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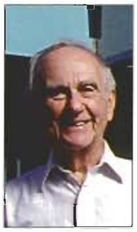
BULLETIN



Letter from the Past President

Professor Ellen Goldberg assumes the office of President of the Santa Fe Institute on January 1, opening a promising new chapter in the development of our growing enterprise. She leaves her post as Associate Provost for Research and Dean of Graduate Studies at the University of New Mexico where she has pursued a distinguished career as a research scientist in microbiology, genetics, and immunology since her arrival as a post-doctoral student in 1972.

The appointment of a biologist as President recalls our early planning discussions concerning the Institute's research agenda. When we proposed to form an Institute which would focus on emerging syntheses at the interface between existing disciplines, the obvious paradigm in the '80s was molecular biology which had emerged from mutually supporting research efforts in the fields of biology, biochemistry, and physics. The burgeoning biological sciences closely adjoined the physical sciences and the interests and skills of the founding group. Here was the model home of the emerging syntheses. I quickly obtained the charters and bylaws of the Salk Institute and spoke with its founders and directors. I also visited Rockefeller University and sought the advice of Josh Lederberg.

Against this background it is not surprising that many of our programs are described in biological terms and metaphors. We study, for example, neural networks, genetic algorithms, relationships between cognitive science and computers and the brain, and theoretical immunology.

However, the best laid plans are not necessarily the most readily funded. As it happens, our first big program represented a much larger leap into the unknown than the biological sciences. When Bob Adams mentioned the new Institute to a friend, Chairman of the Board John Reed at Citicorp, a train of events quickly followed that led to our Columbus-like voyage to the land of economics. It was clear that we were going beyond adjacent territory and invading more distant regions occupied by potentially threatening natives. But Reed's interest and generous offer together with a deep interest in social science discounted our trepidations.

Nevertheless, our interests in the life sciences were never abandoned and are increasingly active today. With the advent of Professor Ellen Goldberg to her new duties, it is timely to remember the early beginnings and to welcome this opportunity to further strengthen the foundations we began to build a decade ago. In the coming years we can look forward to enriching our biological metaphors and extending models of living systems that are at the core of complexity. We welcome and look forward to Ellen Goldberg's leadership in these and all of the interconnected themes at SFI.

George Cowan

Letter from the President

On November 11, 1995 Santa Fe Institute elected a new President, Ellen Goldberg [see article on facing page]. Having been SFI's President for the past five years, I join with my predecessor, George Cowan, in welcoming Ellen into what is surely one of the most exciting jobs in the world.

As I depart I particularly want to acknowledge the extraordinary degree of assistance that many people have given to me and to SFI. This includes our Trustees, our Science Board, our External Faculty—all of whom serve without compensation from SFI and who devote tremendous energy to helping carry out our mission. I especially salute the many scientists who have cast their lots with SFI out of their instincts that what happens here is going to be important for a much larger world of science in the future.

SFI was founded as a bold experiment—a freestanding institute dedicated to multidisciplinary research bringing together teams of researchers from many scientific disciplines to tackle the really difficult problems of the next century. After eleven years, measured in almost any terms—publication of research results in the scientific literature, research grants, requests from scientists around the world to do research at SFI, applications from students and young scientists to participate, collaborations with other research organizations, and interest from businesses—it appears that the experiment is succeeding. SFI complements more traditional scientific institutions, and it is acting as a catalyst for change in the way some science is done.

Perhaps the most important issue facing our new President will be how to ensure that the freshness that characterized our first decade will be maintained. Our rapid growth is evidence of broad interest in the sciences of complexity and of the appeal of multidisciplinary research. The science we championed at SFI has outgrown our limited capacities, and we view with delight the emergence of allied research efforts in many other institutions. Our task is to continue to maintain a unique environment for research that will inspire others. I know that Ellen Goldberg understands this challenge very well, and all of us in the SFI family look forward to working with her in meeting it.

Edward A. Knapp

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cover photos: Dan Barsotti

A NEW PRESIDENT FOR SFI:
ELLEN GOLDBERG

There was irony in evidence on November 11 when the Santa Fe Institute Trustees elected SFI's third President. After a year-long search and consideration of candidates from around the country, they narrowed their choice to someone just 60 miles away. She is Dr. Ellen Goldberg, who comes to SFI from her joint positions as Associate Provost for Research, Dean of Graduate Studies, and Professor of Microbiology at the University of New Mexico.

Ellen is the first life scientist to occupy the President's role at SFI, and her selection underscores the continuing broadening of the range of scientific disciplines in the Institute's mix. She received her undergraduate degree in biology from Russell Sage College (Troy, New York) in 1967 and her Ph.D. in genetics from Cornell University Medical Center in 1971. Among her honors, she has been Chairman and Councilor of the Immunology Division of the American Society for Microbiology and is a Fellow of the American Academy of Microbiologists. Her area of research has been immunogenetics and reproductive immunology.

Ellen succeeds Ed Knapp (1991-95) and George Cowan (1984-91) as President. Like George Cowan, Ed Knapp will remain affiliated with SFI as a researcher.

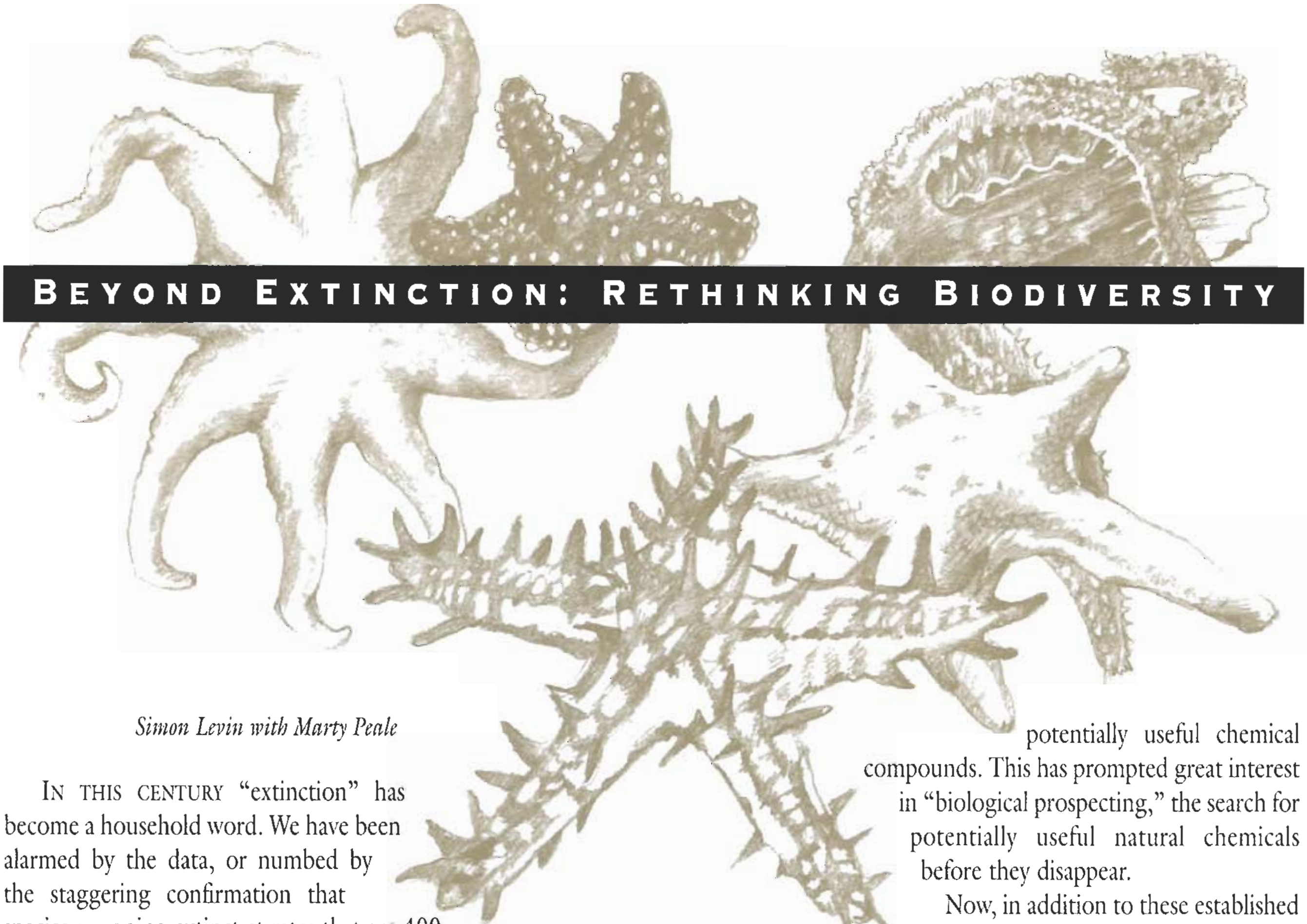
David Liddle, the Chairman of SFI's Board of Trustees, said, "In making their decision, the Trustees pointed out that Ellen had demonstrated a combination of qualities of great importance to the Santa Fe Institute. She understands and is committed to SFI's mission of creating an environment for interdisciplinary research collaborations. She is an outstanding scientist who understands the importance of long horizons in basic scientific research. She has won praise for her judgment and vision as a research administrator. And she is a teacher and mentor who is committed to SFI's determination to provide research opportunities for young scientists."

Ellen, a popular figure at the University of New Mexico's Albuquerque campus, was already a member of the Santa Fe Institute's advisory Science Board. Her enthusiasm for taking on the presidency of SFI stems from her earlier interactions with SFI scientists. She had also taken the lead in previous years in helping build scientific collaborations among SFI and UNM scientists, a process she hopes to accelerate there and at other institutions.

In accepting the position, she said, "SFI and its interdisciplinary approach to complex problems goes beyond the normal boundaries that exist within the university. It is that unique approach to science that I find so exciting."

As President, Ellen will be the Chief Executive Officer, overseeing the broad direction of the scientific program and leading the development of additional funding sources for research. She will oversee a staff of 20 people who provide support to the hundreds of scientists who visit each year. SFI's budget will be $5.5 million in 1996.

BEYOND EXTINCTION: RETHINKING BIODIVERSITY



Illustrations: Catherine Kirkwood

Simon Levin with Marty Peale

IN THIS CENTURY "extinction" has become a household word. We have been alarmed by the data, or numbed by the staggering confirmation that species are going extinct at rates that are 400 times greater than any recorded throughout geologic time. Researchers sketch the magnitude of the situation in numbers of species lost—tens of thousands annually in the tropics alone—and confirm that the rate of loss is accelerating. Yet even more troubling, as we take stock of the data, we forget how little we know. Indeed, ecologists like SFI Science Board member Simon Levin, informed by 100 years of ecological research and, more recently, systems theory, caution that "we barely understand what we are losing."

