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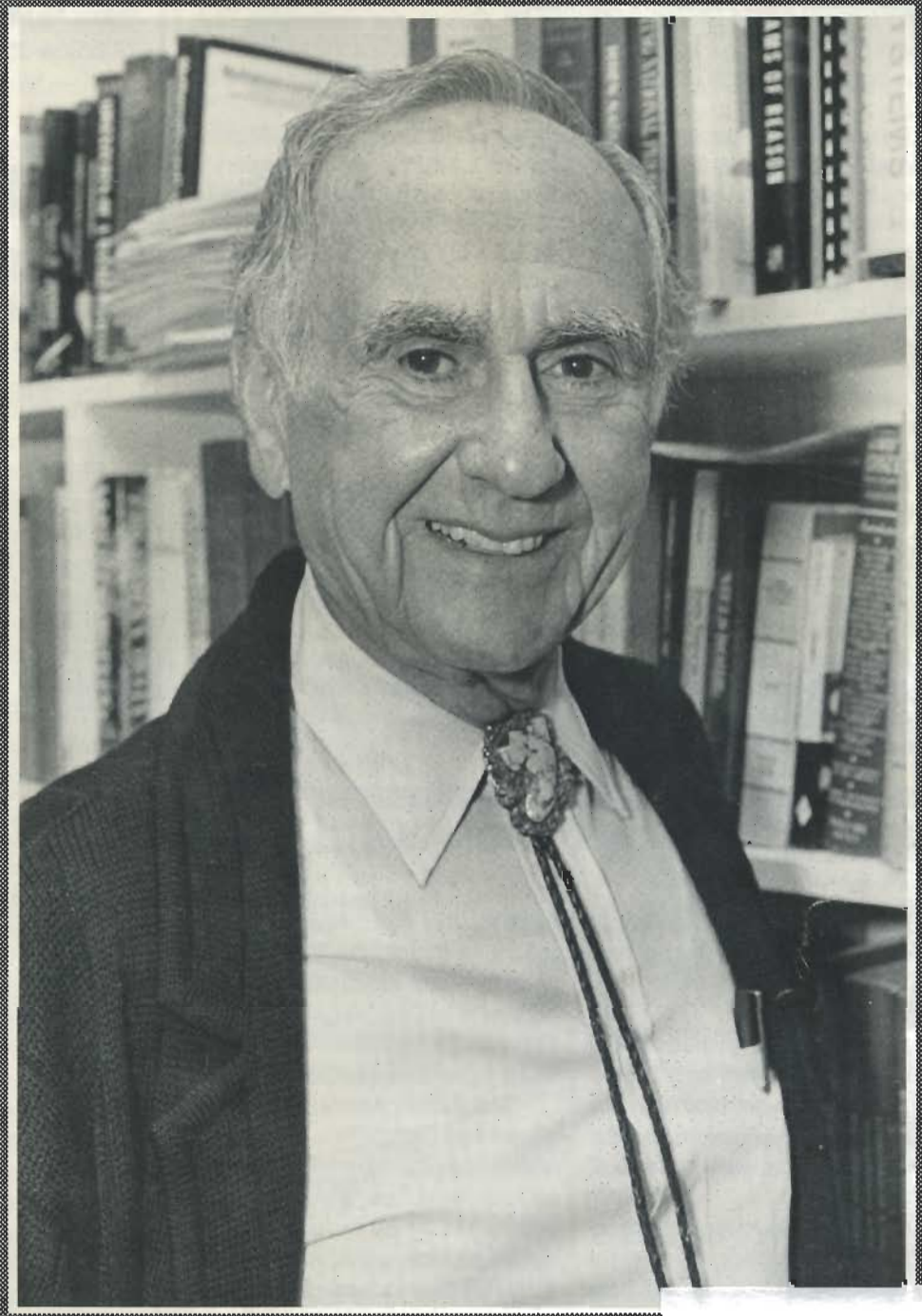

Santa Fe Institute

Knapp Named President

Edward A. Knapp

Photo courtesy of Los Alamos National Laboratory.

Dr. Edward A. Knapp, former director of the National Science Foundation, has been elected by the Santa Fe Institute's Board of Trustees as the second president of the Institute, effective in mid-1991. His unanimous election was announced by Robert O. Anderson, chairman of the Board.

Knapp will succeed Dr. George A. Cowan, the founding president, who has held the office since the Institute's creation in 1984. Anderson said, "Dr. Knapp is an excellent choice to succeed Dr. Cowan, our outstanding first president. Knapp was one of the founders of the Institute, is a Vice-Chairman of the Board of Trustees, and his great qualities of leadership will serve us well."

Knapp, 58, an experimental physicist and Senior Fellow at Los Alamos National Laboratory is currently Director of LAMPF, the Laboratory's Clinton P. Anderson Meson Physics Facility, a national basic research facility for nuclear physics. In addition, he is participating in a high energy physics experiment with an international group at CERN in Geneva, Switzerland. He is past President of the Universities Research Association a consortium of 72 universities, which operates the Fermi National Laboratory in Batavia, Illinois, and the Superconducting Super Collider, under construction near Dallas, Texas.

Knapp received a B.A. from Pomona College, a Ph.D in physics from the University of California at Berkeley, and honorary D.Sc. degrees from Pomona College and Bucknell University.

In a varied career at Los Alamos, Knapp was a key designer of LAMPF, was co-inventor of the side-coupled accelerator system and was responsible for the transfer of this technology to the medical instrumentation industry. He organized and led a large division of scientists, unique in the world, using basic research results on particle accelerator design to build instruments for many applications in defense, research, and medicine.

Knapp said, "I am honored to have this opportunity to continue George Cowan's good work. The Institute is a unique organization which has demonstrated a remarkable power to convene the nation's best scientific minds to address critical problems."

Cowan Receives Fermi Award

George A. Cowan, President of the Santa Fe Institute, has been named as one of two recipients of the 1990 Enrico Fermi Award. The Fermi award is the highest scientific award given by the U.S. Department of Energy. It recognizes outstanding scientific and technical achievement in the development, use, and control of atomic energy.

