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Do we stand on the wreckage of our own human bias?

DAN McSHEA ASKS TOUGH QUESTIONS ABOUT EVOLUTION AND COMPLEXITY

"If I weren't going to SFI this summer, I would be working at the University of Michigan's (UM) Space Physics Lab and also waiting tables," says Catherine Grasso. "Possibly I would serve food at the UM football players' training table like I did last summer." Grasso's research at the University of Michigan focuses on modeling symbiosis with the two objectives of bettering understanding of this biological phenomenon and creating an innovative evolutionary algorithm. She is focusing on an artificial life project that involves modeling green hydra symbiotic with chlorella, a small, unicellular, green algae. While at SFI, she is working with SFI postdoc Tim Keitt, developing an evolutionary algorithm based on prokaryotic genetics. Grasso is supplementing her stay at SFI with her own support from a GE Fellowship; this will allow her to be in residence for more than three months.

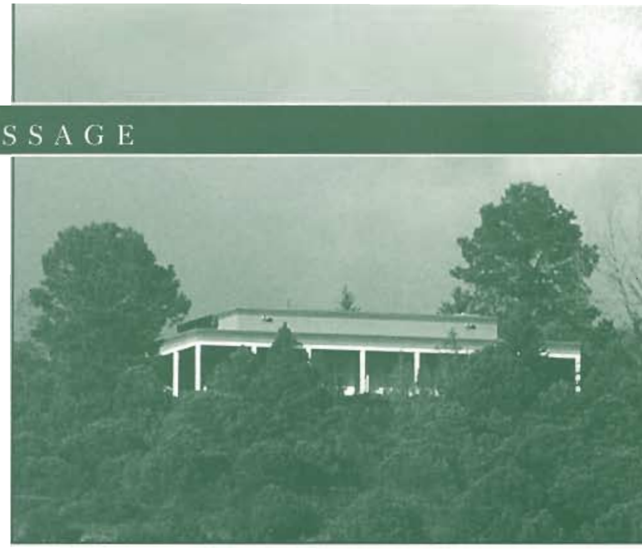
Joshua Berman, a computer science major at the State University of New York, Binghamton, is working with SFI postdoc Cris Moore and with External Professor Mats Nordahl. Berman's project focuses on numerical measurements of simple lattice systems and the development of a theoretical explanation for their glassiness. "Glassy" behavior means these systems "freeze" far from equilibrium under a simple Monte Carlo dynamics. Further, they do so without the usual increasing energy barriers associated with glassy models. When not working on lattice systems, Berman lets his activities in Santa Fe be guided by two "insatiable addictions—Fudgesicles and coffee shops."

Scott Rifkin, a biological anthropology major at Harvard, says he chose his field "to explore how big brains change the rules of behavioral evolution and to explore the interrelationship between culture and biology. I've been approaching evolutionary questions from a variety of avenues, ranging from studying rhesus macaque calls to looking at the influence of metaphors on understanding evolutionary issues to tracking the foraging and social behavior of bottlenose dolphins." At the Institute, Rifkin and SFI resident researchers Bruce Sawhill and Martija Huyaea are researching the effects of one-to-many genotype-phenotype mapping on the dynamics of ribosomal RNA evolution as a first step toward understanding higher-level phenotypic evolution.

Duke's John Tye is helping SFI postdoc Tim Keitt develop computer models of self-organizing, autocatalytic systems. Tye, a twenty-year-old sophomore, is the youngest person at Duke to have a self-designed major approved: it's called "Emergent Properties of Adaptive and Intelligent Systems" and involves classes in computational complexity, nonlinear dynamics, neural networks, philosophy of mind, neurobiology, artificial intelligence and stochastic processes. "In Santa Fe," Tye notes, "I want to start applying all of the things I've been involved with to actually learn something new about our worlds. I want to solve problems by fitting together some of the pieces that I've picked up." He is researching evolution in the context of autocatalytic chemistries by simulating agents that contain catalysts (enzymes) for symbolic chemical reactions. Using a genetic algorithm, he and Keitt are evolving agents that can take advantage of different chemical reactions, allowing them to explore the relationship between the physical chemistry and the ecology of the agents.

Virtually all the Institute's REU interns have plans to pursue careers in the sciences by the time they arrive at SFI. A couple are already well-along multidisciplinary paths; both Grasso and Tye have designed individual, interdepartmental majors on their home campuses. The aim of these summer internships, then, is not to convert but to enrich these students' academic careers – as well as SFI's intellectual life.

Photography: Laurie Smith, except Catherine Grasso photo by Deborah Smith



I STARTED MY TERM AS THE THIRD PRESIDENT of the Santa Fe Institute in January. I have had six months to reflect on the Institute, where it presently is and where we want to go during the next decade. It has been an extraordinary six months getting to know the SFI community and its broad range of interests. I want to tell you about these first months—where I see us presently and our plans for the rest of the year.

Much of January was devoted to a working-group meeting focusing on economics and cognition with participants from several fields discussing cognitive processes in economics. An article in this *Bulletin* describes the workshop and ongoing work. The workshop has led to provocative concepts and approaches that are now being explored by SFI economics researchers and their collaborators at other institutions. What was so interesting to me, with my university background, was the diversity of participants in terms of research interests. I was also impressed by the fact that all were willing to work at understanding the "language" of fields that were unfamiliar to them. It is these aspects of SFI that lead to its uniqueness and that are difficult to duplicate within the university.

Because of this ability to bring together a variety of disciplines to better understand problems of complexity, SFI has been able to attract funding from private and federal agencies that recognize the importance of this approach. This spring, we were favorably reviewed by the National Science Foundation, the MacArthur Foundation and the Defense Advanced Research Project Agency. It was through these reviews that it became clear that SFI, because it is a visiting institution and because of its interdisciplinary nature, is able to approach important problems in a very different manner than the university. The articles in this issue of the *Bulletin* reflect this interdisciplinary approach, ranging from debates about evolution to what is considered an ideal family.

SFI is in good hands. We have a board of trustees that is dedicated to the Institute; a Science Board that consists of outstanding international scientists; a diverse and extraordinary resident and off-campus faculty and postdoctoral fellows and graduate students who are excited about SFI. These individuals understand the importance of the Santa Fe approach to science and are instrumental in bringing new ideas and concepts to SFI and also back to their home institutions. We must continue to expand our horizons to include visitors with different points of view and those who have expertise in disciplines not presently resident at SFI. We also have to network with other institutions, nationally and internationally, so that we can broaden our own perspective and establish additional partnerships.

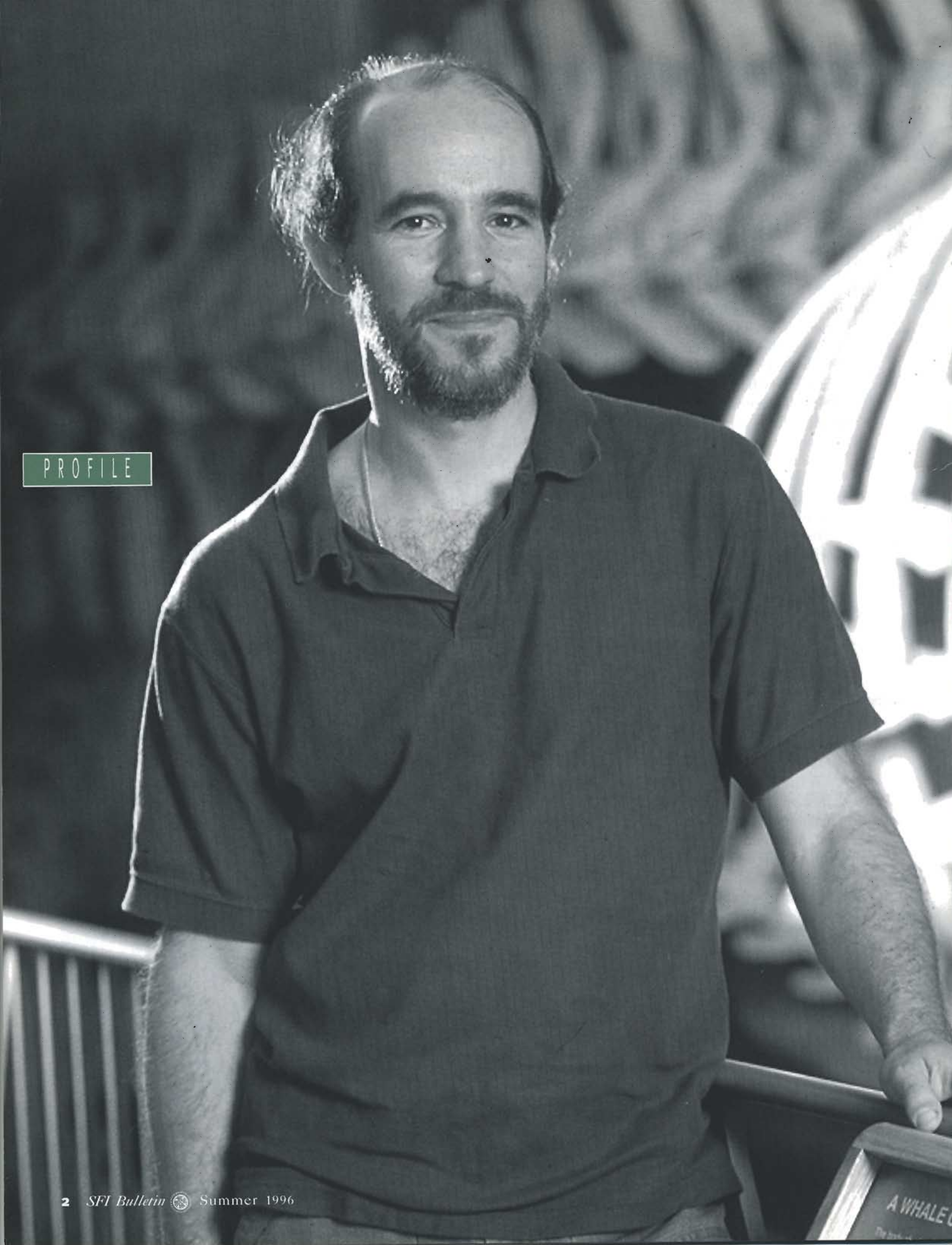
We are concentrating on broadening these partnerships through the addition of new Science Board members and by encouraging researchers who have not previously been involved in SFI to participate in workshops or visit SFI as scholars. We are finishing our plans for a modest expansion of our campus and will break ground this fall. This will permit "decompression" of our present space and will also allow additional desks. Although we are expanding our size physically, we do not intend to increase the number of resident and visiting scientists; we want to maintain the interactive environment that currently exists at SFI.

During these past months, I have come to appreciate more deeply what a unique organization the Santa Fe Institute is. I am looking forward with great enthusiasm and confidence to the next ten years, and I assume they will be as exciting as the last.

