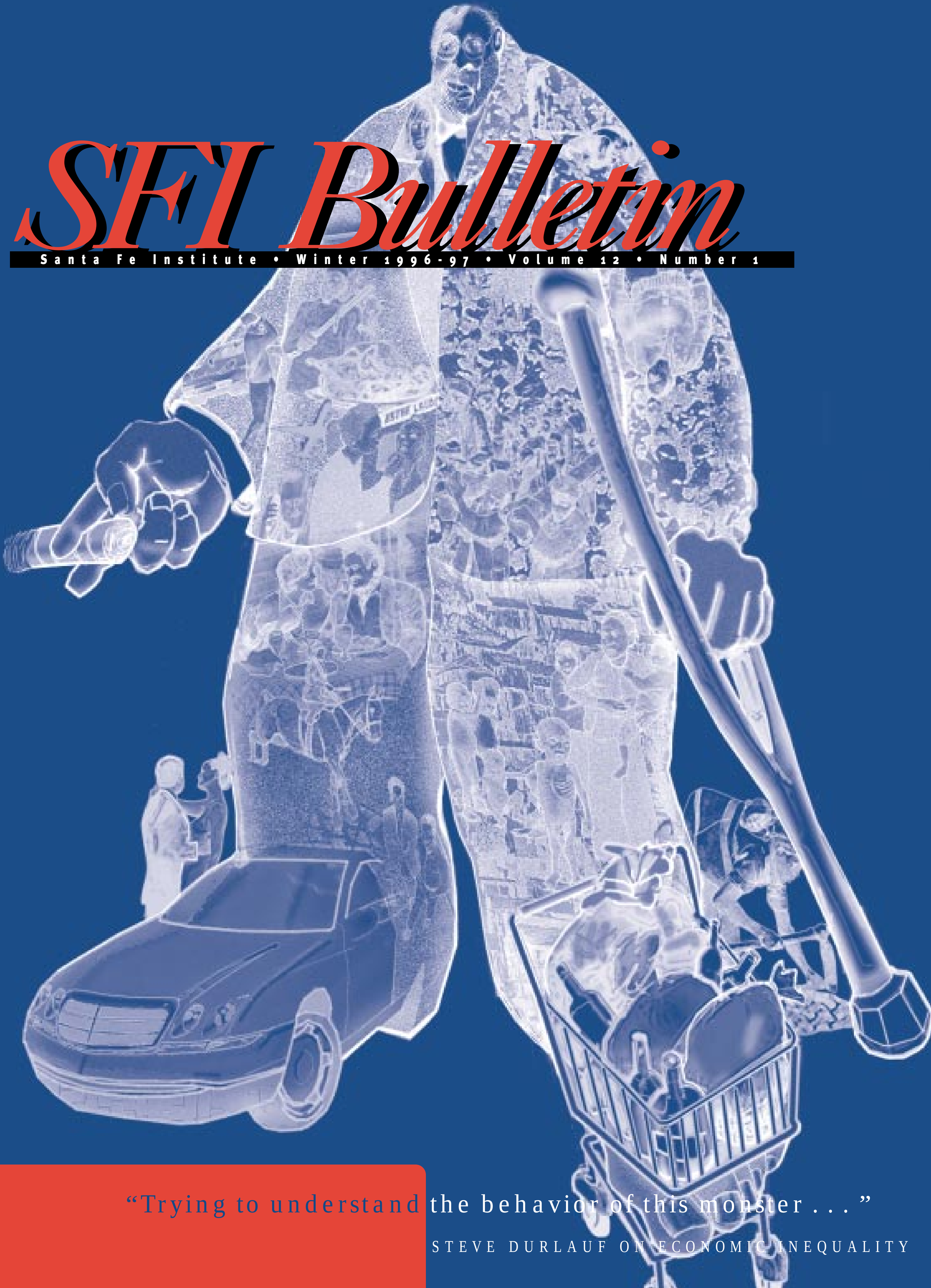
SFI Bulletin

Santa Fe Institute • Winter 1996-97 • Volume 12 • Number 1



"Trying to understand the behavior of this monster . . . "

STEVE DURLAUF ON ECONOMIC INEQUALITY

SFI Bulletin

WINTER 1996-97 • VOLUME 12 • NUMBER 1

The *Bulletin* of the Santa Fe Institute is published by SFI to keep its friends and supporters informed about its work. The *Bulletin* is free of charge and may be obtained by writing to the managing editor at the address below.

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.

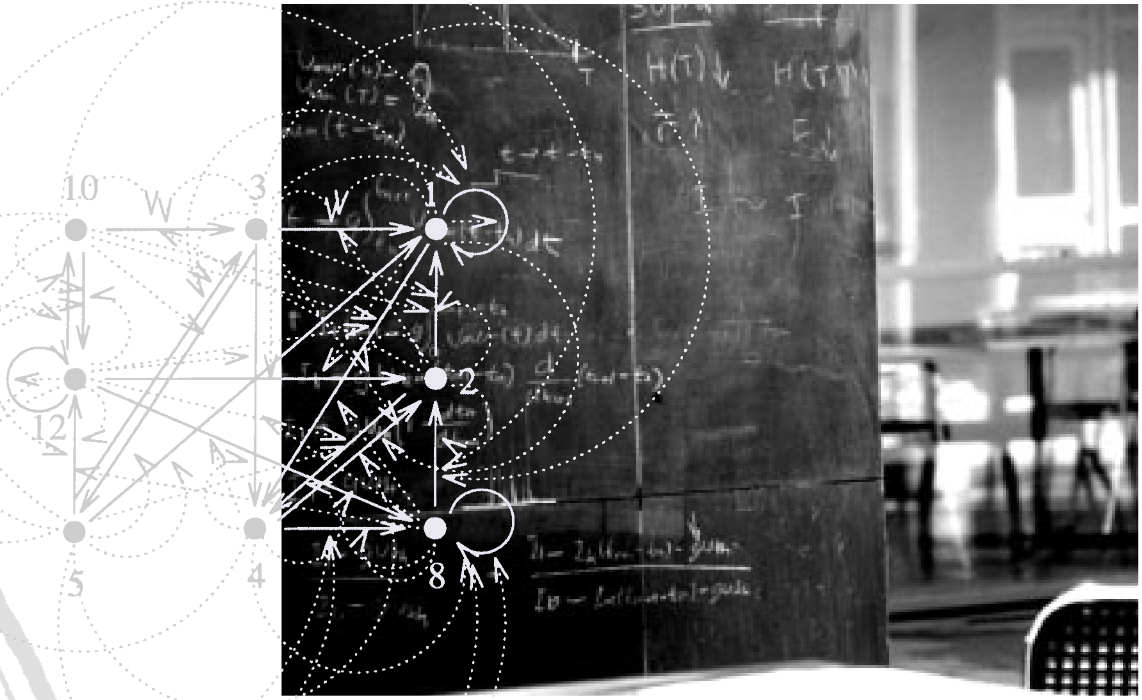
Published by the **Santa Fe Institute**
1399 Hyde Park Road
Santa Fe, New Mexico 87501, USA
Phone (505) 984-8800
fax (505) 982-0565
home page: http://www.santafe.edu

EDITORIAL STAFF:
Ginger Richardson
Pat Reed
Andi Sutherland

CONTRIBUTORS:
William Clark
Richard Palmer
Janet Stites

DESIGN & PRODUCTION:
Patrick McFarlin
Patrick McKelvey

COVER ILLUSTRATION: PATRICK MCKELVEY



SFI's Postdoctoral Fellowships in Complex Systems Studies

The Santa Fe Institute will have an opening for one or more postdoctoral fellows beginning in September 1997.

The Institute's multidisciplinary research program is devoted to the study of complex systems, especially complex adaptive systems. Topics currently under study include nonlinear dynamics and pattern formation; measures of complexity; learning algorithms; agent-based modeling and simulation tools; evolutionary biology; models of the immune system, cellular regulation, and other biological systems; models of economic, political, and social interactions; and others. Postdoctoral fellows work either on existing research projects or on projects of their own choosing.

Candidates should have a doctorate (or expect to receive one before September 1997) in the mathematical, computational, physical, biological, or social sciences, with an academic record of scientific excellence, a demonstrated ability for independent research, and a strong interest in interdisciplinary approaches.

Special consideration will be given to those applicants who propose, as an integral part of their research at SFI, a project involving experimental work or data collection at locations other than SFI. Candidates with such interests are requested to submit an outline of the proposed off-site project, along with a supporting letter from the organization through which the experiments or data collection is to be coordinated. Successful candidates in this category will receive salary and travel expenses from SFI in support of their off-site research.

Applicants should submit a curriculum vitae, list of publications, and statement of research interests as well as arrange for three letters of recommendation. Incomplete applications will not be considered.

All application materials must be received by February 21, 1997. Decisions will be made by April 1997. Send applications to:

Postdoctoral Committee
Santa Fe Institute
1399 Hyde Park Road
Santa Fe, New Mexico 87501

Send complete application packages only, preferably hard copy, to the above address. Include your e-mail address and/or fax number. SFI is an equal opportunity employer.

4

Photo: William Clark

Steven Durlauf

APPLIES COMPLEXITY TO THE STUDY OF INEQUALITY

by William Clark

Economist Steven Durlauf revels in the interplay of ideals, exploring intellectual propositions from perspectives both theoretical and practical, and appreciating them for what they do and do not contribute to our understanding of the world in which we live.

"God's in the details," says the economist with one of the quick, intense bursts of laughter that punctuate his conversations. As Durlauf describes his work at the Santa Fe Institute, where since last summer he has co-directed the economics program, he spins examples and allusions in an almost free-associative way, at one point seamlessly pursuing a metaphor from statistical mechanics through models of magnetism to the dilemma of why teenagers drop out of high school.

It was indeed this way of approaching the world and the rich complexity of the questions it poses that sparked Durlauf's current affiliation with the SFI intellectual milieu, beginning in the summer of 1995. A native of Los Angeles raised in the San Fernando Valley ("Beautiful downtown Burbank," he jokes), Durlauf came early to the study of economics, a field in which, at the age of thirty-eight, he has achieved eminence.

“I THINK INEQUALITY IS A SOCIAL EVIL, AND POVERTY IS AN IMMENSE SOCIAL EVIL, WHICH DISTURBS ME GREATLY.”

“When I went to college, my dad [a real estate appraiser and the apparent source of Durlauf’s signature wry humor] told me that economics was boring and hard, with a lot of mathematics—so he thought I might like it.” That tongue-in-cheek prophesy proved accurate. Durlauf earned his bachelor’s degree in economics at Harvard in 1980 and completed his doctorate in that discipline at Yale in 1986. He taught at Stanford University from 1986 until 1993, when he joined the economics faculty at the University of Wisconsin in Madison, from which he’s now on leave for a year at SFI, serving as co-director (with Larry Blume) of the economics program. Durlauf is also a member of the Institute’s Science Board.

Through the years he’s published more than two dozen papers in scholarly journals and been a faculty research fellow for the National Bureau of Economic Research, a panelist for the Brookings Institution, and a visiting scholar with the London School of Economics and the Federal Reserve Board of Governors. The John D. and Catherine T. MacArthur Foundation has twice funded Durlauf’s studies of socioeconomic inequality in America, including part of his current research at SFI. Durlauf describes his specialty as macroeconomics—the big, collective, interactive economic picture—and, more specifically, income distribution and income inequality, matters of particular interest, he notes, at SFI. “A buzz word you keep hearing here is emergence,” Durlauf says, “and part of what’s exciting here is this metaphor—that you look at emergent phenomena across certain branches of physics, economics, biology, computer science, and on [toward an understanding of] how consciousness emerges from a bunch of neurons. Cross-disciplinary thinking is essential to the mission of the Institute, and it is abstract metaphors that link people, not particular applications. This place doesn’t want to be another university with departments that don’t talk to each other; it provides a community where you can exchange ideas, get feedback.

“It’s a social process, and it really matters that you can talk to others, get some emotional as well as intellectual support, be cheered on if you’re doing good work. You learn new techniques, new ways of thinking about things through the sharing of metaphors.” It can, at times, even be helpful, Durlauf adds with a chuckle and a sidelong grin, “to have people in different fields—extremely smart people—ask, ‘Why the hell would you think or assume something like that?’”

As part of his ongoing examination of the larger, aggregate patterns of the economic world, Durlauf is currently co-authoring (with Wisconsin colleague and SFI external faculty member William Brock) a book on complexity in economics “which is Santa Fe economics,” he quips. “The sort of economics that interests me involves looking at the collective properties of individual decisions, . . . taking a large population of heterogeneous, diverse people with fairly simple rules for how they interact, and asking what collective economic phenomena emerge in that environment.”

Typical economics, Durlauf explains, deals with how people interact through markets—through prices, the assignment of value. His own interest, on the other hand, is in nonmarket interactions—peer-group pressures, for example, or role-model effects or such direct interpersonal contacts as networking, which, says Durlauf, accounts for the acquisition of 50 percent of all jobs in the United States. (That figure would be 100 percent in academia, he observes.)