Cowan's citation reads: "For accomplishments in the development of radiochemical techniques and their applications to the solution of a broad range of scientific problems—including the migration of radioactive waste products from the Oklo natural reactors, the distribution of atmospheric pollution, the flux of solar neutrons—and for extensive contributions to nuclear weapons diagnostics and the assessment of nuclear weapons capabilities of other nations."

The Fermi Award, honors the memory of Enrico Fermi, the leader of the scientists who achieved the first self-sustained, controlled nuclear reaction. The award includes a presidential citation, a gold medal, and a $100,000 honorarium. The awards will be presented at a ceremony in Washington, D.C., on January 28, 1991.

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The Santa Fe Institute is a private, independent organization dedicated to multidisciplinary scientific research and graduate education in the natural, computational, and social sciences. The driving force behind its creation in 1984 was the need to understand those complex systems that shape human life and much of our immediate world—evolution, the learning process, the immune system, the world economy.

The intent is to make the new tools now being developed at the frontiers of the computational sciences and in the mathematics of nonlinear dynamics more readily available for research in the applied physical, biological, and social sciences.

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Retiring SFI President George A. Cowan. Photo by Cary Herz © 1990.

Making A Difference

It was difficult at first to make the decision to leave the presidency of the Institute but it is suddenly much easier. The appointment of Ed Knapp as my successor makes the difference. From years of personal and professional association, I am confident that he will continue to lead the Institute to a position of preeminence in the research and graduate education community. I shall remain ready to help in that task along with his many loyal friends and dedicated supporters of the objectives of the Institute.

The Institute is fulfilling the early promise of its infancy. Its successes lead to higher expectations and needs which are being met. It is good to report that the NSF, which has provided an important part of both our core support and programmatic support for the past three years, has indicated its intention to renew its grant. We expect to hear in the near future from the DOE and believe that news will be good. The lengthening bookshelf of Institute proceedings, papers, and preprints is a measure of SFI academic achievements. There are many other indications, including frequent and favorable mentions in the press, a growing flood of applications from scholars who wish to participate in our programs, and increased support from individuals and foundations in the form of financial contributions and grants to the Institute. The staff has never been stronger or more dedicated to meeting the demands of a growing calendar of activities.

My optimism is running high. I am looking forward with pleasure to the imminent arrival on the scene of a new leader and the opening of the next chapter in the ongoing saga of the Santa Fe Institute.

New Scenarios for Evolution

Our current understanding of evolution in biology centers around the notion of *fitness*. Since the breakthrough of Charles Darwin's fundamental concept of natural selection, fitness is understood as the number of offspring which reach the reproductive age and have progeny themselves. The penetration of biology by chemistry and physics in this century led to new disciplines like biochemistry, biophysics, and molecular biology. The discoveries made in these fields revealed many fascinating details of the overwhelmingly complex molecular machinery and beautiful microscopic architecture of living beings. Despite the enormous progress in the exploration of living matter, molecular life sciences contributed at first only little in the search for answers to the fundamental question in the core of evolutionary theory: How to define and measure fitness without referring to the outcome of selection? This is a particularly important issue in order to avoid the vicious cycle which turns *survival of the fittest* into the mere tautology of *survival of the survivor* if fitness can be measured only by counting offspring.

New Access

Two pioneering studies in the early seventies created a new access to the old fitness problem: Sol Spiegelman's (Columbia University, NY) evolution experiments in the test-tube and Manfred Eigen's (Max-Planck-Institut, Göttingen) kinetic approach towards molecular evolution. Their experiments and theories deal with molecules which are capable of self-reproduction and therefore can be made targets of selection and evolutionary optimization. These molecules are polynucleotides, more specifically RNA molecules which replicate, mutate, and adapt to environmental conditions in an artificial world created by the experimentalist. The artificial world provides everything except the template which is required to synthesize RNA *in vitro:* building blocks of RNA—chemically activated such that they react readily—and a protein enzyme, commonly Qβ replicase which is isolated from bacteria infected by the RNA bacteriophage Qβ. If an RNA molecule suitable for replication is added, synthesis starts. The enzyme is sufficiently sloppy to allow for replication errors which therefore occur now and then. A stepwise increase in the rate of RNA synthesis and final convergence to some optimal value is observed. The course of the process is very much like one we would expect to find in organismic evolutionary optimization.

Molecular evolution *in vitro* provides a possibility to measure—at least in principle—the physical quantities which determine the fitness of RNA molecules. These quantities are rate constants and equilibrium constants of the elementary steps in the complicated mechanism of template-induced replication. The insert *in principle* points at the enormous practical difficulties to determine a great number of relevant kinetic and thermodynamical constants for a representative set of RNA molecules such that real predictions on the outcome of test-tube evolution can be made.

Phenomenological Model

Since 1968 Manfred Eigen and Peter Schuster have been working on a phenomenological model of molecular evolution. In principle, the evolving entities need not be molecules. The model applies equally well to other systems provided they are capable of replication and variation through mutation. It is possible to distinguish two different scenarios: a *Darwinian Scenario* in which a modified kind of selection of the fittest is observed and a strongly coupled *Co-Evolution Scenario* in which the notion of fitness becomes obsolete for the individual types. The Darwinian scenario applies if the replicating entities multiply independently of each other and the population is subjected to some environmental constraint dictated by the carrying capacity of the ecosystem or by the experimental setup. For example, the population size may be restricted to a constant number of individuals. Accordingly, one type can grow only at the expense of the other types; the result is selection. Errors in the replication process—commonly called mutations—create a pool of variants which is the source for evolutionary optimization and adaptation. Mutants are produced steadily and therefore selection cannot yield a single fittest type. Instead a *clan* of closely related types called a *quasi-species* is formed. The quasi-species consists of a master sequence and its most efficient mutants. Intuition suggests that the higher the error-rate, the more mutations are available for selection, and the more efficient should be the optimization process. The suggestion, however, is correct only within limits: at high error rates, mutations *take over,* inheritance breaks down, and then selection finds nothing to act upon. Surprisingly, the transition between efficient optimization and almost random variation in population structure is very sharp. The critical mutation rate at which this phenomenon of uncontrollable error propagation occurs is characterized as *error threshold.* Interestingly enough, simple RNA viruses seem to evolve under conditions very close to the error threshold. The experimental data suggest that the *Darwinian Scenario* applies to *in vitro* evolution as well as *in vivo* virus evolution, and presumably also to many other more complex cases.

