SFI Bulletin

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Beyond the Big Bang • The Amazon's Lost Civilizations • The Truth Behind Lying

The Bulletin of the Santa Fe Institute is published by SFI to keep its friends and supporters informed about its work.

The Santa Fe Institute is a private, independent, multidisciplinary research and education center founded in 1984. Since its founding, SFI has devoted itself to creating a new kind of scientific research community, pursuing emerging synthesis in science. Operating as a visiting institution, SFI seeks to catalyze new collaborative, multidisciplinary research; to break down the barriers between the traditional disciplines; to spread its ideas and methodologies to other institutions; and to encourage the practical application of its results.

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phone (505) 984-8800
fax (505) 982-0565
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EDITORIAL STAFF:
Ginger Richardson
Lesley S. King
Andi Sutherland

CONTRIBUTORS:
Brooke Harrington
Janet Yagoda Shagam
Julian Smith
Janet Stites
James Trefil

DESIGN & PRODUCTION:
Paula Eastwood

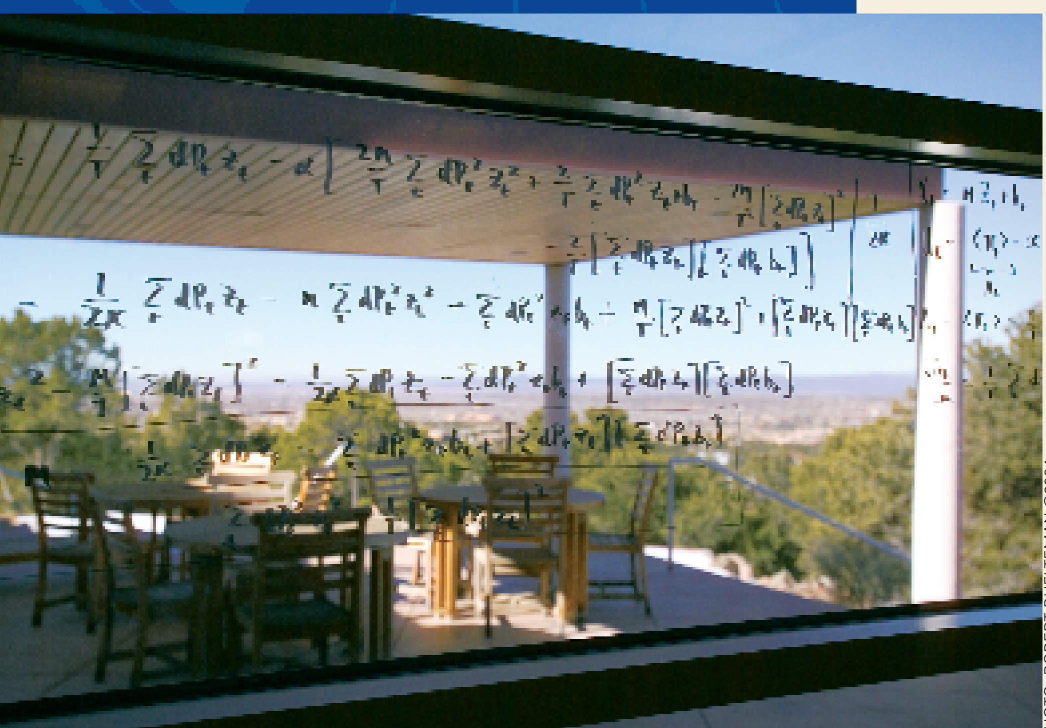

PHOTO: ROBERT BUELTEMAN ©2004

TOC table of contents

3

A Deceptively Simple Formula 2

How Life Began 3

From Finances to Romantic Science: SFI's New Leaders Talk 8

Forrester Research: SFI Epitomizes the Innovation Broker 13

Amazonia's Hidden Civilizations 14

Deception: What Lies Beneath 20

Outsmarting AIDS 26

The Future of Agent-Based Modeling of Financial Markets 30

SFI Community Lectures 36

Transitions 38

Identifying the New 41

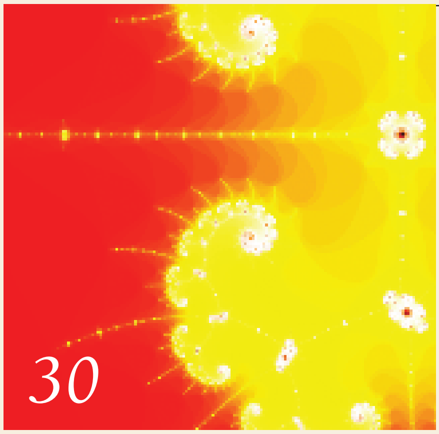

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Photo credits: Top: Yellowstone National Park
Left: David Dewey; Right: © Erich Lessing/Art Resource

A Deceptively Simple Formula

By Geoffrey West, President

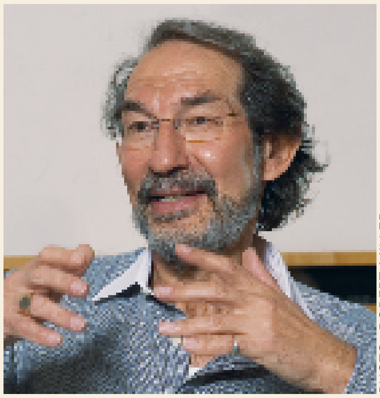


PHOTO: ROBERT MILLER

The Santa Fe Institute is more than 20 years old and, thanks to the visionary leadership of past presidents, board members, and an outstanding array of scientists, it is now well established on the international scientific landscape. Complexity Science, with its tentacles stretching across an astonishing spectrum of fundamental problems, is now viewed as a legitimate, exciting frontier, with SFI playing a central and seminal role. We have extraordinary name recognition and, per dollar, we must be one of the best-known institutes in the world!

This recognition goes well beyond the narrow confines of the traditional scientific community reaching into the corporate and business world. Recently, senior journalists from both *Wired* and *Time* magazines spent time with us prodding and poking around trying to uncover the secrets of our success. Their efforts will result in what we hope to be favorable feature articles (as well as a book) about the Institute. In addition, *Harvard Business Review* will feature an interview with me exploring why SFI is so attractive to businesses. Despite all of this, we remain, by our very nature and design, a little on the outside and "on the edge," namely, a continually evolving experiment not only in the science that we support but in the way we do it.

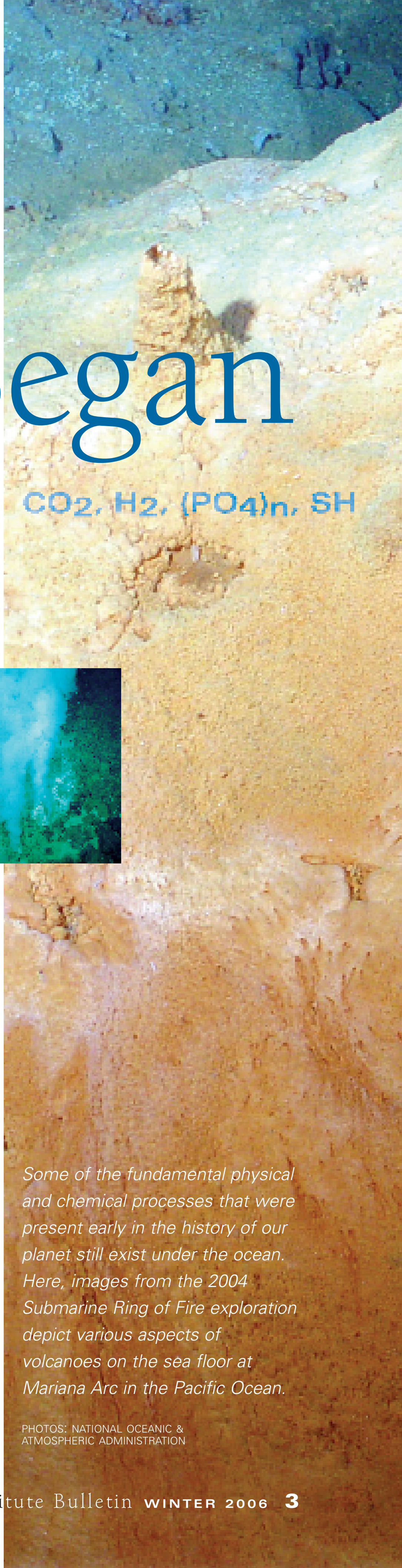
Maintaining the vision of the Institute as a haven for brilliant mavericks, risk-takers, big-thinkers, and synthesizers who are willing to go beyond the more traditional boundaries is an enormous challenge. Identifying such people and convincing them to become part of the SFI community is perhaps the single most important task of being president. I am much influenced by the deceptively simple formula expressed by Max Perutz, who was the director of the notable Medical Research Council Laboratory of Molecular Biology in Cambridge that produced 12 Nobel Laureates (including Watson and Crick): "No politics, no reports, no referees, just gifted, highly motivated people, picked by a few men of good judgment." This is the ultimate challenge for us—if only it were so simple! Of course we have the advantage of being able to depend on a few women of good judgment as well.

Bringing brilliant minds together to attack some of the big problems that might otherwise fall between the cracks is our major challenge. For example, SFI is particularly well positioned to facilitate serious interactions between those from the harder sciences of physics, chemistry, and mathematics with those from the softer, more qualitative biomedical and social sciences. To what extent (if at all) can these be put on a more quantitative, mathematical, predictive basis derived from "universal" underlying principles and laws? Among the sorts of problems being attacked are questions such as, Are there general principles and conceptual commonalities underlying robustness, resilience, innovation, and evolution—concepts that are ubiquitous and central across the entire spectrum of science and technology? To what extent are social organizations an extension of biology? How are energy, resource, and information networks integrated in living systems, in engineered systems, in societies? Such questions are of fundamental importance, sometimes requiring a new way of thinking and a synthesis that can be difficult to accomplish in the often-constrained environment of a particular department in a typical university. But here, it is possible.

There are tremendous opportunities for us as a community to continue the tradition set by the founding fathers and early associates of the Institute: to remain on the frontier of discovery. I look forward to working with all of you to accomplish the dream. ◀

How Life Began

by James Trefil



In the Beginning…

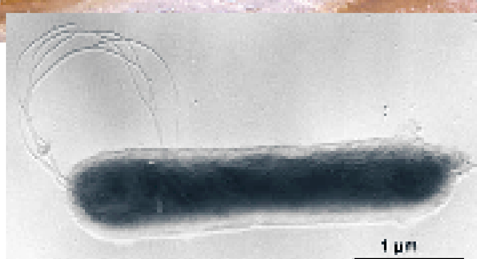
There are few phrases in the English language more freighted with meaning than this. Veteran lecturers know that there is nothing that evokes a sense of awe and majesty (and, in some people, insecurity) like a discussion of the origin of the universe or the origin of life. Now, a nationwide research effort spearheaded by Harold Morowitz of the Santa Fe Institute and George Mason University is forming to attack the ultimate question of how life began, to learn what might have happened— "In the beginning."

This new effort is being funded by a five year, $5 million grant from the National Science Foundation. The Foundation has funded a small number of research efforts in a program they call Frontiers in Integrative Biological Research (FIBR). The idea of this initiative is to identify research projects that, if successful, would result in major advances in our knowledge of living systems, but carry a high risk as well. Three awards were given in 2005. The SFI grant involves scientists at SFI and George Mason University, together with colleagues at the University of Colorado, the Carnegie Institution of Washington, the University of Illinois at Urbana-Champaign, and Arizona State University.

Some of the fundamental physical and chemical processes that were present early in the history of our planet still exist under the ocean. Here, images from the 2004 Submarine Ring of Fire exploration depict various aspects of volcanoes on the sea floor at Mariana Arc in the Pacific Ocean.

PHOTOS: NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

HOT SPRINGS PHOTOS: NATIONAL PARK SERVICE; BACTERIA PHOTO: KARL STETTER



Above: Gases emanating from a hot spring at Yellowstone National Park provide a key to understanding some of the early building blocks that make up living systems.
Left: Aquifex pyrophilus *bacteria may preserve much of the metabolism and way of life of the earliest cells.*

The question the group is trying to answer is deceptively easy to pose. We know that our planet started out as a hot, airless, molten ball in space. The question is, How did we get from that to a planet teeming with life? In particular, what was the first event we can point to and say, "Here it is—here is the first living thing, the first thing clearly different from anything that came before it."

For most of human history, the problem of understanding the creation of a living thing from inorganic materials—of making life from non-life—was simply outside of the realm of experimental science. Then, in 1953, an experiment at the University of Chicago changed all that. Two scientists—the then graduate student Stanley Miller and the Nobel Laureate chemist Harold Urey—set up an apparatus in a basement lab that, they believed, mimicked conditions on the early Earth. A gas containing compounds normally found in volcanic eruptions was subjected to heating (to simulate the action of the sun) and electric sparks (to simulate lightning). After a few weeks, the liquid in the apparatus turned a dark brown and they found, upon analysis, that it contained molecules called amino acids.

As it happens, amino acids are the basic building blocks from which proteins—the workhorses of the cell's chemistry—are made. What Miller and Urey had shown, in other words, was that you could start with simple molecules—ammonia, hydrogen, water, and methane—and end up with the kinds of molecules that are found in living systems. And even though today most scientists do not think that all of the materials in the Miller-Urey experiment were actually present on the early Earth, they acknowledge that their result put the study of the origin of life, for the first

CH_3COOH CO_2 H_2

time, squarely in the domain of science.

Since 1953, there have been a number of important developments on this front. For one thing, we have found that amino acids and other simple molecules found in living systems are made everywhere in nature. They have been found, for example, in meteorites and interstellar dust clouds. The result is that we now realize that the basic building blocks of living systems are not as rare or unusual as originally thought. The problem of understanding the origin of life, then, doesn't arise because we can't find the building blocks to put a living system together, but rather understanding how those building blocks assembled themselves into a functioning cell.

Over the years, two competing approaches to this problem have developed—Morowitz and his colleagues call them the "cells first" and "genes first" approaches. Both of these involve what Morowitz calls a "top-down" methodology. They start with the highly complex and organized cells of today and try to find ways to construct them from inorganic materials. In the "cells first" approach, the membranes that separate living systems from their environment appeared first, and the molecules trapped inside the compartments then evolved the reactions characteristic of life. The "genes (or catalysts) first" approach assumes that, as in modern cells, early chemical reactions had to be governed by the intervention of other molecules acting in the role of catalysts or enzymes. The so-called "RNA world" scenario, in which the complex RNA molecule, which plays a major role in the chemistry of modern cells, develops and acts as a catalyst to bring about the chemical reactions of life, is the best known of these schemes.