“My primary research here,” he says, “is developing theoretical and statistical methods to understand the role of interactions in determining inequality.” To that end, Durlauf is exploring techniques drawn from the branch of mathematics

called random fields, which corresponds to statistical mechanics models in physics methods, he says, “that let you work with populations of objects and discuss their collective properties. It’s a sort of mathematics that lets you model large numbers of economic actors in such a way that you can preserve their heterogeneity, think of them as having different properties, but that lets you determine things about their aggregate behavior.

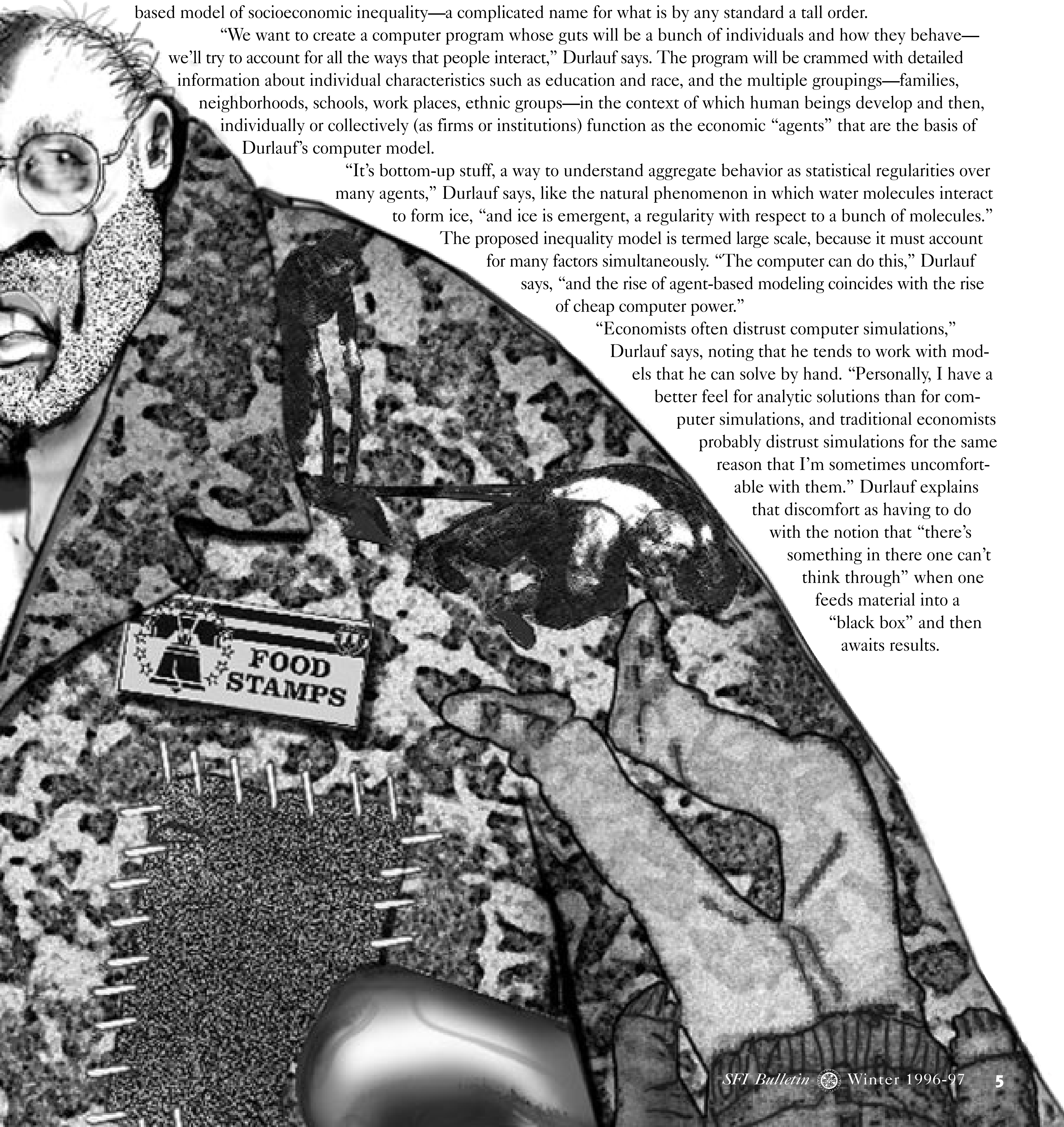
“I’m sure my work is criticized in some quarters for its use of models from physics,” Durlauf says, at the same time expressing confidence that, both in its methodology and its way of thinking about economic agents, his SFI research hones the cutting edge of economic theory.

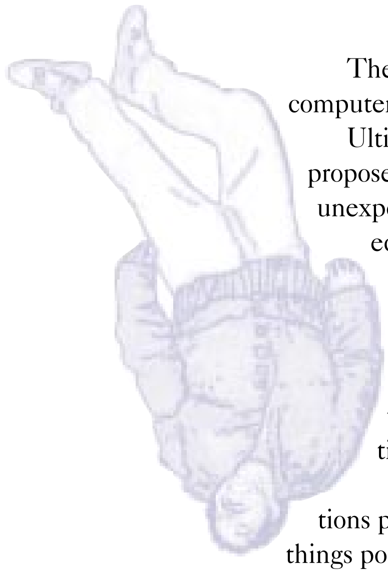
One thrust of that work, a research group that Durlauf is co-heading with Stanford’s Kenneth Arrow (a fellow SFI Science Board member), is initiating the construction, using agent-based modeling techniques, of a large-scale, interactions-based model of socioeconomic inequality—a complicated name for what is by any standard a tall order.

“We want to create a computer program whose guts will be a bunch of individuals and how they behave—we’ll try to account for all the ways that people interact,” Durlauf says. The program will be crammed with detailed information about individual characteristics such as education and race, and the multiple groupings—families, neighborhoods, schools, work places, ethnic groups—in the context of which human beings develop and then, individually or collectively (as firms or institutions) function as the economic “agents” that are the basis of Durlauf’s computer model.

“It’s bottom-up stuff, a way to understand aggregate behavior as statistical regularities over many agents,” Durlauf says, like the natural phenomenon in which water molecules interact to form ice, “and ice is emergent, a regularity with respect to a bunch of molecules.” The proposed inequality model is termed large scale, because it must account for many factors simultaneously. “The computer can do this,” Durlauf says, “and the rise of agent-based modeling coincides with the rise of cheap computer power.”

“Economists often distrust computer simulations,” Durlauf says, noting that he tends to work with models that he can solve by hand. “Personally, I have a better feel for analytic solutions than for computer simulations, and traditional economists probably distrust simulations for the same reason that I’m sometimes uncomfortable with them.” Durlauf explains that discomfort as having to do with the notion that “there’s something in there one can’t think through” when one feeds material into a “black box” and then awaits results.





The inequality model, however, is simply too complicated to pursue without computers.

Ultimately, Durlauf hopes that model can provide a powerful tool for testing proposed changes in government policy before they are implemented to avoid unexpected, unwanted results. "Say, for example, that you want to equalize education quality across school districts," he says. "Your first inclination might be to simply equalize spending. But if you divide up education funding equally between schools, this actually could generate more inequality if, as a result of this policy change, rich families pull out of neighborhoods and public schools and the degree of economic segregation goes up. The point is that, unless you account for all these interactions, what appears to be an obvious result may be dead wrong."

"I hope this model will make clear the complexity of the interactions people experience," Durlauf emphasizes. "I'd like it to be one of the things policy makers use in designing and evaluating public policy." The project is just getting under way, its first eighteen months funded by the MacArthur Foundation. It will likely take five years to complete, using a team of nine economists, one sociologist, and a large number of graduate students to help code the vast amounts of information necessary to make this model comprehensive. "The economy—it's so complex, and trying to understand the behavior of this monster . . . ," Durlauf trails off, shaking his head, noting the possibility that, in the end, the program may not work. "It may prove that building all the stuff into one model is unsuccessful in terms of predictive and explanatory power, but the process through which you construct the model can teach you lots of stuff. Even if the parts don't fit, the parts are individually valuable."

In the end, the economy is so complicated, so drastically affected by small—and unforeseeable—twists of history, shifts in government policy, that long-term economic predictions are almost impossible, Durlauf says. "But the computer model can be successful, even if it doesn't predict the future accurately," he says, "if it lets us understand the consequences of various government policies. The theory of evolution, after all, doesn't predict particular species, but it gives us a way of understanding the diversity out there. So economic models can elucidate, provide insights not related to predictive power."

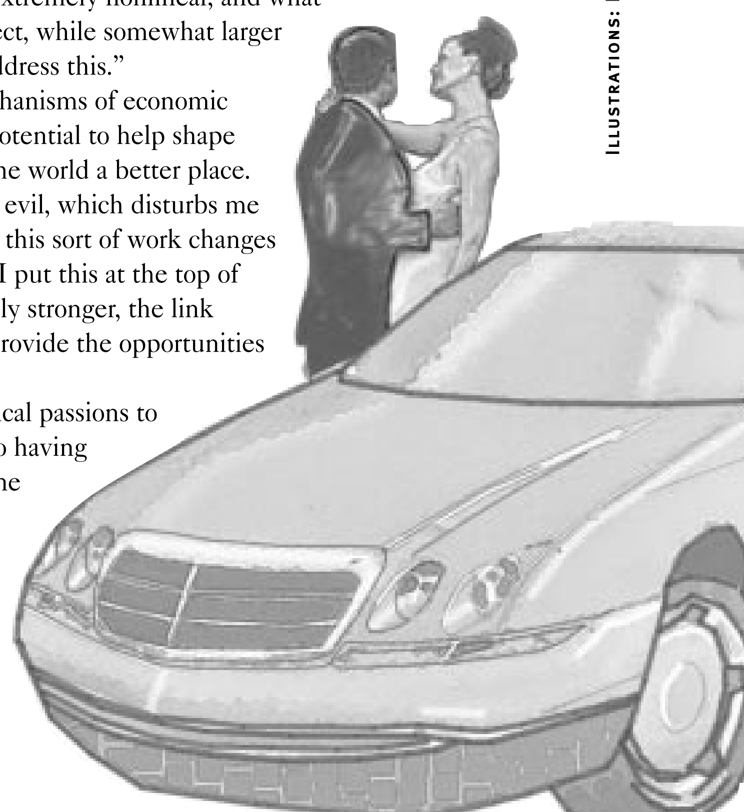
The model's implications for public economic policy are, Durlauf says, twofold. "In attempting to get rid of inequality," he notes, "most mechanisms are forms of income redistribution—progressive taxes or welfare, for example—or associational redistribution, where the government redistributes not income but who people interact with through busing, for example, or affirmative action or housing projects. The [interactions-based] model would require more careful thought be given to associational redistribution rather than just to income redistribution. Associational redistribution refers to redistribution that alter individuals' interaction environments. Also, the model is extremely nonlinear, and what that means for policy is that small acts of redistribution may have no effect, while somewhat larger ones could have great effects; there are thresholds, and the model can address this."

For Durlauf, the creation of this simulation of the broad social mechanisms of economic inequality is clearly no esoteric, hermetic, academic endeavor. With its potential to help shape public economic policy, this undertaking could in real ways help make the world a better place.

"I think inequality is a social evil and poverty is an immense social evil, which disturbs me greatly," Durlauf says. "It's not so much that I have any pretensions that this sort of work changes the world, but I think some things in social science are worthwhile, and I put this at the top of the list. After I had my first child, my concern about it became immensely stronger, the link being that it saddened me no end to think about families that couldn't provide the opportunities for their kids that I could.

"Obviously, my obligation as an economist is not to allow any political passions to affect the answers I find. There's a danger in anybody ever 'fessing up to having a political or emotional concern," he says, his seriousness dissolving in one more quick, hearty laugh, "but it's disingenuous to deny it."

William Clark is a free-lance writer who lives in northern New Mexico.



Illustrations: Patrick McKelvey

WITH ERICA JEN

SFI's New Vice-president Discusses What's Unique About the Institute, What Her Scientific Priorities Are, and Why She Went to China

Editor's note: *Santa Fe Institute President Ellen Goldberg named Erica Jen as SFI's vice-president for academic affairs in October. Before coming to SFI, Jen , who received her doctorate in mathematics from the State University at Stonybrook, had worked at the Center for Nonlinear Studies at Los Alamos Laboratory. This interview, which was conducted by SFI Bulletin staffers Ginger Richardson and Pat Reed, has been edited.*

QUESTION: Do you think SFI is as unique a research institution as it likes to think?

JEN: SFI is certainly remarkable in its emphasis on problem formulation and its focus on mechanisms in addition to the analysis of specific systems. I think it has been successful so far in generating powerful and far-reaching metaphors that significantly change how people think about their research. The basic view, for example, that there is for many systems a regime in which complexity and adaptability are somehow maximal—and that this regime is characterized by being neither highly ordered nor overly chaotic, with information being neither globally shared nor locally frozen—this is a view to which SFI has made major contributions, one that has been suggestive in thinking about problems ranging from economic trading through species extinctions to computer learning algorithms.