Following the intuition of Sewall Wright—one of the great scholars of population genetics—we may visualize evolution as a *hill-climbing process.* What *climbs* in such a sketch is the population, and it climbs on a highly complex and abstract object called the *fitness landscape.* The fitness landscape assigns the fitness value of a pheno-

type to the genotype from which it was derived by unfolding. The number of possible genotypes is enormous: 4^n for RNA molecules of chain length n. It is very hard to measure fitness even in the simplest cases. How should we then be able to construct a landscape which is based on the fitness values of all possible genotypes? Since we know so little about the actual structure of fitness landscapes, one legitimate approach to the problem is to assign fitness values at random to genotypes. A well-known example of such an approach is Stuart Kauffman's (SFI External Professor) *NK* model which found several applications, among them an investigation of protein-folding landscapes by Alan Perelson (SFI External Professor) and Catherine Macken (SFI Visiting Faculty Member).

Alternative Approach

A few years ago Schuster decided with Walter Fontana, then a Ph.D. student in Schuster's group at Vienna University and now a postdoctoral fellow at Los Alamos and a member of the Santa Fe Institute, to choose an alternative approach to study fitness landscapes. These scientists reduced the relation between genotype and phenotype to the simplest possible case: the secondary structure of the RNA—a two-dimensional or planar folding pattern of the polynucleotide sequence—was assumed to be the phenotype in the model. Fitness values related to kinetic constants are assigned to the planar structures by means of a set of rules which mimic present-day knowledge in biophysics. An important feature of realistic rules consists in conflicting trends: there is no trivial answer to the question of what the fittest structures look like. This phenomenon is similar to *frustration* encountered in spin glasses. Populations of a few thousand RNA molecules are subjected to conditions corresponding to those in an *in vitro* evolution experiment as simulated by an appropriately designed computer algorithm. During optimization runs, the molecules learn rules to meet the conflicting constraints of the model. The computer simulation provides full information on the course of the evolutionary process. Genealogies of the *successful* molecules can be retrieved and from these we can learn how populations are caught in evolutionary traps and how they manage to escape. The computer simulations have not only confirmed the applicability of the quasi-species concept to realistic fitness landscapes and small populations, they revealed in addition several unexpected features:

- the efficiency of optimization increases with the mutation rate up to a critical error threshold value above which no genotype is stable over many generations,
- the fitness surface shows a high degree of selective neutrality—many genotypes lead to the same phenotype or to phenotypes with identical fitness values,
- optimization processes on the same fitness landscape may occur stepwise or gradually depending only on the path which is chosen by the population, and
- evolution of small populations on simple fitness surfaces already shows *memory effects*—structural features which are formed early in the optimization process are kept for the whole run because very rare mutation events would be required to remove them.

In addition these investigations showed a number of general features which seemed to be characteristic of *rugged landscapes* as obtained by folding biopolymers into planar or three-dimensional structures. Schuster and his coworkers in Vienna decided therefore to have a closer look on the folding landscapes of RNA molecules.

Peter Schuster

Photo by Nick Secor © 1990.

Systematic Searches

During Schuster's stay at the Institute this year, he started a program on systematic searches on RNA folding landscapes. The folding algorithm was updated with respect to the biophysical parameter set in order to come as close to reality as possible. Statistical properties of landscapes are computed with the end of characterizing folding landscapes quantitatively. These data should help us gain deeper insight into the highly complex processes of optimization and adaptation within the *Darwinian Scenario*.

It is commonplace to say that no species evolves independently in real ecosystems. Co-Evolution is of fundamental importance for any understanding of real biology. Even in simple molecular systems we find frequency dependence of replication rate constants. For example, RNA catalysis as discovered by Tom Cech (University of Colorado at Boulder) introduces concentration dependence if it is involved in the replication process. In the case of catalysis, the rate of synthesis of an RNA molecule depends on the availability—precisely on the concentration of the RNA molecule acting as catalyst. A similar situation is encountered in symbiosis which can be understood best as an extreme case of strongly coupled co-evolution. Consider a lichen: the rate of reproduction of the fungus depends on the availability of algae cells and vice versa.

With Manfred Eigen, Schuster developed a simple dynamical model for co-evolution which leads to symbiosis. They coined the notion of a *hypercycle* for functional

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Nonlinear Modeling and Forecasting

International Forecasting Workshop Held

Stephen Eubank

Photo by Helen McCarty Eubank © 1990.

Doyne Farmer

Photo by Cary Herz © 1990.

The "Nonlinear Modeling and Forecasting" workshop was held September 17–21,1990, under the joint sponsorship of NATO and SFI. The meeting was organized by Martin Casdagli (SFI postdoctoral fellow), Stephen Eubank (Los Alamos National Laboratory), and Doyne Farmer (SFI External Faculty and Los Alamos National Laboratory).

In common with other workshops held by SFI, this workshop was highly interdisciplinary in nature and brought together many researchers who would not have met at more typical specialized conferences. This workshop focused on the question of how to construct nonlinear models with predictive power for data sets gathered from inside or outside scientific laboratories. Speakers who had analyzed data sets from this point of view represented such diverse areas as economics, DNA sequencing, human speech, robotics, experimental fluid dynamics, meteorology, and laser physics. Also several data sets discussed were generated artificially on the computer to address theoretical issues in constructing nonlinear models from data.