WHAT WAS THE FIRST EVENT WE CAN POINT TO AND SAY, "HERE IT IS—HERE IS THE FIRST LIVING THING, THE FIRST THING CLEARLY DIFFERENT FROM ANYTHING THAT CAME BEFORE IT."

The new approach being explored by the Santa Fe collaboration takes just the opposite of the top-down approach. It builds on suggestions made during the 1980s by John Corliss, Gunter Wachtershauser, and Christian de Duve (who will be visiting SFI this spring). Instead of starting with complex modern cells, it begins with simple molecules that would have been present on the early Earth and asks what sorts of self-reproducing chemical cycles could be generated from them. In the words of SFI Research Professor Eric Smith, a physicist who often refers to himself as a "statistical mechanic," the real question to ask is, "What was the problem with the prebiotic Earth that was solved by the appearance of life?"

There is a simple analogy that may help to understand this new way of attacking the problem of life. Suppose you wanted to explain the modern Interstate highway system. One way would be to start with the current system and try to work backwards. Another way would be to go back to the pre-Columbian geography of North America and try to understand the features of the landscape that affected the way humans would have moved around. You would talk about how it is easier to travel on rivers than through forests, easier to go through mountain passes than over the peaks, and so on. Eventually, you would put together a map of where the tracks on the continent would most likely have been located, and only then talk about how those tracks evolved into the Interstate system. And, as anyone who has driven across the country on Interstate 80 can testify, a lot of that primitive map would survive in the modern system.

So in the end, what matters are simple

$CO_2, H_2, (PO_4)_n, SH$ H_2

molecules and how they interact. Smith envisions the problem of producing life from these molecules in an interesting way: he thinks of the possible chemical reactions as a vast system of possibilities, and asks how nature finds a path for energy to get through the system. It's a little like pouring water down a slope. In principle, there's no apparent reason why the water should flow one way rather than another, but, in fact, it will quickly find specific channels that get it to the bottom. In the same way, Smith believes there are "channels" in the chemical landscape through which energy will flow, and it is these reactions that, ultimately, gave rise to life. Needless to say, this revolutionary approach is still controversial within the scientific community. Time will reveal if it can eventually replace the more conventional approaches outlined above.

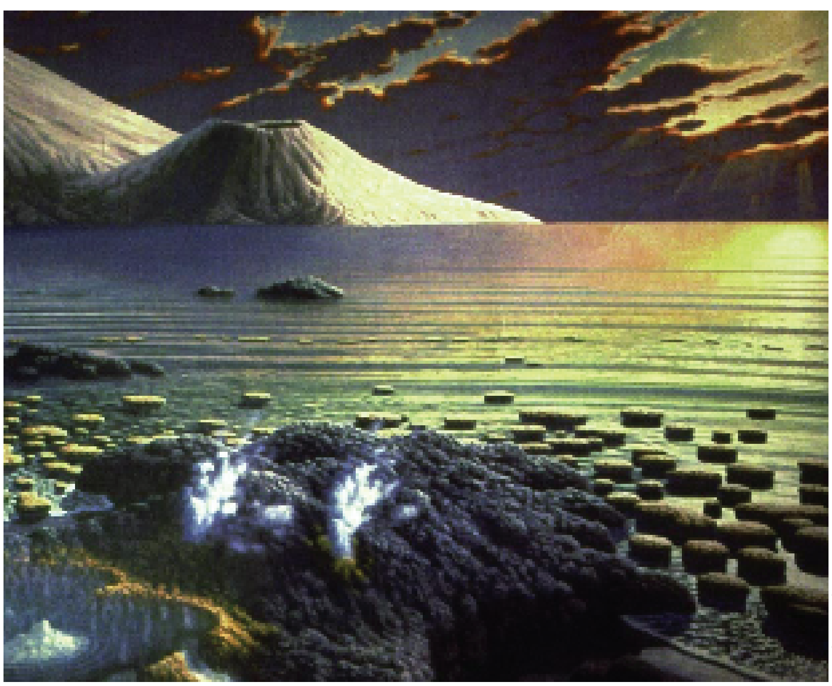


IMAGE: NASA/JPL

This painting depicts an artist's view of what Earth might have looked like during the Archean period, the earlier of the two divisions of the Precambrian era (3.96 billion to 540 million years ago). This was an age of little oxygen, in which the unicellular bacteria and archaea were the only life forms.

In the collaboration, theoretical research of this type will be complemented by experimental work by George Cody at the Carnegie Institution of Washington, who will be examining chemical reactions at the kinds of pressures attained near deep sea vents at the bottom of the ocean, where many scientists now think life originated.

But the group isn't stopping with establishing how the first living things might have originated. Even if that problem is solved, there remains the enormous task of understanding how those first primitive cells gave rise to the enormous complexity of modern cells. In terms of our analogy, even if we get the pre-Columbian game trails right, we still have to trace the development from wagon trails to paved roads to Interstate highways.

Shelley Copley, of the University of Colorado, is examining one of the steps in this process. She is asking how the complexity of DNA could have arisen from the simple chemical properties of the molecules that constitute its basic building blocks. She sees the problem as an accumulation of molecules fitting together like pieces of some impossible three-dimensional jigsaw puzzle, explaining features of DNA that have long been mysterious. Copley's work will be complemented by computer studies done by Zaida Luthey-Schulten of the University of Illinois.

Finally, with this approach to the origin of life, the characteristics of very primitive organisms—the organisms closest to that origin—become very important. It has been known for some time that among single-celled organisms a process called horizontal gene transfer goes on. As the

PHOTO: NASA/JPL

This NASA photo of a Bolivian coastline offers a metaphor for the vast system of possibilities that nature finds for energy to get through a system. In the same way that water finds its way to the sea, there are "channels" in the chemical landscape through which energy will flow, and it is these that, ultimately, gave rise to life.

name suggests, this involves cells swapping genes with each other, rather than having genes develop in distinct lines unique to each organism. Carl Woese and Nigel Goldenfeld of the University of Illinois will be looking at the effect of this process on the development of the universal genetic code embodied in DNA. They will be particularly interested in whether that code is optimized, a possibility Woese first suggested in the 1960s, and what role horizontal gene transfer might play in the optimization process. In this way, the Illinois group, working downward from the genetic code, might connect with the other members of the team working upward from basic chemical reactions.

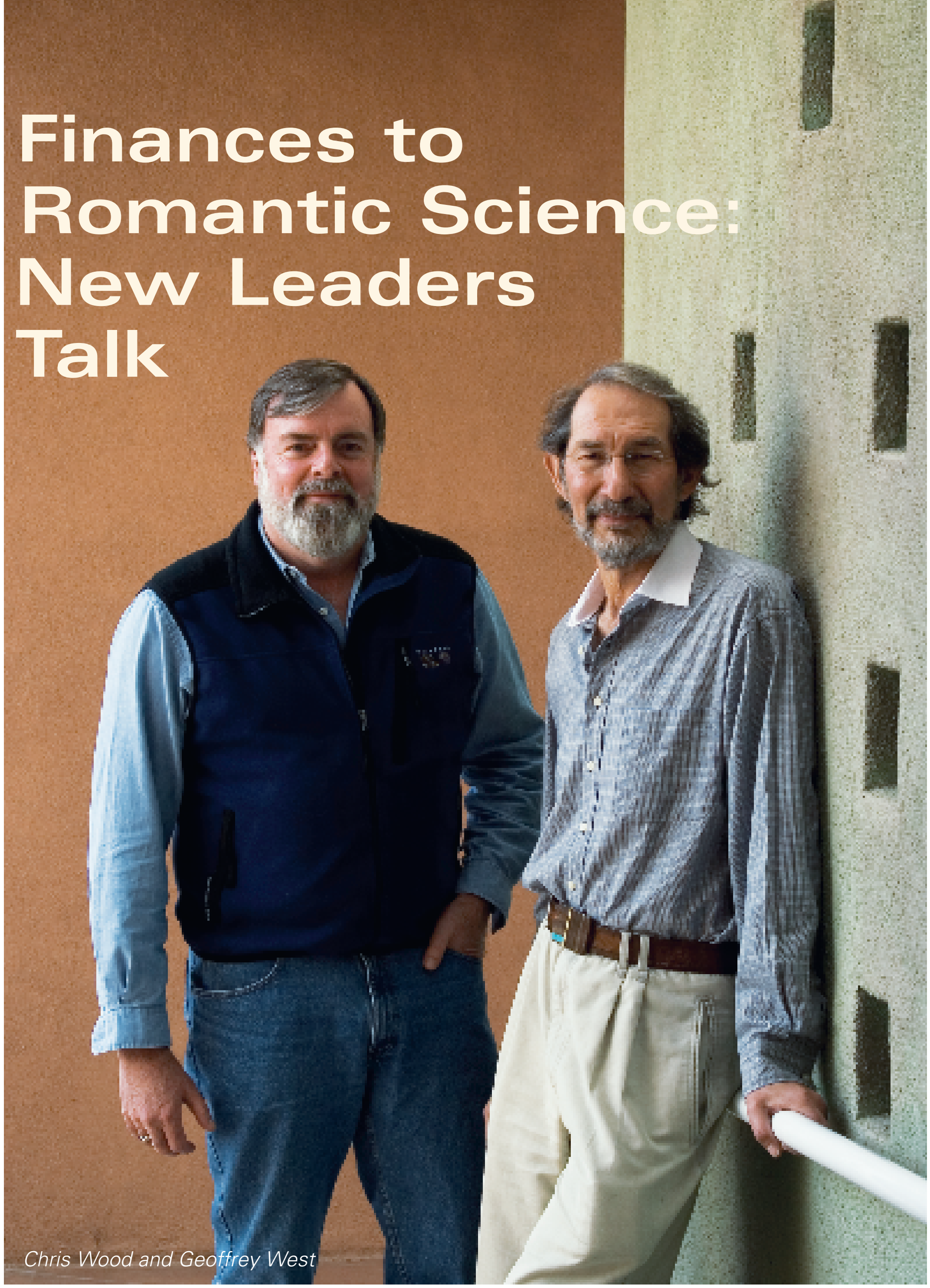
In the end, what is exciting and new about this multi-pronged approach to the origin of life is its focus on the fundamental physical and chemical processes that we know were present early in the history of our planet—the processes we know must have given rise to life in the first place. It encourages us to see life not as some highly improbable frozen accident but as a natural outcome of the workings of the physical universe. It makes us want to agree with Harold Morowitz when he says, "In the end, life is simple."

For a more detailed discussion of the science underwritten by the FIBR grant, see "Searching for the Laws of Life" in the *SFI Bulletin,* Winter 2004, Volume 19, Number 1.◀

James Trefil is Clarence J. Robinson Professor of Physics at George Mason University

From Finances to Romantic Science: SFI's New Leaders Talk

By
Lesley S. King



Chris Wood and Geoffrey West

ALL PHOTOS BY ROBERT MILLER

In the summer of 2005, the Santa Fe Institute took a new strategic direction by naming as president one of its key scientists Distinguished Professor Geoffrey West, whose current work involves exploring universal scaling laws in biology and social systems. At the same time, the Institute named neuroscientist Chris Wood as vice president, with responsibilities covering both academic affairs and the administration of the Institute. In this conversation, West and Wood mull over some of the issues facing their new posts and SFI as a whole.

On Leadership

West: We've gone through many changes in the past months. Chris and I have stepped into our new positions, and also the leadership of the Board of Trustees has changed. It seemed a natural time to reexamine SFI, both in terms of its science and its operations. We also hired three new resident faculty members and eight new postdoctoral fellows at the start of this academic year, so that began the process of rebuilding the science side of the Institute.

It's all part of rethinking the way we do science here and how we carry out the SFI mission. We're reaching out to the larger community, creating a more effective, integrated external faculty, getting the programs more active, and getting more workshops on board.

Wood: One of Bill Miller's actions as new chair of the Board of Trustees was to initiate an "operational review" of the Institute to evaluate the administrative, financial, and operational systems supporting the Institute's scientific programs. The result has been an intense addition to our normal activity. Three members of the board or their associates; Doug Erwin, SFI professor and chair of the Science Steering Committee; plus Geoffrey and I have been busy with it since mid-August. Board Chair Bill Miller and Vice Chair Ford Rowan, and Trustee Jim Rutt have been especially active in the process. Elizabeth Hughes, senior vice president of Legg Mason Capital Management, headed up the project for Bill Miller. We spent a full week here interviewing absolutely everybody who wanted to be interviewed with respect to answering the following question: If today's SFI had not evolved over a 20-year period but instead were created new out of whole cloth, how would we organize it to enable it to run effectively?

This is not a question of what science we are doing. That was off the table in the review and remains in the hands of our faculty. But every non-scientific question about the Institute is on the table. Some of the questions include, Who are our sources of funding and how do we cultivate them? How do we maintain them? How do we organize our visitor programs and our workshops? Exactly what steps do we need to go through in order to insure that a visitor has an office, has the computing resources that she or he needs, and has the support from all of us? What are the strategic goals of SFI's educational and international programs? How do we most effectively achieve them? So the entire "business end" of our operation has been under scrutiny. We expect that the review will have a lasting effect on the Institute, one that improves our support of the Institute's science and scientists.

The Journey to SFI

Wood: I spent 16 years before I came here in a scientific leadership role at Los Alamos National Laboratory, and I had a job there that required scientific judgment and leadership, as well as organizational and administrative skills. Over those years, the climate of Los Alamos changed from a place where science was primary to one in which the science became increasingly secondary to other considerations. That experience, among others, helped prepare me to understand the balance that's needed between science, organization, and administration in any effective scientific organization.