And SFI has a good track record, maybe singular among research organizations, in seeding collaborations among individuals from different disciplines. It's not just that researchers are studying a topic by applying approaches and methodologies inspired by or adopted from other disciplines. What you see at SFI is much more unusual: collaboration on a common topic among researchers from different disciplines. For example, Jim Brown, an ecologist, is working with Geoffrey West, a physicist, on scaling properties of physiology in living systems; and John Padgett, a political scientist, and Walter Fontana, a chemist, are exchanging ideas on the emergence of organizational structure and function.

The best part of collaborating in a truly interdisciplinary fashion, when it works, is that it places a stress on researchers and how they think. By working together with researchers from different disciplines, you are literally forced, in the most constructive of ways, to think about different problems, to use tools and methods from other disciplines with which you are not familiar, and, maybe most importantly, to look at aspects of a problem that, in our traditional disciplinary framework, we are usually comfortable to define away or to completely ignore. It's a kind of stress that can lead to truly innovative science.

All Jen photos: Walter Nelson

QUESTION: What are your scientific priorities?

JEN: The main point for SFI is to be innovative. It may sound peculiar to talk about innovation apart from substance, but there really is no point for SFI to exist if it's going to do research that could be done just as easily elsewhere.

If we are going to remain innovative, we need to encourage more flux and openness to research ideas and personnel in SFI programs, so we will be better able to sort out and push hard on new research directions. We want to be open to new, even "flaky," ways of thinking, including how we formulate a problem and what we define as a solution to a problem.

At the same time, we need to achieve a balance between reaching out to new fields and demonstrating we can solve problems that can't be solved otherwise. We need to focus on our choice of problems, to increase our sensitivities to differences between toy problems and real problems, to maintain a healthy respect for the intricacies of the natural and social phenomena we're studying, and to focus also on sharpening the tools of our scientific activities. It's critical at this point, for example, for SFI researchers to look at the issue of simulations in science, to understand how one constructs a simulation that is, in fact, a realistic model of a phenomenon being studied. How does one validate this is the case? We also need to pay more attention to empirical and experimental data. We want first of all to be innovative, but we also have to make sure we're doing the kind of science that solves problems.

QUESTION: What effect do you think a predominantly female administration will have here?

JEN: As my husband said, "The government already targets female-owned small businesses; maybe we can convince them to give more funding to female-run small research organizations."

Ellen and I, as new members of the administration, will certainly be making changes, and those changes will reflect our backgrounds and work styles. The big change, of course, aside from management by female faces, will be the strengthened emphasis and interest in biology that Ellen brings to the Institute, which I hope to complement with my own background in mathematics. It's also true that both of us would like to increase the representation of women and minorities in the research programs, if for no other reason than the selfish one that we'd like to have the company of more women and minority colleagues at workshops and other scientific activities.

But the fact that Ellen and I are women is not necessarily the major personal characteristic that affects our styles of science management. While I am certainly sensitized to the issues of being a woman scientist, there are a lot of other factors—for example, the fact that, as someone of Chinese origin, I have a longstanding interest in modern China and lived in China for almost two years at the tail end of the cultural revolution—that are for me equally important.

QUESTION: Tell us about your time in China.

JEN: I studied at Beijing University and did physical labor at a machine tool-parts factory and a people's commune. It was a period in China when there was intense, continual discussion about the political and ethical goals of society and also of individuals in the society. I saw a way of life in which people were always trying to work harder in the service of others. For example, when we would wake up in the morning in the student dorms, we'd race to be the first one to clean out the latrines and to fill everyone else's hot water bottles. The basic point was: there was a common goal of making a better world, and you struggled on an ongoing basis to make yourself a better person and to help achieve this goal.

QUESTION: How old were you when you went to China?

JEN: I was nineteen and had just finished my junior year at Yale. Very young and happily not disillusioned.

QUESTION: Why did you go?

JEN: I went to China in 1972 as a tag along to my father's delegation of U.S. Chinese-born scientists. My father had a remarkable life. He was born in 1906 in a poor province in north China into a peasant family and was able to attend college in Beijing only through a quirk of history. During the Boxer Rebellion in the late 1800s, the eight countries that invaded China to quell the uprising required China to pay indemnities as the price of losing the war. Rather than take the indemnity funds, however, the United States used them to set up a scholarship fund in China to send students to study at U.S. universities. Each province had quotas for the number of students awarded the scholarships. Being from a poor province, my father didn't have much competition and got the scholarship to go to the United States at age twenty. He was educated at Harvard and got his Ph.D. in physics there. Amazingly enough, he worked with some of the major scientists of the period. He went back to China before World War II and was teaching in Beijing when war broke out.

My parents, together with other university professors and students, decided to go on what was later called the Academic Long March. They went some 2,500 miles into the hinterlands in southwestern China and set up a makeshift university, initially with no books, no buildings, no paper, no watches to tell them when to meet for a class, certainly no research laboratories. They stayed there for seven years, building up a quite respectable set of research as well as educational programs. The Japanese eventually discovered where they were and bombed the area, but they kept it going. And the students from that period became the nucleus of the future Chinese intelligentsia.

After the war, my father received a fellowship to the United States in recognition of his contributions during the war. He went to Harvard and taught there again. But he had strong feelings about the transformation of China and the fact that China, after a long period of debilitation and oppression, was able, with the communist revolution of 1949, to transform and modernize itself. In 1972, he led the first delegation of Chinese-American scientists to the People's Republic of China at a time when there was no exchange between the two countries. They couldn't get visas. It was illegal to go. There were bomb threats—the delegation members were warned they should take separate planes in case somebody tried to blow up the plane—and the Chinese government was initially at a loss as to how to—or whether to—receive the delegation, although it subsequently decided to treat them with great fanfare.

I went with my parents and my father's delegation—their trip was for six weeks—but I knew I wanted to stay longer to learn about China and the Chinese society. I petitioned Premier Zhou Enlai, and at a reception he hosted for my father's delegation, Zhou Enlai and I had an extensive conversation. He quizzed me on a variety of issues (such as, "What does it mean to be a revisionist?") and gave me a hug at one point, and my petition was approved. So I stayed.

QUESTION: How will your experience in China affect your performance at SFI?

JEN: I was in China at a time when mass movements dominated the political scene, and it had a tremendous effect on how I see myself and how I function as part of a work team. China taught me a lot about the effectiveness of bottom-up/top-down decision making, the need for equity in the work place, and the importance of having an open atmosphere in which you encourage criticism and self-criticism. I guess it taught me humility, which will probably serve me well at SFI.

QUESTION: To continue along these lines, why did you take this job?

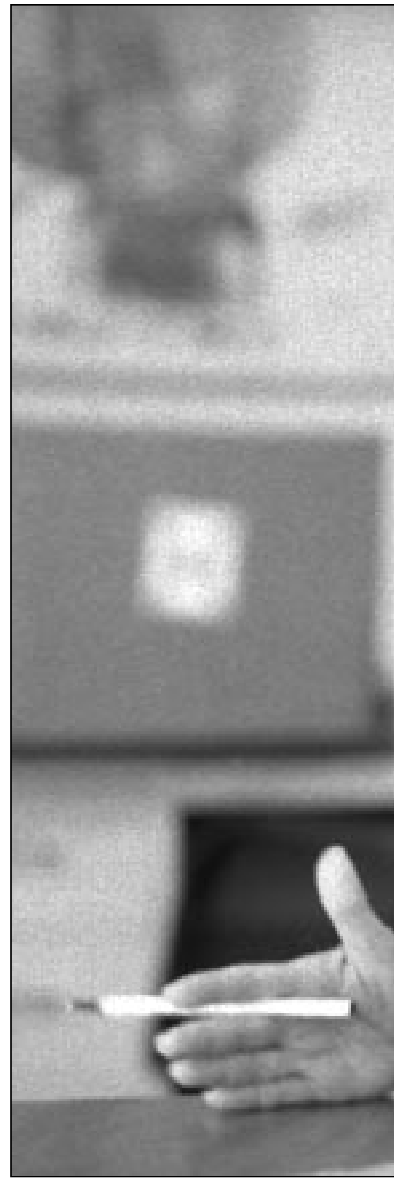
JEN: I have been associated with the Institute for ten years now, mostly as an outside observer and a sometime participant and a Science Board member. Taking this job was a tough decision for me: to what extent did I want to switch my loyalty, to say the Institute was the place I believed in, that I wanted to make it my main institutional focus?

I spent a lot of time talking with external and residential faculty and staff at SFI. What made the difference was their contagious certainty that something is happening in science and, in particular, something is happening here at SFI. There is a certainty here, sometimes more than is warranted, that problems that have not been possible to understand up until now are beginning to break open.

To address these problems, you need to develop new approaches, new methodologies. SFI is, more so than any institution I know of, actively and explicitly, trying to do so. Obviously, SFI may not succeed on a grand scale. But it became clear to me that SFI is already having an impact on how people in the general research community think. The chance to participate in this process—and in particular to play a role in scientific decision making at an institute that thrives on innovation and flux—seemed to be an opportunity too good to miss.

QUESTION: How does your own research fit into SFI's programs?

JEN: My research is in the mathematics of cellular automata. Ever since the extensive simulation studies of cellular automata in the mid-1980s by Stephen Wolfram, Tom Toffoli, Norman Packard, and others, these have been a favorite class of "toy systems" for researchers in complex adaptive systems, since they are simply defined, easy to simulate, and complex patterns of behavior appear to emerge without having been in any obvious way "hardwired" into the definition of the systems. Cellular automata are defined on lattices (the equivalents of "grids" in one, two, or higher dimensions) of nodes, with all the nodes being homogeneous and with the interaction among nodes being totally local. In this sense, cellular automata are the simplest possible prototypes for the more complicated systems—those with arbitrary or random interconnections or heterogeneous agents or stochasticity in their interactions—that are now widely used as the basis of simulation studies of behavior such as fluid flows, percolation through porous media, traffic congestion, bird flocking and navigation, species extinctions, and many other phenomenon in the natural and social sciences.



What I do is try to develop a mathematical understanding of cellular automata. The point is these systems are defined by "rule tables" (you can think of them as lookup tables), and there isn't much of traditional mathematics that applies to such systems. And simulation, which is the primary tool for studying cellular automata, has its limitations. It's really only theoretical analysis that can establish, for example, that two cellular automata that have different interaction mechanisms and that generate different-looking behavior are, in fact, equivalent under some hidden mathematical transformation. Or that a particular cellular automaton will evolve eventually to a state of consisting of spiral waves regardless of its beginning state: it's just not possible to establish that kind of result with simulations, since it would require trying all possible initial conditions and letting the systems evolve for infinite time.

But there has been for me so far no way to think about how cellular automata evolve or what it is in their mathematical structure that might induce them to evolve in appropriate dynamical frameworks. The Institute is the perfect place to think about these questions—to start to integrate what I know about the detailed behavior of specific, fixed systems, and what Jim Crutchfield, Melanie Mitchell, Chris Langton, and others have been working out for evolutionary, adaptive cellular automata. The neat thing is that understanding these questions is going to require the development of new kinds of mathematics in this very small context, it's an example of a part of mathematics starting to be driven by the problems of evolution and self-organization and adaptation being studied at SFI and elsewhere.

research with only theory and neither experiments nor data collection. Traditional science has relied so heavily on the unity between theoretical analysis and empirical observation, and the idea of having a place where you have only theory . . . . That's a real challenge, to think of how to make it work.

QUESTION: Where is simulation in that?

JEN: Simulation is often thought of as being somewhere in between and is even seen by some as closer to experiment since the computer generates results that look like data. But that, of course, is scary, since there's all the difference in the world between computer results and real data. If data are what scientists use in at least some types of problems to keep them honest, and if it starts to get confusing as to what constitutes data . . . .

The problem is that as the scale and complexity of our computer simulations increases, so does our inability in many cases to make sense of those simulations. As yet we lack even the conceptual tools to think about the reliability and scientific validity of many of our most intriguing simulations.

But people here and elsewhere are beginning now to think about developing a science of simulation. And personally I find that one of the most promising areas of scientific research for the Institute: we've got a headstart on the problem, and the payoffs are enormous. Computer simulations are the wave of the future.

QUESTION: What gives you pause about SFI?

JEN: I don't think any of us has a clear idea what will become of the Institute. Nobody knows what form or focus the Institute will have, or should have, ten or even five years from now. And that's a somewhat unusual situation to be in.

It depends so much on what we're able to achieve and what impact we have on the scientific community as a whole. It gives me pause to think about what problems we will be, or should be, thinking about. Will we still be working on complex adaptive systems? Will we be looking much more at problems in human behavior? And what will the Institute look like? A university with permanent faculty or students? Or will it remain more like a visitor/workshop center, as it is now? All these questions give me pause.

On a shorter time scale, it's difficult for me to understand how a scientific organization can do first-rate

QUESTION: Turning from challenges of computer simulation, is there anything you can point to and say, "This is how the Institute has changed things"?