The approaches to tackling such problems are almost as numerous as the number of potential applications. Both Farmer and Casdagli have backgrounds in chaotic dynamical systems and, indeed, much publicity has been generated by the observation that remarkably simple nonlinear rules can give rise to apparently very complicated "chaotic" data. More recently (post-1986), these two researchers, among others, have developed a rag bag of techniques to reconstruct approximations to the simple rule from data, if such a simple rule indeed exists, and have used it for short-term forecasting. Several experts from this rapidly expanding "chaotic school" of nonlinear *modeling* were invited to the workshop to exchange recent results and identify important open questions. Also included were experts from statistics, information theory, control theory, function approximation, and neural networks.

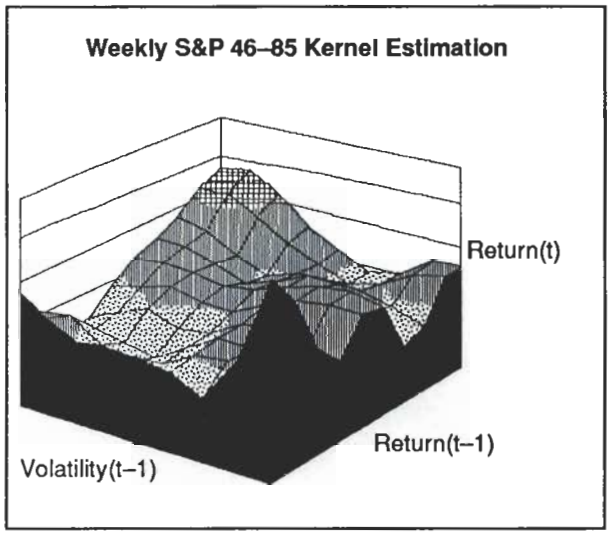
Theoretical talks covered theoretical results on neural nets, comparative studies between different function approximation schemes, optimal state-space reconstruction, nonlinear spectroscopy, nonlinear control, filtering and identification, optimal estimation of fractal dimension, and noise reduction. Considerable excitement was generated by results presented on practical applications of nonlinear forecasting as follows:

- Blake LeBaron (University of Wisconsin) presented the first convincing evidence of statistically significant nonlinear forecastability present in the Standard and Poor's index during periods of low volatility.
- Norman Packard (University of Illinois) presented preliminary results on using a genetic algorithm to identify "windows of predictability" in the Standard and Poor's index and in pseudo-random number generators.
- William Taylor (RTA Corporation) gave an audio demonstration of his results on separating speech from high levels of air-conditioner contamination using nonlinear techniques, rendering the speech intelligible.
- Brent Townshend (AT&T) presented results on very short-term nonlinear forecastability in speech signals, which is of potential use in the improved encoding of speech.
- Chris Atkeson (MIT) gave a video demonstration of robots juggling balls, designed using ideas from nonlinear function approximation.
- Alan Lapedes (Los Alamos National Laboratory) presented results on identifying secondary protein structures from information in the DNA amino-acid sequence, using neural networks. This is of potential use in the human genome project.

At the time of writing it is still too early to tell what the overall tangible research results of the meeting will be, but there are several immediate outcomes:

- Andreas Weigend (Stanford University) and Neil Gershenfeld (Harvard University) are organizing a "forecasting contest," (see ad on page 7) in which the contestants will try out their nonlinear modeling techniques on a wide range of data. This could reveal the comparative merits of the different techniques, in addition to supplying contestants access to scientifically interesting data sets.
- The invited speakers were encouraged to submit written versions of their talks for the proceedings volume, which will appear in the Santa Fe Institute's Studies in the Sciences of Complexity series in 1991. This should be a uniquely valuable source of references for

Martin Casdagli and Doyne Farmer. Photo by Cary Herz © 1990.



Graphical evidence for predictable structure in the weekly Standard and Poor's 500 time series from 1946 to 1985. A linear analysis of the time series reveals no significant predictability. However, during periods of low volatility, the above figure reveals that there may be a small but significant predictability: The return at time t is positively correlated with the return at time t–1. The figure was obtained from the data by a standard nonlinear regression using a Gaussian smoothing kernel. Volatility was estimated from a sum of squares of the returns over a moving window of ten weeks. These preliminary graphical results have been supported by more rigorous statistical testing. Figure courtesy of Blake LeBaron.

future interdisciplinary research in non-linear modeling and forecasting.

So far, it seems one has yet to successfully set loose one of John Holland's classifier systems on such a task, but in principle this is possible. Also computer simulations have proven to be indispensable in much of the research here discussed. These "practical" activities of forecasting should be a useful counterpoint to the other more theoretical research taking place at SFI.

—Martin Casdagli

Martin Casdagli is an SFI postdoctoral fellow.

Contest

A Time Series Prediction and Analysis Competition

The Santa Fe Institute

August 1, 1991 - December 31, 1991

A range of new disciplines are currently being brought to bear on the very old problem of time series analysis, both to learn more about the systems producing the time series and to make useful predictions about the future behavior of the systems. In order to facilitate comparisons between new and old algorithms, and between different techniques that address similar questions, the Santa Fe Institute is organizing a time series prediction and analysis competition. A few carefully chosen interesting time series will be made available through a network server at the Santa Fe Institute during the competition, and results from contestants will be collected in such areas as future prediction and dimension measurement. At the close of the competition the evaluation of the results will be tabulated and published, and the server will continue to operate as an archive of data, programs, and comparisons. Contributions of data are currently welcomed, and analysis programs will be welcomed following the competition.

For more information, send mail to:

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SFI Approach Goes Midwest

As part of its growing program in adaptive computation, the Institute in November kicked off a joint SFI/University of Michigan project to develop techniques capable of modeling parts of real systems involving human societies—methods of practical use to working policy-makers. The effort is funded by the Joyce Foundation in addition to support by SFI and the University of Michigan.

