid and dramatic change, emphasis will be placed on proposed courses of action and research agendas that could inform a particular area of global interest or concern.

Paramount in the initial planning stages is allowing the International Outreach Program to evolve in a manner that is responsive to the specific needs and cultures of each country identified.

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SANTA FE, NEW MEXICO 87501
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