JEN: If you ask how has it really changed things in terms of our understanding of natural or human phenomena, I'd have to think about it, because I don't think the answer is obvious. On the other hand, SFI has had, I think, real successes in terms of seeding networks of people, generating metaphors, making connections among disciplines, getting people to think in new ways, training young people through the summer schools and workshops. That's one thing I think that SFI has been enormously good at: earning a lot of publicity, recognition, legitimacy, even acceptance, for a new set of ideas.

We've made a beginning, but there's a lot to do.

Costa Rica and the Tierra Web
Tom Ray's Organic and Digital Reserves

by Janet Stites

The Dirt Is Cyberspace and the Inhabitants Are Digital

Tom Ray has come out of the rain forests of Costa Rica to build a reserve. But this reserve is not contained by fences, nor is it at the mercy of a land trust or a government. Its dirt is cyberspace, and the inhabitants are digital. The goal of Ray, an ecologist turned computer scientist, is to set off a digital analog to the Cambrian explosion and answer an elusive question: assuming evolution spontaneously generates enormous increases in complexity, how does it do so?

Ray, who is a Santa Fe Institute external faculty member, wants to emulate Darwinian evolution, starting with a set of simple, logical rules, to create, without any external influence, a complex, continuously evolving ecosystem: predators, parasites, mutations, extinction, and all. His digital reserve has its roots in artificial life, territory familiar to SFI's researchers. But Ray doesn't want to confine his reserve to a Sparc Workstation or a parallel computer. He wants it to prosper on the Internet. To do so, he plans to create a new world-wide web, the "Tierra Web," which will be inoculated with digital organisms that will be allowed to evolve freely through natural selection.

These organisms are the intellectual progeny of Ray's artificial-life program called Tierra. The program is an electronic, self-reproducing ecosystem of varied populations, all of which evolved from a single digital organism. In the program, just as in life, organisms have to compete for energy and space. At first, Ray ran Tierra on his laptop computer. But as the program and Ray's understanding of computing matured, he began to look at evolution as a parallel process. "If you look at the history of organic life, most of the complexity appeared during the Cambrian explosion, six hundred million years ago, when single-cell life became multicell life," he says. "I've been looking at this transition and thinking about what the analog is in the digital world." He concluded the problem was a job for parallel computers. He and Kurt Thearling (formerly at Thinking Machine and now at Boston-based Pilot Software) ran some simulations. "We did get some interesting multicell creatures, but they only had one cell type," he says. "And if you have a multicelled organism with only one cell type, it's not going to take you very far."

Although Ray couldn't see a way around this problem, he continued to imagine setting up something like the digital reserve on parallel computers and letting it run for a long period. But to do so was cost prohibitive and therefore science fiction. Enter the Internet. "One day it dawned on me that you could do the same thing on the Internet at no cost," he says. "Not only that, the Internet might provide selective pressures to provoke evolution toward greater complexity."

Parallel computers, he explains, are perfectly symmetrical and uniform. They have a lot of central-processing-unit (CPU) cycles but don't have the selective forces that prompt evolution. The Internet, however, is a heterogeneous environment hooked up to various computers with varied amounts of energy. "The situation [on the Internet] creates complex spatial and temporal patterns of resources, like CPU time, that could provide selection for more complex behavior," Ray says, "whereas on the uniform parallel computers, I just don't see where the selective forces come from." He portrays a scenario where one computer stands out—it is energy rich. If all the digital organisms go to that node, they probably won't fit. They would have to evolve with respect to the other organisms—some social-flocking behavior—to divide the energy. Thousands of generations of life are created within a few hours in the electronic universe. That's one value of the program and what makes it a good tool for studying the process of evolution.

To build the reserve, Ray is soliciting the donation of CPU cycles from thousands of machines connected to the Internet. His program would run on the donor machine's spare CPU cycles. His idea is this: as the digital creatures compete for energy cycles on the system, they'll evolve more sophisticated methods for seeking out places to replicate. Moreover, he believes the digital creatures will migrate across the Internet according to availability of energy, becoming creatures of the night, so to speak, when people are less likely to be using their computers. Noon in Tokyo may find the majority of the organisms in Los Angeles.

The Organisms Look Like Data

Surprisingly, Ray came late to computers. Although he had used a mainframe to collect and collate his research, it wasn't until 1988, when he bought a personal computer, that he began to explore how the computer works. At that time, he recognized the environment was conducive to building his digital ecosystem. He immersed himself in programming and computer manuals with the goal of learning to write even the most elementary code. At the same time, he uncovered what other people were doing in the field, which eventually led him to, among others, SFI researchers Chris Langton, Doyne Farmer, and Stephanie Forrest.

Through discussions with this group, Ray realized he needed to run his program on a virtual computer—a computer emulated by software within a computer—to avoid the danger of his organisms escaping and populating other computers like a virus. The digital organisms are equipped to move from one computer to another but cannot multiply beyond the confines of the virtual computer software. To a real computer, the organisms look like data.

One aspect of the program makes Ray's work unique: much like evolving organic organisms, his digital ones can experience random changes in their instructions and pass on the change. He has also incorporated mutations in the form of errors into the programming language. Historically, when one does so, the program won't work anymore. But Ray's continues to work and to reproduce. (His virtual computer was perhaps the first one for which evolvability was the primary design criteria. He compared the structure of machine language to that of molecular genetic language and obtained some ideas for changes in the design of the machine language to reduce its brittleness.)

Ray's digital organisms are reminiscent of another SFI faculty members work, John Holland's genetic algorithms (GAs). However, Ray explains that GAs are not open-ended because the programmer sets the fitness of particular sets of instructions. "They can tell us little about the origin of novelty through evolution," he says. In contrast, Ray has developed an open-ended evolving system by making the fitness of entities depend only on their ability to survive and replicate in the computer world he has created.

Ray's Other Ambitions

Ray has designed his digital ecosystem to provide scientists with a living lab of sorts for evolutionary studies. He thinks it could be particularly beneficial for understanding the periods of booming diversity and relative stasis that mark the fossil record. What's more, the digital ecosystems may help explain some remaining puzzles in evolution, such as the emergence of sex as a strategy for reproduction.

But he has other ambitions for the project, too, including creating a new way to process information on a grand scale. "The process of evolution by natural selection is able to create complex and beautiful information-processing systems—such as primate nervous systems—without the guidance of an intelligent supervisor," Ray says. "Yet intelligent programmers have not been able to produce software systems that match even the full capabilities of primitive organisms, such as insects. I argue that the information processes we have today are the equivalent of algae—they're single celled."

A new way to process information leads to a myriad of new, practical applications. "Given time, all kinds of useful software might flourish in the cyberspace jungle," he says. "Digital naturalists might spot something they had an application for, breed it, neuter it, and send it to the end user." What applications, Ray can't predict.

But he believes we shouldn't limit the use of evolution to produce superior versions of existing applications. "We should allow evolution to find the new applications for us," he says. Ray qualifies this by pointing to the products of organic evolution, including rice, corn, wheat, carrots, pigs, chickens, cotton, mahogany, silk moths, yeast, and penicillin mold. "If we had never encountered any one of these organisms, we would never have thought of them either. Without the silk moth, we wouldn't have thought of silk." The applications come later. "The advantage we have over the pre-Cambrian era is that we've seen the result of evolution," he says. "We've also seen what multicellular organic life is, and we know about organic information processing systems, so we have a little more to go on."

What is clear is that the programs would be for "fuzzy" applications, such as pattern recognition. An obvious use, according to Ray, would be as information-gathering agents for a network similar to the intelligent agents already in development. Users would program the agents to gather information, such as travel schedules or stock quotes, based on preset parameters—must travel at night, first class, or must be a publicly held technology company with less than two hundred employees. Parallel computers may also benefit from the reserve. "A new generation of parallel computers could be made to evolve their own programs," Ray says, "programs more subtle and clever than those devised by human minds." Ray, who is forty-two, is currently an invited researcher at the Evolutionary Systems Department at Advanced Telecommunications Research International Human Information Processing Research Labs in Japan, where he is living with his wife Isabel and daughter Ariel Ivy. When not in Japan or Santa Fe, he is an associate professor at the Schools of Life and Health Sciences and of computer and information science at the University of Delaware.

The Organic Reserve

Don't be mistaken. Tom Ray hasn't abandoned his roots as an ecologist for the silicon chip. While developing his digital reserve, Ray has proposed the establishment of an organic reserve in the rain forests of Costa Rica. The project is intended to prevent the imminent destruction of some of the last remaining large areas of rain forest in the Sarapiquí region of northern Costa Rica and to generate a conservation economy for the area through community-based nature tourism.

Ray first went to Costa Rica as an undergraduate at the age of nineteen. "I was asked by Donald Strong, a professor of biology at Florida State University, to assist with his research," he says. "We were studying the relationship between a family of beetles and their host plants."

It's not surprising, as an ecologist, he ended up in Costa Rica. The country is a hub of biodiversity, hosting over half a million species, about 4 to 6 percent of the earth's biodiversity, according to Costa Rica's own prestigious National Biodiversity Institute (INBio). Since Ray's first visit, there have been many efforts to preserve the forests of Costa Rica, but many losses, too.

According to an INBio study, exploitation threatens between thirteen hundred and fifteen hundred plant species, and sixty-five hundred species are vulnerable as a result of severe deforestation by timber exploitation. Between 1973 and 1989, total forest cover in the country fell from 58.5 percent to 42.9 percent, with remaining dense forest covering only 28.9 percent by 1989. Fish populations have also been depleted. In fact, most of the remaining biodiversity was found in legally protected areas, giving credence to conservation policies.

Sarapiquí, a canton, or county, in the northeastern province of Heredia, has been a center of conservation activity in Costa Rica for many years, primarily due to an international biological research station owned by the Organization for Tropical Studies. The town of Puerto Viejo de Sarapiquí was a thriving river port in the last century, with the Sarapiquí River leading to the San Juan River. The town was usurped, however, by the construction of a coastal canal, diminishing fortunes in the area, but perhaps this was a hidden blessing for the region.

The forest is home to, among others, monkeys, tapirs, jaguars, kinkajous, sloths, raccoons, margays, porcupines, quetzals, and eagles. Six thousand species of trees, five hundred birds, and one hundred thirty-five mammals have been catalogued in the nearby Braulio Carrillo National Park. The forest produces such varied products as cardamom, palm oil, tea, medicinal products, and rattan—not to mention oxygen. Two-thirds of the animal and plant life in the rain forest reside in its canopy, or at the top of the trees. Such is the case with the iguana. The lizard, which tastes like chicken, is popular among Latin Americans and over the years has been bred as rain forest "livestock." Like most of the wildlife, though, the iguana is threatened by the felling of trees.

Deforestation, however, is not the only problem facing the Sarapiquí region. Accelerated human-population growth and the conversion of forest to other land uses, such as pasture, coffee, sugar cane, and banana plantations, are contributing to the degradation of the natural environment, according to Ray.

The country has made strides in the last two decades, though, in regard to conservation. National parks or reserves protect nearly 22 percent of Costa Rica's territory. This, combined with a stable political situation and generally friendly residents, has contributed to the growth of its nature tourism industry, according to Ray. Large numbers of people from all levels of Costa Rican society are employed in the ecotourism business as naturalists, guides, park guards, and hotel and restaurant employees. With this has come a change in the local population's attitude. For example, some 140 grass-roots environmental groups have been organized in the past twenty years. With this in mind, Ray believes the Sarapiquí project's key to success is to create economic incentives through nature tourism for residents of the region. Following Ray's plan, the Sarapiquí region would have an area of forest easily accessible to tourists (some rain-forest tours require visitors to travel some distance by horse back, tractor, or Jeep to enjoy the forest) and be owned and operated by Costa Rican nationals who are members of the local community. The property would be large enough to preserve populations of flora and the wildlife indigenous to the area.

Clearly, Costa Rica has become more than a field of study for Ray over the past twenty years. The landscape as well as the people draw him back. He and his wife, a native of San Carlos, Costa Rica, own fifty acres of rain forest in the Sarapiquí region and have built a house. "What has made Costa Rica an important area for biological research and conservation is that it has rich, living, natural resources, such as the rain forests," Ray says, "and also a peaceful, friendly, democratic people. There just isn't anywhere else like it in the Americas that I know of."

The Sarapiquí Project

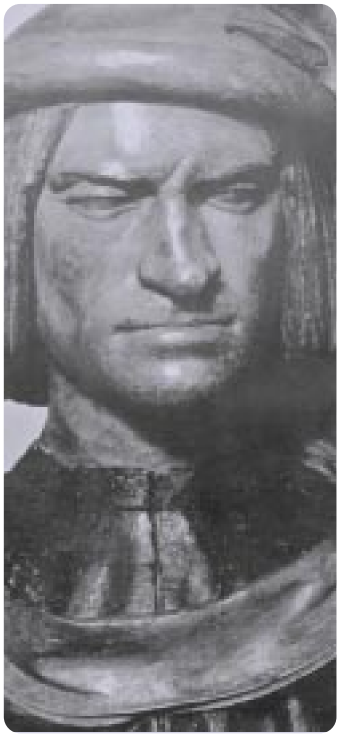
The ambitious project, which is divided into six stages, encompasses both the purchase of over 3,500 hectares (approximately 8,700 acres) of land and the development of community-based nature-tourism trade. A $250,000 grant from the John D. and Catherine T. MacArthur Foundation, with matching funds of $125,000 from the National Fish and Wildlife Foundation, is being used to fund Stage Six of the project, which involves widening the upper portions of the designated corridor to connect La Selva Biological Station to the Braulio Carrillo National Park.