Ellen Goldberg

PHOTO OF ELLEN GOLDBERG: JANE BERNARD, ALBUQUERQUE JOURNAL

PROFILE



PHOTOGRAPHY: JASON GREEN (THANKS TO NORTH CAROLINA MUSEUM OF NATURAL SCIENCES FOR THEIR COOPERATION)

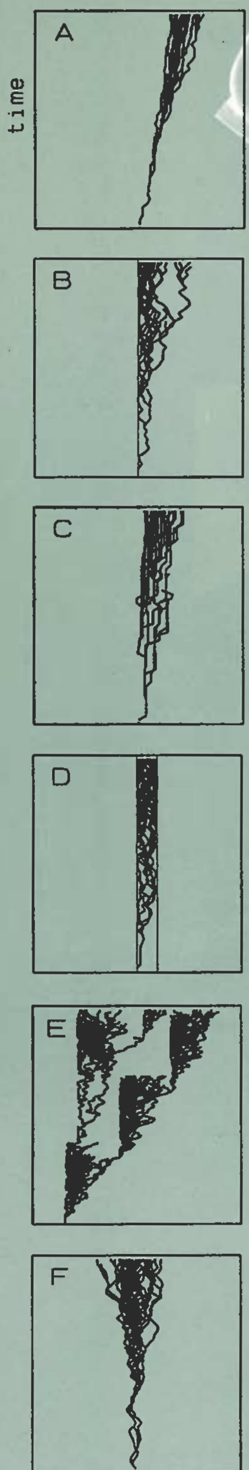
Dan McShea and the Great Chain of Being: Does Evolution Lead to More Complexity?

by Frank Zoretich

Can what everyone knows really be true? Daniel McShea is counting on data to confirm or debunk the common-knowledge notion that evolution favors a trend toward increasing complexity.

It's May, and McShea, a 39-year-old biologist, is sitting on the patio at the Santa Fe Institute. He's in his summer working uniform—running shoes, shorts and loose shirt. His pale legs are exposed to the sun, but his head is shaded by a beat-up Indiana Jones hat he ordered from the Banana Republic catalog a dozen years ago, before going to Montana for a month to dig up dinosaur fossils.

"I'm just naturally skeptical, but I was outraged to read in the evolutionary literature about a claim that was not necessarily false but that was made glibly. There was no clear statement of what is meant by complexity. I was outraged—and inspired."



The simulations show how trends can occur or fail to occur (horizontal axis = complexity; vertical = time). A group begins as a single species, and in every time step, a species can increase or decrease in complexity, speciate (split) or become extinct. In A, the trend is driven, meaning the mean rises because increases are more probable than decreases among species. But in B, the trend is passive, meaning no driving forces are present (increases and decreases are equally probable), but the mean increases anyway on account of the boundary, a lower limit on complexity. C-F are discussed in McShea, D.W. 1996. *Evolution* 50:477-492.

In a few days, after a year and a half on a postdoctoral fellowship at the Institute, he'll be moving to North Carolina to take up a tenure-track position in the zoology department at Duke University.

He hands a visitor a paper he's written during his stint at the Institute: "Metazoan Complexity and Evolution: Is There a Trend?" (Santa Fe Institute Research Paper 96-01-002; it has also just been published in the journal, *Evolution*).

Figure 1 in the paper is a drawing by a friend that shows the shore of what might be a tropical lagoon. In the foreground, in the water, are some single-cell animals, a few primitive plants and a couple of wormlike creatures. Closer to shore, more highly evolved organisms reside: a mollusk, a cup of coral and the once-plentiful but long-vanished trilobite. (A trilobite is a large class of extinct, marine anthropods).

Still closer to shore, a fish—looking like a cross between a coelacanth (primitive marine fishes, possibly ancestors to land animals) and a salmon. A cat, perhaps miffed it's been substituted for the missing Darwinian monkey, eyes the fish as it walks along the shore. The cat is following a naked man.

This is a rough-hand but modern version of The Great Chain of Being, a concept first voiced by Aristotle. It's a depiction of ladder-like steps in the supposed complexity of living things. Lesser creatures occupy the bottom rungs; the human is (well, of course!) at the very top.

A while after Aristotle, though, when the Great Chain was routinely extended upward by Judeo-Christian theorists, Man was dropped several rungs to make room for Angels and for God, who have since–for most instructional purposes—been removed from the picture.

First written about at length in the 1936 book, *The Great Chain of Being*, by Owen Lovejoy, the concept of a chain of increasing complexity culminating in Man had already permeated evolutionary thinking.

Even Darwin, who referred to complexity as "organisation," wrote in his notes in 1859: "The inhabitants of each successive period in the world's history have beaten their predecessors in the race for life, and are, in so far, higher in the scale of nature; and this may account for the vague yet ill-defined sentiment, felt by many paleontologists, that organisation on the whole has progressed."

McShea became entangled with the Great Chain in 1985, when he was a graduate student at the University of Chicago and was looking around for a thesis topic. The Chain, he says, was lurking for him in William Poundstone's *Recursive Universe: The Game of Life*. Although McShea had encountered the concept before in his studies, this time it struck him that the chain's graphic claim of increasing complexity toward the smug human is a hypothesis for which no quantitative proof has ever been established.

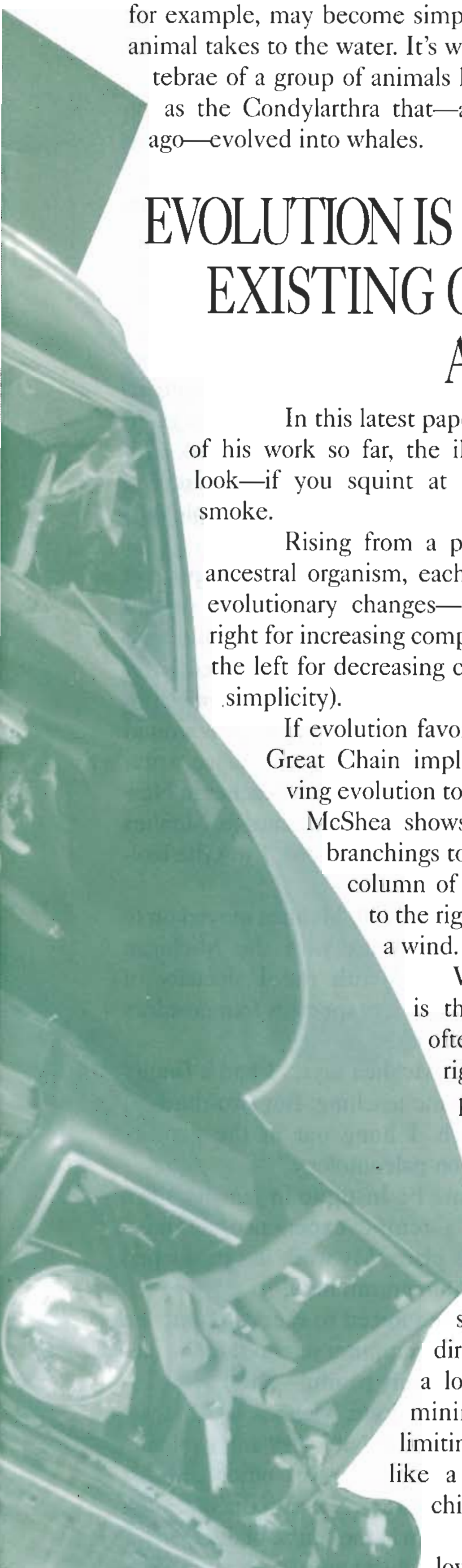
"I was outraged," he recalls. "I'm just naturally skeptical, but I was outraged to read in the evolutionary literature about a claim that was not necessarily false but that was made glibly. There was no clear statement of what is meant by complexity. I was outraged—and inspired."

He asked himself: Is it true? Are we on a higher level of complexity or goodness or anything else—or is the perception that we stand at the top of the wreckage just our own human bias?

Complexity, he realized, had "become a sort of code word for the Great Chain of Being. You can't say progress or perfection anymore. Complexity is vague, but it has the ring of science. I'm fighting that vagueness by looking more narrowly for anything that could be used to measure complexity."

That is to say, he started counting and measuring. For his dissertation, he examined the spinal vertebrae of animals both extant and extinct. We'll skip the technical details, like how in the heck did he ever decide exactly what to count and measure along an individual animal's spinal column? What he's found wherever he's looked so far is that change toward simplicity is as common as change toward complexity in evolution.

"Change toward complexity happens in animals all the time," he said. The vertebrae of a land mammal,



for example, may become simpler, more fishlike, if that animal takes to the water. It's what happened to the vertebrae of a group of animals known to paleontologists as the Condylarthra that—about fifty million years ago—evolved into whales.

lation of evolutionary branchings) spreads only to the right. McShea says it may be just time alone, not any sort of driving force, that makes it seem there is an overall trend favoring complexity.

Natural selection does not seem to select for complex-

EVOLUTION IS ALWAYS RANDOMLY SAMPLING AROUND EXISTING ORGANISMS, TESTING BOTH SIMPLER AND MORE COMPLEX FORMS

In this latest paper, which is a summation of his work so far, the illustrations for Figure 7 look—if you squint at them—like columns of smoke.

Rising from a point-source, a particular ancestral organism, each column is made up of evolutionary changes—with branchings to the right for increasing complexity and branchings to the left for decreasing complexity (or increasing simplicity).

If evolution favored complexity, if as the Great Chain implies, something was driving evolution toward greater complexity, McShea shows there would be more branchings to the right and the entire column of smoke would lean over to the right, as if being pushed by a wind.

What he's found instead is that branchings occur as often to the left as to the right, as often toward simplicity as toward complexity, and so the column of branches rises instead like smoke in still air dispersing both left and right.

But it doesn't spread out evenly in both directions, because there is a lower limit—a single-cell minimum of complexity—limiting movement to the left like a brick wall next to a chimney.

Because of that lower limit, and because no upper limit on complexity has been established yet, the column (or accumu-

ity at all, McShea says. In his SFI paper, McShea writes of the Great Chain's anthropomorphic influence: "Given the historical background and power of culture to penetrate perception, it is reasonable to wonder whether this impression of large-scale directionality is anything more than a mass illusion."

He notes the mood of the paper is skeptical. "But the point is not to make a case that complexity has not increased," he writes. "Possibly it has, in some sense. Rather, the point is to rescue the study of biological complexity from a swamp of impressionistic evaluations, biased samples, and theoretical speculations, and to try to place it on solid empirical ground."

Not everyone agrees with McShea. Ask Harold Morowitz, Robinson Professor of Biology at George Mason University and a member of SFI's Science Board, whether evolution always leads to greater complexity. "Absolutely yes," he answers. "When life emerged, it developed the biochemistry we see today. Our universal ancestor has the same biochemistry as we do now. This gives us a window to the past." Morowitz studies the first one hundred million years of life, which began about four billion years ago.

The Chart of Intermediary Metabolism, he says, outlines the development of chemistry. "On it," Morowitz says, "we can see that chemistry is enormously interconnected." If you want to change the makeup of something, you have to add to it. "This is the reason [International Business Machines (IBM)] can't give up DOS. And because IBM is in competition, the company can't start over."

Biologist Stuart Kauffman is less quick to dismiss the idea that evolution doesn't always lead to greater complexity. But, he says, "things have gotten more complex. Diversity almost always increases. Complexity of cells has gone up in the last four billion years. But it's not so obvious complexity has increased in the last two hundred million years." Nevertheless, Kauffman says he is intrigued by McShea's work.