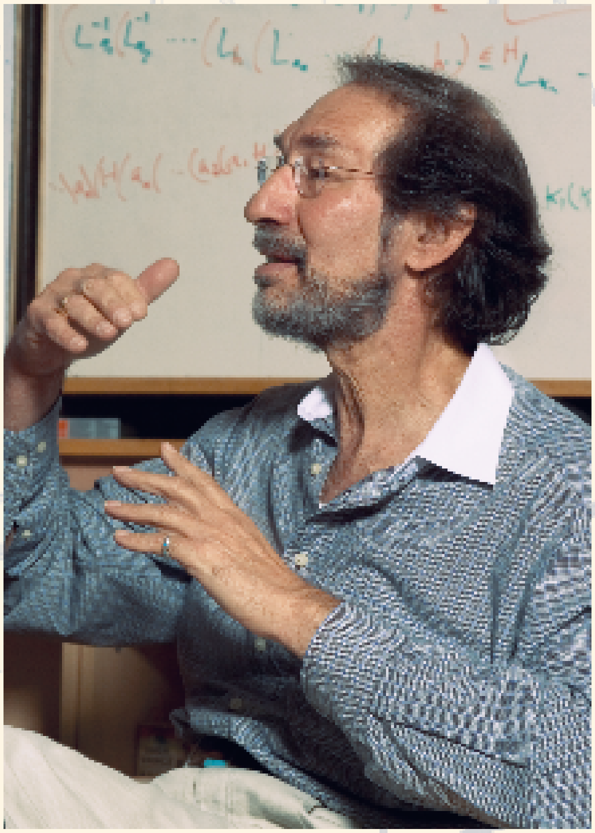
West: I also originally came through Los Alamos, which traditionally was a unique and highly supportive environment to do science. Unfortunately, over the last ten years or so, this situation has deteriorated so that, unwittingly in some ways, the lab has almost become hostile to basic science, in spite of itself. The reality was that if you were leading a basic research group, you had to spend a significant amount of your time defending the very existence of that group and trying to raise funds to keep it alive. I felt my role of running a successful group was to provide a highly supportive environment for them to do excellent science. This is very much the attitude that I brought with me when I came here.

Rethinking SFI Science

West: My own strong propensity is that it's very important for an institution like the Santa Fe Institute to be driven from the bottom up. We cannot impose our version of science on anyone here. We see our role primarily as facilitators, ensuring always that there is a flux of excellent people thinking about deep, fundamental problems at all scales, who also have interests that cross traditional disciplinary boundaries. In addition, we also help to guide the Institute in making decisions, not only about issues such as how many resident faculty members, postdocs, etc., we should have here, but we might also ask of each area of research or each program: Is this an area of science that we should be involved in? How should that be carried out? Who should be involved? Who else should get involved? Where is it going and what is its impact, and over what time scale? These sorts of questions are really part of the continuous dialogue among SFI researchers.

Primarily I'm excited by new ideas, new ways of thinking, and different twists on old problems that people can bring to the table. SFI can play a significant role in doing things that wouldn't normally or easily be done in a university or a national lab—though obviously there's often significant overlap. Identifying the serious mavericks or risk-takers who might make the difference is an enormous challenge.

An example is new work we're initiating in biology. One of the more qualitative fields of biology is ecology and it's one of the most important. It involves questions of sustainability, questions about the future of the environment, and so on. There are, however, relatively few quantitative, predictive aspects to that field. Much ecology tends to be characterized by investigations on specific sets of organisms in specific ecosystems. These investigations might look at a specific pasture, or a square mile on some prairie and analyze it to death—and this is very important to do—but if you're interested in the big picture of what the underlying principles might be, if there are any, and whether there are commonalities connecting ecosystems across the globe—then a much broader approach is required. Ultimately much of the power of science is its search for universality and commonality.



Recently we helped sponsor a small working group in Chile. It was made up of people who have begun to think in these bigger terms; they brought different expertise to the table. Some have thought a lot about questions of the origin and dynamics of the diversity of species, trying to determine the underlying principles. Another group has thought a lot about the questions of the distributions of various quantities like energy and resources in an ecosystem. What was realized was that there was surprising commonality of thinking and there was the potential of forming a unified theory of ecology, if we can bring all these ideas together and integrate them. So there was a tremendous amount of excitement generated, and the result is a more dedicated workshop at SFI in the fall. This is the sort of effort that has been difficult to put together anywhere else but the Santa Fe Institute.

Clearly, on the one hand, we want and need to be involved in some of the big questions that sit at the center of science but tend to get neglected because of the pressures and the nature of science as now practiced in universities. On the other hand, we'd also like and need to be involved in problems that are really at the edges, that are quite speculative, and maybe can't be taken very far, but it's important that they are investigated. An example is a recent workshop led by David Krakauer exploring the science of history.

On Finances

West: Another goal, which we're just beginning to address, is to really get the Santa Fe Institute on a deeply sound financial footing. Without having that real base core of funding to provide a cushion, wherever it comes from, our science potentially suffers, and the ability to attract truly outstanding people and put together the kinds of workshops or working groups we'd like becomes so much of a labor that it doesn't happen. This is becoming particularly crucial as federal budgets for science tighten and the focus of awards becomes ever more narrow. So it's very important.

On The Board

Wood: Absolutely critical to Geoffrey's and my ability to do our jobs is the very strong and vocal commitment of our new board leadership. Bill Miller and Ford Rowan have taken on their new roles with a vigor and a degree of commitment both intellectually and financially that sets really high standards for us and is a great encouragement because it's clear that they, on behalf of the board, are genuinely committed to this institution. Without that kind of commitment from the board it would be very difficult, if not impossible, to do the kind of job that Geoffrey and I want to do and plan to do for the Institute.

The Scientific Landscape

West: I believe that the existence of an institute like the Santa Fe Institute—and maybe there are other places like it, but in particular SFI—is really crucial in the academic landscape. It is a place that is not constrained by the conventional academic tenure process, the kinds of delivery systems that major universities demand of their faculty, and the sorts of constraints imposed by the funding agencies, which all point towards greater and greater narrowness and less and less concentration on some of the bigger questions. I should hasten to add that there is no question that the vast majority of research should, in fact, be disciplinary oriented and highly focused. However, it should not be at the expense of totally excluding the broader view that acts across traditional boundaries. I see SFI as a haven for nurturing such activities.

That narrowness was a problem perceived 20 years ago by the founding fathers of this institution, and they had tremendous foresight in seeing it, but one of the great ironies is that the situation has worsened over the intervening 20 years. Today more and more presidents, provosts, deans, and directors of funding agencies are speaking in favor of doing interdisciplinary work, getting involved with complex systems, and are thinking about some of the bigger questions, both intellectually and in terms of societal needs. And yet, by and large, that's not happening very much at the grassroots level within departments or in governmental agencies, so it's very important that SFI remains at the level of excellence that it is, and that it has the sort of feedback and enthusiasm that it garnishes from some parts of the academic community.

Wood: Geoffrey's right about the irony. One of the great successes of this institution in its 20 plus-year history is that SFI science and scientists are influential all over the world. There are growing complex systems efforts in Europe, South America, and the Far East, all of which can trace influence, if not direct lineage, to work that's been done here at SFI in the past.

> "THERE ARE GROWING COMPLEX SYSTEMS EFFORTS IN EUROPE, SOUTH AMERICA, AND THE FAR EAST, ALL OF WHICH CAN TRACE INFLUENCE, IF NOT DIRECT LINEAGE, TO WORK THAT'S BEEN DONE HERE AT SFI."

West: It is interesting how many people contact us from all over the world telling us about new centers that they are forming—derivations of SFI—and that they'd like to have some formal association with SFI.

Wood: We do need to consider licensing, Geoffrey. (laughter)

West: It's a very schizophrenic landscape, especially in terms of the funding. For example, we get generously funded by the

National Science Foundation, but they warn us that when the budgets get tight the first things to go are things that don't fit into the normal disciplinary boxes, despite the fact that the highest levels—the administrators and directors—are strongly encouraging agencies to get more and more involved in opportunities like this.

Threats to the Institute

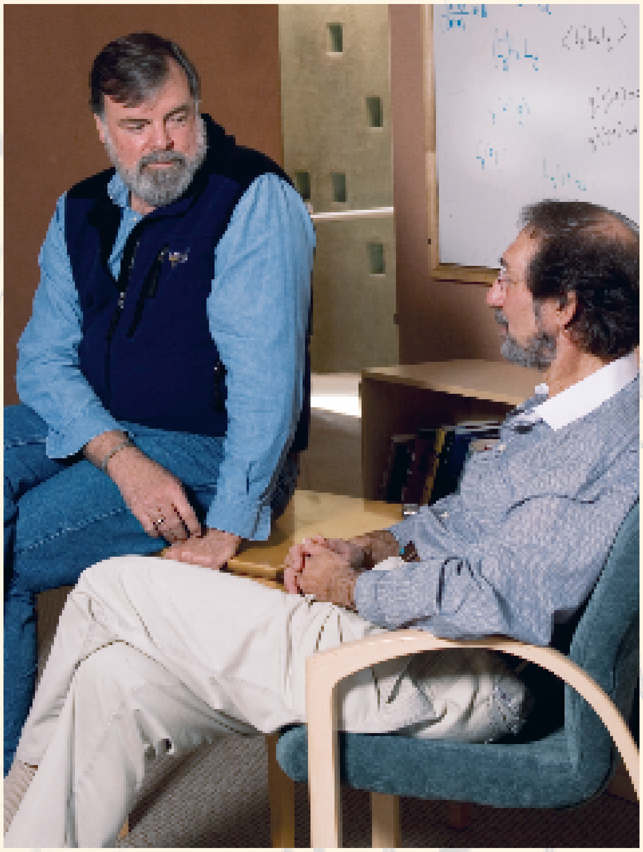
West: One major threat is that we're not going to rise to the challenge of really taking risks and doing exciting things. The pressure to do things that are safe is very strong. We need to facilitate new programs, take on collaborations that are a little bit out of the ordinary—take risks. And yet we have to make sure the ideas are not flakey, but instead have serious intellectual content, value, and potential.

Wood: Another threat would be the temptation to bask in our own success. As important as SFI has been, we cannot succeed by reinventing or revisiting those specific days or scientific efforts of the past. We need to invent the SFI science of the future. The rest of the world, whether we like it or not, is using what we've done and inventing their own versions. Many key scientific questions remain unanswered, and it is clear that the old ways of approaching them will not be adequate.

Romantic Science

West: There's no question that the traditional structure of universities is undergoing examination, especially in regard to crossing disciplinary boundaries, but it's still awfully difficult to accomplish change, and we flourish because of that. And I suppose—and maybe I shouldn't say this—but I would love to see a time come when there's no need for SFI. It would be wonderful if the philosophy of SFI were integrated into the canonical structure of universities. In fact, I often say the following and it resonates: The Santa Fe Institute is the place many of us thought we were going to when we were very young and contemplating academic life. We thought in our naiveté, that that's what universities were, a community of scholars from varying backgrounds with multiple talents and interests thinking about the great and deep issues of our time.

It was a totally romantic, unrealistic image of possibly what might have existed in the middle of the 19th century in some places—I don't know. And possibly it still does, somewhere. There might be remnants in a few Oxford and Cambridge colleges, but basically I don't think it exists now, if it ever actually did. Nevertheless, it's a wonderful and exciting fantasy. And I like to think that such a community of broad-thinking scholars following their noses in the search of a deeper understanding of the important intellectual issues and challenges of the day is what we are trying to approximate at SFI. I think it's a wonderful goal and I feel blessed that in my waning years, I can actually do what I wanted to do when I was sixteen years old. ◀



Forrester Research:

SFI Epitomizes the Innovation Broker

The Santa Fe Institute Business Network connects individuals from the world of business with researchers at the Institute. Recently, Forrester Research, an independent technology and market research company that provides advice about technology's impact on business and consumers, recommended the Business Network to its subscribers. The company writes reports on institutions they deem are pioneering new business models or business practices. It guides marketing executives, business strategists, and IT professionals in creating technology plans to help gain advantages. Forrester characterizes the SFI Business Network as an "innovation broker."

Here's a summary of Forrester's findings:

FIRMS CAN BOOST THEIR INNOVATION IQ BY JOINING THE SFI BUSINESS NETWORK

Forrester's framework for innovation called Innovation Networks emphasizes the interaction of diverse roles (Inventor, Transformer, Broker, and Financier) and abilities. In Forrester's terminology, SFI epitomizes the Broker; it was set up over 20 years ago to be a new kind of academic institution. Rather than being best in one field, it would be a place where world-class researchers in fields as diverse as linguistics and nuclear physics would meet, exchange ideas, and innovate. In our opinion, few institutions perform this role as well as SFI. Firms who want to be innovation leaders should join the SFI Business Network for the following reasons:

▶ **Get a decade-long lead on the next big thing.** Revolutionary innovations often come from the intersection of previously separate fields, and bringing together diverse leaders is SFI's mandate. For example, Honda sends its R&D scouts to SFI Business Network events to help them meet Inventors who can give them ideas about consumer and technology trends that lie on the 5- to 15-year horizon. At the same time, Honda's forays into jet engines and hydrogen-powered cars inform and inspire other attendees.

▶ **Evolve your organizational organism and avoid extinction.** Today's harsh business environment will only get harsher, especially since the major factors in the environment, competitors and customers, are constantly evolving too. Complex Adaptive Systems (CAS) principles show how evolution is likely to proceed and how firms can keep pace or lead. For example, Boeing's Phantom Works applies CAS principles to transform a new military strategy known as network-centric warfare into aircraft and weapons systems. To keep up with the increasing pace of innovation, companies should tap into SFI's insights on evolution's fundamental rules—and how to apply them to their own businesses.

▶ **Get involved in the experiments, and advance the science of business strategy.** Just as products and services evolve, business strategy-making itself is in a constant state of change. Whereas previous revolutions in management and organization came from military hierarchies and time-and-motion studies, tomorrow's strategies will come from understanding how birds flock, snowflakes form, or cells combine to create consciousness. For example, SFI Business Network member Capital One uses CAS principles—putting customer feedback and analytics tools in thousands of entrepreneurial employees' hands—to finance thousands of experimental microstrategies at once. Firms that gain SFI's insights and test them in the real world will find out first what inventions work—and finance their transformation to market faster than slower-moving competitors can.

For a copy of the full report, see www.santafe.edu/business/files/Forrester1105.pdf.

The Santa Fe Institute: An Innovation Broker, Forrester Research, Inc., November 2005.

PHOTO (LEFT): ©GALEN ROWELL/CORBIS; PHOTO (RIGHT): JAMES PETERSEN

AMAZONIA'S Hidden Civilizations

By Julian Smith

The lush rainforests of Amazonia, with their overwhelming profusion of green, fed by massive rivers and torrential downpours, were long thought to be a cultural desert. Despite the richness of the environment and the highly complex and successful cultures that existed just uphill in the Andes, the poor, shallow soils in the Amazon Basin were seen as an insurmountable hurdle to large-scale societies. This was the thinking for much of the 20th century. Recently, however, this view has shifted.

In a May 2005 meeting in Florianopolis, Brazil, sponsored by the Santa Fe Institute and the School of American Research, representatives of a kaleidoscope of disciplines came together to take a fresh look at long-term cycles of social and environmental change in the Amazon. The former image of virgin rainforest occupied by small nomadic groups has been replaced by one that also includes large, complex, long-lived human settlements

The pot sherds illustrating this story were found at the Açutuba II site in lower Negro, Brazil.