The initiative, in fact, has a double goal: the first is to develop a policy-makers' tool-kit through collaborations involving Michigan faculty, primarily from the social sciences, and SFI members, who will primarily bring expertise in the mathematical and computational modeling of complex systems. Within this collaborative process is the project's second aim: to explore the prospects and nature of research exchanges between SFI and university communities.

During the early stages of this project, activities have centered on the Michigan campus, where the focus has been on establishing the basis for research collaborations. In November a two-week seminar on complex adaptive systems, organized by John Holland and taught by SFI external faculty, was scheduled on the Midwestern campus; it attracted faculty from a broad range of departments and colleges. While providing an in-depth introduction to adaptive computation and to the Santa Fe Institute approach to complex systems studies, the program also stimulated joint SFI/Michigan projects as well as University of Michigan interdepartmental collaborations. As part of the seminar, a public colloquium also was held at the University to announce the new partnership. Finally, a graduate-level credit course in complex adaptive systems, to be taught by John Holland, has been scheduled for the Winter, 1991, semester at the University of Michigan. (Indeed, a number of Michigan faculty have indicated interest in attending the course.) Like the seminar, this course serves as an attractor, in this case for prospective younger participants in the SFI/Michigan program. Holland will use this course as one means of identifying the most promising graduate student participants in the project.

One immediate outcome of the November seminar was the formation of several nascent research networks, for example, a collaboration on technological innovation involving Hal Varian, Department of Economics, University of Michigan, and David Lane's research group in Santa Fe. As these collaborations mature, Joyce Foundation funds will be used in 1991 to bring clusters of researchers to the Santa Fe Institute. The emerging format will likely be a number of discrete modeling projects based on suggestions from Michigan participants. These small meetings will offer the opportunity not only to exchange views and to report progress but also to continue collaborative research.

"The preliminary stages of the SFI-Michigan collaboration are proceeding as expected," notes Holland, "except that enthusiasm on the Michigan campus is greater than anticipated." At the Institute, SFI Executive Vice-President, L. M. Simmons, Jr. adds, "We look forward to additional such collaborations at other universities, although it is probable that no generic template for such efforts exists, and that each collaboration will take a unique form. In the meantime, the Institute recognizes the superb work of John Holland, whose efforts have been so instrumental to the initiation of the innovative program at Michigan."

From left to right: John Holland, University of Michigan; Joel Getzendanner, Joyce Foundation; John Jackson, Institute for Survey Research; Dick Nesbitt, University of Michigan; and Murray Gell-Mann, Caltech.

Photo by Bob Kalmbach © 1990.

"I think it is clear that the Santa Fe Institute responds to what is largely missing today on many of these large campuses, a sense of the bold and the daring, a willingness to take risks and in a sense to dream dreams, to step beyond narrow questions and disciplinary boundaries. That is key."

— James Duderstadt, President
The University of Michigan

Prehistoric Complexity

Southwestern Prehistoric Societies

For five days in October, 27 archaeologists, ethnologists, and complex systems theorists in biology, computer science, and physics, met at the Santa Fe Institute to consider the archaeology of the Southwest. Organized by Murray Gell-Mann, SFI Science Board co-chair and Maxwell Professor (California Institute of Technology), and George Gumerman, (Center for Archaeological Investigations at Southern Illinois University), and supported by SFI, the School of American Research, and private donors, the workshop "Organization and Evolution of Prehistoric Southwestern Societies" was devoted to studying and attempting to explain the evolution of societal complexity in the Southwest. It was a result of two years of planning.

From the Records

For those interested in the behavior of complex adaptive systems, the archaeological record of prehistoric southwestern societies offers a unique and challenging resource. That record includes detailed information on 2,000 years of uninterrupted human occupation during which there were patterned technological, social, and ideological responses to a harsh and unpredictable natural environment.

Before the Spanish entered, the record of climate and environmental variables, documented with unusual precision in tree rings, pollen, and alluvial sediments, forms one dimension along which to view social responses that included changes in subsistence practices, economy, and settlement strategy. During the prehistoric period, transitions included adopting domestic plants, developing farming economies, and intensifying agricultural production by means of mechanisms such as irrigation. At other times, some societies shifted more effort to foraging wild plant and animal food. Economic adaptations included periods during which there were strong inter-regional systems of exchange; there were also, however, intervals of subregional isolation. Settlement strategies involved communities that were dispersed and those that were aggregated. Some settlements reflected planning at the supra-household level; others did not.

Despite local variation, broad regional patterns reveal similarities in the timing of particular economic and social changes as reflected in archaeological sites and artifact assemblages. The trajectories of patterned changes can be viewed as complex adaptive systems showing historical changes over time. Recent advances in the mathematics of modeling complex adaptive systems render the models capable of handling the complexity of human behavior. The workshop brought together scientists interested in attempting to explain these patterns by comparison to general models of complex adaptive systems.

(continued next page)

Maxwell Professorship Established

The Institute is delighted to announce the establishment of the Robert Maxwell Professorship in the Sciences of Complexity. With an inaugural grant of $300,000 from the Maxwell Foundation, the term of the professorship began in the Fall, 1990.

The first occupants of the new chair will serve on rotating appointments; beginning (fall, 1990) with Murray Gell-Mann, Nobel laureate and Professor of Physics at the California Institute of Technology. He was succeeded (fall, 1990) by John Holland, Professor of Computer Science, Engineering and Psychology at the University of Michigan. Subsequent appointments in the winter and spring, 1991 will be Stuart Kauffman, Professor of Biochemistry and Biophysics at the University of Pennsylvania; and David Pines, Professor of Physics at the University of Illinois. All are members of the Santa Fe Institute external faculty, a group of some 30 scientists from throughout the world who participate regularly in the Institute's scientific programs. In addition to the support for occupants of the Maxwell chair the grant provides for the support of younger scientists who come to the Institute to collaborate with the Maxwell Professors. These Maxwell Visiting Fellows have included Seth Lloyd (California Institute of Technology and SFI External Faculty), Melanie Mitchell (University of Michigan) and Alan Kaufman (Yale University).