Ecologist Tom Ray doesn't believe evolution has an inherent tendency in either direction. "Evolution is always randomly sampling around existing organisms, testing both simpler and more complex forms," he says. "There are lots of examples where more complex forms have been favored and lots of examples where simpler forms have been favored. The only inherent tendency is to always explore the neighborhood." Viruses as a group, he says, are descended from more complex ancestors. And if an organism switches to a new habitat where some complex structure is no longer needed, then it is likely to lose the structure to economize. "If a structure moves into dark caves," Ray says, "it does not need eyes and may lose them in time."

Basically, McShea has started to quantify two aspects of complexity. "There's complexity in the sense of the number of different parts at the same scale," he says. The question in this case is: "How many different things are inside you?"

"A car is complex because it has lots of different parts," McShea says. "A raindrop is simple. It has only one part at the molecular level. But if you smash that car into a million bits against a tree, the car is still complex." However, there is also "complexity of levels," which he explains as the "nestedness" or "number of levels of parts within parts." McShea has developed further subtypes of quantifiable complexity, but he says all the ones he's working with now fit into these two major kinds.

McShea's vertebral column study was about the number of different parts. But now he has turned to the other sort of complexity—of levels. In particular, he is testing the hypothesis that when cells get together to form an organism, they can lose complexity. "When they get together, they should lose some internal machinery," he says. In other words, when upper levels arise, lover levels disappear.

"Skin cells lead a pretty cushy life," he says. They don't need to do things like reproduce or move around. "But a single-cell paramecium [a one-celled protozoa] needs to do everything."

During his time at SFI, McShea has been using the published work of others to "count parts within the cells of multicellular things and compare them with the number of parts in free-living cells like paramecia." So far in the counting, he says, "there seems to be a correlation" indicating that cells within more complex organisms do have less internal complexity than free-living cells. "People are sophisticated," he says. "But compared to a paramecium, their cells are simple."

If it's true that cells lose internal parts, or become individually less complex, as they "get together" in the evolution of more complex so-called higher organisms, then what's true in the biophysical realm may have implications for complex human systems.

Socioeconomics, for example.

With the Industrial Revolution, McShea says, humans "evolved" into Factory Man. In factories, on the assembly line, "his economic life was reduced to one thing." Factory Man (not counting his home life and other off-the-job activities) is like a single-purpose cell in a vast economic organism. In function, each man became less complex than humans before the Industrial Revolution.

But the Industrial Revolution is old news. Now the economic organism is evolving toward something different. "In society today, people complain that life is too complex, and each person does have to do more than Factory Man. If that impression is accurate—if life today is more complex than it was for Factory Man—it means that functionally each person is becoming more complex, but society is coming apart. The higher organization is no longer liberating. Maybe you would like to be a skin cell, but we're becoming more and more like paramecia."

McShea was born in upstate New York, near Hudson, where his father was a chicken farmer. But after fourteen years in the business, Robert McShea decided to go to graduate school. He moved his family to New York City and then, when Dan was eleven, to Boston. Now retired from Boston University, Dan's dad is a political philosopher, specializing in the field of ethics.

McShea earned his bachelor's degree from Harvard in 1978. In the time between Harvard and graduate studies at Chicago, he knocked around a bit: He spent four years working in Cambridge, Massachusetts, for the Center for Short-Lived Phenomena as a journalist, writing weekly in the *Oil Spill Intelligence Report.* He covered oil spills around the world by telephone. Then he was a free-lance writer for a year. Then he was a fifth-grade math teacher in New York City for a year. And once he got to Chicago, McShea also taught at the Art Institute of Chicago. "I was the biology department," he says.

After earning his Ph.D. in 1990, McShea moved on to postdoctoral work for three years with the Michigan Society of Fellows. Affiliated with the University of Michigan at Ann Arbor, the society sponsors four postdocs a year in science and other fields.

"It was a sweet deal," McShea says. "I had a faculty appointment, and I did some teaching. But two-thirds of my time was for research. I hung out in the geology department and focused on paleontology."

He arrived at the Santa Fe Institute in January 1995. "Being here has been a terrific experience for me," McShea says. "I love this place. My work has developed an enormous amount of momentum here.

"As a biologist, I've been forced to speak in someone else's language. Physics and computer science are the languages here. It's been extremely painful—and useful."

The first month at the Institute, McShea says, he was treated by his colleagues as a handy biology and evolution consultant. "People would come into my office and ask, 'When did elephants originate?' No introductions. Of course, then I got to know them in the course of discussion."

He first visited SFI as a guest speaker several years ago. "That's when I learned how things worked here. Two minutes into my research talk, someone raised his hand and started talking." Then someone else cut off that speaker. And then a third speaker jumped in. "After five minutes, I had to interrupt to get on with my talk. If you were a fly on the wall observing this group, you'd think they were rude, aggressive and unpleasant. But it was as exhilarating as hell for me to be in the middle of the discussion. The level of constructive complaining here is very high."

"What they do here at the Institute is theorize about systems and complexity," McShea says. "It's very much science in the exploratory mode. When I explain to people in biology the virtues of the Institute approach, they say, 'Where's the data?' But they're generating hypotheses here, not data.

"My approach is science in the hypothesis-testing mode. I want to test for the existence of a relationship between complexity and functionality. To do this, I need operational measures of both complexity and functionality. Once you're able to measure, you can simply let the data speak—although often what they say makes no sense at first. That's what makes empirical work so messy and frustrating. But it's also thrilling—when you actually discover something."

McShea describes his wife, Diane Ritchie, also a biologist, as a great resource in his work. "I rely on her for her command of facts of the biological world," he says. "She knows those organisms."

Their first child, Hannah, was born in September. "Now my life is incredibly complex," McShea says.

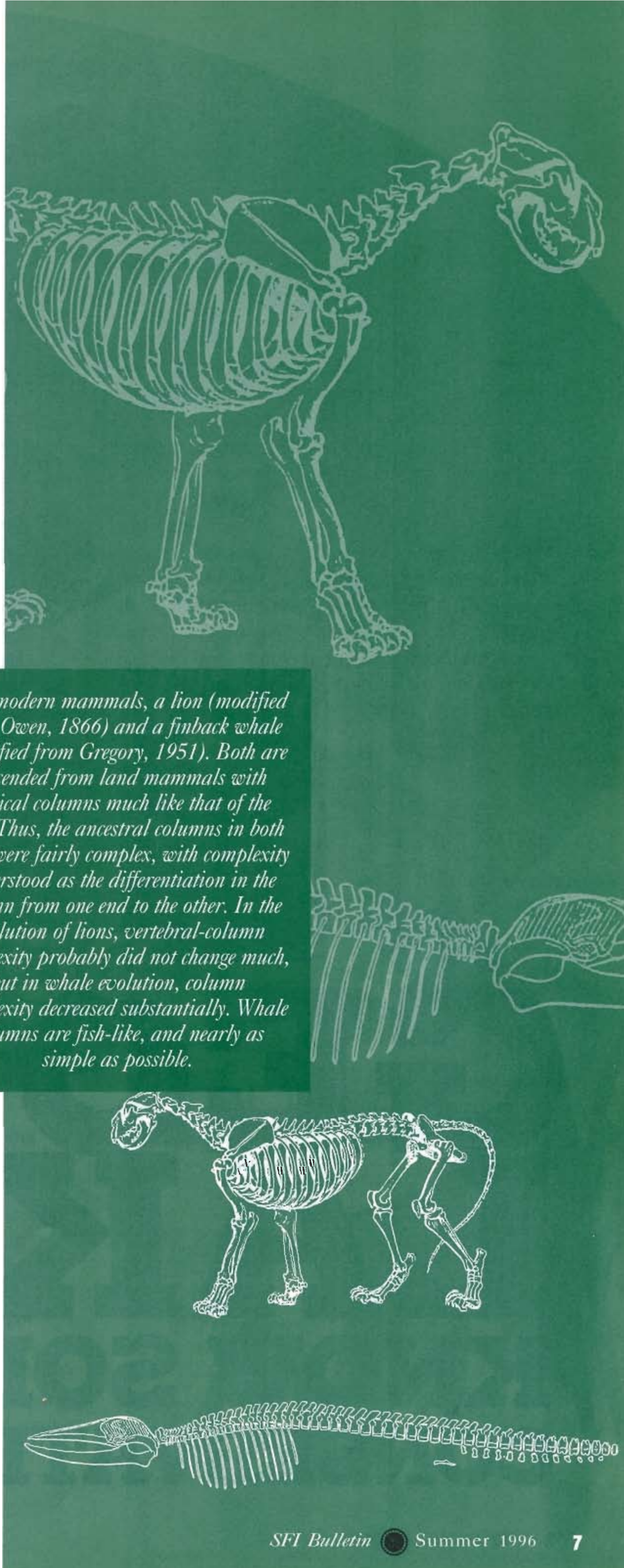
At Duke University, McShea hopes to find graduate students and postdocs—"if I can get them interested in this"—who will help him in his task of counting and measuring in a search for empirical evidence on directionality in evolution.

"I sound pretty strident," he says. "But I'm willing to conclude that there's been enormous progress in evolution and that we are at the top of the Great Chain of Being. But I want to arrive at that conclusion carefully—and believe it when I get there."

He also says he wants to write a book on progress, both evolutionary progress and human social progress. "But I don't want to be just waving my arms," he says. "I want to know what I'm talking about in an empirical sense."

For now, McShea says, "I agree that something has increased. We're more something than a trilobite. But is it complexity? Our brains are bigger than a trilobite's brain. But maybe to be a great thinker you have to be simple."

Janet Stites, a free-lance writer who lives in New York City, contributed to this report. Frank Zoretich is a writer who lives in Albuquerque, New Mexico.



Two modern mammals, a lion (modified from Owen, 1866) and a finback whale (modified from Gregory, 1951). Both are descended from land mammals with vertical columns much like that of the lion. Thus, the ancestral columns in both cases were fairly complex, with complexity understood as the differentiation in the column from one end to the other. In the evolution of lions, vertebral-column complexity probably did not change much, but in whale evolution, column complexity decreased substantially. Whale columns are fish-like, and nearly as simple as possible.

DOES GEORGE LAKOFF KNOW SOMETHING CONSERVATIVES DON'T?

LAKOFF PHOTO: JANE SCHERR

Hayward Alker probes Lakoff about his new book

by *Mary Engel*

IN HIS NEW BOOK, *Moral Politics: What Conservatives Know That Liberals Don't*, Santa Fe Institute Science Board Member George Lakoff traces the political beliefs of both conservatives and liberals to metaphors for the ideal family. Not surprisingly, conservatives and liberals have different versions of that ideal family. For conservatives, political metaphors evolve from a strict-father family model; for liberals, a nurturant-parent model.

Lakoff claims that our common nation-as-family metaphor projects these opposed family models onto politics. Family-based morality, he argues, can explain why liberal and conservative views cluster together: what one's views on gun control have to do with one's views on environmentalism, social programs, taxes, abortion and so on.

Lakoff credits conservatives with being more comfortable and more practiced at expressing politics in terms of family and morality; conservatives have long had a lock on the words family values. But by reviewing the research results on strict and nurturant child-rearing methods in the field of developmental psychology, he concludes liberal family values are empirically superior to conservative.