PHOTO: MICHAEL HECKENBERGER

Villagers wear Atugua masks in a Kuikuro Village in this 1993 photo taken in Brazil.

that left a subtle but increasingly unmistakable mark on their environment. This more accurate picture may shed light on the region's future development path based on its current social and economic realities.

Close to 20 physicists, economists, cultural anthropologists, archaeologists, and computer scientists met on the island to discuss recent research into how past and present indigenous populations in the Neotropics altered the diverse yet fragile surroundings. "We wanted to examine the relationship between environmental complexity and the development of social complexity," says co-organizer George Gumerman, SFI external professor and former interim president of the School of American Research.

Another purpose was also at work in the meeting. The group hoped to find ways in which historical models may inform our understanding of present-day interactions between societies and the environment, and vice versa. But ecologists, economists, anthropologists and archaeologists all look at their subjects at very different scales and formulate their models accordingly, which makes translation difficult. "We have to get our scales comparable," says Gumerman. "We have to combine them. That's where the computer modelers"—which made up roughly a fifth of the Florianopolis group—"came in."

"Part of the goal was to have people from different communities talk to each other—mostly archaeologists and ecologists," says co-organizer Steve Lansing, professor of anthropology at the University of Arizona and SFI research professor. "We're tribal," he says, referring to the way specialists in a field spend much of their time with their own colleagues. "We haven't talked to each other much." Now they are.

This new spirit of collaboration has already resulted in a shift in thinking

THIS NEW SPIRIT OF COLLABORATION HAS ALREADY RESULTED IN A SHIFT IN THINKING ABOUT THE PREHISTORY OF AMAZONIA.

about the prehistory of Amazonia. In the past decade, the stereotypical idea of tropical Latin America as ecologically pristine throughout most of its history has fallen out of favor. "When I was in graduate school," says Gumerman, "the prevailing thought was that 'high' civilization started in the Andean highlands and moved down to lowlands, but because of the depauperate environment, it couldn't maintain social complexity. Lately, though, it's been shown that complex societies did form in the lowlands, but they collapsed."

Evidence continues to mount showing that agrarian cultures thrived in the Amazon during much of the Holocene epoch (from about 10,000 years ago to the present), with large-scale agriculture, orchards, and fisheries, but these had largely vanished by the arrival of Europeans. "It looks like things were a lot more complicated and interesting than we suspected," says Lansing.

For the workshop, four geographical zones—three in Brazil and one in Central America—were selected based on the amount of information available on each. "There is very little archaeological data for so much of the Amazon Basin," says Gumerman. "We tried to find target areas that had the most archaeological, cultural, and environmental data available. Each "target zone" was assigned its own subset of researchers, who met as a group and also gathered with other groups.

Rivers defined two of the target zones in Brazil. Recent evidence suggests that the upper drainage of the Rio Xingu in the southern Amazon Basin may have held towns of 5,000 people, with complex social organization, by at least AD 1000. Unlike other Amazon regions, the ethnographic record in this area is more continuous and less interrupted by physical contact with Spanish and Portuguese settlers and the national governments they spawned.

Discussions about the Xingu focused on how sedentary populations managed to sustain both themselves and their environment. The recent discovery of *terra preta* or dark earth soils, adds fuel to the debate. While archaeological remains don't tend to last long in the warm, humid environment—thus few have been found—in the past decade, patches of darker, more fertile soils have been detected throughout the region, often by remote sensing. It's unclear whether these are the product of indigenous soil management or simply the byproduct of human settlements, but both explanations suggest that larger populations stayed in specific locations for longer periods of time than was once thought.

Past landscape signatures have also helped researchers determine that the next riverine zone, the Central Amazon Basin, may have held communities as large as those in the Xingu as early as 500 BC. The widespread use of polychrome ceramics (which don't travel well) by AD 400 suggested that fish, manioc, and other dietary staples were

PHOTO: BRIAN HECKENBERGER

PHOTO: JAMES PETERSEN

Top: The Açutuba II Site in the lower Negro of Brazil shows terra preta—dark earth—over an ancient plaza area.
Above: Researchers found pot sherds and other artifacts in this excavation site at Açutuba II.

THE SAMBAQUI BUILT BURIAL MOUNDS FOR UP TO 8,000 YEARS, AN EXCEPTIONALLY LONG DURATION FOR AN AMAZONIAN CULTURE, WHICH MAKES THEM AN EXCELLENT EXAMPLE OF STABILITY AND SUSTAINABILITY FOR THE REGION.

abundant enough for larger, more permanent settlements to evolve. Discussions about this zone emphasized the possibility that, based on the availability of resources and ongoing social or environmental changes, the inhabitants might have repeatedly shifted from hunting and foraging to fishing and agriculture.

In the third region, shell mounds up to 22 meters high offer clues to the past. The rich boundary environment inhabited by the Sambaqui peoples of coastal Brazil contains many of the mounds, which are also found as far north as Florida. They were once thought to be simply casual deposits of debris, but more recent archaeological evidence suggests that the piles were built deliberately of uneaten shellfish and other marine life to bury community members. The practice was preceded by feasting, and suggests that important, recurrent events prompted the community to rebury several individuals together.

The Sambaqui built burial mounds for up to 8,000 years, an exceptionally long duration for an Amazonian culture, which makes them an excellent example of stability and sustainability for the region. It's unclear why they eventually passed on, but their passage may have been associated with the arrival of Tupi-Guarani speakers, who brought their ritualized warfare practices to the Amazon Basin by AD 1000 or even earlier.

Researchers considered the fourth zone, the Yucatan Peninsula of Central America occupied by the lowland Maya, to be similar enough to the other three to fit into the larger discussion, but distinct enough to serve as a yardstick for comparison. While it received similar rainfall to the other zones, the natural limestone platform that stretched across what is now southern Mexico, Guatemala, and northern Belize accommodated fertile soils, allowing agricultural production on a much larger scale. Although surface water tended to drain away through the porous and pockmarked terrain, the Maya obviously figured out how to overcome this environmental hurdle, as their peak population reached as high as 2,000,000 during AD 100–900.

Why this highly complex culture suddenly collapsed around AD 900, leaving huge ruins to be swallowed by the jungle, is one of the great questions in archaeology. Warfare, the exhaustion of farmland, and drought may have contributed. In the Florianopolis meeting, talks on the Maya focused on how important the concentration of resources (through the construction of ancient roads and the storage of foodstuffs) was in fostering the development of the complex Maya society.

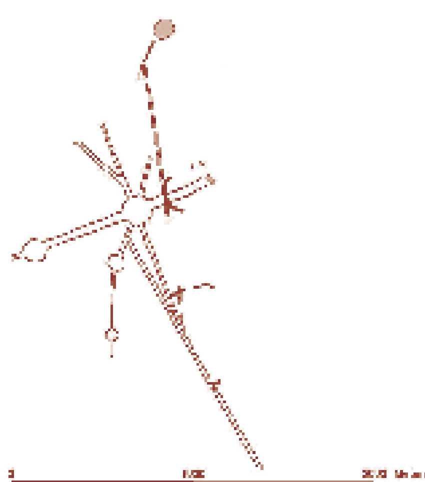
"The Brazil meeting was just a first step," says Lansing, "a success in some ways and less in others. It exposed real gaps in our approach to modeling, but it did create the beginning of a dialogue to be continued not just at SFI but more broadly. Seeds have been planted." A smaller meeting focused on modeling, held in Tucson in mid-December, was the first spin-off, but likely not the last.

"The real strength of the workshop was that researchers found areas where they could overlap," says Gumerman. "You had computer modelers from southern Brazil meeting archaeologists from Arizona. Individual teams are planning separate meetings with each other, to work on problems in specific areas."

"Too many scientists nowadays find reasons why we can't do something," he adds. "It would be easy to say, 'It's a huge area—far too complicated.' We come at questions from different perspectives, all trained in our own disciplines. Maybe we can't get answers out of this, but what's wonderful about SFI is you can say, 'This may be a crap shoot—but what if we win?'" ◀

Julian Smith is a writer and photographer specializing in science and travel. He is based in Santa Fe. This article is based on a workshop report by Vernon Scarborough.

PHOTO: MICHAEL HECKENBERGER



Above: From the air, this Kuikuro village of Ipatse in Brazil is organized around a broad plaza.
Left: This overview map shows the ancient settlement of Heulugihiti, with a GPS mapped road and plaza curbs or berms.

Deception:
What Lies Beneath

By Brooke Harrington

Recent psychological studies of deception indicate that in the course of a day, the average individual tells two to three lies. Though rates of lying generally decrease with the closeness of a relationship, people report lying in one-third to one-half the interactions they have with their mothers and their lovers. The prevalence of deception in everyday life is extraordinary, particularly given the negative valence attached to lying within human societies.

The complex relationship between people and lies has been a topic of interest in a wide variety of scholarly disciplines, from the life sciences, to the social sciences, to the humanities. But despite the wealth of accumulated knowledge, our understanding of lying (and deception generally) has remained fragmented. To ameliorate this problem, 16 scholars met at SFI last spring for a workshop broadly titled, "Deception: Methods, Motives, Contexts and Consequences." The participants included psychologists, a biologist, statisticians, a philosopher, a poet, and an English literature specialist.

We came together to review and compare what our respective fields have to say about deception, with the goal of structuring the disparate sources of knowledge into a more organized whole. The benefits of a broadly cross-disciplinary effort were quickly apparent, as the biologist found analogies and challenges for his work in the presentations by humanities scholars, and an archaeologist discovered useful models for his research in a talk by an economist. Indeed, by the end of the workshop, the elementary questions which had framed our meeting—"What or who deceives?" and "Why do some entities deceive, and how?"—had given rise to new questions, such as "Can we create models of deception that include both the intentional forms—like lying—and the unintentional forms, such as those created by protective camouflage in animals, or self-delusion in humans?"

We convened, appropriately enough, on the day American pop culture celebrates deception:

> "IF YOU TELL THE TRUTH YOU DON'T HAVE TO REMEMBER ANYTHING."
>
> *— Mark Twain*

The Cheater with Ace of Diamonds by Georges de LaTour. Oil on canvas. (1635) PHOTO © ERICH LESSING/ART RESOURCE

April Fool's Day. Bill Miller—chairman of the Santa Fe Institute Board of Trustees and CEO and chief investment officer of workshop sponsor Legg Mason Capital Management—pointed out that our meeting date also coincided with a literary event of particular significance to the workshop. It was the 148th anniversary of the publication of Herman Melville's *The Confidence Man*, which treats deception and the will to be deceived as defining features of the American national character. We could hardly have asked for better auspices.

Why Don't Chimps Lie More?

The workshop opened by considering, from the perspective of biology, the *limits* to deception in the animal kingdom. Carl Bergstrom, a theoretical biologist from the University of Washington, led

“IN HUMAN RELATIONSHIPS, KINDNESS AND LIES ARE WORTH A THOUSAND TRUTHS.”

— Graham Greene

off by asking why such a wide range of organisms—from bacteria to chimpanzees—share truthful information despite conflicting interests. In other words, why don’t animals exploit and undermine communication by sending misleading or manipulative signals more often?

Bergstrom’s questions were particularly provocative, coming as they did on the heels of Murray Gell-Mann’s comments the previous evening. Gell-Mann told us that sentinel birds employ deception in exactly one-seventh of their signals to each other—a behavior that appears to be motivated by the birds’ very sensible desire to distract their fellow sentinels from resources, such as the appearance of a tasty morsel. This is reminiscent of the tried-and-true practice of small children in some families, who create a distraction (“Look! The dog’s on fire!”) in order to scarf their siblings’ desserts. Even the sentinel birds’ strategy of falsifying only one-seventh of their signals makes sense: as most small children learn, deception strategies only work long-term if deployed in limited quantity.

Given the apparent rationality of deception as an adaptive strategy, Bergstrom asked us to consider why animal communication is generally reliable. Drawing on game theory, he explained how “costly signaling models” illustrate the value of truthful communication. In a talk punctuated by vivid illustrations of animal signaling behavior—including octopi bending their bodies into perfect simulacra of sole and other creatures—Bergstrom launched an animated discussion about the role of intentionality in deception, and asked whether we could create models of deception that would encompass both the intentional and unintentional varieties: a topic we revisited throughout the weekend.

KNOPF PUBLISHING

This photograph, taken in 1948 when communism was born in Czechoslovakia, was used extensively in propaganda. In the first rendition, Vladimir Clementis (far left) has placed a hat on the head of Klement Gottwald, the country’s new Communist leader. In the second, Clementis has been removed from the photo. Charged with treason, he had been hanged. “All that remains of Clementis is the cap on Gottwald’s head,“ wrote Milan Kundera in The Book of Laughter and Forgetting.

Desiring Deception

Stanford University statistician Persi Diaconis had a distinctive take on this issue, based on his experience as a professional magician. Diaconis—whose interest in deception provided the inspiration for the workshop—observed that people often *want* to be deceived. In other words, we accept the frequency of deception in social life because we like it that way. Sometimes we find it entertaining or pleasantly diverting, as when theatergoers suspend disbelief to watch Peter Pan "fly" across the stage or to watch a magician pull a rabbit out of a hat.

Sometimes too, as philosopher Sissela Bok of Harvard University reminded us, we find deception a comfort, a palliative for our suffering. Bok's talk reviewed the history of placebo administration, reminding us that—virtually unique in the realm of medical ethics—placebos involve a *sanctioned* deception. In the use of placebos, which dates back thousands of years, patients are given "treatments" by a trusted healer—usually a doctor—who does not tell them the true nature of what they have been given. Such deception is often conducted with the complicity of the patient's family: a conspiracy of kindness, thought to spare the patient needless suffering.

Should either consent or intent matter in our understanding and moral evaluations of deception? Gary Urton, Dumbarton Oaks Professor of Archaeology at Harvard University, posed this question by presenting us with evidence from his long-term study of the Inca Empire at the time of first contact with the Spanish. In a move reminiscent of the sentinel birds' strategy, the Inca fought for survival in part through intermittent use of false signals. Using their "khipu," a remarkably sophisticated form of accounting based on knotted strings, the Inca mislead the Spanish by understating the real extent of wealth and resources held within the Incan Empire. Though their effort failed to distract or discourage the Spanish colonial effort, Urton's research—like Bok's and Diaconis's—foregrounded some unexpectedly positive and adaptive aspects of deception.

A Climate of Distrust

In contrast, other presentations highlighted the corrosive and non-adaptive aspects of deception: the ways in which social life, individuals, and political freedoms suffer when lies go unchecked. For instance, Columbia University sociologist David Stark showed us how political operatives doctor photographs in order to further deceptive political agendas, creating a climate of paranoia and distrust. Ellen O'Connor, a professor of communication at the University of Notre Dame, drew on classics of modern literature—including *To Kill a Mockingbird*, *Glengarry Glen Ross*, and *The Crucible*—to show how deception depends on a climate of fear in order to survive and thrive. Those characters who insist on truthfulness are rare and always at risk of punishment—or even death—in the name of preserving the regime of deception.