Individual species, and biological diversity as a whole, have long been valued for aesthetic, ethical, and utilitarian reasons. The most fundamental argument for the preservation of biodiversity is "appreciation of wild creatures and wild places for themselves." The United Nation's World Charter for Nature, for instance, states that "every form of life is unique, warranting respect regardless of its worth to man, and, to accord other organisms such recognition, man must be guided by a moral code of action." The debate about whether to destroy the last remaining strains of the smallpox virus highlights the power of this deep-seated ethic to accord value to all forms of life.

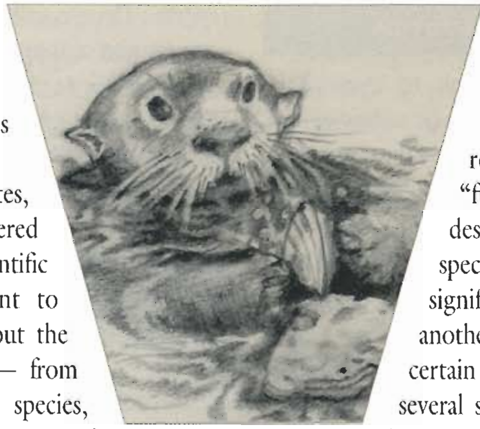
The utilitarian argument for biodiversity rests on the services that are provided to humans. For example, one fourth of all prescription drugs contain active ingredients originally derived from wild plants. To put this in perspective, the World Wildlife Fund in 1991 estimated that only 2 percent of the quarter million described species of vascular plants have been screened for potentially useful chemical compounds. This has prompted great interest in "biological prospecting," the search for potentially useful natural chemicals before they disappear.

Now, in addition to these established arguments, Levin and his colleagues are calling attention to biodiversity as a source of conceptual insights.

A PROBLEM OF DEFINITION

We have, at least since Linnean times, recognized the significance of individual species. The definition of "species," however, is itself problematical. Levin explains, "Historically species were defined according to morphological characteristics, often on the basis of museum specimens. However, Ernst Mayr and others shifted attention to a biological species concept distinguishing species by the degree to which organisms interbreed. This is a more natural definition, but how do we know that individuals are incapable of interbreeding? Do we mean in captivity or in the wild? What if a species is spatially dispersed, one population breeding successfully with its neighboring populations, but not with distant populations. Where do we split it? And what if a species is temporally dispersed? How do we determine whether a contemporary species is significantly different from its counterpart of 1000 years ago?"

Even "good species" produce fertile hybrids, precisely because there is genetic variation within what we call a species. *Canis lupus* and *Canis canis*, wolves and domestic dogs, are very good examples of this. In difficult cases, researchers may set an arbitrary acceptable level of occurrence of fertile hybrids, such as up to 5 per cent, as a working definition. "Now we're into what a mathematician would call a 'fuzzy set,'" notes Levin, "a continuum, with what we can identify as 'the genetic core of a species'— and gray zones. So a species is not so sharply defined."



Preeminent ecologist E. O. Wilson notes, "Although the species is generally considered to be the 'fundamental unit' for scientific analysis of biodiversity, it is important to recognize that biological diversity is about the variety of living organisms *at all levels*— from genetic variants belonging to the same species, through arrays of species, families and genera, and through population, community, habitat and even ecosystem levels. Biological diversity is, therefore, the 'diversity of life' itself."

"For plant communities," Levin notes, "an ecologist would measure both the within-and among-community components of diversity and recognize each as contributing to diversity. Similarly, in the measurement of biodiversity, one must recognize the diversity within species as well as the diversity in terms of number of species—or, more radically, do away with the notion of species entirely in favor of 'continuum' measures of the genetic and functional diversity of communities."

With these considerations in mind, the significance of species extinctions bears revisiting. Levin asserts, "Species extinction is an important indicator of the loss of biodiversity. It is not, however, the whole story." "Although species extinction is the most fundamental and irreversible manifestation of biodiversity loss, the more profound implication is for ecological functioning and resilience," write fellow researchers Edward Barbier, Jo Burgess, and Carl Folke. A.H. and P.R. Ehrlich propose an instructive analogy: "Ecosystems, like well-made airplanes, tend to have redundant subsystems and other 'design' features that permit them to continue functioning after absorbing a certain amount of abuse. A dozen rivets, or a dozen species, might never be missed. On the other hand, the thirteenth rivet popped from a wing flap, or the extinction of a key species involved in the cycling of nitrogen, could lead to a serious accident."

Keystones and Functional Groups

At least since 1935, when Tansley introduced the concept of ecosystems, our understanding of the roles of individual species— and comprehension of the ramifications of loss— have grown. In 1966, Robert Paine introduced the concept of "keystone species," top predators such as starfish and sea otters, whose removal can lead to cascading effects in system properties. Since then, the concept has been extended to species other than top predators. Some, for instance, consider the distemper virus that kills lions in Africa to be a keystone species. Levin cites "a quarter century of research on keystone species—predators, competitors, mutualists, pathogens, among others—demonstrates a diversity of situations in which individual species play critical roles, at least in determining community structure."

Also in the early 1960s, ecologists recognized "keystone groups," or "functional groups." Researchers have since described many systems in which groups of species function as a unit, collectively playing as significant a role as one keystone species plays in another system. Within these functional groups, certain roles are filled interchangeably by one of several species; there is redundancy— "ecosystem insurance," in the words of Stanford University ecologist Harold Mooney. The group as a whole, however, is irreplaceable inasmuch as it controls critical ecosystem processes. One of several Rhizobium bacteria, for instance, can fix nitrogen with a legume, the symbiosis thereby enhancing a whole system. Moreover, the diversity within a functional group may be tuned to maintaining resilience to change.

From the viewpoint of systems theory, it is to be expected that large ensembles of interacting components will self-organize into clusters that interact more strongly among themselves than with other such clusters, and that the within-group dynamics will occur on much faster time scales than dynamics among groups. Such hierarchical organization is characteristic of ecosystems.

Robert Steneck and Megan Dethier provide one of the most compelling studies to date confirming the utility of the notion of functional groups. Drawing from experiments and experiences in subtidal algal communities in Maine, Washington, and the Caribbean, they propose that functional groupings of taxonomically distinct species share morphological attributes and that, when the approach of functional groups is taken, convergent biogeographical patterns in ecosystem organization may be discerned clearly.

> "Species extinction is an important indicator of the loss of biodiversity. It is not, however, the crux of the problem."

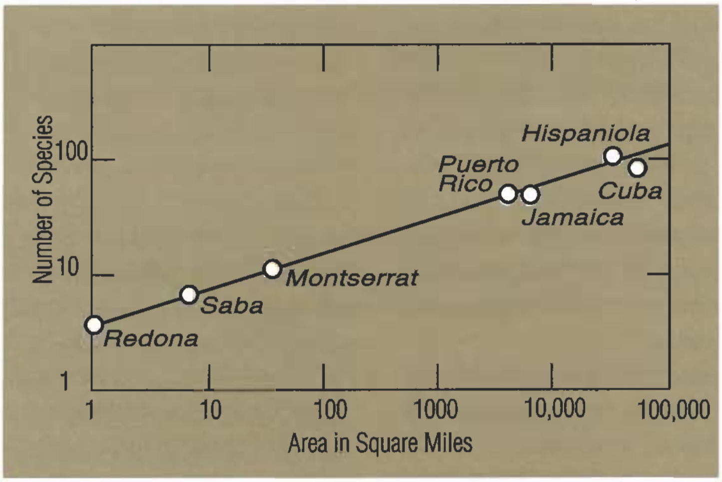
Communities viewed in terms of functional groupings prove much more stable and predictable than when viewed in terms of species composition. The regularity seen in these communities is reminiscent of the regularity seen in the organization of trophic webs—the network of feeding relationships that defines the pathways of energy flow in an ecosystem—when attention is on the macroscopic properties of those webs, rather than on the individual species.

Toward a New Characterization

What, then, is appropriate biotic detail to monitor or preserve? The role of species in ecosystems can be addressed only in the context of how we characterize the boundaries, structure, and function of ecosystems. If the boundaries of the "community" can be stated, for instance, then the shape of the species-area curve is a fundamental aspect of the description of diversity, capturing much more than simply the total number of species in that community.

The perspective of the researcher also affects the characterization of the system. A population or community biologist will describe a system in terms of its biotic structure and organization, while an ecosystem scientist will see it in terms of flows and exchanges.

"The health of an ecosystem," notes Levin, "is measured both in terms of its biotic composition and the flow of elements among its compartments." Yet an understanding of the interconnections among these is woefully lacking. "The concept of keystone species gives a handle for understanding community structure; functional groups control critical system properties. The argument for the maintenance of biological diversity is strong in either case. When species are at issue," explains Levin, "genetic diversity within them governs the capability for resilience. When functional groups are involved, resilience resides in diversity within the groups. Efforts to measure diversity solely in terms of numbers of species, therefore, while a logical place to start, miss much essential detail."



The number of species rises approximately linearly with the area sampled, on a log-log scale.

Levin considers HIV to be a particularly instructive example of the functional importance of diversity. "One of the prevailing theories about how HIV operates is that its high mutation rate fosters a diversity that eventually swamps the host's immune system. Do we call that competition between organisms, or cooperation among them to advance 'the genetic core of the species'? Do we define the pathogen as a species, a genus, a functional group? Once again, we are called to question the definition of 'species'."

How should diversity be measured, and how do system attributes respond to changes in diversity? According to Levin, "We are at the threshold of being able to answer these questions, through combined empirical and theoretical studies. The essential theoretical linkages must come, in part, from a proper theory of ecosystem development and evolution, in which system properties (including organization into functional groupings) are seen to emerge from the self-organizing development of ecosystems and landscapes, within the context of the evolution of individual species."

The scientific community barely understands the definition of "individual species," the boundaries of "community," the functional scale at which to characterize "ecosystems," or the interface between "natural selection and self-organization." In the context of systems and complexity theory, as well as the well-understood aesthetic, utilitarian, and ethical arguments, Levin states, "The idea that humans might make decisions regarding which species to preserve and which to sacrifice is an arrogance that does not sit well on our shoulders." E.O. Wilson has observed that the loss of genetic diversity by the destruction of natural habitats is "the folly our descendants are least likely to forgive us." His prophesy grows only more profound, as we probe at the lines we have drawn between things.

– Simon Levin is George M. Moffett Professor of Biology at Princeton University. Marty Peale is a freelance writer in the Santa Fe area.