Does the research back up these findings? Can family metaphors be extended beyond American politics to international relations? Is there any middle ground between liberals and conservatives? And where should Lakoff's research go from here? These are questions posed by his long-time friend Hayward Alker, professor of international relations at the University of Southern California and professor emeritus of political science at the Massachusetts Institute of Technology. Alker spent the 1996 spring term as a sabbatical visitor at SFI, where his special interest was the modeling of natural and social histories. Lakoff talked about his book at an SFI lecture this spring.

In a conversation with Alker, Lakoff, an unapologetic liberal, explains how he uncovered his family-based metaphors through his study of linguistics and cognitive science, which he teaches at the University of California, Berkeley.

Berkeley free-lance writer Mary Engel moderated Lakoff and Alker's discussion, which took place by phone and over e-mail. Their comments have been edited for brevity and clarity.

LAKOFF: I discovered, when I started talking to both liberals and conservatives, each thought the other was irrational. Liberals didn't understand how you could be prolife and for the death penalty. And if you talk to conservatives, they find liberals seem just as irrational. How could you be against putting murderers to death but sanction abortion?

ALKER: That's the point where you feel cognitive science methodology is especially relevant, because these apparent illogicalities tend to indicate something else is going on.

LAKOFF: Exactly. If you look at these positions, people do hold them. But if you ask them what they have to do with each other, they don't know. And before I started studying this, I didn't know myself.

There are no statistical techniques known to get to complex world views

During the 1994 congressional campaign, I watched a lot of television and read the papers a great deal and started noticing liberals and conservatives used different metaphors for morality. When I stared at this long enough and started listening to conservatives talking about family values, it occurred to me the conservatives actually had the answer: there were two different models of the family behind the values. Both liberals and conservatives have family-based value systems. What I did was work out, going backward, what the models of the family had to be to arrive at the answers I was seeking.

ALKER: George, could you summarize some of the key features of the different family-morality models?

"The strict-father model

LAKOFF: First, for conservatives, the strict-father model takes as a background the assumption that the world is fundamentally dangerous and difficult and that people are fundamentally not good. They have to be made good. It's the father who teaches children right from wrong and assumes there is an absolute right and wrong. He teaches them right from wrong by setting strict rules for their behavior and enforcing them through punishment.

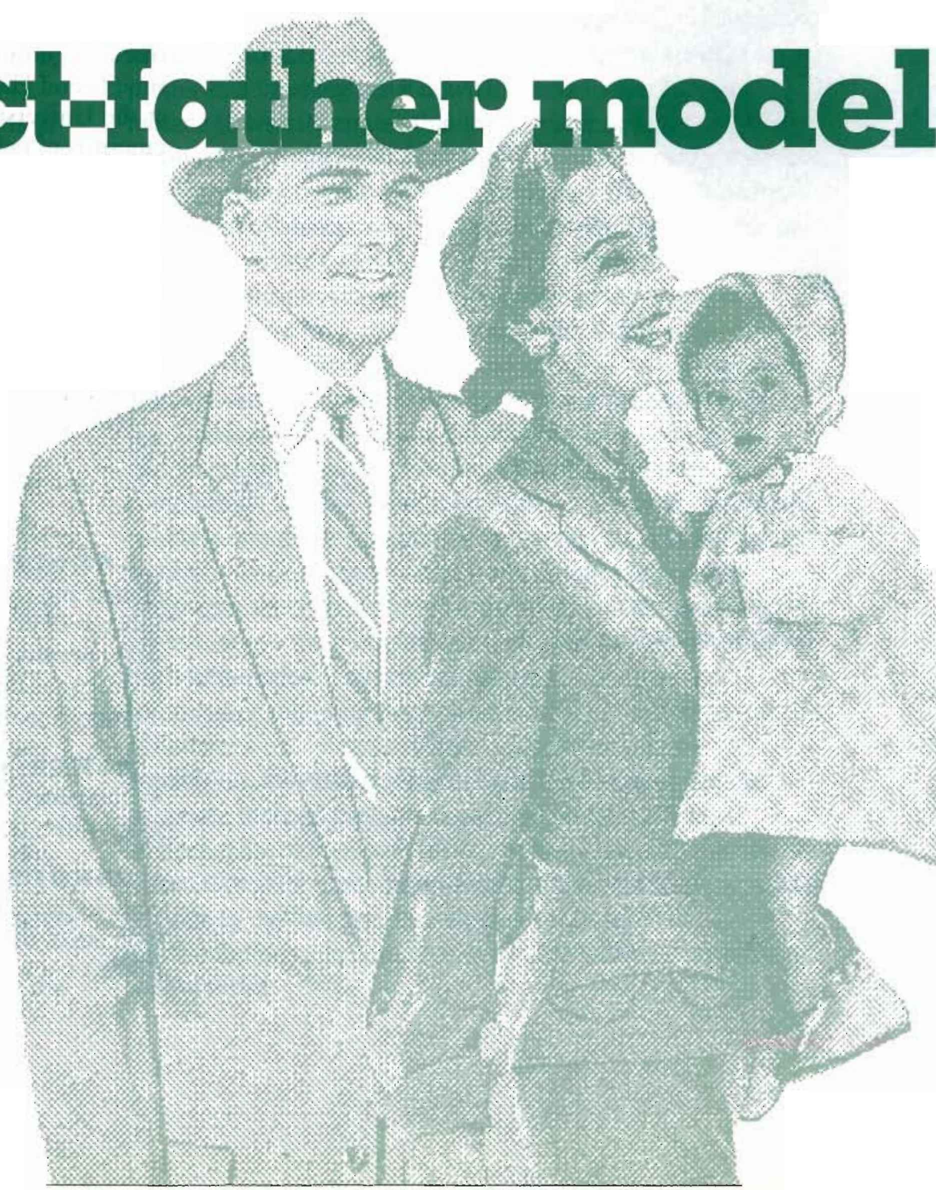
ALKER: And rewards, right?

LAKOFF: Reward and punishment are central to the whole idea. In the newspaper today, Bob Dole was talking about tough love and about how punishing people is part of tough love. That's part of the strict-father model. What the strict-father model attempts to accomplish is this: it is assumed children have to learn self-discipline and self-reliance and respect for authority. Now another important part of this model, in America but not in other countries, has to do with what happens when such children mature. The slogan, "eighteen and out," is common. The mature children are supposed to be off on their own as soon as possible. Good parents don't interfere in their lives. If the nation is the family and the government is the parent, in the strict-family model, the government shouldn't meddle in their lives. When I looked at the liberal model of the family, I found it a very different model. It assumes the main thing a parent has to do is care for and care about his child. It is through being cared for and cared about that children become responsible, self-disciplined and self-reliant. The purpose is to make children become nurturers, too. Obedience for children comes out of love and respect for parents, not out of fear of punishment. Instead of punishment, you have restitution.

ALKER: It's like in prisons, whether you try to treat prison as a way of incorporating people back into society versus the attitude you got in some of the crime-bill discussions – put them in prison and throw away the key. That's retribution.

LAKOFF: And it comes directly out of the family model.

Now, in the nurturing-parent model, one of the major requirements is communication – open, two-way, mutual communication. The parents have to tell their children why they're doing what they're doing, and children are expected to question them. That's a positive thing, because children have to learn how to become nurturant themselves. Then there's the issue of protection. Liberal parents are high on protection. Not just from crime and drugs, but also from cigarettes, cars without seat belts, pollution, asbestos, lead paint. If you take the nation as family model, these are just the kind of things a nurturant government is supposed to protect its citizens from.



ALKER: And that goes with the more positive attitude among liberals toward government, because there's this sphere of nurturant and caring things government could and should do to help citizens enjoy their lives more fully.

LAKOFF: Right. Government is supposed to not be somebody who's punitive, but somebody who cares for you and protects you.

ALKER: Enables you, in some sense.

LAKOFF: Part of nurturance is individuals being fulfilled and happy in their lives. You can't nurture someone else unless you nurture yourself, take care of yourself. The promotion of happiness is not the promotion of self-indulgence; it's a moral process.

ALKER: I think you try hard, and do pretty well, in giving a fair, or at least plausible, reconstruction of some deep strains within our common American culture. But there is always a special problem in representing alternative perspectives. How much assent have you obtained from liberals or conservatives about the roots of their views in strict-father and nurturant-parent conceptual metaphorical systems? Now your argument is not shot down merely by disagreement—the claim of nonconscious adherence often can save you, at least for a while. But I am interested in how many times you have been able to take people through the metaphorical-meaning systems inherent in their language to the point they accept your cognitively inspired reconstructions.

LAKOFF: It's not something I've done a lot of. I used several kinds of sources and models. One was written sources—books by conservatives, books by liberals—where I asked what made sense of what they were saying, sentence by sentence. The same for political speeches on television, interviews on political talk shows, interviews with the man on the street. The criterion was to be able to make sense of everything you heard.

ALKER: And how it fits together.

LAKOFF: Right. I've been trained as a linguist who is able to listen, to know the theory and know exactly whether it fits or doesn't, and then take account, carefully, of all the pieces where it doesn't.

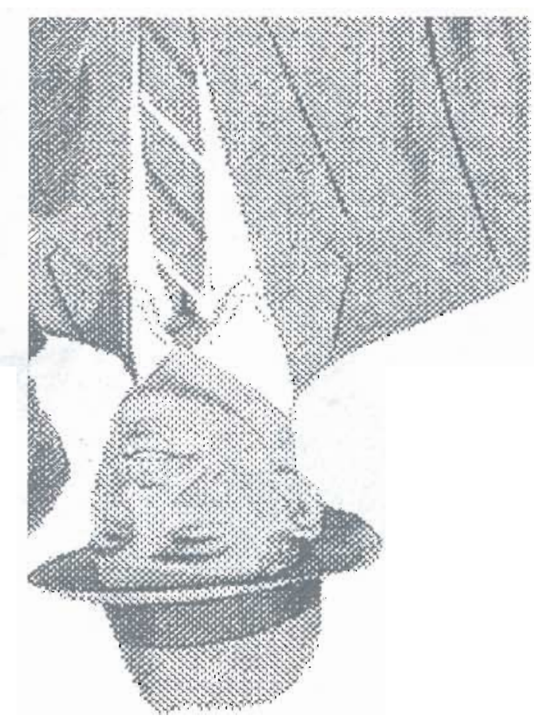
ALKER: Given so many variant possibilities, how, George, should I go about testing your views, trying to prove you wrong, as Popperian falsificationist philosophers of science would have me do? How much of this work has been done? How much needs still to be done?

LAKOFF: The term *testing* means lots of different things. In my field, one of the things we do is try to account for what makes a discourse coherent. Part of my job was to try to find a theory that would make both liberal and conservative discourse make sense. It also accounts for why the various positions fit together the way they do. It accounts for the variations of liberals and conservatives. And it accounts for their use of language. That's a lot to account for. There's infinitely more research that could be done. You could try to figure out, person by person, unconscious conceptions. No one knows how to do such research on a large scale using survey. There are no statistical techniques known to get to complex world views.