PHOTO COURTESY OF THE SKEPTISEUM

In the early days of photography, "spirit photographs," produced by spiritualists, did not exist. Not until the double exposure was made possible did such illusory images appear.

Harvard University economist Richard Zeckhauser—in research conducted jointly with his Kennedy School of Government colleague Fred Schauer—showed how deception can infiltrate and damage social interactions through the seemingly innocuous form of partial truths. Deception, Zeckhauser argued, actually comes in two forms: lying and paltering. While lying involves wholesale fabrication, paltering employs only the truth as its raw material—strategically distorting the truth or conveying only selective favorable information. Yet paltering has the same motivations as lying, and the same potential consequences for recipients' beliefs and actions. Its basis in truth—however distorted—makes it difficult to identify palters, even when all information comes to light. As Zeckhauser pointed out, the truthful basis of palterers' claims gives them "plausible deniability," making it difficult to punish them, either directly or through reputation losses. This difficulty makes paltering arguably worse than lying; at a minimum, it degrades the quality of social interaction, creating a climate of distrust in the truth itself.

Truth Wizards

Given these hazards, it was somewhat surprising to learn just how vulnerable humans are to being deceived. As several workshop participants showed, the vast majority of people are virtually unable to detect deception when it is literally staring them in the face. This is all the more extraordinary because liars have a common set of involuntary facial movements—particularly in the small muscles around the eyes and mouth—that should make them easy to spot.

With training, we can learn to spot these facial cues, as we learned from Mark Frank, a professor of communications at Rutgers University. Frank does research on the physiology of deception in humans, drawing in part on a group he called the "Truth Wizards": 32 men and women with an extraordinary ability to detect when others are lying to them. Members of this group, culled from psychological testing on thousands of ordinary people, are diverse in every sense, with little in common except this unusual power of perception. Using the findings from the group, and from his other research, Frank trains law enforcement and counter-terrorism experts to see the involuntary physical signs of deception that most of us fail to notice in daily interactions.

Maureen O'Sullivan, a professor of psychology at the University of San Francisco who has also studied the "Truth Wizards," addressed the "why" question: That is, why can't we all be Wizards? Why are most people so bad at detecting deception, especially since such a deficit would seem to be a significant liability from the point of view of adaptation and natural selection? O'Sullivan's talk focused on systemic cognitive errors and self-delusion motives, both of which can be adaptive in many circumstances. Indeed, she noted that research on "positive psychology" shows that failure to spot lies, or a willingness to deceive oneself, can contribute to a positive, optimistic outlook, and thus a longer, happier life.

In this regard, we are aided and abetted by modern communication technologies. Research by Cornell University Communication Professor Jeff Hancock suggests that the telephone is the medium of choice for deception. While email might seem like the likeliest mechanism for deception, Hancock said, it also carries with it a sense of greater permanence or commitment—because it is in writing and often backed up—compared to the ephemeral and usually unrecorded remarks exchanged in conversation. Finally, telephone communications provide a veil of sorts for would-be deceivers, shielding many of their non-verbal cues (like the hard-to-control facial muscles that Frank and O'Sullivan discussed) from detection.

> "DURATION IS NOT A TEST OF TRUTH OR FALSEHOOD."
> — *Anne Morrow Lindbergh*

Heroic Liars

The workshop closed with a panel that—somewhat uncharacteristically for SFI gatherings—invoked the perspective of the humanities. It turned out to be an ideal way in which to explore the ambiguities and complexities that had been suggested by the other talks. As biologist Carl Bergstrom noted: "Bringing the conversation around to the humanities in the closing sections of the workshop helped us come back to the fullness of the phenomenon which aroused our wonder in the first place. It was similar to the way that good naturalists can help us return to the whole organism once we become overwhelmed by the reductionism of molecular biology, and as such made a deeply valuable contribution.”

Tom Lutz—a professor of English at the University of Iowa, and author of a well-known book on the history of emotion—drew from a combination of literary theory and autobiography to explore a question raised by several of the other talks: does deception require intent? In recounting his own history, Lutz delved into a number of ambiguities involved in deception, including cases in which people tell “honest lies”: making statements that they believe to be true at the time, but later recognize as false. As a result, Lutz argued, some emotional displays can be both honest and deceptive *at the same time*.

Poet Ken Fields, who teaches in the English department at Stanford University, closed the workshop with the observation that while deception is often condemned in modern Western societies, ancient cultures often made liars their heroes, and even their gods. What does it tell us about the ancient Greeks, Fields asked, that their pantheon included a god of deception (Hermes), and that their best-known epic hero—Odysseus—was lionized for his cunning tricks? As Fields pointed out, among the most common of the Homeric epithets used to describe Odysseus was *polymêtis*, signifying “much cunning intelligence.” Odysseus himself frequently celebrated his deceptions of others, as when he said, “My heart within laughed/ at how my name and faultless cunning had fooled him.” These examples bear particular scrutiny, Fields noted, given the purported embeddedness of modern American political, philosophical, and ethical reasoning in the Greco-Roman tradition.

Such observations deserve fuller exploration, and will likely get it since many of the participants found that the workshop renewed their passion for the subject. One of the most exciting aspects was the common ground they found across widely divergent fields of study. Ultimately, the workshop laid the foundations for a kind of “complexity theory of deception”—one that acknowledges the many facets, contradictions, and ambiguities surrounding the phenomenon.

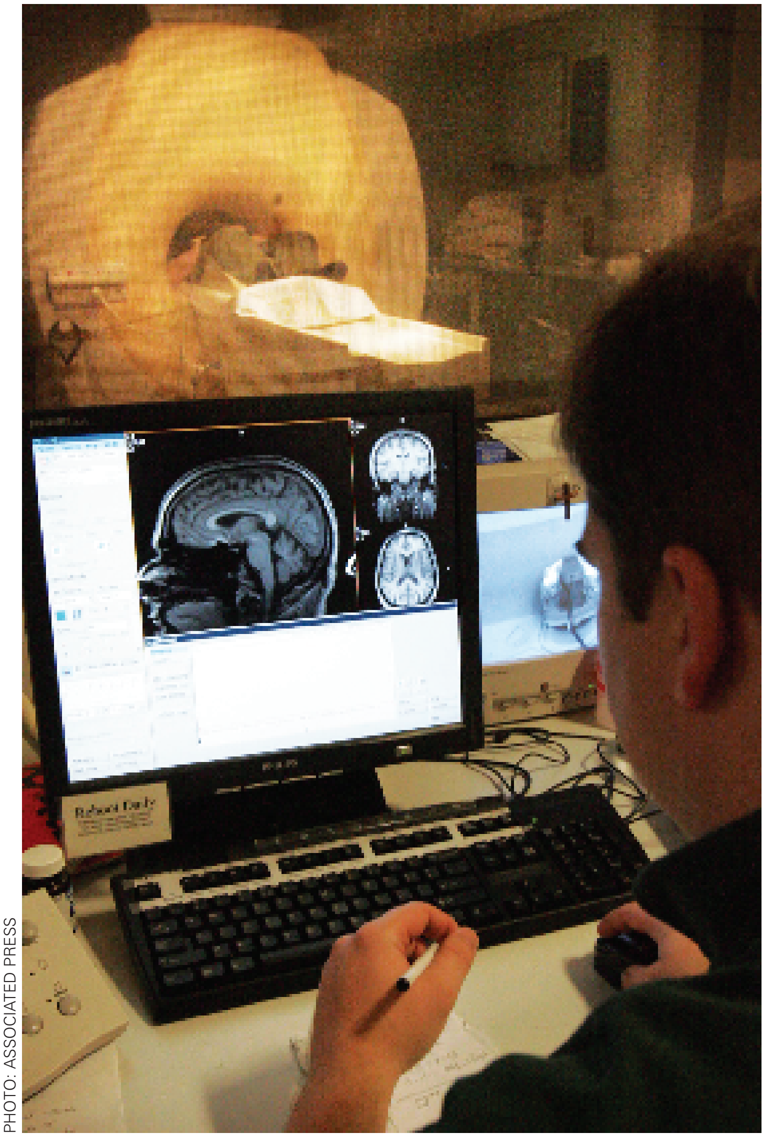


PHOTO: ASSOCIATED PRESS

Researchers at the Medical University of South Carolina and other notable institutions believe that use of functional magnetic resonance imaging (fMRI) technology could prove more accurate than polygraph tests in determining when a person is lying.

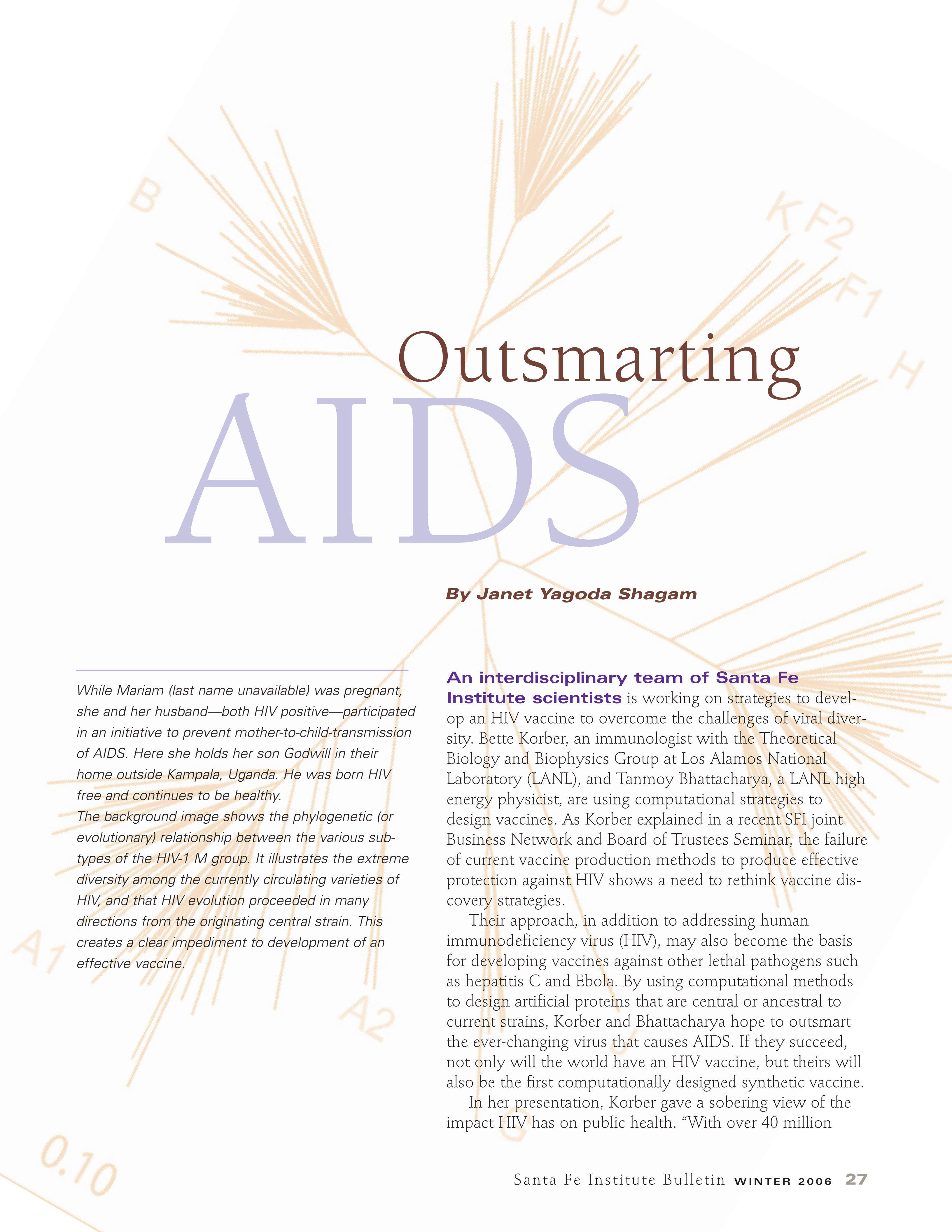
You can read more about the workshop, including participant biographies and supplemental material by accessing the workshop website at http://discuss.santafe.edu/deception. ◀

Brooke Harrington, Ph.D., is assistant professor of sociology and public policy at Brown University.

PHOTO: MAUREEN M-BARRACLOUGH

Outsmarting AIDS

By Janet Yagoda Shagam



While Mariam (last name unavailable) was pregnant, she and her husband—both HIV positive—participated in an initiative to prevent mother-to-child-transmission of AIDS. Here she holds her son Godwill in their home outside Kampala, Uganda. He was born HIV free and continues to be healthy.
The background image shows the phylogenetic (or evolutionary) relationship between the various subtypes of the HIV-1 M group. It illustrates the extreme diversity among the currently circulating varieties of HIV, and that HIV evolution proceeded in many directions from the originating central strain. This creates a clear impediment to development of an effective vaccine.

An interdisciplinary team of Santa Fe Institute scientists is working on strategies to develop an HIV vaccine to overcome the challenges of viral diversity. Bette Korber, an immunologist with the Theoretical Biology and Biophysics Group at Los Alamos National Laboratory (LANL), and Tanmoy Bhattacharya, a LANL high energy physicist, are using computational strategies to design vaccines. As Korber explained in a recent SFI joint Business Network and Board of Trustees Seminar, the failure of current vaccine production methods to produce effective protection against HIV shows a need to rethink vaccine discovery strategies.

Their approach, in addition to addressing human immunodeficiency virus (HIV), may also become the basis for developing vaccines against other lethal pathogens such as hepatitis C and Ebola. By using computational methods to design artificial proteins that are central or ancestral to current strains, Korber and Bhattacharya hope to outsmart the ever-changing virus that causes AIDS. If they succeed, not only will the world have an HIV vaccine, but theirs will also be the first computationally designed synthetic vaccine.

In her presentation, Korber gave a sobering view of the impact HIV has on public health. “With over 40 million

To give an idea how fast HIV changes, Korber compared it to the influenza virus. In a recent review published in the *British Medical Bulletin,* the researchers wrote, “The diversity of influenza sequences worldwide in any one flu season appears to be roughly comparable to the diversity of HIV sequences found within any single individual at one time point.”