Mr. Maxwell, in establishing this innovative chair, expressed his desire to support and accelerate the application of advanced mathematical and computational techniques to help policy-makers, specifically to provide them with useful options for handling complex and rapidly changing global problems.

Robert O. Anderson, chairman of the SFI Board of Trustees, welcomed Mr. Maxwell's initiative as "an enormous boost for the Institute's pioneering program to merge several fields of science in research on global issues."

Economics

New Economics Research Groups Formed

The Institute's Economics Research Program, now in its third year of operation, has new co-directors, John Geanakoplos, an economist from Yale University, and David Lane, a statistician from the University of Minnesota who took over leadership of the program this fall. The SFI economics program's aim remains the exploration of the economy as an evolving complex system. Its object is to describe the dynamic processes that result from the actions of agents who are neither perfectly informed nor perfectly rational, but must learn to adapt to the world in which they find themselves and, by their collective actions, continuously recreate. In this world, new economic institutions arise as emergent properties, and the particular forms that they take matter, as they constrain and direct the behavior of the agents who operate within them. To study such a world, program participants rely heavily on computer simulation and stochastic modeling rather than the traditional topological methods of neoclassical economics.

Research Groups

At the heart of the Economics Research Program are its associated research groups, which create the models and interpretative frameworks that give substance to the vision of the economy as a complex adaptive system. In addition to the ongoing activities described in the last issue of the Bulletin, three new research projects emerged last fall.

Technological Innovation

The aim of the *Techological Innovation* project is to construct a computerized, microfounded model for an economy fueled by technological innovation. Researchers in this project bring expertise from a range of disciplines: in addition to David Lane are economists Giovanni Dosi, Marco Lippi, Franco Malerba, and Luigi Orsenigo; John Miller, who

Prehistoric Complexity (cont'd.)

Ground Rules

Since the nature of archaeological data and reasoning are not generally understood outside the discipline, a day-long field trip prior to the conference was organized by Rolf Sinclair of the National Science Foundation. Stephen Lekson of the Museum of New Mexico led a group of workshop participants to archaeological sites near Santa Fe that represent various prehistoric eras and exemplify interpretive quandaries. Once underway, conference working sessions on historical process, the nature of explanation in archaeology, systems modeling, demography and health, and environmental and evolutionary modeling were preceded by general overviews of the history and goals of the workshop by Gumerman, complex adaptive systems by Gell-Mann, southwestern prehistory by Lekson, cultural evolution by archaeologist Joseph Tainter (U.S. Forest Service), and problems in modeling prehistoric population dynamics by archaeologists Ben Nelson (SUNY Buffalo), Keith Kintigh (Arizona State University), and Timothy Kohler (Washington State University).

Workgroups

One pattern common in the prehistoric Southwest is that of sequential subregional abandonment. For example, the Chaco Canyon and Virgin River regions were abandoned in the late 1100s, Mesa Verde in the late 1200s, and the Middle Little Colorado River area in the 1400s. Despite these abandonments, the overall temporal trajectory of population growth was positive. One workshop group investigated the utility of viewing the sequential abandonments in terms of rugged fitness landscape models. The working group suggested that some prehistoric settlement relocations may have been due to increasingly stable environmental contexts where deformation of fitness landscape was more difficult.

Another working group examined how changes in the complexity of regional systems of exchange and sociopolitical alliances might be modeled using Holland's genetic algorithm, as modified by workshop participant Robert Reynolds (Wayne State University). The generic algorithm is based on a Darwinian paradigm of fitness modified to include learning. Using surrogate measures to monitor dimensions of demographic, economic, social, and political behavior, the working group investigated the potential of a model generated from the genetic algorithm to reproduce systems of comparable complexity to those known archaeologically. Efforts such as this one will eventually allow identification of the ways in which systems of human behavior mirror or depart from the behavior of other complex adaptive systems.

Papers generated by the working groups during the conference, along with position papers distributed before the conference, are being collected into a volume edited by Gell-Mann and Gumerman, to be published as part of the Santa Fe Institute Studies in the Sciences of Complexity series.

—Linda S. Cordell

Linda S. Cordell, Irvine Curator and Chairman, Department of Anthropology, California Academy of Sciences.

contributes expertise in adaptive computation as well as economics; management consultant Paul Tayler; and investor James Pelkey. The model consists of an Artificial Economy, populated by two kinds of firms, one of which manufactures machines which the other uses to produce consumer goods; two types of workers, laborers, who work in the firm's factories, and researchers, who design more efficient or cheaper machines; and a central bank, which lends to firms and accepts savings from firms and workers.

In the model, firms learn how to make their decisions—about how much to spend on research, what and how much to produce, how to price their products, and so on—in the light of the successes or failures they achieve in the marketplace, based on the decisions they have already made in the past. The aggregate effects of these decisions determine the macroeconomics of the Artificial Economy: its growth, unemployment, labor productivity, and capital stock. In addition, as a result of their decisions, some firms prosper, some languish, and some die, determining distributions of firm size and life cycles. A key test of the relevance of this model involves its ability to reproduce a number of stylized facts from three traditionally distinct economic subdisciplines: macroeconomics, industrial organization, and the demography of innovations. If the model succeeds, it can be used as an experimental tool to probe a number of questions about coordination effects in economics, as well as about the design and operation of public policy, from banking and bankruptcy to patent law. A workshop related to this research entitled "Learning and Adaption" will be held at the Institute in April, 1991.

On a related front External Faculty member Stuart Kauffman and economist Paul Romer, National Bureau of Economic Research, are analyzing random grammar models in which a symbol string represents a good or service, and symbol strings act on other symbol strings to produce new strings according to the grammar. Such systems are models of the evolution of technological webs, as new goods and services enter the economy and old ones are disposed.