ALKER: The grounds for these different positions—is there a scientific basis for them?

is dysfunctional"

LAKOFF: How can you choose between these moralities? That's something I had to ask myself once I found them. Was there a reason why I believed what I believed? Was there any empirical way to go about deciding between these moral positions? The answer I found was, yes, there was. Since they're family-based models, you look at the research on the family to find out what studies have been done on how family structures affect the development of children. People who have done work in different, unrelated traditions of research have all come to the same conclusion. Namely, the strict-father model is dysfunctional. It turns out even if you start with a strict-father model's criteria of what a child should be, the facts about child rearing show the model gives the opposite results. In the strict-father model, you want your children to be socialized. Well, the strict-father model produces less socialized children than nurturing parents. Similarly, the strict-father model wants the children to be self-disciplined so they can resist temptations. It turns out it doesn't make them resist temptations any better than anyone else. The strict father wants children to have a strong conscience. And children of strict fathers have a less strong conscience. And so on, with all the other desiderata.



ALKER: Although I like your appeal to cognitive science and attachment research in supporting your variant of nurturant liberalism, I feel this part of your book is too one-sided. Although international relations show signs of an emergent global society, parts of it—Syria-Lebanon over the last decade or two, the former Yugoslavia and Rwanda-Burundi–fit a more dreary, Hobbesian version of life than even your conservative folk model of human nature. This might be made into a more general realist claim about human nature for which the twentieth century gives all too much empirical support. And there are those like James Wilson [at the University of California, Los Angeles], Irenäus Eibl-Eibesfeldt and Konrad Lorenz in Germany, who think there is sociobiological evidence for the naturalness or innateness of humans' searching for hierarchy in their moral order and elsewhere. Would not presenting some of the scientifically important evidence for conservative views of human nature have made your argument more nuanced, less decisive, yet more persuasive in its special focus on child-rearing ideas?

LAKOFF: I don't accept the sociobiological metaphors. Sociobiology has used the metaphor of the survival of the strongest, not the survival of the best nurtured. Survival is not just a matter of whether one animal can beat up another but at least as much a matter of who's offspring is best nurtured and learns adaptive cooperation. I find the metaphors of sociobiology to give a skewed view of survival. I also find the implicit metaphor that people are animals is a partial truth, at best.

ALKER: I agree about nurturance, which is a component of fitness, often biologically defined in terms of a product of the probability of a girl child's staying alive until child-rearing age and the probability distribution for the number of her own offspring. This is one of those areas where conservative and nurturance and survival of the fittest overlap in meaning. But I disagree about sociobiology; I don't take the paradigm at face value. The field is ideologically charged, and we must be sensitive to ideological (including gendered) differences within supposedly scientific discussions. But I do think both liberal and conservative students of the overlap of sociological and biological phenomena are coming up with results that challenge a variety of the simpler ideological positions. This work includes newer DNA-based findings on personality differences, the work of those following along Richard Dawkin's discussion of replication-prone cultural memes [traits or practices] and of selfish and unselfish genes, recent models of culture-gene co-evolutionary development, as well as the work on within-species animal hierarchies and conflict-resolution behavior. But think about the problems of extending family relations as a model to [nurturing] Saddam Hussein when he's aggressing on Kuwait.

LAKOFF: Of course not, just like you don't want to be nurturant to the car company that's making unsafe cars.

ALKER: But, to return to the international domain, you may have to go beyond a family model to a model of intersociety relations or international relations to think of what's an appropriate policy response.

LAKOFF: We could get into that if you want. We could have a model of nations.

ALKER: But they're [considered] grownups, aren't they?

LAKOFF: No, no, no. Our foreign policy uses the nation-as-person metaphor with industrialization as maturity. Thus "underdeveloped" nations are immature or backward children who need to be taught how to develop properly or punished for failing to do so.

ALKER: So China is an adolescent even though it has 5,000 years of civilization.

LAKOFF: According to the developing-nations metaphor, unindustrialized nations have to learn how to industrialize. That's how they "mature." That a major part of American foreign policy. We see many nations as children.

"She's not very good at defending herself, but she does very well at identifying her feelings."

ALKER: So we keep introducing hierarchies, in self-flattering terms.

LAKOFF: But you can have that model and then have a strict-father or nurturant-parent version of that model. I'm looking at what defines conservative and liberal world views.

ALKER: Where and when—and to what contexts and time periods—do you think your models will generalize? Will they work in contemporary Iran, for example, where Islamic ideals of the unity of religion and political practice are strongly supported? In India and Japan, where gender relations are different than they are in the United States in many ways? In the eighteenth and nineteenth centuries, when what we now call economic liberals were in fact political radicals? How about the different Pueblo cultures Wolfgang Fikentscher and others have studied?

LAKOFF: I don't know enough about the details of those cases in the relevant areas to know whether the models apply. I'd be interested in finding that out.

There are implications for other societies. Take Chinese culture. One of the conditions of the strict-father model does not apply; there, the children are not supposed to become independent. They're supposed to obey their father and not criticize him, not make him lose face in any way, and do what is necessary to keep supporting the family and the parents in their old age. What does that say about the nature of politics in such a country? First, it would predict you wouldn't have massive resentment of government.

Second, it would predict mature citizens are not supposed to just think of themselves but support their government. Therefore, it would also predict that, in human rights issues, criticism of the government would be like criticism of one's parents. Student demonstrations would be considered a terrible thing. That's exactly what we saw in Tiananmen Square.

ALKER: Sometimes I think of your models as ideal types, with reality as a mix of the opposites you present. While reading your book on the plane, a Texan woman asked me what your book was about. She suggested both strict-father and nurturant-parent morality, in some less defined sense, were both prevalent and desirable in an overlapping way. Is there room for hybrid moral systems in your work?

LAKOFF: You can have pragmatic liberals and pragmatic conservatives who can get along on many issues because of their pragmatism. [And] you can be more or less strict and more or less nurturing. If you take the various parameters of pragmatism and intensity, then sometimes you can get people who look superficially similar, even if one is conservative and one is liberal. But what I have not found is a world view, an overall world view, in the middle. It doesn't exist.

ALKER: In public opinion polls, a third say they're liberals, a third say they're conservatives and a third say they're in-betweens, moderates?

LAKOFF: I've found some people are conservative in parts of their lives and liberal in others, but there isn't a middle-ground world view. But if you understand what the world views are, you can at least respect each other and understand where you're coming from and not attribute beliefs to irrationality, venality, simple-mindedness. You attribute them to idealism. And that gives you a new respect for other people. You can't have discourse without that.

ALKER: Isn't your commitment to enlightenment values of scientific analysis and rational discussion a political commitment? And isn't your commitment to increased respectful understanding of different political perspectives within American society also a politically engaged point of view? One not shared by strict-father conservatives?

LAKOFF: It's entirely true. I am a liberal. Although my analysis doesn't depend on liberalism, the idea of applying the analysis to better communication is a liberal idea. I don't know that a dialogue can take place. You do have opposite moral world views. But I also discovered something I didn't know when I started, which is the conservative world view is a truly idealistic world view. You don't have to be selfish or a tool of the rich to hold conservative values. That alone means liberals can have a discussion with conservatives. Similarly, if conservatives can read about liberals, they will know liberals are not mushy headed or permissive. There may be some sort of rapprochement possible.

ALKER: What are your ideas about computerizing your modeling approach? What traditions of modeling would you rely on? How does your sense of the adaptive mind link to your political conceptual dynamics?

LAKOFF: I'm interested in attempting to see how one could model conceptual narratives in general and how they change. It's clear complexity theory enters in. You don't just throw together a bunch of concepts and have them fit. They have to mesh conceptually. Given that we all have the same metaphors for morality, the fact that one conceptual system for the family gives one set of priorities over those metaphors and another gives another suggests some optimization is coming into play. How do cultural narratives change over time? How do they compete? It's possible to begin to study that in modeling terms, and I would welcome the chance to do that.

ALKER: In broaching such goodness-of-fit considerations, I think you must link up with other kinds of data on psychological, cultural and politicoeconomic selection pressures. This is an area [in which] I hope to be your collaborator.

Economics and the Modern Theories of Cognitive Behavior

Economics, unfortunately, has not made contact with modern theories of cognitive behavior. The emerging discipline of cognitive science represents a revolution in our understanding of cognition, but modern economics has largely left unnoticed developments in this area.

To explore what economists and cognitive scientists can learn from each other, Citibank Professor W. Brian Arthur; Andy Clark, the Stirling Professor of Philosophy at Washington University, and Santa Fe Institute external faculty member David Lane organized an Economics and Cognition Workshop last January at SFI. This workshop brought together economists who study the cognitive aspects of economic processes and cognitive science researchers. The workshop format was novel: Participants came and went during a three-week period. There was no formal program of talks, but informal discussions on topics of interest were arranged as the workshop progressed. In the best SFI tradition, the program was self-organizing.

Among the numerous issues raised during the workshop, three stand out—economists and cognitive scientists had much to say to each other in these areas. First is the nature of social reality. Economic models treat two kinds of learning activities, distinguished by the subject being learned. The first presumes some objective fact can be learned: Is there a potentially productive oil field here? What percentage of the people in this life insurance pool will die in the coming year? In the second, the subject being learned is a social construct, a consequence of the learning activity and decisions based on learned knowledge. The most obvious example of this phenomenon is paper money (*fiat* money to an economist). Everyone learns certain recognizable pieces of paper have value and is willing to accept the paper in return for the provision of goods and services. But these pieces of paper have value only because everyone is willing to accept them. A hyperinflation is the unwinding of this common understanding. Another example is financial asset prices. Investors try to discern patterns in financial asset prices to predict profit opportunities. But the trading decisions they make, based on the information they collect, determine the price patterns they are trying to learn.

For more than a century, sociologists have referred to facts, such as the use of paper money and the pattern of stock prices, as social facts. This distinguishes them from other kinds of facts–such as the answer to the question: is there oil here?–whose validity is independent of social convention.

Economists have long been cognizant of the nature of social facts. The hypothesis that stock market prices follow a random walk is based on the argument that, if there were a persistent pattern, traders would trade against it until it disappeared. But this view is overly simplistic.

SFI Economics Program Director Lawrence Blume and his Cornell colleague, Professor David Easley, have demonstrated that whether a social fact is learnable depends upon the initial beliefs of those trying to learn. It is possible the beliefs necessary for the validity of a given social fact–or indeed any conceivable social fact–may never arise through the learning activities of the learners. Arthur and external faculty members Blake LeBaron, Richard Palmer and Phillip Tayler have built a simulation model of a simple stock market that dramatically illustrates this observation; it also demonstrates the complex price dynamics that can arise when a social fact—e.g., the price of a stock is the present value of its dividend stream—is unlearnable.

The relation between reality and the observer is a subject of discourse in the cognitive science community. One approach to this problem is through the concept of situated cognition, which emphasizes the close proximity of the individual and her/his environment. Cognition, according to this point of view, does not rest solely in the brain. Instead, it can be understood as the interaction of the individual's nervous system with her/his environment.

The situated approach to cognition emphasizes the lack of an objective set of facts to be learned by a distinct mind whose existence is independent of the set of facts. This rejection of Cartesianism is reminiscent of Heideggerian phenomenology. In one of the most popular talks during the workshop, participants were given an introduction to Heidegger's view of the relation between the human being and its world by SFI Business Network Member Howard Sherman.