Vaccines, by presenting the immune system with specific viral proteins, either on particle surfaces or as isolated proteins in solution, stimulate an immune system response. Because HIV surface proteins constantly change, the immune system cannot make an effective protective response against rapidly evolving new viruses. HIV infections last on average 10 years before one has AIDS signs and symptoms. This is ample time for unique mutations to develop and accumulate in each infected individual. This immune evasion and evolution within each person, and subsequent transmission of variant viruses, ultimately leads to the extraordinary diversity of HIV found at the population level.

Together, Korber and Bhattacharya, along with colleagues from Duke University Medical Center and the University of Alabama, Birmingham, have created an artificial consensus protein by computationally select-

“THE DIVERSITY OF INFLUENZA SEQUENCES WORLD-WIDE IN ANY ONE FLU SEASON APPEARS TO BE ROUGHLY COMPARABLE TO THE DIVERSITY OF HIV SEQUENCES FOUND WITHIN ANY SINGLE INDIVIDUAL AT ONE TIME POINT.”

people worldwide infected with HIV,” she said, “AIDS is destroying whole societies.” She cited statistics: The situation is particularly devastating in developing nations where as many as 25 to 40 percent of the adult population live with HIV. In South Africa, which has one of the fastest expanding HIV epidemics in the world, over 6.3 million people have the disease and one out of every three pregnant women is HIV positive. At the end of 2003, nearly 1.2 million people in the United States had been diagnosed with HIV.

Unlike viral pathogens that cause diseases such as polio and hepatitis B, HIV changes so rapidly that vaccines cannot protect from the ever-expanding number of antigenically distinct strains. To complicate matters further, the viruses within each patient eventually develop into a unique collection of HIV substrains or quasispecies, and divergent viruses can infect the same person and recombine to create distinctive new forms.

ing the most common amino acid at most positions in all viral subtypes and testing it in preliminary vaccination studies on small animals. In a sense, this is analogous to determining a biochemical or physiologic “common denominator.” By taking this approach, Korber explains, “we use data rather than the environment for optimizing genetic fitness.”

So far the results are promising. The artificial proteins are biologically functional. They cross-react with patient sera containing multiple viral subtypes and they stimulate antibody production and cytotoxic T-cell responses in mice and guinea pigs. “Our colleagues

Above: SFI Research Professors Tanmoy Bhattacharya, a Los Alamos National Laboratory (LANL) high energy physicist, and Bette Korber, a LANL immunologist with the Theoretical Biology and Biophysics Group, use computational strategies to design vaccines.

are moving forward to begin testing this vaccine in macaques in a direct comparison with conventional natural protein vaccines," says Korber. The team hopes the results will be good enough to eventually begin small-scale human vaccine trials.

As a prelude to this work, Korber and Bhattacharya have used parallel computing tools to reveal the evolutionary origins of HIV. Many believe that HIV arose fairly recently, but their model suggests that HIV was quietly living among us for at least 50 years prior to the discovery of AIDS in 1981. There are several experimentally proven cases that support the view that HIV was with us prior to the discovery of AIDS as a disease; the earliest case comes from a frozen blood plasma sample taken from an adult male living in the Democratic Republic of the Congo (Zaire) in 1959. As people who die of AIDS die of an opportunistic infection that can manifest in many ways, it was probably difficult to detect AIDS in the human population in the early phases of the epidemic.

However, Korber and Bhattacharya's model pushes HIV emergence back to an even earlier date. Using the global HIV sequence database developed and maintained by Korber at the Theoretical Biology and Biophysics Group (LANL), they used parallel computing methods to "clock" genetic changes back to a common viral ancestor. Their computational model correctly predicted two historical data points—the 1959 blood plasma sample and the HIV strains present at the beginning of a well-documented Thai epidemic in 1986-88. Prediction of these two "test points," supports the validity of their assumptions, computational methods, and an emergence date that, according to Korber and Bhattacharya, could be around 1930, as early as 1915, or as late as 1940. Using the tools they developed for this study to model the emergence of HIV, they were able to create model ancestral sequences that they could ultimately use for HIV vaccine design.

For Korber, HIV is considerably more than a theoretical puzzle or an academic exercise. The origins of her passion and perseverance for HIV research goes back to her graduate school days at Caltech and a housemate who died of AIDS. In an understated, yet revealing statement, Korber says, "He taught me a lot." To overcome her frustration and her grief, she left strictly physiological immunology and took a postdoctoral position in a laboratory doing retrovirus research as her way to "do science in service."

In 2004, Korber received the Ernest Orlando Lawrence award for her work in delineating HIV genetics and the development of the Los Alamos HIV database. In addition to a citation signed by the Secretary of Energy and a gold medal bearing the likeness of Ernest Orlando Lawrence, the award also includes a $50,000 prize.

In keeping with her philosophy of doing science for the benefit of others, Korber used the award money, along with donations from family and friends, to build an AIDS orphanage in South Africa. "Now," she says, "one hundred sixty five children have a place to live and people to take care of them." ◀

Janet Yagoda Shagam, Ph.D. is a freelance medical and science writer living in Albuquerque.

PHOTO: MAUREEN M-BARRACLOUGH

Villagers stroll home from church Sunday morning on a street leading to the small fishing town of Gaba on the shores of Lake Victoria in Uganda.

PHOTO © ALAMY IMAGES

THE FUTURE OF AGENT-BASED MODELING

by Janet Stites

In the early 1960s, mathematician Benoit Mandelbrot began to study the prices of a number of commodities, of railroad securities, and of diverse interest rates. Although the nature of how the products were sold varied, he found the prices followed scaling laws; that is, when the price movements were observed at different time intervals, they showed similar patterns. Like fractals, which he named and made famous as modeling tools, these price series showed structure and self-similarity at different scales.

At the time, his findings were summarily dismissed, even disputed, as they contradicted popular economic theory that prices on financial markets followed the toss of a coin. “Hardly anybody knew what I was talking about,” he says now from his position as Sterling Professor of Mathematical Sciences at Yale University. “And if they found I was right, they didn’t publish it because it wasn’t fashionable.”

Mandelbrot continued to expand his work and by the 1980s other studies began to appear confirming his earlier findings. His 1963 paper on cotton pricing resurfaced as his best-known work on the topic and became the inspiration for modern-day agent-based modeling, particularly for the financial markets.

In October, Mandelbrot opened a day-long session in New York City on “Agent Models in Financial Economics,” hosted by SFI, Credit Suisse First Boston, and Legg Mason Capital Management. The seminar served as a time to reflect on the history of agent-based modeling, and SFI’s role in it, as well as give a blueprint for the future of the modeling approach. Leaders in the field who spoke at the event included Prediction Company co-founder and SFI researcher Doyne Farmer, Brandeis’s Blake LeBaron, MIT’s Andrew Lo, and Yale’s Shyam Sunder.

As computers become more and more sophisticated and markets continue to spew out an increasing amount of data on a daily basis, researchers are eagerly collecting data sets, and people in the financial industry are taking notice. Many suspect that if economists can build computer models illuminating patterns in various financial markets—particularly mapping volatility—investors could minimize risk and reap the rewards. But the task is daunting and still in its infancy.

The models may not be able to prove or disprove an economic theory, but the practice can distill a certain aspect of a theory or illuminate a single mechanism. Most importantly, the models allow economists to study volatility, something long overlooked and long dismissed in terms of recognizing patterns. As Mandelbrot has written, “If the weather is moderate 95 percent of the time, can the mariner afford to ignore the possibility of a typhoon?”

While financial gain is a clear motivator for modeling financial markets, researchers outside of the commercial world are interested in the data and patterns they reveal for reasons other

OF FINANCIAL MARKETS

> "IF THE WEATHER IS MODERATE 95 PERCENT OF THE TIME, CAN THE MARINER AFFORD TO IGNORE THE POSSIBILITY OF A TYPHOON?"

than potential wealth. For one, economists such as LeBaron, who has been involved in modeling since the early 1990s when he spearheaded the economics program at SFI, believes key debates in finance, such as those on market efficiency and rationality and the role behavior plays in decision making, might be deflated by analyzing the data of the markets. From the pure scientific perspective, particularly in regard to evolutionary biology, financial markets provide a good approximation to a crude fitness measure through wealth or return performance.

Doyne Farmer says researchers often use modeling as a way to try to understand statistical properties about the market that don't involve things you can profit from, such as how big a price change can be, but not whether it goes up or down.

Early models, developed in the late 1980s and early 1990s included SFI's own Santa Fe Artificial Stock Market (SF-ASM), the idea for which was fostered by economist Brian Arthur and genetic algorithm developer John Holland, who reached out to physicist Richard Palmer and computer scientist Paul Tayler (LeBaron joined the team in 1993). SF-ASM was one of the first studies to challenge the idea that financial markets are in equilibrium. Ultimately the model was merged with artificial intelligence guru Christopher Langton's SWARM project. While the SF-ASM project is currently dormant, the SWARM version of the model is still available and people continue to experiment with it. Other models of that time came from French economist Alan Kirman, German economist Thomas Lux, and the team of Haim Levy, Moshe Levy, and Sorin Solomon.

Twenty years after the first models, there is not one prevailing method of modeling. "The field is very much all over the place," says LeBaron. He notes that researchers tend to focus on one aspect of the market to model, whether it be prices, trading volume, or order flow.

LeBaron's own work has shown how agent-based computational markets can generate patterns in liquidity and how these patterns are connected to generating realistic dynamics in both price and trading volume time series. Over the years, he has seen some unexpected results. "What I've seen is a tendency for the agents to occasionally concentrate on a small number of strategies," he says. "When this happens it is hard to find other people to trade with and the market becomes unstable. Somebody needs to take the opposite side of the trade." As a result, prices and trading volume may drop dramatically. It is during these times, LeBaron posits, that you see high volatility, big changes in pricing, and crashes.

The "agent" part of agent-based modeling can have many characteristics. In some models agents are programmed as a series of "if–then" statements: If A happens…Do B; If C happens…Do A. Others use genetic algorithms (GAs), allowing them to learn from their errors and evolve. Others use neural networks.

According to Farmer, the big challenge for agent-based modeling is this: Can it work well within the classical scientific method? "It's hard to match up the model to the real world," he says. "When you build the model, you're forced to make a lot of ad-hoc assumptions about how the agents behave. Sometimes these assumptions are far from reality."

Farmer uses the example of building a simulation of traffic in a particular city. "It's easy to model the streets and

PHOTO © ALAMY IMAGES

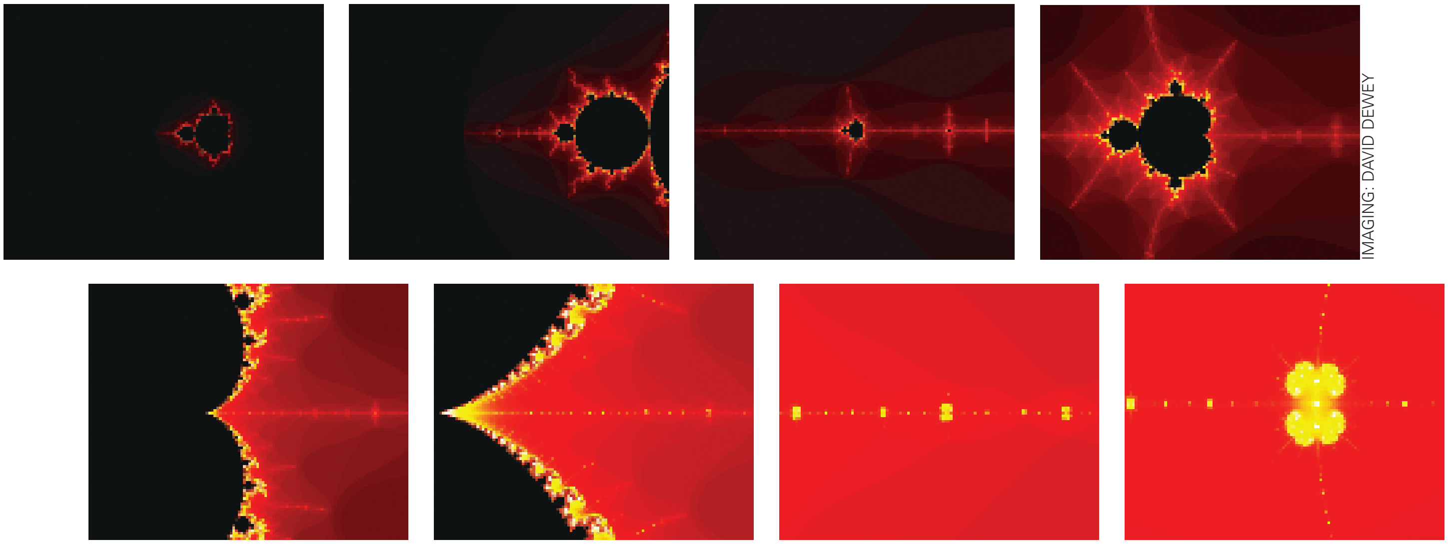
Trading at the London Stock Exchange: Data allows SFI Research Professor Doyne Farmer and his team to work with a complete record of actions by the traders.

the stop signs or take into account the speed of a car on the freeway versus the speed of a car on a side street," he says. "It's harder to determine how people make decisions, such as why they take a side street on a particular day instead of the freeway."

For his latest project, which models price formation, Farmer chose to work with data from the London Stock Exchange because it contains a complete record of actions by the traders as well as their effect on prices. He and his team began by assuming that the traders had "zero intelligence" (ZI), an approach initially developed by Yale's Shyam Sunder and New York University's Dan Gode in 1989.

"To get a feeling for how the trading process interacts with people's decisions, we began by assuming that people are stupid and behave randomly," says Farmer. "The agents in the model randomly place orders, flipping coins to decide whether to buy or sell and what price to pay." As extreme as these assumptions are, they produced results that agree with the real data in many respects. "This shows that there are many aspects of market behavior whose explanation does not depend on rationality or even intelligent decision making—they just depend on the market structure," he says.

To improve on these results, Farmer uses an approach that he calls "empirical behavioral modeling," which lies between the standard econometric and microeconomic approaches to model building. "Instead of imposing a preconceived model of human behavior, such as rationality," he says, "we look carefully at the data to find behavioral patterns." Farmer and his team then simulate the market based on the patterns, and make predictions about how prices will behave. "Note that we aren't trying to predict the market," he says. "We're just trying to predict system



IMAGING: DAVID DEWEY

Enhanced Mandlebrot sets depict complex geometric shapes. Buried deep within these mathematical forms are self-similar "fractal" patterns that emulate shapes found at higher levels. Natural systems often display similar behavior; for example, a coastline has a similar shape whether we view it from outer space or zoom in on just a few feet of beach front.

properties, such as why prices fluctuate more in one market than they do in another." The resulting models make very good predictions about price volatility and the difference between buying and selling prices.