Dynamics Modeling

Institute researchers Buz Brock and Blake LeBaron, seeking footprints of chaos in financial time series, developed sensitive statistical tests to guide their quest. They failed to locate chaos, but did find intriguing clues to an underlying nonlinear structure that is not captured by any of the standard finance models of asset pricing and volatility prediction. This fall Brock formed the research group *Stock Market Dynamics Modeling*, whose aim is to capitalize on the Brock-LeBaron findings to better understand the nature of this nonlinear structure and thus increase the predictability of the series in question. Working with Brock and LeBaron are Allan Kleidon, Graduate School of Business, Stanford University; David Hsieh, Department of Finance, Duke University; and Chera Sayers, the Commodity Futures Trading Commission. The group has assembled an extensive database on returns and volume for over 400 NASDAQ firms. These data will allow them to compare the asset returns dynamics of large firms and small firms and to evaluate whether the evidence for predictability conditional on such variables as past volatility and volume behavior is stronger for smaller firms than larger ones. Researchers will also consider how individual firm dynamical patterns change when the firms are pooled into portfolio aggregates such as the Dow, the Value Weighted Index, and the Equal Weighted Index. Much financial research has focused on these indices, but only recently have researchers looked at how the individual dynamics combine into the dynamics of the index. So far, however, this research has been restricted to the use of linear models. In fact, much financial returns data shows trends that change in ways apparently contradictory to standard linear-based efficient market and asset pricing theory. It is likely that a nonlinear, stochastically changing trendlife model is needed to make sense of these data.

Theory of Money

The focus of the *Theory of Money* research group is a strategic market game developed by Martin Shubik and Ward Whitt that describes a stochastic dynamic exchange economy with money and loans of various periods. Working with Shubik and Whitt are Lane and Geanakoplos, John Miller, and probability theorists W.D. Sudderth and Ioannis Karatzas. The group is studying modeling questions about this game; it will try to solve mathematical problems about the existence and uniqueness of equilibria for different versions of the game, and will implement the game for artificial learning and adaptive agents. The key economic question that this research addresses is how to account for the emergence of the term structure of interest rates as a function of the rules governing the loan markets and the psychological characteristics of the lending and borrowing agents. In addition, the group's research will explore the connection between the adaptive dynamics induced by learning algorithms and game theoretic concepts of equilibria, extending the pioneering work in this area carried out at SFI by Ramon Marimon, Ellen McGrattan, and Tom Sargent.

(continued next page)

Workshops

An Exchange of Ideas

In tandem with its research groups, the Economics program holds workshops throughout the year. One of the major purposes of these meetings is to formulate research agendas and put together teams to pursue them.

Investigators

The Predictability of Stock Market Dynamics

W. A. Brock, Department of Economics, University of Wisconsin

David Hsieh, Department of Finance, Duke University

Allan Kleidon, Graduate School of Business, Stanford University

Blake LeBaron, Department of Economics, University of Wisconsin

Chera Sayers, CFTC, Washington, DC

Technological Innovation, Macroeconomics, and Industrial Demography

Francesca Chiaromonte, University of Rome

Giovanni Dosi, Department of Economics, University of Rome

David Lane, School of Statistics, University of Minnesota

Marco Lippi, Department of Economics, University of Rome

Franco Malerba, Faculty of Economics, Bocconi University, Milan.

John Miller, Department of Social and Decision Sciences, Carnegie Mellon University

Luigi Orsenigo, Faculty of Economics, Bocconi University, Milan

James Pelkey, investor, Santa Fe

Paul Tayler, Coopers & Lybrand Deloitte (management consultants), London

Price Formation and Interest Rates: A Strategic Market Game Approach to the Theory of Money

John Geanakoplos, Department of Economics, Yale University

Ioannis Karatzas, Department of Mathematics, Rutgers University

David Lane, School of Statistics, University of Minnesota

John Miller, Department of Social and Decision Sciences, Carnegie Mellon University

Martin Shubik, Department of Economics, Yale University

W. D. Sudderth, School of Statistics, University of Minnesota

Ward Whitt, AT&T Bell Laboratories, Holmdel, NJ

Such is the intent of the January meeting, "Learning in Economics, Psychology and Computer Science: An Exchange of Ideas." Psychologists have studied how human beings, individually and through the organizations they build, learn about the worlds in which they must operate. Computer scientists have constructed machine-implementable models of learning agents. In this workshop, workers in these two fields will meet with leading economics researchers who are grappling with the problem of how to incorporate the process and effects of learning into models of economic phenomena. The hope is that elements of a research strategy for this problem can emerge which draws on the insights of psychology and the techniques of machine learning. The workshop is sponsored by a grant from the Russell Sage Foundation to its three organizers: economist Brian Arthur, psychologist Richard Herrnstein, and computer scientist John Holland.

Wall Street & Economic Theory

Workshop meetings also provide researchers with an opportunity to collaborate with working practitioners on developing techniques; this is the case with "Wall Street and Economic Theory: Prediction and Pattern Recognition," a gathering chaired by John Geanakoplos and David Lane, scheduled to take place in Santa Fe in February, 1991. In this workshop, technical analysts from several Wall Street firms will pose practical problems about predicting financial time series and determining the attributes of "good" risks to a group of SFI researchers who have developed techniques that might be applied to these problems. These techniques include machine learning models, expert systems, nonlinear regression procedures, forecasting in the presence of noise and chaos, and nonparametric pattern recognition algorithms. The workshop will attempt to formulate plans for joint projects applying these techniques to representative practical problems. Several economic theorists will also be on hand to provide feasibility checks and possible alternative approaches. This meeting is supported by Citicorp.

Learning and Adaptation

Standard economic theory starts from the assumptions that economic agents are perfectly informed and perfectly rational. Clearly, to begin to describe the world in which we live, these assumptions have to be relaxed. The aim of an April, 1991, "Learning and Adaptation" workshop is to explore the different strategies that economists are currently pursuing to model adaptive, boundedly rational agents and to see what kinds of insights into economic phenomena are emerging as these strategies are implemented. About forty scholars—mainly leading economists, together with several experts in psychology and machine learning—are expected to take part in this five-day comprehensive overview of learning and adaptation. The workshop's proceedings will appear in the Santa Fe Institute Studies in the Science of Complexity series (Addison-Wesley).