Other organizations involved in the project are The Nature Conservancy, the Costa Rican government, the Sarapiquí Association for Forests and Wildlife, The Organization for Tropical Studies, The Foundation for the Development of the Central Volcanic Mountain Range, and The Conservation and Management of Tropical Forests. Close to home, SFI's Murray Gell-Mann has been involved with the project, particularly helping to secure funds from the MacArthur Foundation. For more information on Tom Ray's proposal to form his organic reserve, visit: http://www.hip.atr.co.jp/~ray/pubs/reserves/reserves.html. Tom Ray's home page can be found at http://www.hip.atr.co.jp/~ray/.

Janet Stites is a free-lance writer who lives in New York City.

Tom Ray explains his Tierra program during a video-taped demonstration

John Padgett, Cosimo de' Medici, and the Renaissance



A Political Scientist Believes the Territorial State and the Concept of the Individual Emerged from Early Florence

John Padgett believes that two important concepts developed in Florence during the days of Cosimo de' Medici and Italy's Renaissance: the formation of the territorial state and the idea of the individual.

Padgett, a SFI external faculty member who teaches political science at the University of Chicago, is currently on sabbatical at the European University in Florence. He is interested in understanding the dynamic relationship in history among social networks, social cognition, and behavioral routines.

Why would the Santa Fe Institute be concerned about the outgrowth of the territorial state and the individual during the Renaissance? Padgett asked at a recent symposium in Santa Fe on "Complexity and the Political Process."

SFI is interested in these ideas, he answered, because they embody a powerful metaphorical framework the Institute believes may be central to such social applications. The metaphor involves the emergence of higher orders of organization out of complicated interactions among simple components. In Florence, a new form of organization, called a state, developed out of personal interactions among individuals and families.

In fact, SFI is planning a new social science initiative called "State and Market Formation" to encourage research and collaboration in this area. In 1997 a workshop is planned on state formation; others on market formation, and one on social cognition may follow.

"What I am going to say about the formation of the state and the formation of the individual is deeply at variance with the mythology of the Renaissance," Padgett told about one hundred people at the symposium in Santa Fe. "The Renaissance is founded on the idea that a great, creative genius emerged out of nowhere and that it deposed a world view on the creative world and on science. This is antithetical to a complex-systems notion, where you have a lot of people walking around in highly complicated interactions. How could a highly individualistic genius like Michelangelo be produced by this Santa Fe-esque framework?"

These people, the families of Florence, Padgett said, had complicated patterns of interaction: marriages, patronages, business relations, friendships. And from the counterintuitive concatenation of these networks, people such as Michelangelo and Cosimo de' Medici emerged.

Until the time of Cosimo de' Medici, Padgett said, Florence was governed on the basis of its families and their alliances with each other. But because of Medici, the city was transformed. It became a place governed by the idea of territory and the state. It wasn't yet Italy, he said, but it was Tuscany. Florence also had a deeper transformation—the birth of the concept of a modern, autonomous individual. "I'm going to claim that states and the Western conception of an individual," Padgett said, "emerged as the payoff of this particular story."

The Territorial State

Padgett's story begins around 1400, when the idea of a geographically based state developed across northern Italy, including Florence. Up until this time, taxes had been worked out on an individual basis, and no uniform legal code existed. Each person had private arrangements with the government. But in Florence, the legal system started to become uniform, at least over a territorial-based idea of residence. Everyone within this geography was subject to the same laws and tax system.

In 1434, Cosimo de' Medici's opponents, the oligarches, headed by the Albizzi, plotted to take over Florence. At a secret night time meeting, the group agreed to a coup d'Çtat the next morning at the square. But in the morning, only half the people showed up. The oligarches sent messengers for the missing. Some showed up; some didn't. Meanwhile, some people drifted off. Indecision, Padgett said, marked the oligarches' organizational capacity.

In the meantime, the Medicians, who had gotten word of the coup, showed up early in the Palazzo Vecchio in the city council hall. This happened in spite of the fact that Cosimo de' Medici was exiled in Venice, and there was no head man present. Scholars don't know how or why the Medicians knew what to do in his absence. However, Padgett said he had always thought the Medicians had been left standing orders to follow or at least some policy guidance.

Since both sides had money, troops, and horses, historians believe Cosimo do' Medici won this showdown because of his ability to coordinate and centralize. He brought his forces into play in a clear way, while the oligarches' structure was less effective.

Although homogeneity might appear to be necessary for such an action, the Medici supporters were heterogeneous in social class, wealth, neighborhood residence, and other variables. "In fact," said Padgett, "they hated each other. This was a divided group composed of multiple neighborhoods, multiple social classes, and deep social cleavages. How did this heterogeneous and conflicted set of people become the raw material for centralized action? The other guys, who were more homogeneous, especially in social class, were frittering around."

The Medici group's heterogeneity came from its social and business contacts. As a result of political manuverings after a workers' revolt in Florence in 1378, the relatively upstart Medici family forged an alliance with the conservative, patrician Rondinelli family—Rondinelli daughters married Medici sons—and thus became a part of the city's social network. In contrast the people the Medici did business with were social climbers, new immigrants who had just come into the city, entrepreneurial people, working their way up the ladder. The Medici also ignored neighborhood cleavages. Some associates lived on the opposite side of town from the Medici; some lived next door. Even though these people may not have disliked each other, they didn't run into each other often; they didn't interact socially.

The Albizzi, on the other hand, were more cohesive; they married the people they did business with. The Medicians' dislike of each other, which was reinforced by social class, social ties, and neighborhood, kept the system centralized.

When centralization emerges, it is rooted in heterogeneity, Padgett emphasized, but heterogeneity is also the reason for centralization. Why were the Medicians so centralized? In a centralized system, Padgett said, people don't talk to each other. They get their information from one source. Although Cosimo de' Medici was in Venice he apparently had left standing orders. Medicians followed the rules. There were no conflicting conversations. Everything was centralized and simple, and its simplicity was its power.

Cosimo de' Medici was a grand, almost idolized figure, Padgett said. He was smart and shrewd, although he was inscrutable and had a passive style of management. Medici didn't construct his party to take over Florence or to move his party into a position of power. He only did this well after his party emerged. The party emerged around him, and then its formation propelled him to take over Florence.

The Concept of the Individual

Perhaps more important then the emergence of the idea of state was the transformation of the concept of the individual in Western civilization. The great art of the Renaissance was founded in the creation of linear perspective by people such as Masaccio, Brunelleschi, Alberti, and Donatello. These artists constructed a novel approach to perspective, one that imposed a new system of naturalism in the artistic world. In linear perspective, the artist draws an object in such a way that its edges move to a single, imaginary point on the horizon. According to Padgett, the transformation in the conception of individuality was rooted in linear perspective.

"Imagine yourself as an isolated eyeball floating around in space," Padgett said. "You cannot see yourself as a physical entity. All you can see is the world around you. How would you infer that you, an individual, exist in such a disembodied eyeball? It's obvious, if you know the rules of linear perspective. You have to notice, as you move around, that objects don't move discretely. They move in fields of objects, rotating. The edges of these objects are like children's toys whose eyes follow you as you move.

"Linear perspective also has that feature. Linear perspective gives you the ability to see the world this way I am a spot, I am a person, I am an individual, I am a powerful individual. Why am I a powerful individual? As I move, the world is reconstituted around me, so my constitution of the world and my impression of myself as a single point are bound up in the same linear perspective images."

The Medieval idea of an individual, Padgett said, was as a morally ordered system of rules from God, and the individual was judged morally worthy or not, depending on how he carried out the rules. Individuality was a path on a two-dimensional plane. The person's identity consisted of his or her path, a static, fixed belief of one's place in the universe. Using linear perspective, however, a transformation occurred: the individual was a work of art who created his own world.

"Think of yourself," Padgett said, "as an embodied self rather than an imaginary eyeball. If you see yourself this way, in linear perspective, you understand you have a core. There is a true self. Everything else is secondary selves. A hierarchy of personality, of identity, emerges naturally. This idea of a coherence is what the modern conception of an autonomous individual is about."

How is the emergence of the city state in Florence related to linear perspective? After the Medici took control of the city, they eliminated their opponents or exiled them. The remaining people saw their positions vis-Ö-vis Cosimo de' Medici. The Medici were the central organizing point to which all Florence's networks were pointing.

"In this way," Padgett said, "linear perspective, while not literally invented by social networks, came to make sense of the actual (and new) social world around them. Powerful people and states, but also powerful new conceptions of people and states, emerged from unintended centralization in political networks. Such at least in the Santa Fe-esque hypothesis guiding this research."

Focus on FOCAS Simplifying for Science

The FOCAS Program

The Santa Fe Institute has formed an integrative Foundations of Complex Adaptive Systems (FOCAS) program aimed at building simplified theoretical models of complex adaptive systems. FOCAS is intended to strengthen and bring coherence to many of the existing theoretical efforts at SFI as well as to introduce new directions. It grew out of a desire to balance better the creative tensions at SFI between simulation work, empirical studies, and mathematical modeling.

FOCAS cuts across several existing programs, including adaptive computation; ecology; Swarm; immunology; and computation, dynamics, and inference. It has new components of its own, too, especially an increased focus on tools from statistical mechanics, stochastic processes, and dynamical systems theory. SFI's grant from the government's Defense Advanced Research Projects Agency, better known as DARPA, is funding the program.

The theoretical work will not take place in a vacuum. The methods will be developed within a limited number of application areas, attempting where possible to compare different approaches to the same problems and testbed cases. The application areas chosen for the coming year fall into three broad areas: distributed problem solving, biological defenses, and search and optimizations. These areas, and some important research questions within them, are described in more detail in Boxes 1, 2, and 3.

The scientific director of FOCAS for the 1996-97 academic year is Richard Palmer. Palmer, normally based at Duke University, where he is professor of physics and of computer science, is currently visiting SFI for a sabbatical year. He is a member of SFI's external faculty, Science Board, and Science Steering Committee. James Crutchfield will take over from Palmer after he returns to Duke. Crutchfield is an SFI research professor and director of the program on computation, dynamics, and inference. He is also a member of SFI's Science Steering Committee.

Simplify, Simplify, Simplify

FOCAS is based on the premise that a useful route to scientific understanding of a phenomenon is the construction of simplified theoretical models. Even if such a model throws out or ignores many of the variables in the problem, it may still lead to insights by showing, for example, that ingredients A, B, and C lead generically to phenomena P and Q. Including more detail might modify this association of cause and effect quantitatively, but not qualitatively if the association is truly generic.

This is a physicists' picture of the world—it's no coincidence that Palmer and Crutchfield are both physicists by training. In physics, there is a well-developed notion (based in renormalization-group theory) of "universality classes." Within such a class, diverse physical systems all exhibit the same qualitative behavior. This picture also leads to the identification of natural "relevant" and "irrelevant" variables. Changing an "irrelevant" variable leaves one in the same universality class—giving much the same behavior as before—and in many physical situations most variables are found to be irrelevant in this sense. Then a program of simplification works well, typically aiming for a mathematical model in which only the relevant variables are included explicitly.

The extent to which the same sense of genericity applies in other areas of science is yet to be determined. In other domains, it could be every variable is "relevant," with no broad universality classes. Such problems are easily constructed artificially, but it is not clear where real-world problems (e.g., in biology or ecology) lie on this scale and thus how much useful simplification is possible. FOCAS is taking a pragmatic approach, attempting to build idealized mathematical models in new domains. Even in cases where the approach is unsuccessful, much may be gained by the attempt, including the identification of some relevant and irrelevant variables. Two successful examples of simplification are described in Boxes 4 and 5.

But What Happened to Realism?

Not all scientists agree philosophically with the approach of active simplification. Some argue that every known detail should be included in a model, making it as realistic as possible. After all, how is it possible to tell whether an ingredient is relevant without trying the effect of including it?

Whenever Brian Arthur, Blake LeBaron, or Richard Palmer give a presentation on the SFI Artificial Stockmarket model, they report a large fraction of the question period is usually taken up by suggestions of the form, "Why don't you add X to the model?" The X's frequently include such things as multiple stocks, transaction costs, and stock options, but there are also unique suggestions on almost every occasion. The set of possibilities is effectively infinite—a fully realistic model would be as complicated as the New York Stock Exchange, together with all the dynamics of the companies whose stock is traded there and the behavior of all the traders and their clients and their clients' peers and advisors and their advisors and so on without end.