Yale economist Shyam Sunder uses the zero intelligence model to try to understand if there is intelligence in not being intelligent. "A degree of randomness may give one a strategic advantage," Sunder says. "If I knew in a game of tennis that every time my opponent lobbed the ball to the baseline, my best shot is forehand down the line, and I continued to follow that rule, he could figure it out and react accordingly. If I introduced a degree of randomness, I might do better."

Sunder's initial foray into using agent-based modeling to better understand the financial markets came in 1989 when he had his MBA students teamed with computer science students to try to determine if, in fact, program trading (that is, trades made automatically by pre-programmed computers) had caused the stock market crash of 1987. He was especially interested in the problem because the idea that it had done so threatened to stifle the promise of technology in the financial markets.

The students found several surprising outcomes, including that short and simple trading strategies did well in the market, not because they were smart in the sense of being sophisticated, but because they were "there" all the time and were fast. What's more, markets populated entirely by zero-intelligence traders, who had no ability to anticipate or strategize, were at least as efficient in aggregate, doing as well, or better than, the strategies devised by students which had been based on their own ideas.

Nearly two decades after the "program trading" scare of 1987, the use of technology on Wall Street has not lessened. Sunder warns, however, that before we can build a proper model, we need more data and we need to learn how to map expectations. He plans to continue to pursue the idea that randomness confers advantage by continuing to work with zero intelligence models. One advantage of his "keep the agents simple" strategy is that he doesn't need additional computing power or data sets. "I can pretty much do what I need on my desktop computer," he says.

While there is no comprehensive list of economists and scientists doing agent-based modeling of the financial markets, there are those whose work

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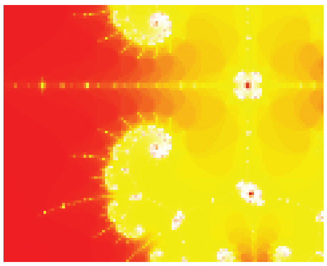
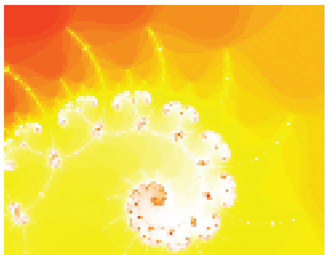
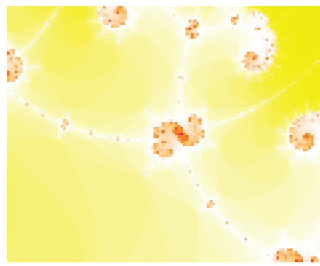
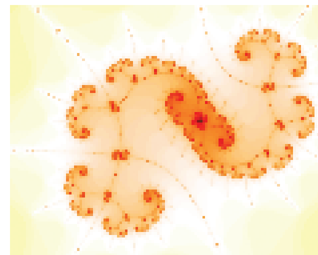








has, and continues to, contribute to the foundation of the field. Teams like Haim Levy, Moshe Levy, and Sorin Solomon have gotten much attention for using "microscopic simulation" to model markets, a methodology that was developed to solve physics problems. The model uses a computer to represent and keep track of individual elements in order to investigate otherwise intractable complex systems.

Another researcher who has been a pioneer in modeling financial markets is economist Alan Kirman, currently at Princeton's Institute for Advanced Study, on leave from the University of Marseilles. He develops models with the underlying idea that agents in the markets meet each other and learn to trade together. They imitate each other and are influenced by what others expect. "The fundamental difficulty in modeling financial markets is that you cannot treat the traders as one glorified average individual," he says. "You have to handle the fact that the behavior of the aggregate is basically different from that of the individuals that make it up."

The modeling work of former SFI graduate student Vince Darley, of London-based consulting firm Eurobios UK, gained attention when he was asked by NASDAQ to build a model to predict how the exchange's plan to move from denominating shares in sixteenths of a dollar to dividing its dollars into cents would affect trading. According to a report in *The Economist*, Darley's predictions were not perfect (his agents traded at larger volumes of shares than real people did), but some of his other forecasts were accurate.

As the amount of data increases, the potential of computer modeling will grow exponentially. "There will be more features and data to estimate various parameters and models with," LeBaron says. "This is a big plus."

In the meantime, researchers such as Farmer, LeBaron, and Sunder struggle to find the tools to make their model legitimate, whether they be data or computer power. "The big needs now are in software," LeBaron says. "I still dream of the ultimate software package to model with and share pieces with others. It doesn't exist." Not yet anyway. ◀

Janet Stites is a freelance writer specializing in science, technology, and finance. She has written for The New York Times, OMNI Magazine and Fortune Small Business. *She lives in New York City.*

SFI Community Lectures

Wednesday, February 22, 7 p.m., Lensic Theater

Co-sponsored with the School of American Research

The "Hobbit" of Flores Island: Body and Soul

Dean Falk, Hale G. Smith Professor and Chair, Anthropology, Florida State University
With J. Stephen Lansing, Professor, University of Arizona and Santa Fe Institute

Scientists were shocked at the recent discovery of a miniature human species (LB 1, Homo floresiensis) that lived a mere 18,000 years ago on the Indonesian island of Flores. The most complete specimen is a three-foot tall woman, nicknamed "Hobbit," who had long arms, and a little ape-sized braincase. Associated archaeological evidence suggests that this tiny species fashioned sophisticated tools, hunted miniature elephants, made fire, and cooked. How could this be, given its tiny brain? To glean details about its brain, an international team analyzed three-dimensional computed tomographic (3DCT) reconstructions of Hobbit's internal braincase. Their findings have startling implications for the evolution of the brain and intelligence not just in hobbits, but throughout the human fossil record.

Wednesday, April 5, 7:30 p.m., James A. Little Theater

The Origin of Life

Christian de Duve, Nobel Laureate (Medicine 1974): Founder, International Institute of Cellular and Molecular Pathology; Professor Emeritus, University of Louvain and Rockefeller University
With D. Eric Smith, Professor, Santa Fe Institute

The origin of life is generally taken to be the outcome of progressive chemical complexification. This process presumably led from small organic molecules, such as amino acids, sugars, and nitrogenous bases, now known to be produced on a large scale by cosmic chemistry, to an organism called the LUCA, or last universal common ancestor, from which all known living organisms have been shown to be descendants. In spite of a considerable amount of high-level research, the nature of the chemistry used by the LUCA remains largely unknown. Consideration of the mechanism whereby early small-molecule chemistry may have changed into biochemistry suggests that life may have been launched by processes related to those used by cells today. If this is so, enzyme-like catalysts probably were involved. De Duve will discuss the possibility that small peptides and other "multimers" may have played catalytic roles in an era before large protein enzymes had formed, a view of the emergence of life that he has pioneered.

Wednesday, May 10, 7:30 p.m., James A. Little Theater

More than You Know: Finding Financial Wisdom in Unconventional Places

Michael Mauboussin, Senior Vice President, Legg Mason Capital Management, Inc.
With John Miller, Professor, Carnegie Mellon University and Santa Fe Institute

Because most occupations encourage a degree of specialization, most of us end up with pretty narrow slices of knowledge. For example, many economists base their models on rational investors or normal distributions without looking at how the world really works. The core premise of this talk is simple to state but devilishly difficult to live: you will be a better investor, parent, friend—person—if you approach problems from a multidisciplinary perspective. Mauboussin will discuss how lessons from Babe Ruth, Tupperware parties, the Wright Brothers, and ant colonies can make you a better decision maker.

Wednesday, July 12, 7:30 p.m., James A. Little Theater

The Mother of Mass Extinctions: How Life on Earth Nearly Ended 250 Million Years Ago

Douglas Erwin, Professor at the Santa Fe Institute and Senior Scientist, National Museum of Natural History, Smithsonian Institution
With David Krakauer, Professor, Santa Fe Institute

During the greatest biodiversity crisis in the history of life some 250 million years ago, over 90 percent of all the species in the oceans died off in just a few hundred thousand years. Douglas Erwin, author of the new book *Extinction! How Life on Earth Nearly Ended 250 Million Years Ago* discusses his research in China, South Africa, and the western U.S. in search of the causes and consequences of this great mass extinction.

Tuesday, Wednesday, Thursday, September 12, 13, 14, 7:30 p.m., James A. Little Theater

Stanislaw Ulam Memorial Lectures: On Plants—From Genes to Genomes to GM Foods
Nina Fedoroff, Evan Pugh Professor of Biology, Willaman Professor of Life Sciences, Pennsylvania State University; External Professor, Santa Fe Institute. Fedoroff is co-author (with Nancy Marie Brown) of *Mendel in the Kitchen: A Scientist's View of Genetically Modified Foods.*

Tuesday, September 12: **How Plants See, Feel, and Smell: the Perceptual Apparatus of the Plant Kingdom**
Plants detect and respond to light, touch, gravity, humidity and the myriad chemicals they encounter in the air and soil. They also react to other plants, to animals, and insects that chew on them, and to microorganisms that invade them. This lecture focuses on how plants change their shapes, their growth patterns, and their chemical arsenals in response to what they encounter in the environment, describing the molecules inside plant cells that detect and respond to the outside world.

Wednesday, September 13: **The Jumping Genome: Changing Ideas about Heredity and Evolution**
The first half of the 20th century witnessed the birth of genetics as the science of genes, identified as units of heredity by the monk Gregor Mendel late in the 19th century. Genetics became the study of the regular and measured inheritance of genes from parents to offspring. Watson and Crick's 1953 model of DNA structure provided a solid molecular scaffold for the geneticists' ideas. But even at midcentury, a revolution was brewing when Barbara McClintock announced that genes didn't always stay in place, but could sometimes jump from chromosome to chromosome. This lecture explores how molecular biology, and especially the sequencing of the DNA of many animals and plants, profoundly changed our understanding of both heredity and evolution.

Thursday, September 14: **Genetically Modified Foods: Monsters or Miracles?**
We're bombarded with conflicting information about genetically modified (GM) foods. There are many claims: Rice modified to produce vitamin A will save millions of malnourished children. Bt cotton will reduce pesticide use. Bt varieties will reduce fungal toxins in corn. But there are also warnings: Round-up Ready soybeans will require more herbicides. Pollen from Bt corn will kill gypsy moths. Gene flow from GM crops could decrease biodiversity. What are we to believe? This lecture examines the history of food crop modification, describes the differences between previous and present methods of modifying food plants, and addresses food safety and biodiversity concerns about GM foods and crops.

Wednesday, November 15, 7:30 p.m., James A. Little Theater

Forecasting Natural Disasters in the Chaotic and Complex Earth
John Rundle, Interdisciplinary Professor of Physics, Civil Engineering and Geology; Director, Center for Computational Science and Engineering
With Geoffrey West, President and Distinguished Professor, Santa Fe Institute

In the recent past we have seen the December 2004 Sumatra earthquake and tsunami; the August 2005 Hurricane Katrina that destroyed New Orleans and the Gulf Coast; and the October 2005 Pakistan earthquake. Other, less catastrophic disasters include a multiplicity of landslides, flooding, wildfires, tornadoes, and epidemics. For many of these events, vast quantities of satellite data are opening new horizons to better understanding. Using space-time patterns and information about the dynamics of these high-dimensional nonlinear earth systems, it is often possible to construct numerical simulations that can be used to make predictions about the evolution of the system and the possible occurrence of extreme events.

The lectures are made possible through support from community supporters, and they are underwritten by Los Alamos National Bank. For information on how you can help support the Public Lecture Series, please contact Ginger Richardson at 505-946-2749, or grr@santafe.edu.

There is no admission charge, but seating is limited. The talks are generally held at 7 p.m. at the James A. Little Theater on the campus of the New Mexico School of the Deaf, 1060 Cerrillos Road, Santa Fe.

For more current information about a particular talk, visit our website at http://www.santafe.edu/sfi/events/publiclectures.html or call 505-984-8800.

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

TRANSITIONS

Research Professors

Tanmoy Bhattacharya, in a joint appointment with Los Alamos National Laboratory, works on evolution of viruses and host-virus interactions, phylogenetic methods and their applications, rational design of vaccines and observed quantum systems.

Paleobiologist **Doug Erwin**, is in a joint appointment with the National Museum of Natural History, Smithsonian Institution. His research interests are evolutionary innovation, causes of end-Permian mass extinction and biotic recovery following mass extinction, and evolution of development.

Jon Wilkins comes to SFI from the Society of Fellows at Harvard University. His prior work focused on coalescent theory and genomic imprinting; his current research expands into human demographic history, altruism, cultural evolution, and statistical inference.

External Professors

Nihat Ay, mathematics and physics, University of Erlangen-Nuremberg. His research interests are in information-theoretic approaches to neural networks; mathematical aspects of robustness in biological systems; mathematical learning theory; and classical and quantum information theory.

Bailin Hao, T-Life Research Center at Fundan University and the Institute of Theoretical Physics, Beijing. His research interests include theoretical physics, computational physics, nonlinear science, and theoretical life science.

Supriya Krishnamurthy, Distributed Systems Laboratory, Swedish Institute of Computer Science. Her research focuses on using the tools and techniques provided by non-equilibrium statistical mechanics to understand problems in other fields such as biology, computer science and finance.

Fabrizio Lillo, economics and biology, Universita` degli Studi di Palermo. His research focuses on modeling classical or quantum processes with power-law distribution and/or long memory properties; microstructure of limit order book-driven financial markets; and the role of genomic information in determining gene regulation.

John Pepper, ecology and evolutionary biology at the University of Arizona. He works on dynamics of multilevel selection, or systems in which natural selection acts simultaneously at more than one level in a biological hierarchy.

Postdoctoral Fellows

Lauren Buckley received her Ph.D. in biological sciences in 2005 from Stanford University. Her research examines how energy use and availability govern the density, distributions, and diversity of reptiles and amphibians across spatial scales.

Stanca Ciupe is an SFI postdoctoral researcher working with Alan Perelson on the Human Frontiers in Science project. Her research focuses on developing mathematical models for the study of immune system reactions against viral diseases, namely HIV infection and hepatitis B infection.

Michael Gastner's interests include complex networks including transportation networks, Internet, utility networks, social networks, network models, network algorithms; statistical mechanics-Monte Carlo simulation, simulated annealing, diffusion; and geography-cartography, visualization of social phenomena on maps. His 2005 doctorate in physics is from the University of Michigan.

Chen Hou's 2005 Ph.D. in physics is from the University of Missouri at Columbia. He works with Geoff West on universal scaling laws.

From Cornell with a degree in neurobiology and behavior, **Joshua Landau** works in the areas of null model analyses, mathematical ecology, random graph theory, community ecology and entomology.