A second theme has to do with the methods by which we interpret our world. The techniques with which economic actors make sense of their world determine how they act in it. Pattern recognition, analogy and metaphor, statistical inference and deduction are four cognitive processes that are important in economic contexts. Modern economic theory models only the last two methods, but the other two may be even more fundamental.

Pattern recognition and analogy and metaphor are history-dependent processes that lead to complex adaptive behavior. Cognitive scientists have studied these first two methods at length. (SFI Science Board Member George Lakoff gave workshop participants an introduction to metaphorical reasoning.) Bringing this knowledge to theoretical models of economic behavior would lead to different understandings of the relation between knowledge, learning and behavior than those embedded in the rational expectations models and rational learning models of modern economics.

On the same theme, cognitive scientists have clarified the importance and some of the mechanisms of parallel, distributed and bottom-up information processing. Economists are still locked into sequential, top-down models of thought and action. These new approaches—both as models of individual cognition and more broadly as metaphors for how "organization" happens and functions—have powerful implications for thinking about a wide range of economic phenomena. But economists must be exposed to these ideas and internalize them. One route to achieving this may be to create an economics/cognitive science discourse community.

The third theme has to do with the social aspects of cognitive activity. Cognitive science is beginning to grapple with cognition in groups, just as economic theorists are trying to understand the implications of information sharing in groups as well as the possibilities for what they call the problem of social learning, that is, learning by observing the actions of others. John Padgett, a professor of political science at the University of Chicago, illustrated some of these dimensions in a talk on social networks and political parties in Medici Florence. Padgett argued that localized actions, ambiguity and multiple-agent identities, as opposed to planning and self-interested, goal-oriented action, lay at the root of Cosimo de' Medici's political success.

Both the economics and the cognitive science approaches to the social dimensions of cognition face barriers imposed by different historical biases in the two communities cerebro-centrism in cognitive science (the idea that the locus of all interesting cognitive action is the human brain) and methodological individualism in economics. According to participants, opportunities exist for fruitful interaction between the economics and cognitive science communities, especially those parts of the cognitive science community drawn from anthropology, sociology and the other "social" sciences.

Plans are under way to continue the economics program's cognitive science initiative. Workshop participants have been invited to put together small research groups and to meet at the Institute to continue work on the issues discussed during the workshop.

Economics and Cognition participants: Howard Sherman and W. Brian Arthur, above and Henry Lichstein and David Lane, below.

Today Locomotion, Tomorrow Chess? Dynamical Hypothesis Meets Cognitive Science

The computational/representational model of the mind has dominated the fields of cognitive science and artificial intelligence since the early 1960s. In this computational hypothesis, cognition consists of the creation, storage and manipulation of symbolic representations according to a set of rules. The goal of research is to identify the structure of the representations and the rule set that underlies any cognitive process from perception to reasoning. Such a syntactic system preserves meaningful relations among its symbols. Or, in the words of philosopher John Haugeland of the University of Pittsburgh, "If you take care of the syntax, the semantics will take care of itself."

But it also implies an outside user needs to assign and interpret the meaning of the symbols and tends to beg the question of where such elaborate structures come from. Further, it has had limited success with the lion's share of behavior in which formal cognition bumps up against the physical environment. The result is disenchantment with GOFAI (good old-fashioned artificial intelligence).

The Santa Fe Institute Workshop on Dynamics, Computation and Cognition, organized in May by Melanie Mitchell of SFI and Randall Beer of Case Western Reserve, ratified the emergence of a new approach to cognition, which has been developing somewhat independently in psychology, neuroscience, computer science and philosophy. The dynamical hypothesis, as phrased by Tim van Gelder, a philosopher at Indiana University, proposes that cognitive agents are better understood as continuous dynamical systems that evolve in real time. In a stroke, this shifts the emphasis from static structures and discrete operations to continuous change, puts cognition in the same dynamical domain as the brain, body and environment and makes contact with principles of self-organization. The hypothesis thus offers a different conceptual framework that could dramatically alter the questions asked, the research performed and the theories developed by cognitive scientists.

Take the Julliard problem of synchronizing movements to a metronome that is changing tempo or synchronizing the motion of different limbs during locomotion. Elegant experiments by Scott Kelso of Florida Atlantic University and Michael Turvey of the University of Connecticut have shown that a simple dynamic model can predict the appearance of attractors and bifurcations in the phase relation between two limbs (or limb and metronome) as the tempo increases, as well as the way these features shift when the limbs have different length and mass. A similar model of the swimming lamprey – an eellike animal—allows Avis Cohen, a neuroscientist at the University of Maryland, to account for the sequence of spinal activity that produces a traveling wave down its body. Esther Thelen of Indiana University argues that the dynamic approach, with its emphasis on trajectories of change, is also naturally suited for understanding cognitive and motor development in humans.

A frequent objection: while dynamics may be applicable to low-level problems like these, it can't be extended to high-level cognition, such as reasoning, planning and language, which seem to cry out for internal representations of remote objects—the traditional stronghold of GOFAI. Daniel Dennett of Tufts University warned of simply reversing AI's failed rallying cry, "Today chess, tomorrow locomotion!" and counseled a middle ground between the "Mount Turing" of symbolic computation and the "Mount Poincare" of dynamics. But some counterexamples are beginning to emerge, such as Jeff Elman's recurrent neural networks that learn simple, context-free languages. Work at SFI by Jim Crutchfield and Melanie Mitchell seeks to move the mountains at their base by formally relating the mathematics of dynamical systems to the theory of computation, allowing them to determine, for example, the class of functions a dynamical system can compute. In one application, they use a genetic algorithm to evolve cellular automata that will perform a specified function. Mitchell interprets the higher-level structures that appear in the cellular automata's state space as emergent representations involved in computing the function, but whether these serve as representations and computations in the GOFAI sense remains controversial.

An intriguing possibility, raised by Andy Clark of Washington University and Brian Smith of Xerox's Palo Alto Research Center is a Secular Grail of representation that is consistent with the dynamical hypothesis. Clark distinguishes between weak representations, internal states that are coupled to the world during the on-line control of behavior, and strong representations, inner states that stand in for remote objects, enabling off-line thought and reflection. The latter could originate as dynamical subsystems that become decoupled from the immediate environment and hence are nonsymbolic. Representations may thus be reconstructed as dynamics operating over different time scales. Despite the appeal of this sort of rapprochement, Kelso and Turvey noted the need for internal models in any given task may evaporate as the relevant dynamical concepts are developed; they urged a strategy of gradually pushing the approach as far as it will go.

A second obstacle also exists: dynamical systems do not possess an intrinsic semantics any more than do computational systems. How, for example, would an attractor acquire meaning for an agent? The current approach, presaged by the ecological psychology of the late James Gibson, is to embed the agent in an environment with behavioral consequences, such that a semantics is derived from their interactions. Further, the organization of behavior itself emerges from these interactions as agents come to exploit the dynamical and informational regularities of their environment, yielding simple behavioral solutions. The lamprey, for example, exhibits a traveling wave in the water but, when placed on dry land, a useless standing wave appears; the lamprey's design thus complements the hydrodynamics without representing them internally. Beer's simulations of embedded agents, in which a genetic algorithm is used to evolve neural networks that perform simple perceptual-motor tasks, aim to reveal how the structure of the task comes to be reflected in the dynamics of both neural activity and the agent's behavior.

A third point of contention is whether dynamic models offer anything more than description and prediction of observed behavioral patterns. Neuroscientists typically seek to explain cognitive behavior by reducing it to a lower level of neural components. Others ground the observed dynamics in physical law, Yet most current dynamic models do neither. Rather, they play a role analogous to that of the gas laws in thermodynamics, long before the subject was reduced to the level of statistical mechanics: they offer a way to characterize regularities in the behavior of cognitive agents, which may in time lead to a theory of how such regularities emerge from interactions of the system's many components.

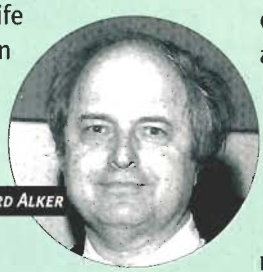
Whether the dynamical hypothesis yet imparts the warm, fuzzy, explanatory glow that workshop participants ultimately seek, a new conceptual framework for understanding cognition has arrived, one that will be influencing cognitive science in the coming decade.

Tentative Conclusions for Better Approaches to Historical Complexity

Any enduring academic discipline has a special sense of its own history. This is partly recreated through the retelling of its greatest controversies and its greatest discoveries or found in the textbooks incorporating its most significant paradigm shifts. Bridging both humanistic and scientific concerns, history is no different in this regard.

Hayward Alker, on sabbatical from the School of International Relations at the University of Southern California (USC), came to the Santa Fe Institute to see whether SFI modeling techniques could contribute to a better understanding of international history's own "historicity." Historicity, according to Alker and Frederich Olafson, is the sense of time-ordered self-understanding shared among members of a continuous human society. Although Alker's immediate interest has been in recasting SFI-style models to incorporate larger memories and better cultural and historical representations, his work can also be understood in terms of exploring how history's historicity can be mathematically modeled.

Alker has teamed with Simon Fraser, an SFI postdoctoral fellow, to look at ways in which memories and histories can be incrementally incorporated into artificial life simulations. Fraser has been reprogramming Tierra—an artificial-life model developed by SFI External Professor Tom Ray—on the Macintosh platform to allow one to observe the agents' evolutionary histories. Although Tierra's creatures are not able to comprehend the development of their social relationships the way their users can, the pieces of the evolutionary story that Tierra captures can be probed and retold with great detail at the level of genetic mutations, a kind of natural scientific "transparent historicity" that may prove helpful to social scientists.



HAYWARD ALKER

Fraser and Alker are also working with ECHO simulations, developed by John Holland and his collaborators, exploring ways in which this more complex and social artificial world can be historically enriched. This model's agents fight, trade and mate; remembering patterns of such interactions and transmitting the lessons derived from them to offspring would provide a new class of nongenetic social learning, reproduction and developmental dynamics. Perhaps in a Swarm implementation, Alker hopes to use ECHO (as well as MacTierra) in his USC teaching.

Finally, Alker has begun discussions with George Lakoff about how historical understandings might more explicitly be modeled. Hayden White's *Metahistory: The Historical Imagination of Nineteenth-Century Europe* has influenced them both, and they want to look further into the metaphorically informed historical and ideological ways humans from particular cultural backgrounds have made historical sense of their experience. Wolfgang Fikentscher's rich typologies of different modes of historical understanding in his *Modes of Thought* present an even more general typology of historical mapping possibilities. Several of Lakoff's students are using parallel processing models of adaptive-meaning construction similar to the computational methods used by Alker in his rediscoveries and reformulations. So a common approach to historical understanding might be possible.

Alker has come to several tentative conclusions in his quest for better scientific approaches to historical complexity. Starting with a concern to reformulate humanistic yet increasingly scientific variants of human history, he now sees the project as part of a larger one: the incorporation of human history into the longer and larger time and meaning frames of natural history, especially the natural history of all forms of living systems. This approach informs the Tierra and ECHO models. In Olafson's characterization of history, noted above, Alker suggests replacing "human society" with the "natural order of living systems" as a way of incorporating human collective historical consciousness within the larger natural history of the planet.