Clearly, it is essential to stop somewhere in such infinite regressions. Some detail must be omitted or approximated or averaged. This is equally true in modeling a biological system, for example, where trying to account for the position and motion of every individual water molecule (or every quark!) would not normally be productive. The key is knowing—or deciding—where to stop including detail or conversely where to stop simplifying.

Actually, for a well-defined closed system, a completely detailed model may sometimes be possible. For instance, many of the algorithms and interacting-agent models used at SFI to explore computational problems, ecologies, and artificial life can be fully represented mathematically as "Markov processes" with large numbers of variables. But such a representation gives little or no insight into why the systems behave the way they do. A fully realistic model is normally just as complicated as the original system being modeled and is typically little help on the path to understanding.

To take another fanciful example, we might suppose, in some future time, it will be possible to make a neural-network "brain" capable of learning and developing on a par with a human child. We could imagine raising this creature in a human family, letting it learn to be human through parenting, schooling, play, and so on. But even supposing such a process were one day possible, it would not necessarily lead to any greater understanding of how a human brain works, the nature of consciousness, or the process of child development. We could take the artificial brain apart, but there is no reason to believe that it would be any easier to understand than a human brain.

Scientific Understanding

Palmer argues that building simplified models is not just a way to make research easier; it is a crucial path to scientific understanding. If one asks twenty scientists what they mean by scientific understanding or how to reach it, they would probably give twenty different answers. But Palmer suggests most would include a sense of getting to the essence of a phenomenon, stripping away the trimmings from the tree, and understanding how at the core a few main ingredients interact to produce the essential behavior of the whole. A complete reproduction of a system by a highly faithful simulation, for example, does not in itself lead to understanding (though it may be useful in other ways). Copying Nature is not the same as understanding Nature; understanding necessarily involves some sense of reduction to essentials. The only common exception, according to Palmer, is the achievement of understanding by a "horizontal leap"—mapping one problem onto another that has previously been understood, often by analogy or metaphor. But of course this only displaces the step of simplification.

Explore, Identify, Model

To develop theoretical models of particular complex adaptive systems within the three application areas of the program (see Boxes 1, 2, and 3), FOCAS emphasizes a three-step approach:

- Explore the terrain with empirical observations and/or simulations.
- Identify the relevant and irrelevant (or important and subsidiary) variables, ingredients, interactions, or structures.
- Build simplified mathematical models based on those most important ingredients, averaging out or freezing the rest. Test these models against empirical data or experiments and revise or reject as appropriate.

Of course, in some cases, these stages of analysis may blend and merge, while in others, some steps may be unnecessary or impossible.

Identifying Relevant Variables

The second step of this scheme—identifying the relevant variables—is often the hardest and will be an important ingredient of FOCAS. In a complex system of many parts, it is often not clear which variables to focus on and which to finesse. This is especially true when the right variable may be a "collective" one—some composite or average of the more elementary variables originally used to describe the system.

If researchers wanted to understand a bran muffin, for example, in terms of the molecules of which it was constructed, it would be of little use to focus on the position of just this molecule or the speed of just that one. And they certainly couldn't hope to describe in detail what all the molecules were doing, since no current computer could hold the number of variables needed for a mere crumb. Even if it could and they simulated a tiny morsel, they'd still have the same problem of which numbers to look at in mounds of printouts. That's not the route to understanding. Instead, they'd need to select collective quantities like the average energy of all the molecules, their mean spacing, and so on, and then build a simplified muffin theory in those terms.

Isn't this all rather obvious? Well, yes, for bran muffins (and even blueberry ones), but these are familiar systems and are almost homogeneous. One molecule is much like any other in the same muffin, so it doesn't take much to think of averaging over them all. But in the case of many of the problems studied at SFI, the right variables, or the right averaging procedure, are far from evident. This is closely related to the phenomenon of "emergent behavior," where the behavior of a complex system is unexpected and not obviously specified by the system's low-level description. A necessary step toward finding the appropriate relevant variables is characterizing the emergent behavior mathematically, generally a hard task.

FOCAS will use a number of approaches to address these problems of quantifying emergence and identifying relevant variables. Some emphasis will be placed on new methods—developed at SFI by Crutchfield and co-workers—that use concepts from the theory of computation. By analyzing observations in terms of the minimal computational mechanisms required to produce them, it becomes possible in some cases to extract their emergent patterns and relevant variables systematically and even to quantify their complexity unambiguously. FOCAS will develop this theory further and apply it to understanding and quantifying the emergence of many novel phenomena in complex adaptive systems.

Simple Models, Complex Systems

The goal of FOCAS is to develop scientific understanding of complex adaptive systems by building simplified mathematical models. The resulting models will often be only for a modified version, special case, or aggregation of the original problem. Nevertheless, that can often provide insight and understanding, in many cases more effectively than a fully detailed but intractable model. Once sufficient understanding has been reached in this way, it can be used to guide the construction of more detailed models (usually based on simulation) or lead to an approximation scheme for more realistic cases.

Palmer summarizes: "I know it's an old cliché, but this really is like the forest and the trees. If you focus on modeling a lot of trees in gory detail, you may not learn much about forest dynamics as a whole. You need to start by thinking about the forest and try to see what aspects of the trees really matter to you. Then use just those variables, as few as possible, to start your mathematical modeling."

Palmer also says he's thinking of reducing himself to a stick figure.

Box 1:

Distributed Problem Solving

Many practical problems involve the coordination of many parts or subsystems to achieve an overall goal. While some cases are easy to design or understand, there are many examples where even a fundamental understanding is lacking, such as how the individuals in an ant colony are coordinated to produce a global effect. When simple local rules are combined with local interactions, as with cellular automata and boolen networks, the range of global problems that can be solved is not at all well understood. Thus the design and understanding of distributed problem solving systems forms a rich area for development of theory in the FOCAS program.

Some research questions being addressed in this area are:
How can one construct local rules of interaction and decision-making such that all system components can be guaranteed to be coordinated before some fixed time?

- How and when can higher levels of computational capability emerge from the interaction of simple machines?
- How is the capacity for global computation or problem solving affected by the interaction topology between processors (or agents)?
- In a system of cooperative processors (or agents) with dynamically changing interaction topologies, how can role diversification and specialization be stably maintained and optimized?
- If a spatially distributed problem must be divided up into smaller parts (patches or organizational units), how can one find the optimum patch size and appropriate interactions between patches?
- In a problem with both spatial and temporal information propagation, what are the tradeoffs between spatial and temporal horizons for search and optimization?
- What types of problems are efficiently parallelizable?
- How can standard measures of computational complexity be extended to apply to distributed, continuous, or stochastic systems?
- How do natural distributed problem solving systems form and adapt their goals and strategies in dynamic and uncertain environments?
- How can different scheduling paradigms and constraints be efficiently handled in simulations of interacting agents?

Box 2:

Biological Defenses

Organisms defend themselves against pathogens and toxins in many highly adaptive ways. But pathogens also adapt or might be introduced artificially in biological warfare. Understanding how natural defenses work and how they might be improved is an important goal both for public health and for national security. While SFI does not engage in direct defense contract work, a number of issues raised by biodefense problems are of considerable scientific interest and form an excellent application area for theory development in FOCAS. The work is focused on understanding and modeling the complex adaptive systems in immunology and molecular and cellular biology that play roles in pathogen response and countermeasures.

Some research questions being addressed in this area are:

- How can the immune-system response be enhanced or controlled by external intervention?
- How does the immune system choose its response modality: is there central control or some sort of distributed winner-take-all competition or some alternative mechanism that allows it to have such a wide array of responses?
- How does the immune system distinguish self and nonself (both for antibodies and for major histocompatability (MHC) molecules), and can this process be modulated?
- How rapidly do drugs (and other agents) become ineffective through the evolution and propagation of resistance, and what strategies can be used to enhance or retard the process?
- How does the propagation of an infection depend on the spatial and temporal patterns of interaction between potential carriers?
- How can biocatalysts for particular tasks and interventions be designed and engineered rapidly?
- How can complex circuits in gene-regulatory networks be inferred and exploited for effective intervention?

Box 3:

Search and Optimization

The continuing development of efficient search and optimization methods for complex-problem domains is a crucial area of practical research. The work at SFI in the FOCAS program focuses mainly on parallel adaptive-search methods, especially those involving the evolution and interaction of populations of searchers on a problem landscape. This work overlaps with the "Distributed Problem Solving" area (Box 1) but is more concerned with evolution on fixed landscapes, whereas "Distributed Problem Solving" involves coevolutionary (interdependent) landscapes. The emphasis is on developing theoretical understanding of how, when, and why particular algorithms work or fail on different classes of problems.

Some research questions being addressed in this area are:

- How can one find optimum parameter settings or schedules in adaptive-search methods?
- Why do evolutionary search methods (and biological evolution) frequently show long periods of little progress, punctuated by discovery events, and can this be avoided?
- When does recombination between different solution candidates improve search, and can this be done automatically in a domain-independent way?
- How can problem representations be modified to reduce the barriers between different local optima?
- Are there automatic ways to break down a problem into semi-independent subproblems that can then be solved in parallel?
- How can one rapidly estimate the difficulty of a search problem for different algorithms and hence choose an appropriate method and/or representation?
- How do the effects of cumulative local improvements in a system affect the possibility of global optimization?

Box 4:

Dynamics of Genetic Algorithms

Genetic algorithms provide a way to search a large problem space for regions of high "fitness," where fitness is defined by the problem under study. Most search and optimization algorithms use one searcher at a time, but a genetic algorithm has a whole population of searchers working in parallel and exchanging information. This approach is modeled loosely on genetics, with the individual searchers governed by selection of the fittest and mutation and the exchange of information between individuals corresponding to sexual reproduction.

There are many theoretical questions to ask about the dynamics of genetic algorithms, including:

- When do they converge to the highest possible fitness?
- How rapidly do they converge?
- On what problems do they work well or poorly?
- How should the parameters be tuned?
- Why does improvement often come in sudden innovations separated by long periods without progress?

Much of the past theoretical work has focused on describing every detail of a genetic algorithm, describing precisely how the whole population evolves stochastically over time. Unfortunately, that approach has not been very productive and has shed little light on the above questions.

A new approach within the FOCAS program (pioneered by Jonathan Shapiro and Adam Prügel-Bennett) has been to simplify the problem by focusing attention on the "fitness distribution" of the population. This leaves out all the detail about the individuals but then allows the construction of some relatively simple mathematical models for the dynamics, using methods from statistical physics and dynamical systems theory. These new methods do help to answer the above questions and give considerable insight into the full problem. In particular, Erik van Nimwegen, James Crutchfield, and Melanie Mitchell have developed a convincing explanation of the "ephochal evolution," mentioned in the last question above, seen in a particular genetic algorithm application (Forrest, Holland, and Mitchell's "Royal Road" problem). Similar metastable behavior is seen in a wide range of models of evolutionary processes and arguably in real biology ("punctuated equilibrium"), so contributions from this work will probably have wide applications.

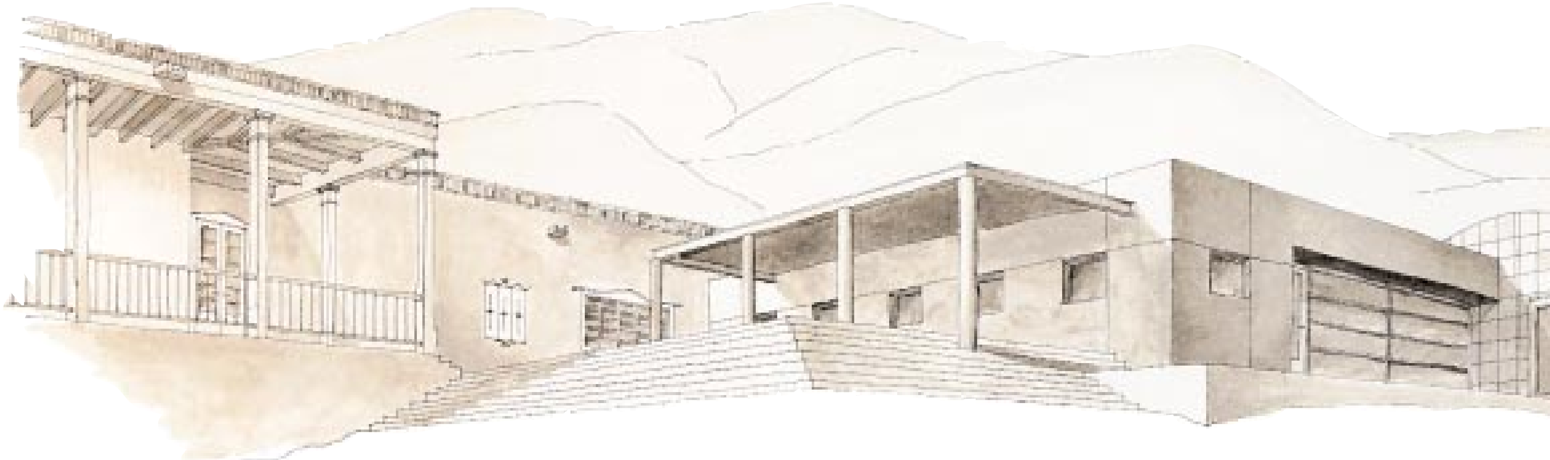
Box 5:

Biological Extinction Models

Why did dinosaurs die out? This is a question almost everyone has wondered about at one time or another. In fact, a number of so-called "mass extinctions" have existed in the Earth's history, when a large fraction of the species on the planet died out, apparently simultaneously. Explanations of these extinctions have been proposed over the years, but recently, following the work of Stuart Kauffman at SFI, a new possibility has emerged that links mass extinction to the way in which the ecosystem evolves. The basic theory revolves around the idea of coevolution—the evolution of one organism because of an evolutionary change in another. Famous examples of coevolution include the increasing speeds of cheetahs and their prey on the African plains or the ever-rising height of the rain forest canopy. Coevolution can give rise to waves, or "avalanches," of change that propagate across the ecosystem. Sparked by the initial chance mutation of a single species, one of these avalanches can cause thousands of other species to evolve to new forms. Some have suggested that such a disturbance could be enough to cause the extinction of whole groups of species, just as is seen in the fossil record.