Thimo Rohlf received his Ph.D. in theoretical physics in 2004 from the University of Kiel. Most recently he was a postdoctoral fellow with the J. Jost group at the Max-Planck Institute for Mathematics in the Sciences in Leipzig, Germany. At SFI, Rohlf works on regulatory networks and evolution of multicellularity.

From Cornell with a background in materials physics, **Jessika Trancik** researches sustainable energy generation and, in particular, ways to reduce the costs of renewable energy systems, including nanoscience research on low-cost photovoltaics and driving innovation in the photovoltaics industry.

International Fellows

Miguel Fuentes, from Centro Atomico Bariloche, Argentina, was in residence June 2005 to work with David Krakauer on robust signal transduction through kinetic spatial patterning.

Francisco Gutierrez, Universidad Nacional de Colombia, visited SFI in July 2005. His main interests are political economy of war, democratization, and political parties.

Jorge Velasco-Hernandez was at SFI July 2005. From the Instituto Mexicano del Petroleo, he researches the mathematics of function and structure of bacterial consortia and the mathematics of the population dynamics of computer viruses in networks.


PHOTO: ROBERT BUELTEMAN ©2004

Undergraduate Fellows, Summer 2005

Bradley Chase, computer science and physics at Rice University, worked with Alfred Hubler examining the relationship between information and energy in the context of simple physical systems.

Virgil Griffith worked with Doyne Farmer examining the relationship between information and energy in the context of simple physical systems. Griffith is a cognitive sciences major at Indiana University.

Chris Kempes from Colorado College joined Geoff West's working group on universal scaling laws exploring in particular tree vascular networks.

Michael Miller's work focused on strategy-based wealth distributions, exploring with Doyne Farmer a simple game-theoretical betting model where players' bets influence the outcome of a probabilistic game. Miller majors in physics at Stanford.

International Undergraduate Fellow **Felipe Andres Motta,** from the University of the Andes in Bogota, Colombia, worked with Sam Bowles on an agent-based model of a monetary pre-capitalist economy.

Carleton College's **Alex Petroff,** a physics and math major, worked with Geoff West and Jim Brown on plant geometry. Theoretical work was done at SFI with an experimental component at the University of New Mexico.

Devorah West, from Brown University (where she majors in social science), collaborated with Elisabeth Wood examining radical racial ideals and sexual violence in Rwanda, Bosnia, and Nazi Germany.

Secondary School Fellows, Summer 2005

Stoyana Alexandrova (Los Alamos High School) worked with Virgil Griffith on principles of self-reproduction in a stochastic environment.

Dylan Allegretti's (Santa Fe Preparatory School) project featured a bottom-up simulation of an economic system. He was mentored by REU Felipe Motta.

Mentored by Alex Petroff, **Alexei Pesic** (Santa Fe Preparatory School) worked with Geoff West's group on a plant-scaling project.

Matt Matson-Tibbetts (Monte del Sol Charter School) used the article "Experimental demonstration of chaos in a microbial food web" (*Nature*, 2005) as the basis for a modeling project.

Veronica Cordova (Santa Fe Secondary School) collaborated with Chris Kempe on a model dealing with one aspect of plant physiology called trans-evaporation.

Sonja Romero (Santa Fe High School), mentored by Michael Miller, worked on a project that modeled gambling.

Science Board

Persi Diaconis is Mary V. Sunseri Professor of Statistics and Mathematics at Stanford University.

Don Glaser is professor of physics and neurobiology at the University of California–Berkeley. He works on constructing computational models of the human visual system which explain its performance in terms of its physiology and anatomy.

Bill Greenough is Swanlund and Center for Advanced Study Professor in the University of Illinois departments of psychology, psychiatry, and cell and structural biology; and a full-time faculty member in the Beckman Institute NeuroTech Group.

Art Jaffe is Landon T. Clay Professor of mathematics and theoretical science at Harvard University. Jaffe's major scientific work has been in the realm of understanding quantum field theory and the mathematics that it inspires.

Paleontologist **David Raup** is Professor Emeritus at The University of Chicago. He is best known for his theory that mass extinctions occur every 26 million years. This theory was originally proposed in 1984 with University of Chicago colleague Dr. J. John Sepkoski.

Trustees

Stewart Greenfield, Chairman of Alternative Investment Group, divides his time between environmental activities and hedge fund investing. His Environmental Venture Fund, in conjunction with the Nature Conservancy, has initiated projects that have preserved over 18 million acres in Bolivia, Brazil, Paraguay, Chile, Panama, and elsewhere.

John Holland is professor of computer science and engineering and professor of psychology at the University of Michigan. In his 40-year career he has formulated genetic algorithms, classifier systems, and the Echo model as tools for studying the dynamics of complex adaptive systems.

Diana MacArthur is co-founder, chair, and chief executive officer at Dynamac Corporation, a science, engineering, and technology company specializing in space, life, and earth sciences; natural resources management and ecological restoration; environmental management and compliance; and defense services and homeland security.

Robert Maxfield is president of the Maxfield Foundation, which he founded in 1986 to support scientific research and education. He was a co-founder in 1969 of ROLM Corporation. Since 1988 he has been a consulting professor in the management science and engineering departments at Stanford University.

David Robinson is a consultant to Carnegie Corporation of New York. He has been a trustee of the City University of New York and has served on committees of the National Research Council, the Council on Foreign Relations, the American Association for the Advancement of Science, and the President's Science Advisory Committee.

Awards

Princeton University ecologist and SFI Science Board member **Simon Levin** is a 2005 Kyoto Prize Laureate. The international awards are presented by the Inamori Foundation to individuals and groups worldwide who have contributed significantly to mankind's betterment. Levin's award cited his work "for the establishment of the field of spatial ecology and the proposition of the biosphere as a complex adaptive system." Considered among the world's leading awards for lifetime achievement, the Kyoto Prize recognizes lifelong contributions in the categories of Advanced Technology, Basic Sciences, and Arts and Philosophy.

Passings

Armand Bartos, former SFI trustee and active member of the Institute community, died late in 2005. Bartos, a consulting partner in the New York firm of Bartos & Rhodes Architects, received his bachelor's degree in architecture from the University of Pennsylvania in 1934 and his master's degree in architecture from MIT in 1935. He was a partner with Kiesler and Bartos in New York City from 1957–62, and then became principal partner at Armand Bartos and Associates, NYC, in 1962.

Former Science Board member **Theodore T. Puck**—a genetics researcher who devised techniques for growing human cells in the laboratory and who helped determine the number of chromosomes in a gene—died in November. With a career spanning more than 60 years, he was credited with many advances that have become basic elements of research in oncology and the human genome and have helped unravel some of the mysteries of genetic diseases. Puck, who in 1961 founded the Eleanor Roosevelt Institute of Cancer Research (now part of the University of Denver), performed some of the first studies of radiation doses and the effects of environmental contaminants on DNA. He was a fellow of Los Alamos National Laboratory, an editorial board member of the *Encyclopedia Britannica*, and a member of the National Academy of Science and the American Academy of Arts and Sciences.

Sergei Anatolyevich Starostin died suddenly of a heart attack on September 30, 2005, shortly after delivering a lecture in Moscow. A historical linguist and scholar, Starostin was best known for his work with proto-languages, and for his formulation of the Dene-Caucasian hypothesis. He was instrumental in the reconstruction of Proto-Kiranti, Proto-Tibeto-Burman, Proto-Yenisseian, Proto-North-Caucasian, and Proto-Altaic languages. He devoted much of his later life to developing the theory, originated by Roy Miller, that Japanese is an Altaic language. At the time of his death, he was a professor at the Russian State University for the Humanities, a visiting professor at the Santa Fe Institute, and a frequent guest lecturer at Leiden University in the Netherlands, where he was awarded the degree of *doctor honoris causa* in June 2005. ◀

PHOTO: ROBERT MILLER

Identifying the New

By Chris Wood, Vice President

One of the great challenges at the Santa Fe Institute is to effectively identify truly new ideas and invest in people who are likely to generate them. The invention of the transistor, the understanding of optical physics that led to lasers, those kinds of breakthroughs have impact far beyond what could have been envisioned by their inventors. And yet, very little is known about where such breakthroughs come from. They clearly build on what's been there before, but are not simple extrapolations. A key characteristic is connection: out of pre-existing connections arise new ones that no one anticipated.

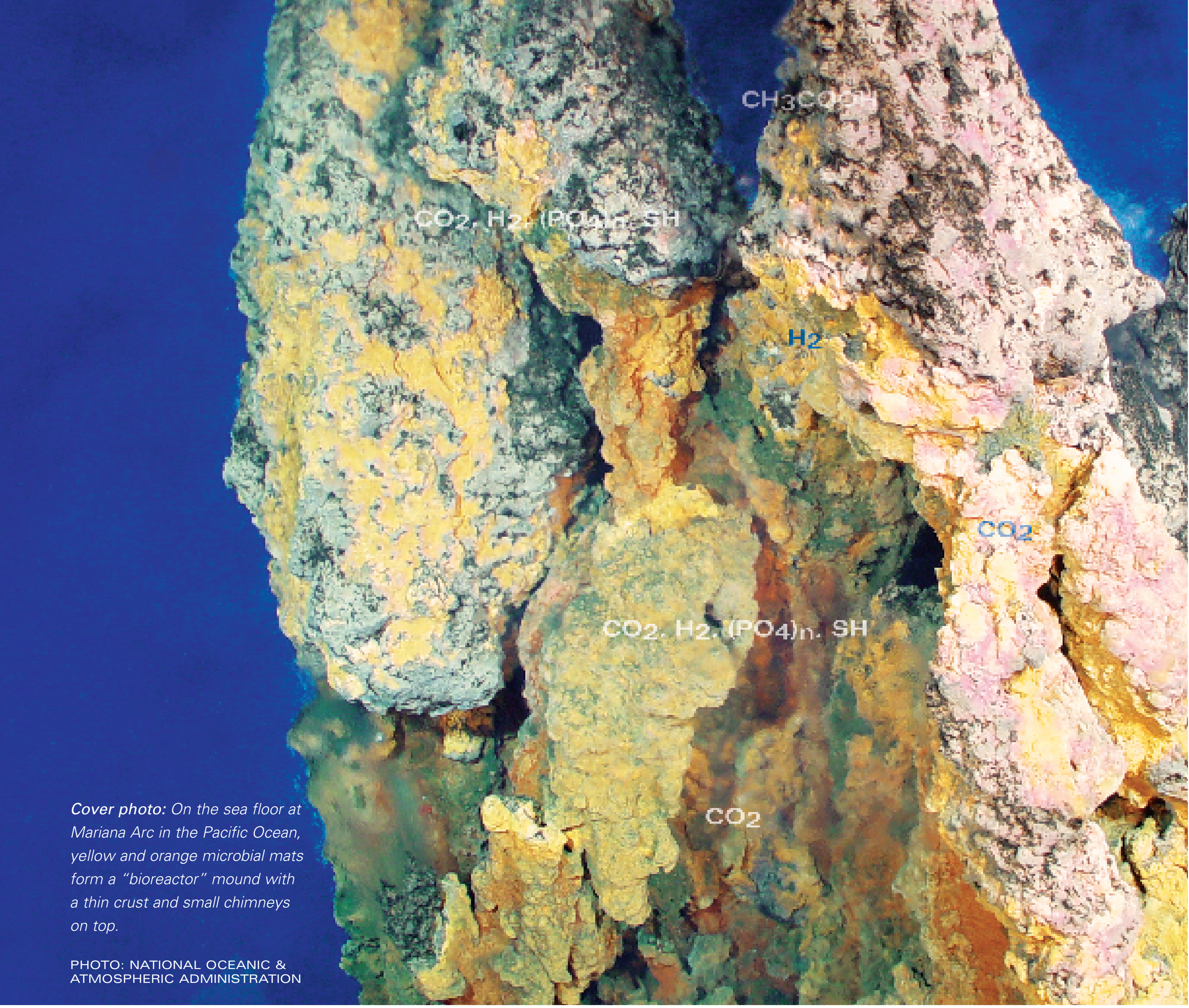
Finding out more about such ideas and thus increasing the likelihood of coming up with them is where some of my scientific interests and administrative responsibilities for the Institute come together. We should not be surprised that innovation has been a recurrent theme in SFI activities, and we're not the only ones thinking about this important issue. The National Science Foundation's (NSF) National Science Board recently held a task force meeting of about 40 people at SFI focused on the problem of "identifying and fostering transformative research," that is, research that is likely to produce truly revolutionary changes in a particular field.

One of the major talks at the workshop was presented by historian Rogers Hollingsworth of the University of Wisconsin, who has spent much of his career studying characteristics of institutions that foster innovation (http://history.wisc.edu/hollingsworth/). Hollingsworth summarized a large body of research by saying that many of the key institutional characteristics needed for effective innovation are present at SFI, a wonderful homage to the Institute's founders and to its scientists and leadership since.

But in order to maintain and extend this strong record into the future, we will need to understand innovation at even deeper levels and to develop continuing means to support research that is truly high risk, with great potential for high impact. Despite the National Science Board Workshop on Transformative Research mentioned above, the NSF and other federal sponsors remain conservative in their risk-taking and focused on near-term, incremental progress.

SFI has rightly emphasized the importance of pursuing pure research, independent of potential applications or specific sponsor-directed deliverables. Yet some of the world's most important scientific breakthroughs have come from the interaction between the independent and the applied. Consider Alan Turing, for example. He is responsible for breakthrough work in pure mathematics, in the theory of computation, and in cognitive science, all of which were influenced by his work at Bletchley Park during World War II, when he and colleagues developed techniques to break the German Enigma codes (for a wonderful biography, see Alan Hodges' book *Alan Turing: The Enigma,* Simon and Schuster, 1983).

Citing Turing (or other equivalent examples) is not intended to foreshadow a "tilt toward the applied" for the Institute: far from it! Rather, it is intended to emphasize that innovation is likely to arise out of broad connections and interactions well outside the "usual suspects" in a given area. SFI's Business Network provides a fertile source of interactions with "real-world" problems and constraints, and SFI resident and external faculty continue to generate exciting new opportunities for interactions beyond the "usual suspects" (e.g., the Krakauer-Gaddis working group on History and Complexity). A better scientific understanding of innovation at all levels and in all its manifestations will serve the Institute well. ◀



Cover photo: *On the sea floor at Mariana Arc in the Pacific Ocean, yellow and orange microbial mats form a "bioreactor" mound with a thin crust and small chimneys on top.*

PHOTO: NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

SANTA FE INSTITUTE

1399 HYDE PARK ROAD

SANTA FE, NEW MEXICO 87501

U.S.A.