Reading List

T. Abe, M. Higashi and Simon A. Levin (eds.), *Biological Diversity*, Springer-Verlag, New York. To appear 1996.

E. B. Barbier, J. C. Burgess and C. Folke, *Paradise Lost? The Ecological Economics of Biodiversity*, Earthscan, London. 1994.

P. R. Ehrlich and A. H. Erlich, *Extinction: The Causes and Consequences of the Disappearance of Species,* Random House. 1981.

R.T. Paine, "Food Web Complexity and Species Diversity" in *American Naturalist*, Volume 100: 65-75

E. O. Wilson, *The Diversity of Life*, The Penguin Press. 1992

"Glasses for the Ears:" Intervening to Enhance Child Development

At the recent SFI workshop "Intervening to Enhance Child Development" Paula Tallal from Rutgers University and Michael Merzenich from the UC School of Medicine at San Francisco presented 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.

This new approach grows out of a collaboration sparked nearly three years ago at an SFI workshop when Merzenich, an expert on the plasticity of brain organization, and Tallal, an expert on language impairment in children, began talking about the problem some children have in hearing certain sounds.

Tallal has been exploring how the brain's processing of phonemes—the basic sound units of a language—relates to language acquisition. Some sounds occur in a steady flow that lasts more than 100 milliseconds, but other sounds require very rapid transitions, as short as 40 milliseconds. Apparently in some language-impaired children, cells in the primary auditory cortex cannot detect rapid-transition phonemes.

RESEARCH UPDATES

Tallel and Merzenich have devised a method to mitigate such language impairment using computer-generated "processed speech." It helps the children hear these fast-transition phenomes, an ability which may in fact eventually cause change in the auditory cortex itself. Using the computer-generated speech, fast transitions are stretched out artificially. To a normal individual, the speech sounds like someone shouting underwater. To language-impaired children the slowed pace brings clarity: they can hear clearly for the first time in their lives.

Two summers ago Tallal and Merzenich applied their experimental treatment to seven language-impaired children ranging from five to nine. Intensive sessions were held five days a week for six weeks. Individuals were tested initially and at the end of the program. The results were striking. "The children made two years of progress in just one month," Tallal said. Follow-up testing three months later showed they had not lost these gains. These findings show promise, although long-term studies remain to be done, the two researchers cautioned. Dyslexia has many causes and clearly this approach will not help every sufferer. This treatment, however, may be the first therapy of its kind based on a growing understanding of how the brain is organized.

Tallal and Merzenich's findings corroborate other recent research results which present new information underlining the importance of environment in relation to brain development. Environment can be viewed not just as a source of sensory input for the brain but as an active agent which interacts with the cerebral cortex and actually molds its neurophysiology. Inherent in this view is a picture of the central nervous system as both robust and flexible, as something far more plastic than previously thought. These recent discoveries about cortical malleability suggest the importance of taking a new look at the whole question of learning and rehabilitation in human infants and adults.

In fact, brain plasticity, and especially its implications for child development, has been the focus of two previous SFI meetings. The first—where Merzenich's and Tallal's collaboration began—was a 1993 workshop led by former SFI President George Cowan and Rutgers psychologist Bela Julez. It precipitated a continuing review of current work on maturational windows and brain plasticity from a complex adaptive systems (CAS) perspective. This approach proposes that cognitive skills depend on intracortical networks strengthened by repeated stimulation. The October workshop this year further developed the approach begun two years ago. It included presentations focusing on new developments in computational modeling of cognitive competence from a connectionist perspective as well as recent findings from new brain assessment approaches with children such as the Tallal/Merzenich work. The meeting was co-chaired by Cowan and Dorothy and Jerome Singer from the Psychology Department at Yale University. It was supported by funding from the Gladys B. Foundation.

Last year's workshop on child development formed an "Intervention Study Group" for long-term exploration of some modest theoretical models for intervention at the physiological, behavioral, and social levels. This informal work will be continued with attention to determining how to best use the information from the three SFI meetings.

MODELING BUSINESS AS USUAL: ORGANIZATIONAL ROUTINES

Last summer SFI External Faculty member Michael Cohen convened the workshop "Routines and Other Recurring Action Patterns of Organizations" to explore current work in the field. The notion of "routine" is now widely used by many researchers, especially those working with evolutionary models of economic phenomena, but its meaning has become increasingly vague. Cohen and his colleagues feel the time is ripe for reappraisal of the concept in light of general research developments as well as the new perspectives offered by a complex systems approach.

The meeting was held at SFI under the joint sponsorship of the Institute and the International Institute of Applied Systems Analysis (IIASA).

Routines can be thought of as the organizational analog of the skills of individuals. They are practiced means of accomplishing objectives that organizations develop over time. Like skills, routines serve as the foundation of an entity's capabilities. The distinctive thing about routines, however, is that, unlike skills, they are distributed across multiple actors. Touch typing is a good example of a skill—but organizational document production—such as the production and distribution of this SFI *Bulletin*—is commonly a routine, with different portions of the process being carried out by different people, whose individual skills must interlock to complete the task.

As with an individual's skills, organizational routines are a basis of efficient performance, but also a barrier to change. Once established, each may serve its original purpose well, but can be difficult to alter. Because there are now enormous pressures on organizations to change rapidly and effectively, there is considerable interest in how routines arise, are maintained, change, and decay.

The complex adaptive systems (CAS) viewpoint of SFI provides a natural framework for the analysis of routines. From this perspective, the co-adaptation of actors that occurs as routines are learned, the tendency of routines to carry along the accidental historical trappings of their "birth," the difficulty of changing one part of a routine when it is surrounded by other, co-adapted parts, all make sense instead of appearing to be puzzling departures from expected "rationality." Within a CAS framework firms are not frictionless reflections of their momentary environments, but rather the product of more inertial "action repertories," which respond to, indeed dictate perception of, today's environment largely in terms of lessons learned from previous actions.

RESEARCH UPDATES

Meeting discussions were wide-ranging, touching on the implications of recent cognitive studies; the relationship of evolution to routines; and the categorization of routines and other recurring patterns. One recurring topic was simulation tools, and how models might contribute to a better theoretical understanding of organizational routines.

The current artificial intelligence community has been described as falling into two subgroups— "symbolic" and "behavioral." The approach of the behaviorists is strongly connected to models of intelligence that can be captured in systems that take real actions in a messy, real world. Behaviorists attribute much of the responsibility for keeping track of details about the changing world to the world itself, rather than to an elaborate internal model of the world maintained by the software or actor, as the case may be. Performance occurs as a modest number of simple rules interact with each other via their effects on the actor's environment.

Many features of this behavioral approach strongly parallel aspects of research on routine. For example, work on routine often sees artifacts and spatial arrangements as forming an essential part of the organizational memory from which the routine performance is drawn. It is argued that some organizational routines may have a distributed, implicit quality, so that it is not possible to find an account of the whole routine—or even an awareness that there is a routine—located in any one document or any one person's head. Extending this line of thinking, organizational routines can be considered as emergent properties of the interaction of distributed learning and adaptation processes.

Simulation work also resonates with certain cognitive aspects of routines. Recent work on the distinctive properties of *procedural* memory in individual humans seems to mirror properties of institutional routines observed in the field and laboratory. Procedural memory centers on skills, while *declarative* memory focuses on facts and episodes. Procedural memory differs from declarative in its long decay times, and the greater difficulty of transfer and verbalization. In fact, effective organizational performance apparently involves a mixture of automatic procedural elements together with a certain amount of decision-making that is more deliberative and self-aware (declarative) in character. The challenge of finding an appropriate balance among tacit and deliberate elements is implicit in model building also.

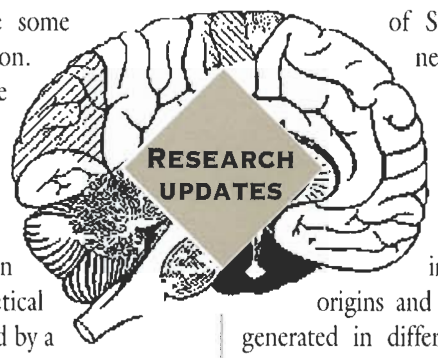
The group agreed that it would be helpful to have further meetings; they suggested that the next meeting be devoted to the many questions and challenges pertaining to the simulation of routine. For instance:

- There is variation in what builders of models take as their fundamental objective: to model a routine in its steady state, for which a hand-crafted system of rules often suffices, or to model the learning process by which the steady state emerged, which requires a commitment to some learning mechanisms of the individuals or an adaptive process acting on the relations among individuals.
- Much of the interest in routines centers on what happens as systems of actors learn action patterns; the basis, however, is a bewildering variety of methods for modeling individual learning.
- Handling of time has been a serious deficiency in much simulation of organizational action. Many reported phenomena would be unlikely to occur if time were modeled in a more plausible way.
- Understanding interactions between learning and evolution should be a primary concern for any evolutionary theory of institutions which asserts that learning plays a fundamental role in shaping organizational life. Researchers in the field of artificial life have made important advances in the simulation of learning and evolution, but more research is needed.
- Finally, theoretical development would be accelerated if it were easier to compare simulation models to each other, and if there were more opportunities to reuse computer code—which, itself, would facilitate comparison. A computing architecture that can facilitate comparison and reuse will be of considerable value to the field. In demonstrations of early versions the Swarm system appears to offer many of the needed advantages. If Swarm does not prove sufficient, it might be valuable for a team of organizational researchers to create a framework adequate to the required comparison and sharing.

Note: A full report of this meeting is contained in the SFI Working Paper "Routines and Other Recurring Action Patterns of Organizations: Contemporary Research Issues" No. 95-11-01

Theoretical Neurobiology

Understanding the Complexities of the Brain



Three years ago SFI External Professor Charles Stevens, a neurobiologist at the Salk Institute, had an idea to form a unique working group: his aim was to have theorists and experimentalists meet to try to stimulate some much-needed intradisciplinary collaboration. The ultimate goal was to catalyze the emergence of a new field, theoretical neurobiology. "Such interaction is becoming more and more important," Stevens said at the time, "because understanding the complexities of the brain requires increasingly sophisticated theoretical approaches." Stevens voiced an insight shared by a number of his colleagues across many biological fields; indeed as this fledgling project has developed, a number of researchers including Francis Crick, Nancy Kopell, and Michael Stryker have been involved.

Now this brainchild has become a reality both in a literal and figurative sense. As an outgrowth of the neurobiology summer working groups at SFI which began in 1992, five national centers for the study of brain theory have been "born" with funding from the Alfred P. Sloan Foundation. (Support for the SFI summer working groups was also provided by the Sloan Foundation as well as by the Pew Charitable Trusts.)