Kauffman and others have studied these questions using highly simplified mathematical models of evolution. Typically, a change in one species causes a random change in a few others. The details of which species affect which and by how much are reduced to some simple random choices. Although most of the complications of any real ecosystem are absent from these models, their inventors hope the crucial elements of evolution are represented well enough that the all-important coevolution effects will be visible. Initial results have been promising, with good fits to experimental-extinction distributions, though there are many open problems too.

Whether or not they eventually shed light on where the dinosaurs went, these models raise many intriguing questions about how an ecosystem evolves. And the tools developed to treat such systems will likely be applicable to artificial coevolutionary problems, including both distributed problem solving systems (Box 1) and evolutions-search algorithms (Box 3).



SFI to Add 9,000 Square Feet

The Santa Fe Institute has announced a three-year program, costing $7.7 million, to expand its current facility. The Founder's Phase of the campaign begins in January and has raised $2.2 million of the necessary money.

"Additional space at the Institute is critically important if new programs and new scientific opportunities are to begin," said SFI President Ellen Goldberg, who announced the program. "Momentum for SFI's model of scientific research is growing, requests for new programs are backlogged, and the desire for scientists to spend time at SFI is increasing."

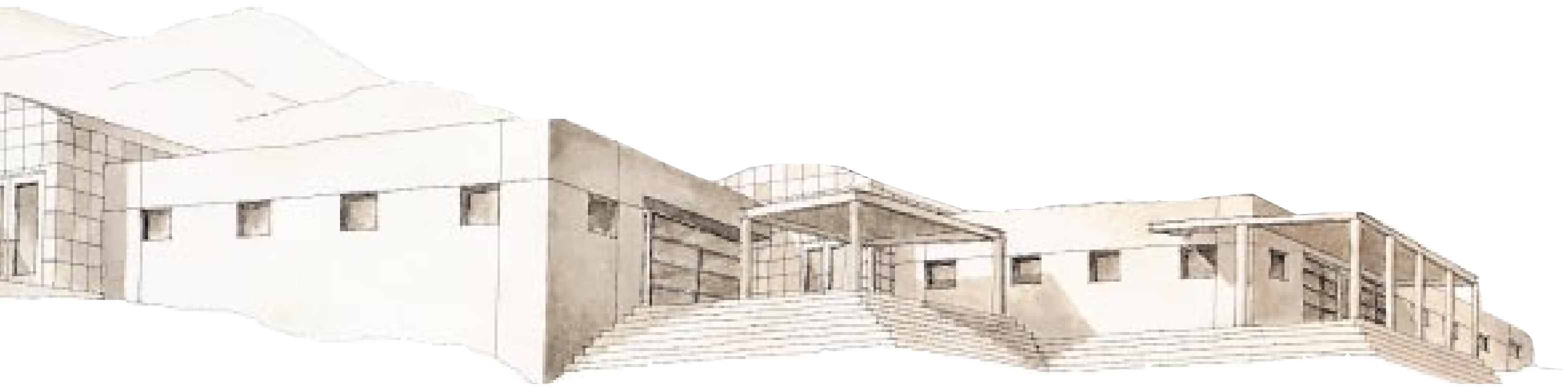
The expansion—9,260 square feet of space from the south of the main building—will complement SFI's best feature: its collaborative, multidisciplinary approach to scientific research.

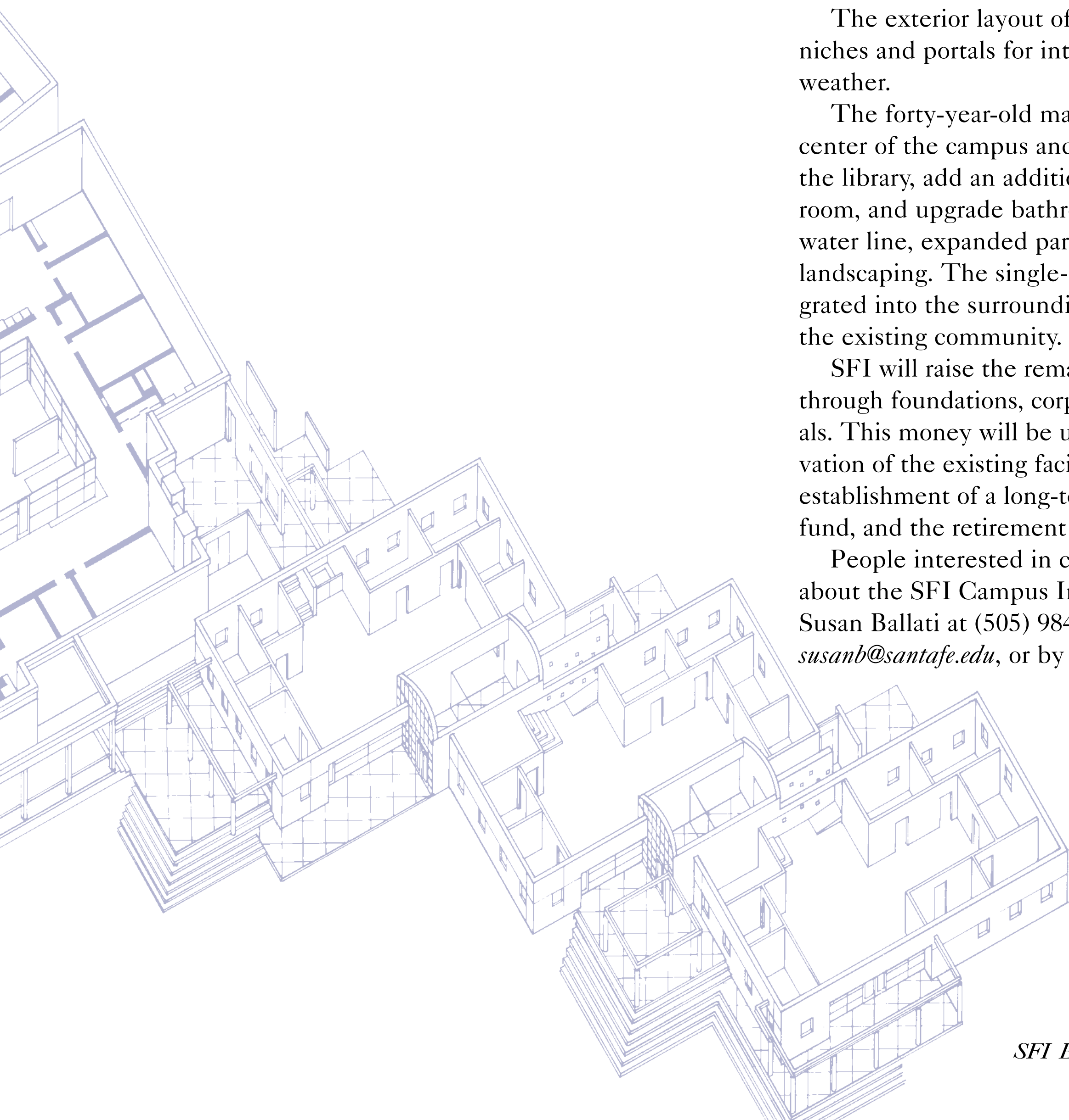
Shared offices will surround three common areas so that group discussions can facilitate individual work. In addition, the expansion program will also enlarge the library and meeting-room space in the main building. With the additional space, SFI will be able to accommodate up to fifty researchers and scientists.

More specifically, the south wing will use what is called an interior-street floor plan and a caves-and-commons approach. The caves-and-commons approach groups small offices around a large space that contains tools and other amenities that are to be shared. The interior-street floor plan uses a wide corridor, with shared amenities, that links the long building into a whole.

Most of the new rooms will be 10 by 16 feet. These rooms will serve as offices for one single senior or long-stay occupant, offices for two junior or short-stay occupants, or small meeting rooms. Such rooms can also be divided with an added wall into two small private offices opening onto the commons.

All offices and meeting rooms will take advantage of natural light from the outside through operable windows and from the skylit interior street or commons. The interior windows will allow small-room occupants to see what is going on in the common areas, and passersby on the interior street will be able to observe when someone is in his or her office.





The exterior layout of the wings will also provide niches and portals for interaction outdoors during warm weather.

The forty-year-old main building will remain the center of the campus and will be renovated to expand the library, add an additional medium-sized conference room, and upgrade bathrooms. Plans also call for a new water line, expanded parking, a paved driveway, and landscaping. The single-story extension will be integrated into the surrounding environment to blend with the existing community.

SFI will raise the remaining funds for the expansion through foundations, corporations, and private individuals. This money will be used for new construction, renovation of the existing facility, furnishings, equipment, establishment of a long-term maintenance operating fund, and the retirement of related debt.

People interested in contributing to or learning more about the SFI Campus Initiative should contact Susan Ballati at (505) 984-8800, by e-mail at *susanb@santafe.edu*, or by mailing contributions to:

The Development Office
Santa Fe Institute
1399 Hyde Park Road
Santa Fe, NM 87501

SFI COMMUNITY

Community Talks Probe the Role of Science in Society

Although the 1997 schedule for the Santa Fe Institute's popular public lecture series covers the usual far-ranging scientific topics, it has an integrative thread. "When I look over the roster, more than ever, the topics come back to the role of science in society," says Ginger Richardson, coordinator of these monthly events. "This slant wasn't by design. I think it reflects the increasingly profound role of science in our lives." A number of local businesses and organizations join the Institute in supporting this series, making these Wednesday evening talks free to the community.

Risk, Inequality, and Patterns of Disease

Baruch Fischhoff, professor of social and decision sciences and engineering and public policy at Carnegie Mellon University, leads off the series in January with a discussion of risk management and the public. "Modern life has many risks," Fischhoff notes. "The risk-management process often depends on how competent citizens are thought to be when it comes to understanding risks." Fischhoff will talk about new research in this field and its implications for social policy.

Steven Durlauf, professor of economics at the University of Wisconsin and 1996-1997 co-director of SFI's economics program, will explain the new economics of inequality in a March talk. Recent thinking interprets long-term inequality as emerging from the socioeconomic interactions of many individuals. Related new economic models are able to incorporate the effects of peer groups, role models, and racial and economic segregation in plausible ways. Durlauf will explain this approach and some of its policy implications.

Jonathan Samet, chairman of the epidemiology department at Johns Hopkins University, will discuss the role pattern recognition plays in epidemiologists' search for the causes of health and disease in a May lecture.

Jonathan Haas, curator of New World archaeology at the Field Museum of Natural History, will provide historical counterbalance to these discussions of contemporary society when he discusses Pueblo life in New Mexico before European contact in his July talk. When the first Spanish explorers arrived in 1540, they encountered a complex native community of more than sixty individual Pueblos, speaking five different languages, spread across the mountains and valleys of northern New Mexico. Haas will discuss the everyday lives, social relationships, economy, and material culture of the Pueblo world, based on his extensive archaeological field research in the region.

Life in the Computer Age

Two presentations this spring focus on the social dimensions of computerized society. On February 19, Sherry Turkle, professor of social studies of science and technology at the Massachusetts Institute of Technology and author of *Life on the Screen: Identity in the Age of the Internet*, will describe how some people confront issues of identity through parallel lives lived in the virtual reality of the Internet.

Ellen Knapp, vice-chairman of technology at Coopers & Lybrand, will discuss computing and telecommunications in a knowledge economy on April 16.

The Human Brain

Lynn Nadel, professor of psychology at the University of Arizona, on June 18 will discuss how the brain is organized to store memories, how stress affects these brain-memory systems, and why severe stress can lead to the disorder known as post-traumatic stress syndrome. He will explore why events early in life are poorly recalled; why traumatic events in particular may be forgotten; and the phenomenon of recovered memory of trauma, particularly whether reports of such recovered memories have any scientific backing.