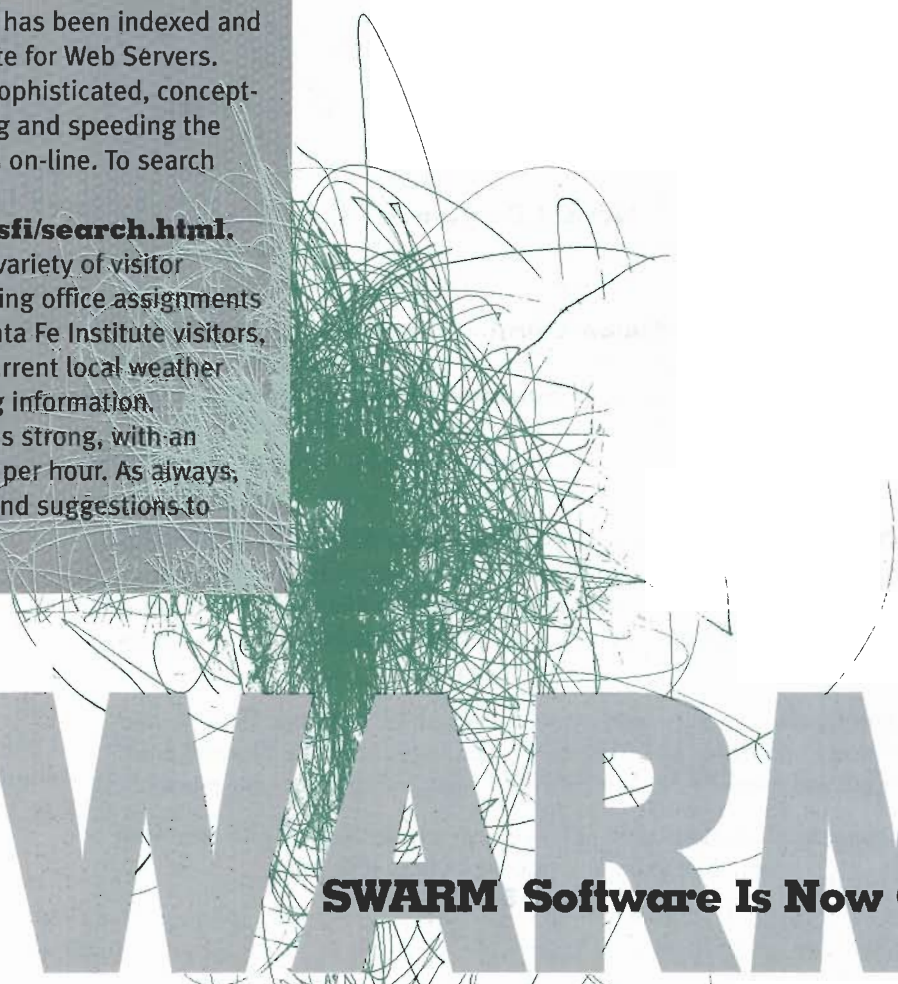
Within this larger context, Alker argues that agent-based models may encourage a new kind of sustainability-sensitive social science modeling appropriate in an age of increasingly constraining ecological limits. Falling within a tradition of modeling that goes back at least to Gottfried Leibniz, the "godfather of cybernetics," this approach achieved exceptional mathematical clarity in the von Neumann-Burks Theory of Self-reproducing Automata. The parallel processing computer architectures used by Lakoff and his students to model meaningful historical constructions reflect the common origins of a modeling tradition oriented toward multicellular dynamics, the reconstruction of evolutionary history and a greater appreciation of the way human cognition reflectively understands and transforms both itself and the natural world of which it is a part.

SFI Web Update

The Santa Fe Institute Web site has been indexed and is now fully searchable via Excite for Web Servers. Excite gives users access to a sophisticated, concept-based search engine, enhancing and speeding the capability to obtain information on-line. To search SFI's site, see **http://www.santafe.edu/sfi/search.html.**

Work is under way to post a variety of visitor information on the site—including office assignments and directions for first-time Santa Fe Institute visitors, restaurant and event guides, current local weather reports and Institute computing information.

Interest in the project remains strong, with an average of 122 visits to the site per hour. As always, SFI welcomes your comments and suggestions to **www@santafe.edu**.



SWARM

SWARM Software Is Now Online

In mid-May, Swarm software became available to the general public, marking two years of intense development by the Santa Fe Institute team of Chris Langton, Nelson Minar and Manor Askenzai and Deere & Company's Roger Burkhart. Interest so far has been strong; in the first two weeks, over two hundred copies of Swarm were downloaded from SFI's ftp site.

Swarm is a set of software libraries for building multiagent simulations. It is a domain-independent system, and it has been used to model ecology, anthropology, chemistry, economics, political science, evolutionary systems and computer science. Since October, Swarm has been in limited release to select beta testers, including groups at the University of California, Los Angeles; University of Michigan; Monash University; Yale University; the University of Venice, and Washington State University. Results from the limited beta-test period have been encouraging: testers have been successfully using Swarm to aid their research, the Swarm team has received valuable feedback, and the Swarm-user community has grown into a supportive and useful resource.

Swarm is still in beta test, but it is now complete and stable enough to be of general use. To date, the effort has been largely on the fundamental framework of the Swarm system; with that in place, the next phase of development will be the higher level modeling libraries needed for building and analyzing particular kinds of simulations.

Swarm is free software. Information and copies to download are available on **http://www.santafe.edu/projects/swarm**.

Free Public Lectures

The Santa Fe Institute's public lecture series continues through this summer and fall.

On **August 21,** Harvard's **Gerald Fischbach** explains his research on the malleability of the human brain's neural connections and how this adds to the complexity of the brain.

Science Board member **Simon Levin,** George M. Moffett Professor of Biology at Princeton, will give the third annual Ulam Memorial Lectures over three consecutive nights, on **September 10, 11** and **12.** These lectures will explore the structure and function of ecological systems and the implications of biodiversity and system organization for resilience in the face of environmental change.

On **October 16,** Harvard anthropology professor **Maryellen Ruvolo** discusses her research, which focuses on how genetic data can help answer two long-standing questions central to our understanding of human evolution: how are humans related to the other primates, and what are the origins of modern humans?

Support from community sponsors—Alphagraphics, Jackalope Pottery, The Levinson Foundation, Los Alamos National Bank, Santa Fe Neuroscience Institute and Santa Fe Accommodations—makes these free talks possible.

For more detailed information or for people outside the Santa Fe area who would like to borrow videotapes from this series, call **(505) 984-8800.**

Cyberspace Heroes

Brett Logan and Jay Mitchell, Santa Fe High School seniors who have been working with SFI's Melanie Mitchell this year, have won several science fair prizes for their computer model of the immune system using genetic algorithms. Their work captured the grand prize at the New Mexico State Science Fair, which includes a trip to the International Science Fair in Tucson, where their project was in the competition. "I'm really proud of them, and they're, rightly, very proud of themselves," says Mitchell. "It would be great to try to expand SFI involvement in activities like this. I think it's one of the best ways that scientists here can interact with local high schools and have a real impact on education."

SFI PRIZE FOR SCIENTIFIC EXCELLENCE

Six high school seniors from Santa Fe were recently chosen as recipients of the Santa Fe Institute Prize for Scientific Excellence. The purpose of the award is to honor outstanding graduating science students who embody the spirit of scientific pursuit at the Santa Fe Institute and to encourage students to pursue science.

The students are Clea Lopez, Santa Fe Preparatory School; Thomas Suina, Santa Fe Indian School; Dawn Kaufman, Capital High School; Kathleen Van Luchene, St. Michael's High School; Brett Logan, Santa Fe High School, and Joline Cruz, St. Catherine Indian School. The six selected for the new award were recognized for their "creativity, originality and academic excellence."

SFI professor Murray Gell-Mann proposed the awards earlier this year. "It is essential to encourage students in the community with an interest in science to peruse that interest in college and beyond," he said.

Left to Right: 1. Kathleen Van Luchene 2. Clea Lopez 3. Thomas Suina 4. Brett Logan 5. Joline Cruz 6. Dawn Kaufman

OUTREACH

Fort Lewis College

Late this spring, the Institute welcomed a group of math and physics students from Fort Lewis College in Durango to learn more about the Institute. "The opportunity for our students to experience the research atmosphere of SFI was invaluable," said math professor Tim Schaffter. "Fort Lewis is a relatively small liberal arts school and, as such, concentrates on undergraduate teaching. Our small classes and dedication to teaching provide, for many students, a preferable atmosphere. But we cannot provide the experience of a first-rate research center. SFI has done just that for us."

"The trip was a wonderful experience" added student Jim Story. "This day really gave me a perspective on the applications of dynamical systems. I'd like to thank all of the people who took time out of their day to present their studies and a special thanks to the nice lady who drove me to the hospital after my odd encounter with the attack squirrel." (The squirrel, which bit Story, had earlier attacked SFI Professor Murray Gell-Mann.)

TAP Program

Santa Fe Preparatory School sophomores Sam Brannen and Micah Sze worked as computer assistants at SFI this past spring—part of their school's Teen Action Program (TAP)—under the guidance of System Manager Tim Carlson. Community service is required at Santa Fe Prep. Therefore Prep has started a TAP project with SFI to give students with lots of enthusiasm and some computer skills the opportunity to broaden those skills in the Institute's heterogeneous computer environment and to learn more about computer and network management.

With those enhanced skills in hand, Brannen and Sze will be able to provide support to community service agencies with computer needs. Areas of help could range from PC or Macintosh troubleshooting to supporting applications such as databases and communications software to internetworking. This year, one TAP student helped set up software and trained personnel at the Randall Davies Audubon Center. SFI looks forward to continuing to be an incubator for student assistants.

ICAD Workshop at Xerox PARC

The International Conference on Auditory Display (ICAD) is cosponsored this year by the Santa Fe Institute and Xerox. It will be held November 4-6 at Xerox's Palo Alto Research Center or PARC, as it is known.

ICAD is a forum for presenting research on the use of sound to display data, monitor systems and provide enhanced user interfaces for computers and virtual reality systems. At SFI, ICAD was an outgrowth of the search for perceptually rich ways of comprehending complex systems. Now broadened to a wide array of auditory representation and interface issues, it is unique in its singular focus on auditory displays and the array of perception, technology and application areas these encompass.

As a 1996 Osher Fellow at the Exploratorium in San Francisco, SFI Research Professor Jim Crutchfield has been one of the principal scientific advisors to a current exhibit there, "Turbulent Landscapes: The Natural Forces that Shape Our World" (through January 5, 1997). The exhibit presents works in which artists use the forces of nature as their media—water, air currents, etcetera—to capture and expose the complex systems to nature. The show is made possible by funding from the National Science Foundation.

Artists from around the world created the more than thirty works included in the exhibition. Together they demonstrate the richness of patterns and movement hidden in the fluid world of nature that surrounds us. Internationally exhibited environmental artist Ned Kahn conceived the exhibition.

To access "Turbulent Landscapes" on the Web, type: *http://www.exploratorium.edu/complexity*.