This past summer representatives from each national site—Brandeis, Caltech, New York University Center for Neuroscience, Salk Institute, and UC San Francisco—met at SFI for the first annual Sloan Theoretical Neurobiology Centers Meeting. Nearly thirty people, about equally divided between senior faculty and postdocs and graduate students, took part in the two-week gathering. Daily meeting presentations focused both on describing mathematical techniques with illustrations of neurobiological applications, and on reviewing the status of specific neurobiological problems. These talks served to establish a baseline against which future evolution in the field can be compared. The meeting also served to familiarize participants with the character and scientific direction of each Center, and enabled the researchers to establish personal and professional connections.

Another SFI meeting this summer, "Oscillations in the Nervous System: Implications for Human Health and Disease," is a prime example of exactly the kind of theoretical and experimental exchange Stevens and others envisioned. This meeting mixed clinical researchers with theoreticians ranging in expertise from neurophysiology to modeling. The workshop was led by Science Board member Nancy Kopell, a mathematician at Boston University (and, with Michael Stryker, a co-leader of SFI's 1993 working group in theoretical neurobiology) and Dr. Laszlo Tamas who is a Parkinson's disease neurosurgeon at the University of California at Davis. This meeting also was funded by the Sloan Foundation.

The oscillations meeting addressed three interconnected topics. One was the biophysical origins and potential functions of a variety of rhythms generated in different parts of the brain—the hippocampus, thalamus, and cortex—and associated with different behavior states such as attention, motor activity, and sleep. These rhythms have now been tentatively linked to processes of learning, memory, and the binding together of aspects of perception.

The second topic was the pathological synchrony of neuronal activity which occurs in some forms of epilepsy. Epileptic rhythms are thought to be pathological versions of normal rhythms, and some of the central questions about them focus on what kinds of changes turn normal rhythms into diseased states, and what interventions might reverse the process. Discussions dealt with the most current information about how intrinsic properties of neurons interact with network properties to produce complex dynamics, and included speculation about how the dynamics might encode information. As a result, mathematicians and physiologists working on the limbic systems and motor control have initiated several new collaborations.

Participants also discussed movement disorders, especially the tremor and other dysfunctional movements associated with Parkinson's disease. These tremors are generated in a collection of neural structures that include the rhythm-producing structures implicated in the genesis of other oscillatory activity. Talks centered around the dynamics of the disease and on types of data necessary for modeling studies. Extensive data are available from human surgery and from models of Parkinson's that are based on research involving monkeys. A notable result of the meeting was an agreement among the three major laboratories working on the physiology of Parkinson's to coordinate the protocols of their operations and monkey research to provide comparable data relevant to understanding the dynamics of the disease.

NEW WAYS TO FIGHT SEXUALLY TRANSMITTED DISEASES

RESEARCH UPDATES

Family Health International, a part of the U.S. Agency for International Development (AID), is supporting a new research initiative at SFI for computational approaches to predicting protein structures in the human papillomavirus (HPV). The research ties to other SFI work in HIV transmission and protein secondary structures. Although HPV and HIV infect different cells, display different evolutionary potentials, and probably necessitate totally distinct anti-viral strategies, there are abundant analogies between the complex ways the two viruses interact with host-cell molecules and pathways.

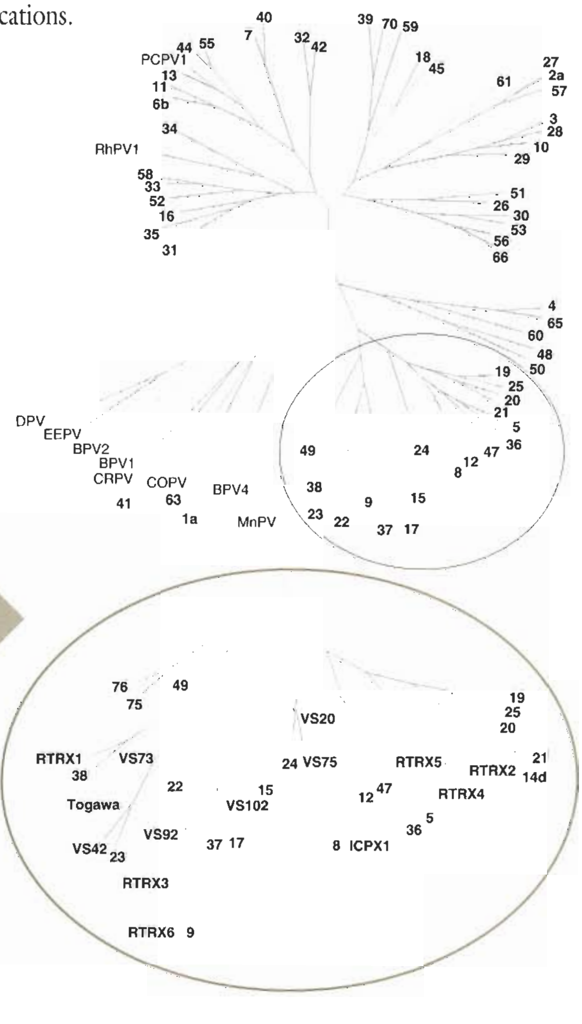
The World Health Organization currently estimates that more than 18 million individuals worldwide are infected with HIV, the cause of AIDS. HIV infections enhance the pathogenicity of HPV, and HPV in turn increases the risk of HIV transmission. Moreover dual infection by HIV and HPV leads to molecular interactions between the two viruses, a combination which may be implicated in the subsequent incidence of some cancers. This project's goal is to the lay the foundation for novel molecular intervention strategies to fight these diseases.

Although there is extensive information about the molecular genetic structure of HPV, relatively little is known about its RNA and proteins as compared with those of the HIV virus. For this reason the new biophysical and computational approaches will focus on discerning certain HPV structures. Emphasis will be on the structural and functional relationships of HIV and HPV, and on viral interactions with the host cell that result in genital warts and cervical cancer.

The work is being led by SFI Member Gerald Myers from Los Alamos National Laboratory. Project members working at the Institute are new SFI Postdoctoral Fellows Aaron Halpern and Martijn Huynen and Research Associate Andrew Farmer. (See New Members of the SFI Community.)

Collaborative experimental work at several institutions will guide analysis of HPV protein structure and RNA prediction. Using advanced computer applications, Martijn Huynen has successfully analyzed the full distribution of base-pairing probabilities for the HIV genomic model. At SFI he will undertake a comparable analysis of HPV, as a basis for generating more reliable information about HPV transcripts and their regulatory features. Huynen will be collaborating with Dr. Carl Baker at the National Cancer Institute. Dr. Goutam Gupta, head of the Nuclear Magnetic Resonance (NMR) laboratory at Los Alamos National Laboratory, will study the structure of the HPV virus in connection with Halpern's computational analysis at SFI.

This computational and experimental work will culminate in a 1996 SFI workshop involving approximately forty participants drawn worldwide to discuss the resulting models and their implications.



An unrooted phylogenetic tree for papillomavirus sequences. The branching structure reflects an attempt to reconstruct the evolutionary history of the genetic sequences using algorithms designed to minimize the number of mutational events needed to explain the contemporary range of sequence diversity given the hypothesis that these sequences have all originated from a common ancestor. The clustering patterns that are obtained on the basis of evolutionary relatedness are often indicative of relationships on the phenotypic level between the different strains of papillomavirus.

from Human Papillomaviruses 1995, edited by Myers, G., Bernard, H.U., Delius, H., et al., Theoretical Biology and Biophysics, Los Alamos National Laboratory, Los Alamos, 1995

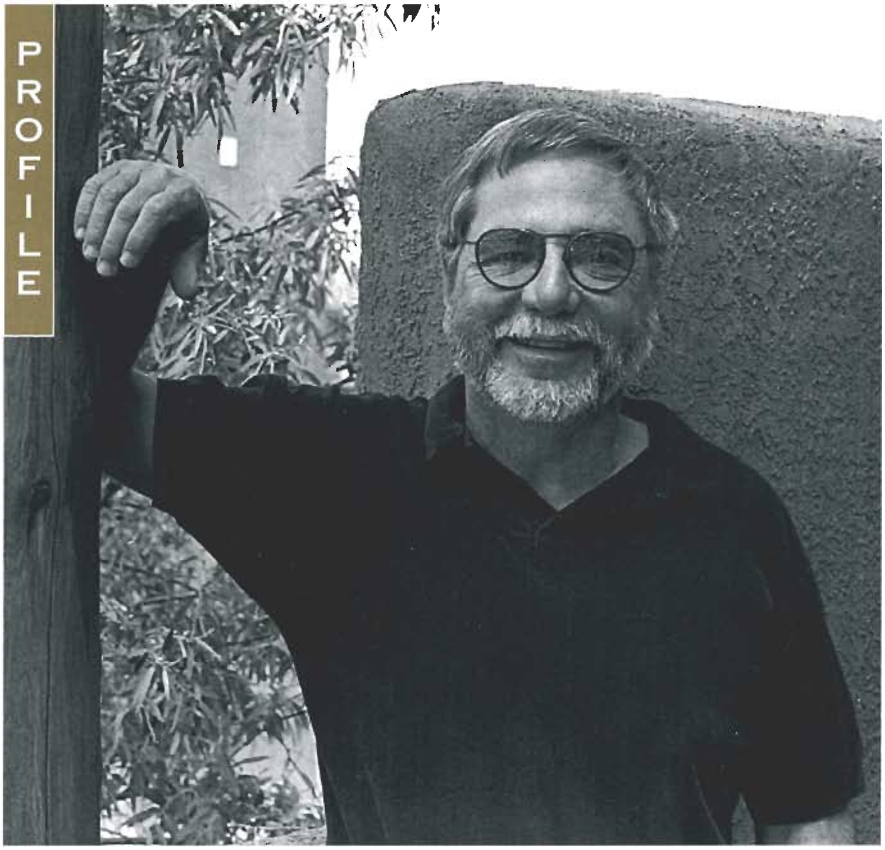


Photo: David Noble

GEORGE GUMERMAN

John Ware

LONG HOUSE VALLEY is a narrow band of alluvium separating the terraced escarpment of Black Mesa from the massive sandstone dome of the Shonto Plateau in the northeastern corner of Arizona. The present home of the pastoral Navajo, for nearly two thousand years before the Navajo arrived Long House Valley was settled by Anasazi farmers, ancestors of the modern Pueblo Indians. The valley is named for Long House Ruin, a large masonry pueblo abandoned by the Anasazi during their general exodus from the Colorado Plateau at the end of the thirteenth century. After nearly 800 years, the stone walls of the main roomblock still project several meters above the surrounding valley floor.