Paula Tallal, co-director of the Center for Molecular and Behavioral Neuroscience at Rutgers University, Science Board Member and her collaborator, Michael Merzernich, from the University of California, San Francisco, have achieved some provocative results involving a novel treatment for children with severe language and reading disabilities. The treatment, which they label "glasses for the ears," may also be helpful for some children with dyslexia. In October, Tallal discusses her research and presents the results of novel remediation strategies that integrate technological advances with neuroscience research.

New Paradigms, New Theories

In recent years, much attention has been paid to a collection of scientific efforts now known as the science of complex systems. These efforts are bringing together ideas from many disciplines to discover general laws governing systems of great complexity with powers of self-organization, such as the brain, the immune system, global economies, biological evolution, and increasingly lifelike computer systems. In September, the Institute will sponsor the forth annual Stanislaw Ulam Lectures. Melanie Mitchell, director of SFI's adaptive computation program, will discuss the past and future of the sciences of complexity. Some people say the complex systems approach is the likely locus of the next great conceptual revolution in the scientific understanding of nature.

The lectures will trace the intellectual history of these efforts, including the pioneering, cross-disciplinary work of figures such as John von Neumann, Norbert Wiener, Alan Turing, and Stanislaw Ulam, and explain how these historical roots have influenced and guided the current work in conscious and unconscious ways. The current accomplishments and future prospects of complex systems research are grounded in this early work. These lectures will focus in depth on links between current and early work as well as on the prospects for revolutionary new discoveries and paradigms from the science of complexity.

A product of the lively imagination of British atmospheric chemist James Lovelock, the Gaia hypothesis states the atmospheric temperature, reactive chemical composition, and oxidation/reduction state are regulated by Earth's biota—the sum of its flora, fauna, and microbiota. In November, well-known biologist Lynn Margulis from the University of Massachusetts at Amherst will discuss this provocative conjecture and the scientific research it has generated.

OUTREACH

1997 Santa Fe Institute Community Lectures

JANUARY 9
"Risk and the Public," by Baruch Fischhoff, professor of social and decision sciences and engineering and public policy, Carnegie Mellon University
SPONSORED BY BARRACLOUGH & ASSOCIATES

FEBRUARY 19
"Life on the Screen: Identity in the Age of the Internet," by Sherry Turkle, professor of social studies of science and technology, Massachusetts Institute of Technology, author of *The Second Self: Computers and the Human Spirit* and *Life on the Screen: Identity in the Age of the Internet*
SPONSORED BY SANTA FE ACCOMMODATIONS

MARCH 19
"The New Economics of Inequality," by Steven Durlauf, professor of economics, University of Wisconsin, co-director, SFI Economics Program
SPONSORED BY ALPHAGRAPHICS, SANTA FE AND LOS ALAMOS

APRIL 16
"Computing and Telecommunications in the Knowledge Economy," by Ellen Knapp, vice-chairman, technology, Coopers & Lybrand, New York
SPONSORED BY SANTA FE ACCOMMODATIONS

MAY 14
"Epidemiology: Finding Patterns and Causes of Health and Disease," by Jonathan Samet, chairman, epidemiology, Johns Hopkins University
SPONSORED BY DISCOUNT OFFICE SUPPLY

JUNE 18
"Stress, the Brain and Memory," by Lynn Nadel, professor of psychology, University of Arizona
SPONSORED BY SANTA FE NEUROSCIENCE INSTITUTE

JULY 16
"New Mexico in 1500: Pueblo Life Before European Contact," by Jonathan Haas, curator of New World archaeology, Field Museum of Natural History
SPONSORED BY JACKALOPE POTTERY

SEPTEMBER 16, 17, AND 18
Third Annual Stanislaw Ulam Lectures: "The Past and Future of the Sciences of Complexity," by Melanie Mitchell, director, SFI's Adaptive Computation Program

OCTOBER 15
"Attacking Learning Disabilities: Integrating Technology and Neuroscience," by Paula Tallal, co-director, Center for Molecular and Behavioral Neuroscience, Rutgers University
SPONSORED BY LEVINSON FOUNDATION, SANTA FE

NOVEMBER 17
"Gaia to Microcosm," by Lynn Margulis, professor of biology, University of Massachusetts, Amherst
SPONSORED BY THE PAPER TIGER, SANTA FE

LOS ALAMOS NATIONAL BANK PROVIDES GENERAL SUPPORT FOR THIS SERIES.

KORBER WINS CHILDREN'S AIDS AWARD

The Pediatric AIDS Foundation has selected the Santa Fe Institute's Bette Korber as a recipient of an Elizabeth Glaser Scientist Award. Korber is one of five international research scientists to be named award winners.

Each award recipient will receive up to $682,000 for five years of pediatric AIDS research.

"We are creating a brain trust for pediatric AIDS research which is unique in the international research community," said Pediatric AIDS Foundation co-founder Susan DeLaurentis. "We [are] the only national foundation to identify, fund, and conduct basic pediatric AIDS research. We are continuing our commitment by investing in the rising stars we feel will have the most impact upon pediatric AIDS research in the future."

Korber, who has a doctorate in immunology from the California Institute of Technology, was a 1989-90 post-doctoral fellow at the Harvard School of Public Health. She is currently a staff member in theoretical biology and biophysics at Los Alamos National Laboratory and a visiting professor at SFI.

Also named Glaser winners were Andrew Lackner, Harvard Medical School; Katherine Luzuriaga, University of Massachusetts; Marta Marthas, California Regional Primate Center, University of California, Davis; and John Moore, The Aaron Diamond AIDS Research Center.

The Centers for Disease Control estimates that 1,200 HIV-infected babies are born each year in the United States. According to the World Health Organization, ten million children will be infected with HIV by the year 2000.

FINDING SPACE FOR SCIENCE

EDITOR'S NOTE: *This is the first of a series of columns in which the Santa Fe Institute's president, Ellen Goldberg, will share her perspective on the challenges facing SFI as it heads into the twenty-first century. It is meant to be an open dialog with the readers of the SFI Bulletin, and we hope it generates feedback from you. This column deals with a topic that could significantly impact both the science and organization of SFI-space.*

THE SANTA FE INSTITUTE RECENTLY ANNOUNCED a capital campaign to raise funds to expand its present facility. These plans, which have been in the making for more than two years, will include additional offices as well as common space for us all. This expansion aims to reduce the current overcrowding and to provide a better environment for our researchers to think, work, and interact.

The expansion will also allow us to increase the number of researchers at SFI from the current thirty-six up to forty-five. (Due to space limitations SFI has had to occasionally turn away or postpone the visits of extraordinary, creative researchers who wanted to spend time at the Institute.) This increase in researchers will generate new initiatives and expand existing ones. In addition, the new space will eventually give our new vice-president, Erica Jen, a real office rather than a desk in the back of a conference room, her situation today.

But with the increased space, we must carefully outline where SFI is heading scientifically. Erica Jen, the SFI faculty (both resident and external), and the Science Steering Committee are currently looking at where we are scientifically and evaluating our vision of where we want to be. What new programs, perhaps in the social and biomedical sciences, do we want to add? Do we want to increase the number of long-term visitors or decrease them in favor of short-term visitors? These are just a few of the question we're asking ourselves.

At the same time, I'm considering how we can expand both intellectually and physically and yet not lose the flavor of SFI—the lack of departmentalized structure, the interactions among researchers of diverse disciplines, the collaborations between the more established researchers and the less established postdoctoral fellows and students. How can we expand and bring in new initiatives that interest and engage the entire SFI family? And, most importantly, how can we ensure that, as a result of this growth, we do not get caught up in process and procedures that commonly plague America's universities. Our mission is to develop new ways to approach complex problems, and we need to remain focused on this mission.

PHOTO OF ELLEN GOLDBERG: WALTER NELSON

Clearly, we must go slowly. But at the same time, SFI shares a lot of excitement about these new initiatives and the expansion of some of its more established programs. We're in the process of planning two exploratory workshops to be held over the next year, one on state and market formation and the other on cellular computation and decision making. The latter is being structured much like the first workshop in economics held in our initial home in the Cristo Rey convent in 1987. That workshop, which had the interest and enthusiasm of a group of creative researchers of diverse scientific backgrounds, was the springboard from which the SFI community emerged. We need to retain that environment and enthusiasm and not let our successes diminish or change the scientific mix and milieu in which we currently exist. These two workshops will likely result in several themes that could become the basis of future interdisciplinary initiatives headed by SFI researchers. Both promise to lead to important insights and breakthroughs that will provide new ways of approaching problems in these two diverse areas.

This is what SFI is all about, and it's what we should be doing. Accommodating these new initiatives means bringing together at SFI, either on a long-term or short-term basis, additional researchers who can become the leaders, the catalysts, for these programs. For this reason, we are looking forward to the expansion of our facility, not only to accommodate these new initiatives, but also to permit researchers involved in our current activities to have a better and more friendly environment in which to conduct research.

Tenth Annual Complex Systems Summer School

June 1-27, 1997, Santa Fe, New Mexico

The Complex Systems Summer School offers graduate students and postdoctoral scientists an introduction to the study of complex behavior in mathematical, physical, and living systems. A four-week program, it features intensive tool-kit introductions to basic topics, week-long lecture courses on selected subjects, seminars, and computer-lab workshops. An interactive format encourages group and individual research projects. Participants are expected to have graduate-level training in one of the mathematical, physical, biological, or information sciences. In addition, students are expected to attend the program for its duration. The school is held at the College of Santa Fe.

Week One

"Complexity and Evolution"
DANIEL MCSHEA, ZOOLOGY, DUKE UNIVERSITY

"Probabilistic Methods in Complex Systems"
RICHARD PALMER, PHYSICS, DUKE UNIVERSITY

Week Two

"Bifurcation and Fourier Methods in Mathematical Neuroscience"
FRANK HOPPENSTEADT, SYSTEMS SCIENCE AND ENGINEERING RESEARCH CENTER, ARIZONA STATE UNIVERSITY

"Complexity and Prediction in Earth, Environmental, and Medical Sciences"
SUSAN W. KIEFFER, FORMER CHAIRPERSON, GEOLOGY, UNIVERSITY OF BRITISH COLUMBIA, MACARTHUR FELLOW, MAHN-LIN WOO, MATHEMATICIAN, KEIFFER AND WOO, INC.

Week Three

"Lessons from Olfaction: Membrane Proteins, Dendrites, and Microcircuits and How They Make a Neural System"
GORDON SHEPHERD, NEUROBIOLOGY, YALE UNIVERSITY MEDICAL SCHOOL

Week Four

"An Anti-reductionist Approach to Modeling Processes in the Desert and at the Shore"
BRADLEY WERNER, SCRIPPS INSTITUTION OF OCEANOGRAPHY

"Structure and Evolution of Foams and Grain Boundaries"
MICHAEL TABOR, MATHEMATICS, UNIVERSITY OF ARIZONA, TUCSON

CO-DIRECTORS ARE LYNN NADEL, PSYCHOLOGY, UNIVERSITY OF ARIZONA, AND DANIEL STEIN, PHYSICS, UNIVERSITY OF ARIZONA.

Support

Subject to funding availability. If support is not available from their departments, graduate students receive full support for room and board and postdocs receive one-half support for room and board. Housing is provided in the College of Santa Fe dormitories. There are no funds available for travel.

Credit

Three units of graduate credit is offered for this program through the University of New Mexico. (Approximate cost to participants is $300 should they elect to get credit.)

To Apply

Applications are due on February 1, 1997. There is no standard application form. In one complete package, you will need to provide: a statement of research interests, a statement of why you want to attend the school, a curriculum vitae (including a list of publications, if any), and two letters of recommendation. Please include your e-mail address and fax number in your materials. The complete packet of materials should be sent by postal mail to:

Summer School
Santa Fe Institute
1399 Hyde Park Road
Santa Fe, NM 87501, USA

Participation in the Complex Systems Summer School is not limited to U.S. participants. Non-U.S. applicants are encouraged to apply, although the school cannot support travel expenses from foreign points. Foreign student participants would enter the United States on either a B or J series visa.

Professionals are welcome to apply. Tuition is $750/week and attendance can be arranged on a weekly rather than monthly basis.

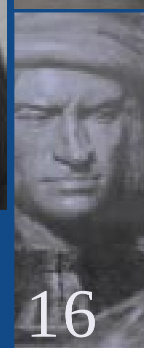
Women and minorities are encouraged to apply.

If you have additional specific questions contact:

Andi Sutherland, Program Coordinator
Santa Fe Institute
1399 Hyde Park Road
Santa Fe, NM 87501, USA
(505) 989-7372; fax (505) 982-0565
e-mail: ars@santafe.edu

Support for the Summer School is provided by the National Institute of Mental Health, National Science Foundation, and a consortium of universities and national laboratories including the Center for Nonlinear Studies at Los Alamos National Laboratory, the University of Arizona, and the Santa Fe Institute.

IN THIS ISSUE...



Santa Fe Institute
1399 Hyde Park Road
Santa Fe, New Mexico 87501
U.S.A.

Non-Profit
Organization
U.S. Postage
PAID
Permit No. 338
Albuquerque, NM