PHOTOS COURTESY THE EXPLORATORIUM, SAN FRANCISCO

NEW BOARD MEMBERS

New Trustee

Douglas Carlston, the chairman of Brøderbund Software in Novato, California, has been elected a trustee of the Santa Fe Institute. Brøderbund, founded in 1980, pioneered the development of innovative educational software for young people. Two of its products are *Where in the World Is Carmen Sandiego* and *Myst*. Carlston graduated magna cum laude from Harvard and studied economics at Johns Hopkins School of Advanced International Studies before entering Harvard Law School. Following the commercial success of his first two games, *Galactic Empire* and *Galactic Trader*, Carlston quit the practice of law to devote himself to programming. In addition to the responsibilities of his office, he continues to foster the creative process behind Brøderbund's product development.

Six Join SFI's Science Board

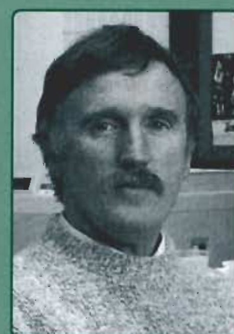
In March, six distinguished scientists joined the Santa Fe Institute's Science Board, which advises SFI on broad issues related to its scientific program.

May Berenbaum is professor and head of the entomology department at the University of Illinois at Urbana-Champaign. She has received the George Mercer Award from the Ecological Society of America in recognition of her research on plant/insect interactions and the Founder's Award from the Entomological Society of America in acknowledgment of her contributions to the science of entomology. She is a fellow of the American Association for the Advancement of Science and a member of the National Academy of Science.

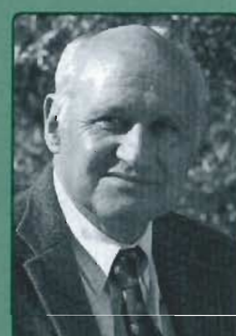
Steven Durlauf, University of Wisconsin, Madison, takes over the leadership of the Institute's economics program, beginning this summer. "The Santa Fe Institute has been an essential contributor to much of the most exciting research in economics in the last decade," says Durlauf, whose work focuses on inequality and segregation. Durlauf and Kenneth Arrow of Stanford University head a working group using agent-based methods to construct a large-scale, interactions-based model of inequality. Durlauf is on the editorial board of the *Journal of Applied Economics*, *American Economic Review* and *Journal of Economic Growth*.

Richard Lewontin is Alexander Agassiz Professor of Zoology, Harvard University, and professor of population sciences, Harvard School of Public Health. Lewontin is the recipient of the 1994 Sewall Wright Prize from the American Society of Naturalists. Lewontin and J.L. Hubby, using gel electrophoresis, demonstrated high genetic variability in sexual populations, results that contradicted the belief that natural selection would tend to reduce variability. Lewontin's work appears in numerous journals and in the popular press, including the *New York Review of Books;* his most recent book is *Biology as Ideology: The Doctrine of DNA*.

George Oster is a professor in the departments of cell and molecular biology at the University of California, Berkeley. He has also held appointments in mechanical engineering and entomology at Berkeley and has worked in many areas of biology, biophysics, zoology and ecology. A MacArthur Foundation Fellow from 1985 to 1990, Oster also held the Weldon Memorial Prize from Oxford University from 1992 to 1995. He sits on numerous editorial boards, including the *Journal of Theoretical Biology, Journal of Mathematical Biology, Modern Physics Letters D: Biophysics;* and the *IMA Journal of Mathematics Applied to Medicine and Biology.*



Martin Shubik is Seymour H. Knox Professor of Mathematical Institutional Economics at Yale University. A fellow of the American Academy of Arts and Sciences and the Econometric Society (among many other organizations), Shubik is a member of the editorial board of the *Review of Income and Wealth, Simulation and Games, Journal of Conflict Resolution* and *Eastern Economic Journal.* Shubik's most recent book, which he edited, is *Risk, Organizations, and Society: Studies in Risk and Uncertainty.*



Paula Tallal is professor of neuroscience and codirector of the Center for Molecular and Behavioral Neuroscience at Rutgers University. Tallal's research is broadly directed to the neurological basis of language, using behavioral, neuroimaging, genetic and psychopharmacological approaches. Currently, she is principal investigator for the Dana Foundation project, "Dana Consortium on Language-based Learning Disorders." Tallal's recent collaborative research with Michael Mezernich (University of California, San Francisco) has produced provocative, widely reported results involving a novel treatment for children with severe language and reading disabilities.

MOTIVATED, TALENTED INTERNS ARRIVE AT SFI

Can a summer at the Santa Fe Institute top a bike tour of the Western states? Sean Mooney, a junior at the University of Wisconsin, is betting on it. He has postponed his third 3,500-mile trip to join the Institute's summer program, sponsored by the National Science Foundation's Research Sites for Undergraduate Interns (REU). Mooney, along with six other undergrads from the United States, is in Santa Fe working with Institute mentors on an individually designed project.

"I want to get a feeling for how different physical forces function in protein stability," he says. "There is a big push in modern biochemistry to analyze computationally the structural features of a protein using only the primary amino-acid sequence. I'd like to extract statistical data from protein or nucleic-acid sequences to see how sequence and functional change affect structural changes." Mooney is working with Alan Lapedes of Los Alamos National Laboratory and SFI.

Terence Kelly traveled to Santa Fe on his motorcycle, detouring through New Orleans. He is currently working with SFI postdocs Bennett Levitan and Bill Macready, searching landscapes whose neighbor relationships are defined by random graphs. Searching such landscapes is a difficult but important task in physics, biology, economics and evolution studies. The project entails generating and searching graph structures to learn more about the nature and causes of these complex structures.

For the past three years, the Institute has welcomed a small number of highly motivated and extremely talented undergraduates – like Kelly and Mooney – who benefit from exposure to the rich interdisciplinary mix of ideas at SFI. Students are matched with one or more mentors with meaningful research problems of interest to the student and to which the intern can make a significant contribution. These mentorships have produced continuing collaborations and have resulted in four coauthored papers in the refereed literature.

"I find that I make most progress when I am completely lost, when all the material I am exposed to finds its way—with great proficiency—over my head," says Bard College's Brandon Weber. "In such an environment, one can embark on a great sojourn, until finally, perhaps, the mystery begins to unravel." Weber is making this summer's sojourn with Visiting Professor Larry Blume, working on the model of an Artificial Stock Market (ASM) designed by the Economy as a Complex Adaptive Systems group at SFI. He is trying to understand the dynamics of the model and will introduce some advanced learning principles into the model's agents. He plans to implement ASM using Swarm, a more sophisticated model of agents and their interactions. He will also study ASM's dynamic properties, running simulations and changing system parameters.

Pictured clockwise beginning top right:
1. Terence Kelly 2. Sean Mooney 3. Josh Berman
4. John Tye 5. Brandon Weber 6. Scott Rifkin

Catherine Grasso

"If I weren't going to SFI this summer, I would be working at the University of Michigan's (UM) Space Physics Lab and also waiting tables," says Catherine Grasso. "Possibly I would serve food at the UM football players' training table like I did last summer." Grasso's research at the University of Michigan focuses on modeling symbiosis with the two objectives of bettering understanding of this biological phenomenon and creating an innovative evolutionary algorithm. She is focusing on an artificial life project that involves modeling green hydra symbiotic with chlorella, a small, unicellular, green algae. While at SFI, she is working with SFI postdoc Tim Keitt, developing an evolutionary algorithm based on prokaryotic genetics. Grasso is supplementing her stay at SFI with her own support from a GE Fellowship; this will allow her to be in residence for more than three months.

Joshua Berman, a computer science major at the State University of New York, Binghamton, is working with SFI postdoc Cris Moore and with External Professor Mats Nordahl. Berman's project focuses on numerical measurements of simple lattice systems and the development of a theoretical explanation for their glassiness. "Glassy" behavior means these systems "freeze" far from equilibrium under a simple Monte Carlo dynamics. Further, they do so without the usual increasing energy barriers associated with glassy models. When not working on lattice systems, Berman lets his activities in Santa Fe be guided by two "insatiable addictions—Fudgesicles and coffee shops."

Scott Rifkin, a biological anthropology major at Harvard, says he chose his field "to explore how big brains change the rules of behavioral evolution and to explore the interrelationship between culture and biology. I've been approaching evolutionary questions from a variety of avenues, ranging from studying rhesus macaque calls to looking at the influence of metaphors on understanding evolutionary issues to tracking the foraging and social behavior of bottlenose dolphins." At the Institute, Rifkin and SFI resident researchers Bruce Sawhill and Martija Huyaea are researching the effects of one-to-many genotype-phenotype mapping on the dynamics of ribosomal RNA evolution as a first step toward understanding higher-level phenotypic evolution.

Duke's John Tye is helping SFI postdoc Tim Keitt develop computer models of self-organizing, autocatalytic systems. Tye, a twenty-year-old sophomore, is the youngest person at Duke to have a self-designed major approved: it's called "Emergent Properties of Adaptive and Intelligent Systems" and involves classes in computational complexity, nonlinear dynamics, neural networks, philosophy of mind, neurobiology, artificial intelligence and stochastic processes. "In Santa Fe," Tye notes, "I want to start applying all of the things I've been involved with to actually learn something new about our worlds. I want to solve problems by fitting together some of the pieces that I've picked up." He is researching evolution in the context of autocatalytic chemistries by simulating agents that contain catalysts (enzymes) for symbolic chemical reactions. Using a genetic algorithm, he and Keitt are evolving agents that can take advantage of different chemical reactions, allowing them to explore the relationship between the physical chemistry and the ecology of the agents.

Virtually all the Institute's REU interns have plans to pursue careers in the sciences by the time they arrive at SFI. A couple are already well-along multidisciplinary paths; both Grasso and Tye have designed individual, interdepartmental majors on their home campuses. The aim of these summer internships, then, is not to convert but to enrich these students' academic careers – as well as SFI's intellectual life.

Photography: Laurie Smith, except Catherine Grasso photo by Deborah Smith

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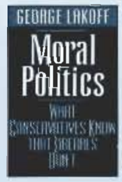
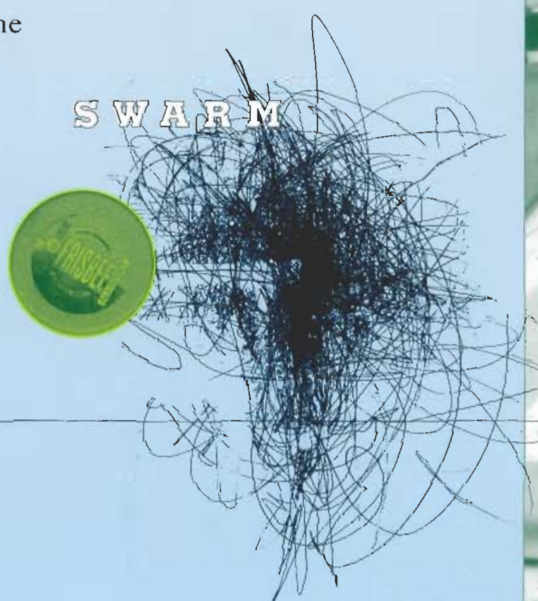
FEATURE STORIES



WORKS IN PROGRESS



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