My favorite view of the valley is from the rim of Black Mesa to the south. I've stopped along the shoulder of the Black Mesa road countless times over the past 25 years, and have never ceased to be awed by the spectacular sweep of the valley below: the gray-greens and subtle blues and browns of the valley floor contrasting with the darker greens and buffs of the pinyon washed sandstone slopes, and rising above the valley, the great arc of the Shonto Plateau, incised by Tsegi Canyon and flanked by a brooding Skeleton Mesa, with the high dome of Navajo Mountain looming above the horizon in the northwest.

Long House Valley looking north from Black Mesa

THE LONG VIEW

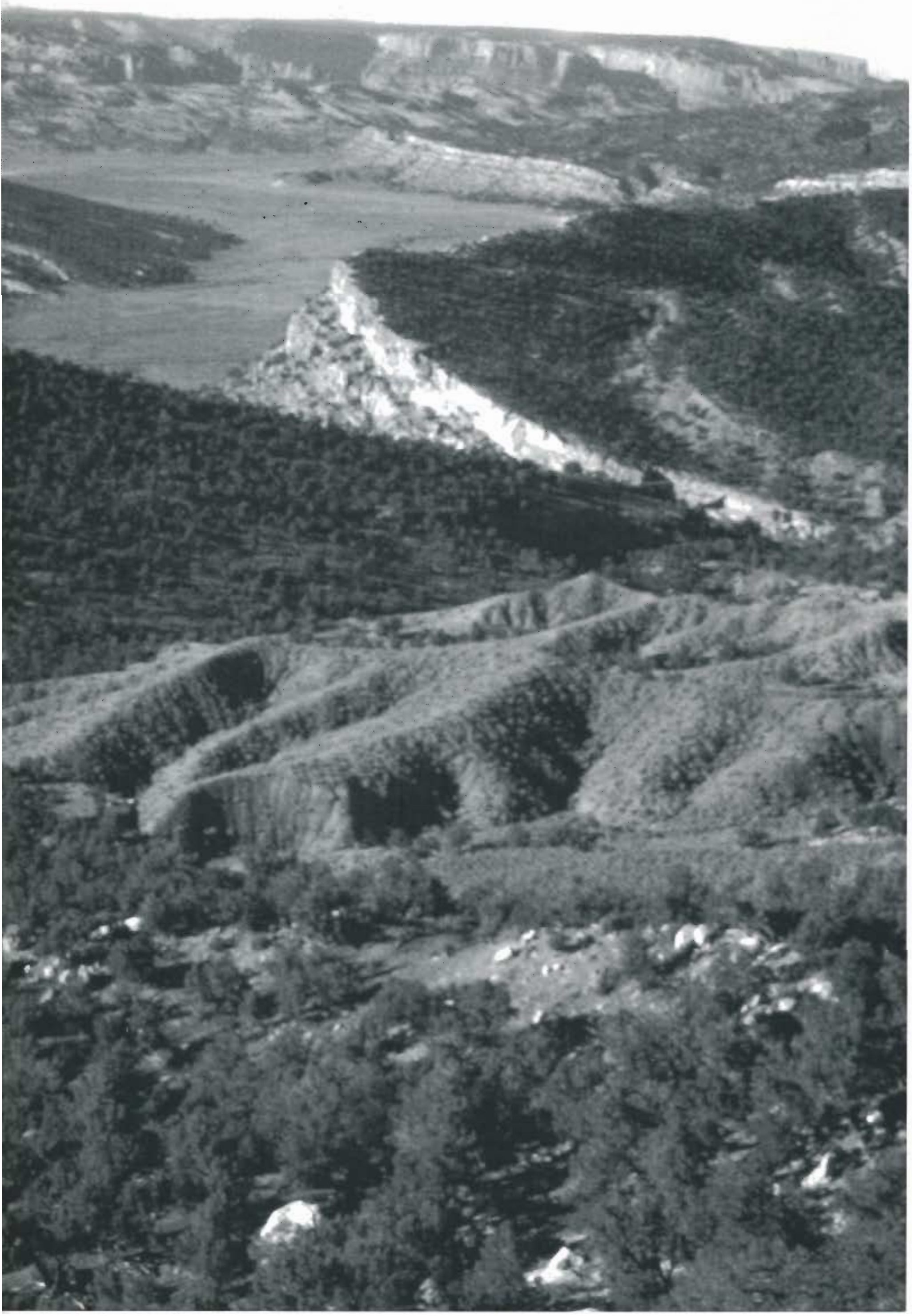
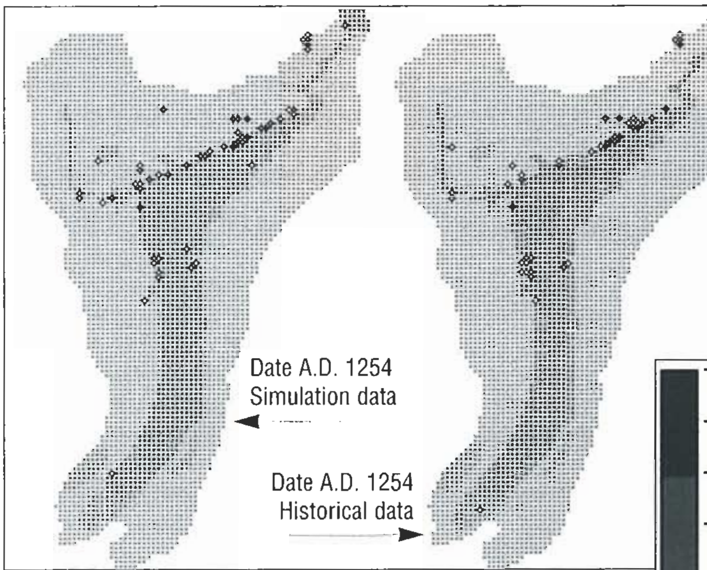
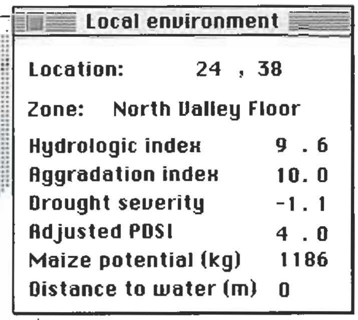


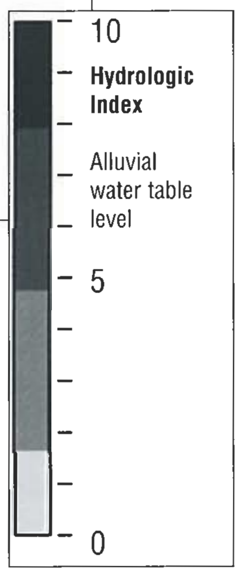
Photo: John Ware

The image I have at this moment of Long House Valley could not be more different. The sinuous outline on the computer monitor is an exact reproduction of the valley in plan view, but the colors are more intense—brilliant reds, blues, and yellows—and every few seconds the image is erased and quickly re-drawn with slightly different colors, contours, and spacing of bright red dots, representing archaeological sites. I'm looking over the shoulder of a bearded man in a Hawaiian shirt and Birkenstocks, hardly the field attire of a working archaeologist, but this archaeologist has always been somewhat different—the beard is one of his few concessions to the archaeologist stereotype. He's sitting at the keyboard of a computer terminal explaining to a group of colleagues how, each time the computer screen is refreshed, ten years have elapsed. In less than a minute we see the 11th Century A.D. flash by. As the screen flickers into the 12th Century the pixels regroup into larger and larger red clusters, depicting the growth and aggregation of prehistoric Anasazi farming villages. A minute later, at the end of the 13th Century, only a few large clusters of dots remain on the digital landscape. One especially large amoeba-like cluster has materialized on the west flank of the valley where the ruins of Long House Pueblo still stand.

The man before the computer screen at the Santa Fe Institute is George Gumerman, member of the Institute's Science Board, former chair of the Department of Anthropology at Southern Illinois University and founding director of SIU's Center for Archaeological Investigations, and one of the most respected "big-picture" archaeologists currently working in the Southwest. Members of George's profession still spend much of their time excavating the ruins of extinct cultures, sorting artifacts into arcane descriptive categories, and attempting to read the history of ancient people from the constructions they abandoned and the objects they discarded, but increasingly, archaeologists are turning to the digital computer to assist in the reconstruction and interpretation of the past. And the Long House Valley computer simulation project at the Santa Fe Institute, nicknamed "Project 1050," is an ambitious attempt to model thirteen centuries of change in an intensively-studied prehistoric cultural and environmental system.







The historical location of prehistoric households known to exist in A.D. 1254 in Long House Valley is shown on the right. The simulated location of households that were derived from demographic trends, movement rules for households, and estimated nutritional needs are shown on the left for the same year. The darker the dot representing the household the greater the number of households residing in any one site. Shading represents the relative depth of the water table (the Hydrological Index), one of the several reconstructed environmental variables. Tree-ring analysis, surficial geology, and biological data have permitted the reconstruction of soil erosion and deposition (the Aggradation Index), rainfall, and soil moisture (Adjusted PDSI), as well as the water table on an annual basis from A.D. 200 to 1500. The environmental variables are ranked on a scale of 1 to 10 for each hectare for each year. The annual maize growing potential of each hectare is calculated from a combination of the environmental conditions.

psychology. In part because so many disciplines converge on the problems of archaeology, the director of an archaeological project is like an orchestra conductor. The best ones know not only how to select and interpret a dynamic score, but also how to encourage the different sections of the orchestra to perform at their peak. George is accomplished in both areas.

He's been at the forefront of most of the major theoretical advances in Southwestern archaeology since his entry into the field in the 1960s, and from the beginning he has played the role of organizer and coordinator. Early in a project he is usually instrumental in defining its scope and direction; when the research is completed, he usually edits the results. More than a few of his colleagues have remarked about George's theoretical prescience. He always seems to be in the right place at the right time.

At the 60th annual meeting of the Society for American Archaeology in Minneapolis last May, a group of George's colleagues and former students organized a symposium in his honor. The diversity of paper topics was extraordinary, from Micronesian burial practices to Hohokam agave cultivation, reflecting the extraordinary breadth of George's scholarship and the extent of his influence on a generation of students.

Retired now after 25 years of teaching and active research, George is devoting his considerable energies to writing and editing, fly fishing, and several collaborative research projects at the Santa Fe Institute. SFI is perhaps the perfect working environment for Gumerman—a university without walls with a central, cutting-edge focus: the evolution of complex adaptive systems.

On a balmy day last May, George and I met in the atrium of SFI following a lecture on cultural systems modeling; one of a series of talks scheduled during "Cultural Modeling Month" at the Institute, a month-long series of collaborations organized by George. I asked him what a nice archaeologist was doing in a place like this and got an uncharacteristically serious response. "Why not?" he replied. "SFI is concerned about the evolution of complexity, and archaeologists deal with some of the most complex systems that have ever evolved: human cultures.

Like most projects that have attracted Gumerman over the years—and like much of SFI's work—Project 1050 is a collaborative effort. Jeff Dean of the University of Arizona's Laboratory of Tree-Ring Research brings over thirty years of experience in Long House Valley and the Kayenta region of northeastern Arizona to the project; years spent locating and mapping hundreds of archaeological sites, reconstructing paleoclimatic patterns through tree-ring and other climatic indices, and mapping soil, vegetation, and other environmental characteristics of the region. George would be the first to acknowledge that Jeff has the most intimate grasp of the archaeological data from the study area. Joining the two archaeologists are two mathematicians and computer modelers from the Brookings Institution, Josh Epstein and Rob Axtell, authors of the "Sugarscape" simulation program, who rewrote their program to model the complex prehistoric environment and cultural landscape of Long House Valley. Axtell and Epstein, along with Steve McCarroll, a research assistant at the Brookings Institution, bring not only computational expertise to the project, but also long-term interests in growing artificial societies using agent-based modeling techniques—models in which simple agent-based rules interact in time and space to form complex models of social behavior.

George is, first and foremost, an organizer, synthesizer, and collaborative matchmaker. His genius was developed and honed in over a quarter century of administering large archaeological research projects. By far the largest, the Black Mesa Archaeological Project, centered just ten miles south of Long House Valley, was one of the largest archaeological undertakings in the history of North American archaeology. Because archaeology relies for its historical reconstructions on material rather than textual evidence, archaeologists borrow heavily from other disciplines, from geology and biology to art and architecture—from nuclear physics and statistics to ethnohistory and social

Moreover, archaeologists are the only scholars with actual *data* on long-term culture change, from the beginning of cultural behavior almost three million years ago to the present; data that can be brought to bear on a host of questions concerning the evolution of complex systems."

I wondered if George's experience running large multidisciplinary projects "pre-adapted" him for the kind of intense collaboration that goes on at the Institute. "Of course," was his response. "But you have to understand, most people here are good collaborators or else they wouldn't be here. Most of us don't even have offices, so we *have* to collaborate—there's no place to hide! It's one of the most exciting things about SFI—the opportunity to work with so many accomplished collaborators."

The collaboration that is the essence of the Santa Fe Institute has already resulted in a number of important contributions in archaeology and the evolution of complex cultural systems. Project 1050 promises to provide even more. The record of human occupation of Long House Valley is one of spectacular successes and failure. In this respect, the story is timeless.

The earliest Anasazi farming villages in Long House Valley date to the first centuries of the last millennium. These earliest farmers were as much committed to hunting and collecting the wild resources of the Shonto Plateau and its labyrinth of canyons as they were to farming the alluvial bottom lands of Long House Valley. Remains of their hunting and collecting sites are scattered tens of miles beyond their seasonal base camps in the rock shelters and alcoves of Kin Biko and nearby Tsegi Canyon. By the end of the first millennium A.D., the Anasazi's commitment to farming had increased to the point where their small homesteads and agricultural fields filled virtually every arable niche in the sixteen square mile valley.

Between A.D. 1150 and 1250 the eastern and southern portions of the valley were abandoned and population concentrated in the north and northwest, in farmsteads clustered around one or more large plaza pueblos. In the last half of the 1200s, all of the remaining Anasazi farmers were concentrated in five community clusters, one centered on Long House Pueblo. By A.D. 1300, the Anasazi were gone, abandoning not only Long House Valley, but the entire northern half of the Colorado Plateau.

What caused the growth of Anasazi population in Long House Valley and the explosion of farms and fields in the 11th and early 12th Century A.D.? Why did populations aggregate during the second half of the 12th Century, and abandon the region entirely at the end of the 13th Century? These are the kinds of questions that Gumerman and his colleagues hope to address in the Long House Valley simulation. Important environmental and demographic dimensions have already been incorporated into the evolving model: changing vegetation and soil distribution patterns, climatic cycles, and area-moisture conditions will be used to calculate a suite of derived variables such as "corn growing potential" that will provide insights into changing patterns of food production in the valley. With the addition of stochastic environmental events such as flash floods and crop-killing frosts, the model will be ready to run. "Our goal," according to Gumerman, "is to understand the dynamics of the prehistoric adaptive system. For example, how much of the observed variation in prehistoric population levels and distributions can be explained by cyclical changes in moisture and corn production potentials?"

Eventually, if insights into such basic adaptive questions are obtained, the simulation may suggest answers to even more interesting, and hence, complicated questions: How did social behavior change, how were adaptive decisions made, what were the changing patterns of cooperation and conflict, and perhaps most important, what can we learn about human behavior and cultural adaptation from the Long House Valley Anasazi that might inform us about contemporary social and environmental problems and interactions?

These are the kinds of questions that generate a great deal of excitement at the Santa Fe Institute among George and his colleagues, and computer simulations may be the quickest way to arrive at testable answers. Simulations allow the historical scientist the incredible luxury of replaying the tape of history. They allow us to ask "if . . . then" and "what if . . ." type questions, to see what happens if initial conditions are changed, and to test the validity of our operating assumptions. As the tape is replayed in digital time, questions are refined, hypotheses are reformulated, and we move closer to an understanding of long-term cultural change and the evolution of complex adaptive systems. And that, according to an unconventional archaeologist who has always been captivated by the long view and the big picture, "is what it's all about."

Photo: Laboratory of Tree Ring Research, University of Arizona

Long House Ruin, Long House Valley

John Ware is an archaeologist at the Museum of New Mexico. As an undergraduate at Prescott College, Ware was one of Gumerman's first students more than two decades ago. Since then the two have collaborated on many research projects.

Alan Perelson Gives the Second Annual Stanislaw Ulam Memorial Lecture

WARRIORS WITHIN: HOW YOUR IMMUNE SYSTEM

"It's partially an academic exercise . . . but more than that, we'd like to treat human disease." At the beginning of his first Ulam Memorial lecture, that was how Alan Perelson explained what drives his nearly two decades' research in theoretical immunology. This work has been done at Los Alamos National Laboratory where Perelson is a Fellow and at SFI as a member of the External Faculty and Science Board.

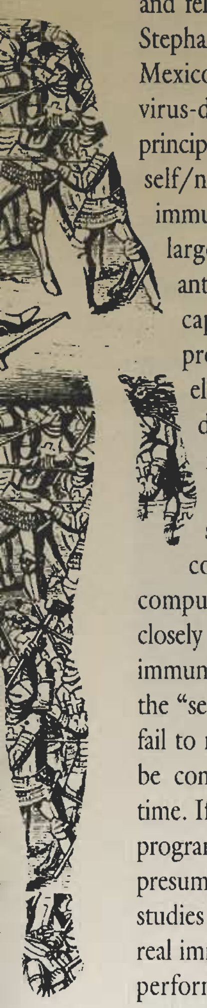
During the three consecutive community talks, Perelson drew a coherent, detailed picture of how the immune system works, based on both experimental findings and theoretical interpretation. The September series was sponsored by Addison-Wesley Publishing Company, and the lectures will be collected in a book due out in 1997.

Perelson's work has already made medical news. Mathematical analysis of data from David Ho's laboratory at the Aaron Diamond Research Center by Perelson and former SFI Postdoctoral Fellow Avidan Neumann resulted in discoveries announced earlier this year in *Nature* that are causing a real paradigm shift in treating the disease. The conventional view of HIV infection was one of a largely quiescent virus hiding in a pool of latently infected cells and remaining dormant until chance activation of the cell. The new results show that rather than a dormant period between HIV infection and the appearance of AIDS, the virus is growing and being destroyed at massive rates. The rapid turnover of the virus now known to take place coupled with its rapid mutation rate explains why the resistant forms can so quickly predominate in the body after a drug has been administered. This new picture of AIDS virus infection means that some research enterprises may have gone down the wrong path. But it also suggests new strategies for combating the virus: Perelson said in his talks that the new plan should be "to hit early, and hit hard." The battle between the immune system and the virus is apparently so close that any drug that gives the immune system an edge could be enough to tip the balance. Further, inhibiting the viral growth in the early stages of the disease when the viral load is still relatively low will cut mutations which result in drug resistance. Last month the FDA announced a new generation of AIDS drugs called protease inhibitors—the substance used in Dr. Ho's clinical studies—that are very efficient at inhibiting HIV and can be used for this type of therapeutic approach.

Probably the best-known player in the human immune system is the antibody, a molecule that helps neutralize infectious agents by recognizing their shapes and locking on to them. To defeat these infectious invaders, called antigens, the human immune system must make a huge repertoire of antibodies capable of recognizing every new antigen shape devised by nature. Exactly how does the system manage to pump out millions of these highly specific antibodies, particularly in light of the fact that the antigens are always mutating and changing shape? Perelson and former SFI Postdoctoral Fellow Thomas Kepler, now on the faculty in biomathematics at North Carolina State University, think they have found the answer. A mathematical model developed by them suggests that the best way to make the most effective antibodies is to have periods of rapid mutation followed by periods of rest. Their work suggests that the immune system, when stimulated, may turn on mutation to produce many variants of antibodies then turn mutation off to allow the resulting, improved antibody enough time to reproduce to numbers large enough to become significant. This cyclic behavior probably occurs in the lymph nodes and spleen, germinal centers in the body which are regions of rapid B cell growth. (Antibodies are formed on the surface of B cells, so-called because they are born in the bone marrow.) The on-off cycle repeats many times, allowing mutation to create variants of increasingly successful antibodies.

Even as a pure "academic exercise," theoretical study of the immune system has produced practical results. The immune system is a prime example of a complex adaptive system (CAS)—a distributed collection of specialized cells that self-organizes to perform highly complex, predictable tasks. It is capable of sophisticated pattern recognition and, although the individual components live only for days, the system itself has a "memory" that persists for decades. Because it displays these classic characteristics, Perelson is looking carefully at the operating principles of the immune system and at ways of

COMBATS DISEASE

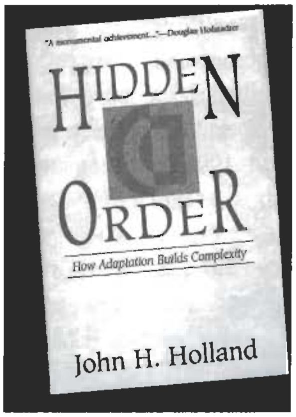


implementing them in other contexts. He and fellow SFI External Faculty member Stephanie Forrest (University of New Mexico) have developed a computer-virus-detection method based on principles used by the immune system for self/non-self discrimination. The immune system continually generates large numbers of highly diverse antibody bearing cells. Those that are capable of recognizing self—the proteins native to the body—are eliminated, leaving a collection of defenders that recognize and attack non-self molecules not native to the body. The Forrest-Perelson system uses strings of computer code that fail to match the computer's native code, in a system closely analogous to that used by the immune system. Antibodies that match the "self" are eliminated, while those that fail to recognize self are kept on hand to be compared with the program at any time. If a match is indeed later found, the program or set of antibodies has changed, presumably through viral infection. Early studies show that this method—like the real immune system—isn't fail-safe, but it performs with a high degree of probability and can detect heretofore unknown foreign invaders.

First Book in the Ulam Series Now Out

Perelson's Ulam lectures continue a well-established academic tradition: a brilliant researcher doing cutting-edge research delivers a series of public talks which are captured in a book for the general reader. Many notable works including *Relativity* by Albert Einstein and *QED* by Richard Feynman originated this way.

HIDDEN ORDER–How Adaptation Builds Complexity — based on the inaugural 1994 Ulam lectures by SFI Science Board member and MacArthur Fellow John Holland — is available. The book emphasizes the search for general principles that govern the behavior of complex adaptive systems, enlarging on the intuitions of a broad spectrum of scientists.



Holland, a faculty member at the University of Michigan, identifies seven basics that are common to all CAS: *aggregation* refers to the fact that agents get together and act as a group; *nonlinearity* means that the whole system is more than the sum of its parts; *flows* refer to the fact that resources in any system move from point to point; *diversity* is a hallmark of complex adaptive systems, which are always changing in response to new information flowing toward them; *tags* are emblems identifying individual agents that may alter aggregation and allow mimicry; *building blocks* are used by complex adaptive systems as efficient encoding strategies and internal models; and finally, complex adaptive systems can build *internal models* of their world.

The book explores how complex adaptive systems learn. A basic feature is that all such systems are composed of adaptive agents—individual actors that aggregate to the larger system. These agents are interactive, and they learn through a succession of activities that can be modeled by if/then rules. In fact, CAS perform within the framework of collections of rules, with adaptation taking place through new rule discovery and through a complicated set of interactions called credit assignment. If a system makes a mistake, the rule that was followed loses credit. If a rule makes the system stronger or increases its fitness, it gains credit.

Holland then goes on to describe his computer model, ECHO, which provides a framework for examining CAS. Because complex adaptive systems are so intricate, computer-based models like ECHO – with their well-defined manipulable mechanisms – provide a crucial intermediate step in the search for CAS laws.

The 1996 Community Lectures

The Ulam Lectures are part of the Institute's continuing series of public talks, now entering its seventh year. These free Santa Fe community presentations cover a wide range of topics and draw from a roster of nationally-known scholars. Talks upcoming in 1996 range from a demonstration of virtual environments to consideration of how the human mind creates language. For a complete roster of next year's talks call 505-984-8800 or visit the Institute's home pages at http://www.santafe.edu.

NEW MEMBERS OF THE SFI COMMUNITY

Each year a handful of young scientists joins the SFI research staff as postdoctoral or graduate fellows or research assistants. These residencies usually last one to three years, and, as they move on, these scholars become some of the Institute's most effective spokespeople for spreading the Institute's multidisciplinary approach to other institutions. In 1995 ten young scholars took up residency at SFI.

TIM KEITT received his Ph.D. in ecology and evolutionary biology from the University of New Mexico earlier this year. As a SFI Postdoctoral Fellow, he's modeling self-organization in ecological communities. Traditionally, ecologists have focused on selection pressures acting on individual organisms; however, many problems in ecology, conservation biology, and global change research involve interactions among many organisms along with abiotic components. Keitt is studying spatial replicator networks to better understand the dynamics of ecological communities. He is especially interested in how food web structure emerges from mechanisms independent of Darwinian natural selection. Keitt looks forward to applying ecological theory to real-world conservation problems. He is studying metapopulation dynamics of the Mexican Spotted Owl, a threatened species, and is developing an individual-based owl model incorporating satellite habitat imagery. The results should allow more effective management of the owl's habitat.

Postdoctoral Fellow SIMON FRASER comes to the Institute from the Center for Population Biology at Imperial College in London. He is looking at the ECHO model as an abstract representation of an ecosystem. "Most ecologists have yet to wake up to the messages coming out of the Santa Fe Institute," notes Fraser, "and yet ecosystems are often cited as the archetype of complex adaptive systems." ECHO models the dynamics of large numbers of independent, reproducing agents, which interact in ways determined by genetically-encoded tags and interaction conditions. Right now Fraser is studying whether ECHO realistically simulates a generalized ecosystem; preliminary results suggest this is indeed the case. Future development of the ECHO model will include adhesion between agents and the inclusion of one agent inside another. This opens up the possibility of using ECHO to study the evolution of multicellularity, and the origin of new hierarchical levels of organization. These are known to be the source of many evolutionary innovations, and involve shifts in the levels at which natural selection acts.

TERRY JONES is also working with the ECHO model along with other projects. Jones recently completed a doctorate in computer science at the University of New Mexico. As a SFI Postdoctoral Fellow, his current research involves developing statistical characterizations of fitness landscapes that correlate well with search difficulty; collaborating with Stephanie Forrest, Simon Fraser and Peter Hraber on ECHO; writing generalized search libraries for the Swarm project; and working on theoretical aspects of genetic algorithms. He is also interested in evolutionary biology, modeling, artificial intelligence, machine learning, search algorithms, design and analysis of algorithms, and theoretical computer science.

MANOR ASKENAZI has joined the Swarm project as a parallel programmer responsible for the design and implementation of a multi-processor kernel for the Swarm simulation system. He joins the team after graduating from London's Imperial College, with a Master of Engineering in Computing. His previous employers include Thinking Machines Corporation for whom he helped design a performance analysis tool for parallel hardware and software. It was during this period that Askenazi was first introduced to the concept of complex systems and emergent phenomena. He writes, "Researchers like Danny Hillis and Bruce Boghosian made me realize the enormous potential benefit which could be reaped if we could somehow harness emergent phenomena—from scalable

Photos: Dan Barsotti

operating systems, through robust hardware architectures, to adaptive networks—not to mention applications in non-computational fields such as fault-tolerant military command and control systems or self-optimizing industrial production lines." Askenazi plans to use the parallel version of Swarm in order to model and investigate the application of emergent phenomena to specific real-world problems.

Martijn Huynen is a Postdoctoral Fellow at SFI as part of a new initiative using computational approaches to predict protein structure of the human papillomavirus (HPV). The project is funded by Family Health International, a part of the Agency for International Development. HPV is one of the most prevalent sexually-transmitted viruses and considered to be involved in subsequent incidence of some cancers. A large set of sequence data is available for the different variants of the virus, but little to nothing is known about its structure. Says Huynen, "I consider these data a gold mine. We have recently developed methods that allow us not only to assess the reliability of predictions concerning the structure of RNA molecules, but also point out functional regions within them. We can test our methods in these sequences, aiming to find new, biologically important structures which can shed light on the molecular biology of the virus. This is just one example of a wealth of sequence data that are becoming available at an ever increasing pace, and that need interpretation. The study of this virus has a high relevance not only scientifically but also socially, given its role in cervical cancer."

Research associate Andrew Farmer is collaborating with Huynen on the HPV project at the Institute. He is applying computational methods to human and animal papillomavirus genetic and protein sequences to uncover evolutionary history and biologic function. Farmer received a B.A. from St. John's College in Santa Fe in 1993 and joined the HIV sequence database project at Los Alamos National Laboratory (LANL) the same year. This work, which ties to other research in HIV transmission and protein secondary structure, is being led by Los Alamos scientist Gerald Myers.

Aaron Halpern did his graduate work in linguistics at Stanford University, and was a postdoc at Ohio State University. An interest in parallels between problems in computational linguistics and computational biology led to a postdoc at LANL working on the Human Papillomavirus Database. That postdoc is now being continued part-time at LANL and part-time at SFI. Recent and current interests include phylogenetic analysis of PVs, (eclectic) structural modeling of PV proteins, population genetics of viruses, detection of recombination in a set of sequences, and user-curation of databases.

Graduate Fellow Erik van Nimwegen, a native of Amsterdam, is conducting his Ph.D. research at SFI as part of Jim Crutchfield's and Melanie Mitchell's working group on evolving cellular automata (EVCA). Van Nimwegen is trying to define more rigorous concepts to describe the dynamics of populations of cellular automata. His research focuses on how stochastics appear as noise at one level of description of a system, yet at a higher level of description the noise can be an important positive ingredient in the system's behavior or the strategy it uses to perform a certain task.

"The laws of physics teach you how to take apart different things and reduce them to a set of rules which allow for the thing to exist. Since I was a kid, I have always been interested in reversing this process. For instance, what will gravity do if you just start with thousands of things flying around randomly? Unfortunately, most physicists seem to be more interested in taking apart even more things, instead of trying to find out about the rules behind the building of a complex thing from a set of simple rules."
— *van Nimwegen*

Fellow countryman Wim Hordijk joins van Nimwegen on the EVCA project. Hordijk graduated from the Erasmus University in Rotterdam with a major in Operations Research and came to SFI in early 1995 as a Graduate Fellow. Hordijk is exploring the "evolutionary relations" of evolved CA-rules. He wants to see, for example, whether the best CA-rules in a certain generation are descendants of the best CA-rules in previous generations. Currently he is working on a program that models the strategy that the evolved CA use to perform a given task. He hopes that this model will offer insights into how the CA implement the global computation needed to accomplish the task in question.

Board Members

BARUCH S. BLUMBERG, Distinguished Scientist and Senior Advisor to the President at the Fox Chase Cancer Center, has joined the Institute's Science Board. Blumberg's career includes serving as Master of Balliol College at Oxford University, Distinguished Visitor at the National University of Singapore, and Visiting Professor at the University of Otago in New Zealand. He also holds an appointment as Professor of Medicine and Anthropology at the University of Pennsylvania. Among his numerous awards Blumberg received the Nobel Prize in Physiology/Medicine in 1976, the Modern Medicine Distinguished Achievement Award, and election to the National Inventors Hall of Fame. Blumberg is a member of the American Philosophical Society, the National Academy of Sciences, and the American Society of Human Genetics. He is also a Fellow of the American College of Physicians and of the Royal College of Physicians, London.

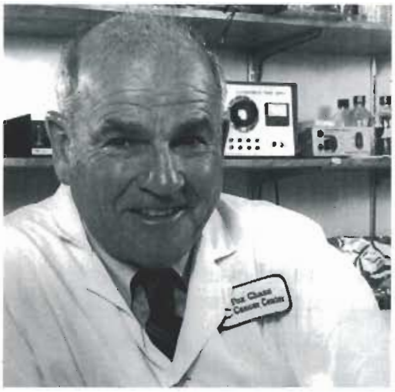


Photo: WHYY/Dufor Studios

New SFI Trustee ROBERT J. DENISON is the founder and President of First Security Management, Inc. He has managed funds for First Security Associates since 1967. In 1968 he co-founded Data Resources, Inc. the nation's first full-scale electronic information company. He is Vice Chairman of the Board of the California Institute of the Arts, an Advisory Director of the Metropolitan Opera Association, and a member of the Council on Foreign Relations. In 1962, Mr. Denison graduated from Harvard College and in 1964 from Harvard Business School. From 1964 to 1967, he was a securities analyst at Wertheim and Co.

WILLIAM H. MILLER, III has become a member of the Institute's Board of Trustees. He is President of Legg Mason Fund Advisor, Inc. and has responsibility for over two billion dollars worth of assets for Legg Mason. He assumed overall responsibility for the equity funds management in 1990. Prior to that he co-managed the Legg Mason Value Trust from its inception in 1982. Miller was also the Director of Research at Legg Mason from the early to mid-'80s. He has an economics degree from Washington and Lee University, and has pursued graduate studies in the Ph.D. program in Philosophy at John Hopkins University. Prior to joining Legg Mason in 1981, Miller served as Treasurer and Pension Fund Manager of the J.E. Baker Co., a major manufacturer of products for the steel and cement industry.

Photo: © Janet E. Rettaliata

Staff

TIM CARLSON joins Scott Yelich as a Computer Systems Manager at SFI. Carlson recently completed a Ph.D. in numerical analysis at Montana State University, and he was the computer systems manager in the mathematics department at Montana State for five years. More recently he has been a systems manager for Los Alamos Technical Associates.

MARY JOHNSON joined the Institute in September as an accounting analyst. Her primary areas of responsibility with SFI include the payroll and general ledger. Mary holds a degree in Business Administration with a concentration in accounting from the College of Santa Fe, and has extensive prior experience including several years as a controller of a small company. A long-time resident of Santa Fe, she is originally from the Northwest.

Graduate Workshop in Computational Economics

June 23 – July 8, 1996, Santa Fe, New Mexico

Photo: Jordan Rapporport

1995 workshop participants

This workshop will bring together a group of advanced graduate students and a small faculty for an intensive two-week study of computational economics. The workshop will consist of lectures by faculty, special topic seminars by members of the Santa Fe Institute, and presentations of work-in-progress by graduate student participants. The aim is to encourage graduate students pursuing research agendas with a computational component; a significant portion of the workshop will be devoted to analyzing and improving participants' current research.

For more about workshop activities and focus, check the 1995 workshop pages located at http://zia.hss.cmu.edu/econ/cw95.

Sponsored by the Economics Program at the Santa Fe Institute

To Apply: Participation is limited to fifteen. Travel, accommodations, and living expenses are covered. Applicants should have completed a minimum of two years of graduate study in economics and be actively pursuing research in computational economics. Interested students should submit a recent curriculum vitae, at least one letter of recommendation and two other references, and a one-page outline of a current or proposed research project in computational economics. Preference will be given to applicants who best demonstrate the ability to successfully complete research in the area of computational economics. Application deadline is April 5, 1996. Completed applications should be sent to Scott E. Page at the address below.

Women and minorities are encouraged to apply.

For more information contact John H. Miller, Social and Decision Sciences, Carnegie Mellon University, Pittsburgh, PA 15217 miller@zia.hss.cmu.edu, (412) 268-3229, or Scott E. Page, 228-77 California Institute of Technology, Pasadena, CA 91125, scotte@mrfloods.caltech.edu, (818) 395-4216

Letters

I enjoyed reading the Bulletin of the Santa Fe Institute Vol 10 #1. However, page 3, which indicates the Typical Steps in Building an Exploratory Simulation of a Complex System, mentions "Run program many times with different random number seeds, collecting data and statistics from the different runs." I do hope that Melanie Mitchell's presentation indicated different rng's (random number generators)—and what was printed in the Bulletin was a typo—since changing only the seeds may simply result in shifts and cyclic permutations of the same rng's (if, e.g., it is of the linear congruential class). For any simulation, it is necessary to use different rng's and compare the results obtained with each in order to be confident that the rng is not introducing a bias into the results. Even generators that perform well in standard statistical tests may be unreliable in certain applications, as has been found in some Monte Carlo simulations. (I would be happy to supply references.)

Ora Percus
Courant Institute of Mathematical Sciences New York University

Melanie Mitchell replies:

Dr. Percus' point is well taken. Most people use a single pseudo-random-number generator when doing different runs of a simulation. In principle this should be acceptable, since in principle the different outputs of a pseudo-random-number generator should be independent of one another with respect to any relevant correlations in the simulation. However, as Dr. Percus points out, in practice this is not always the case. I would add that replication of results of simulations by different groups using different code is also highly desirable, since any single instance of simulation code may have its own bugs and other artifacts. Interested readers should see "Aligning Simulation Models: A Case Study and Results" by Robert Axtell, Robert Axelrod, Joshua M. Epstein, and Michael D. Cohen, SFI Working Paper 95-07-065 for one example of such a replication study.

Software Releases

Swarm

A "beta version" of the Swarm simulation software is currently being tested in very limited release. General release is expected in early 1996.

Swarm is a multi-agent software platform for the study of complex adaptive systems. In the Swarm system a basic unit of simulation is the "swarm," a collection of agents executing a schedule of events. Swarm accommodates multi-level modeling approaches in which agents can be composed of swarms of other agents in nested structures. Swarm scheduling is based on a hierarchy of time management, yielding a natural model of concurrency and a straightforward path to parallel implementation. In addition to the execution kernel, Swarm includes libraries of standard computational objects such as agents, spaces of various types and dimensions, probes, and display tools. Swarm is written in GNU Objective C and requires Tcl, Unix and X windows.

Example applications, papers describing Swarm design, and regular informational updates can by found on SFI Web pages, *http://www.santafe.edu/projects/swarm*. Two Swarm mailing lists are available by sending e-mail to *majordomo@santafe.edu*, and you can reach the Swarm developers at *swarm-request@santafe.edu*.

Discrete Dynamics Lab

DDLab is an interactive graphics program useful for exploring a wide variety of phenomena associated with discrete dynamical systems including cellular automata (in one or two dimensions), Boolean networks, and neural networks. Such systems are useful to the study of complexity, emergent phenomena, and aspects of theoretical biology such as gene regulatory networks.

The program can iterate the discrete dynamical system forward in time to display space-time patterns. It can also run the system "backward" to generate a pattern's predecessors and reconstruct its branching sub-tree of ancestor patterns. For smaller networks in which it is possible to exhaustively visit all states of the system, whole sub-trees, or the whole basin of attraction field can be reconstructed and displayed as a directed graph or set of graphs in real time.

DDLab runs on DOS platforms (386 or higher). Unix and Mac versions are under development. The software is available via anonymous ftp at alife.santafe.edu:

* ddlab.txt: overview of ddlab's function (48k).
* ddlab.zip: the DOS software and reference manual (545k).
* http://alife.santafe.edu/

NINTH ANNUAL JUNE 2 TO 28 1996 SANTA FE NEW MEXICO

COMPLEX SYSTEMS SUMMER SCHOOL

The school offers graduate students and postdoctoral scientists an introduction to the study of complex behavior in mathematical, physical and living systems. The four-week program features intensive tool-kit introductions to basic topics; week-long lecture courses on selected subjects, seminars, and computer lab workshops. A highly 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.

COURSE LECTURES

FUNCTIONAL BRAIN IMAGING
Peter Bandettini
Massachusetts General Hospital

DEFINING, MEASURING AND ESTIMATING COMPLEXITY
Yaneer Bar-Yam, Computer Science, Boston University

COMPLEX AND SIMPLE MODELS OF EVOLUTION
Joseph Felsenstein, Genetics, University of Washington

COMPUTATIONAL MECHANICS OF CELLULAR PROCESSES
James Hanson, Santa Fe Institute

THE HIPPOCAMPUS, SPACE AND MEMORY
Bruce McNaughton, Psychology, University of Arizona

MODELING IMMUNE MEMORY AND IMMUNE FAILURE
Avidan Neumann, Theoretical Biology/Biophysics, Theoretical Division, Los Alamos National Laboratory

SPIN GLASSES, PROTEIN FOLDING, AND THE STRUCTURE OF ENERGY LANDSCAPES
José Onuchic, Physics, University of California at San Diego

GENES, PROTEINS, AND BIOLOGICAL REGULATION
David Peabody, Cell Biology, University of New Mexico

CO-DIRECTORS

Lynn Nadel, *Psychology*, University of Arizona

Daniel Stein, *Physics*, University of Arizona

SPONSORS

Support for the Summer School is provided by the Department of Energy, 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, the University of California, and the Santa Fe Institute

APPLICATION PROCEDURE:

Provide a current resume (including publications); a statement of your current research interests; comments about why you want to attend the School, and two letters of recommendation from scientists who know your work. Send complete application packages only, preferably by postal mail, to Summer School, 1399 Hyde Park Road, Santa Fe, NM 87501.
Include your e-mail address and/or fax number. For further information contact ***summerschool@santafe.edu; http://www.santafe.edu/sfi/education/summer-school.html***

Application deadline: February 2, 1996.
Applications incomplete at this time will not be considered.

SUPPORT

Students will be supported with room and board, subject to funding availability. No tuition fees for students. No funds available for travel.

Graduate credit for this program is offered through the University of New Mexico

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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 small, 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 applications of its results.

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World Wide Web

We welcome you to visit our newly-designed World Wide Web pages at **http://www.santafe.edu**. *This is a work in progress and additional changes will be made, but there are many design and content improvements with links to our research networks, visitor programs, and business network, to name a few, plus a calendar of events. The Publication Department pages give access to books, journals, newsletters and working papers. Sixty-five percent of our 1995 working papers are now available electronically. Forthcoming will be a searchable index to facilitate access to a wide variety of information ranging from a resident's e-mail address to details on a specific research project. Our usage statistics, compiled since July 1995, show an average of 2,400 visits to the site per day. Kimberly Bodelson, Office of Academic Affairs, and Ronda Butler-Villa, Publications Department, have taken the lead responsibility on this project with artistic design assistance from Patrick McFarlin.*

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