Bounded Rationality

One of SFI's main research foci has been to apply the ideas of machine learning—especially those of SFI Maxwell Professor John Holland—to these adaptive agents. The key idea is that "bounded rationality" ought to be operationally defined in terms of the processing capabilities of an "agent" that can be programmed on a computer. A number of such artificial agents can then be introduced into an environment where they learn about some relevant states of the world, including some of the effects of each others' actions, in response to which they must act in order to obtain rewards from the environment. Their actions then in turn modify

the environment, and their learning must take account of these changes. When interesting economic environments have been modeled in such a computer program, one can observe what kinds of behaviors the agents engage in (and even learn what their "motivations" are) and see what kinds of collective patterns and structures emerge. For example, in a model of a stock exchange developed by SFI researchers Brian Arthur, John Holland, Richard Palmer, and Paul Tayler, the "artificial agents" learn quickly to buy low and sell high, and more interesting phenomena, such as speculative bubbles and technical analysis, emerge. As mentioned above, SFI researchers are applying this strategy to study technological innovation, the term structure of interest rates, and the evolution of market structures. Results from these models will be discussed at this workshop and compared with those of alternative strategies to modeling learning and adaptation.

Computerized Strategies

Black Monday offered a hint of the kind of deviant dynamics that can result from computerized trading strategies operating against one another. The phenomenon of computerized trading has been the object of intensive research at SFI. External faculty members John Miller and Richard Palmer and Economics Program participant John Rust have concentrated their attention on double auctions, a type of trading institution used by, among others, the New York Stock Exchange and the Chicago Board of Trade. Buyers and sellers are simultaneously able to call out offers to buy (bids) or to sell (asks), or to accept an outstanding bid or ask. The rapid flow of information and the ability to undercut instantly an existing bid or ask makes the double auction a close approximation to the economists' notion of a perfect frictionless market.

Tournament

In 1989, Miller, Palmer, and Rust initiated a Double Auction Tournament, soliciting computerized strategies for a particular version of the Double Auction that closely resembles that used by the Chicago Board of Trade. The entries they received varied from simple rules of thumb to complex artificial intelligence systems (in general, in the tournament, simpler strategies did better than the more complex ones!). In the computer implementation of the auction designed by the three Santa Fe researchers, up to thirty of these programs can trade against each other (and against human opponents). Thousands of controlled computer experiments can be run per day. Supply and demand curves can be varied at will, as can price-controls, asymmetry between players, and exogenous fluctuations. The influence of computerized traders on market stability (in particular, the emergence of bubbles and crashes) can be investigated. Research on these questions is currently underway.

Workshop

The purpose of the Double Auction workshop, scheduled in late Spring, 1991, is to present the results of this research to the wider community of interested scholars and traders, to develop theoretical explanations for the main empirical findings, and to explore the practical implications of these findings for the design and regulation of real-world markets. About thirty participants will attend the three-day meeting, and its proceedings will be published in the Santa Fe Institute Studies in the Sciences of Complexity series (Addison-Wesley Press).

This program is funded in part by NSF. One grant supports a research assistant (Shawn LaMaster) and an undergraduate student who will work under the supervision of Prof. Vernon Smith at the University of Arizona conducting the actual DA experiments. Another grant funds subject motivational experiments at the workshop. —Ginger Richardson

Co-Directors

John Geanakoplos

David Lane

Photos by Nick Secor © 1990.

John Geanakoplos is Professor of Economics at Yale University with areas of specialization including general equilibrium theory concentrating on problems arising from the absence of some markets (incomplete markets), game theory, and mathematical finance. Geanakoplos has spent terms as Visiting Professor at Harvard University, University of Pennsylvania, Stanford University, MSFI at the University of California, Berkeley, and Churchill College, Cambridge. A Fellow of the Econometric Society, he is Associate Editor of the *Journal of Economic Theory, Journal of Mathematical Economics,* and *Journal of Games and Economic Behavior.*

David Lane is Professor of Theoretical Statistics at the University of Minnesota. He has published extensively in a variety of fields, including the theory of stochastic processes, the foundations of inductive inference, pharmacoepidemiology, and medical decision-making. In 1985–86, he was awarded a Guggenheim fellowship for his work on causality assessment for adverse drug reactions. Among other professional honors, Professor Lane is a Fellow of the American Statistical Association and the Institute of Mathematical Statistics, and an elected member of the International Statistical Institute. He has held visiting Professorships at Duke University, McGill University, and Bocconi University in Milan, Italy.

Book Review

Touring the Universe

The Cosmic Blueprint
by Paul Davies
Simon & Schuster Touchstone Books, 1989

"Are the seemingly endless varieties of natural forms and structures, which appear as the universe unfolds, simply the accidental products of random forces? Or are they somehow the inevitable outcome of the creative activity of nature?"

In the course of seeking to answer that question, Paul Davies takes us on an exhilarating tour through an incredible variety of topics: cosmology, chaos, fractals, symmetry, cellular automata, complexity, and self-organization, thermodynamics and the arrow of time, dissipative structures, molecular biology, evolution, morphogenesis, Gaia, quantum measurement and non-locality, neural networks, and the nature of consciousness, as well as surveying related philosophical issues: causation, determinism and free will, reductionism vs. holism, emergence, the nature of physical vs. biological laws, and the mind-body problem!

Davies, a theoretical physicist who has worked on quantum field theory and cosmology, is a superb science writer. In a number of non-technical books, he has lucidly described the latest ideas and speculations in modern physics. His skill in swiftly summarizing a topic can occasionally leave us breathless, holding on with both hands as we race off to the next scenic overlook. And sometimes he succumbs to exaggeration, preferring to mystify and dazzle rather than illuminate.

Toward Organization

The chain of Davies' reasoning includes the following: The universe began in an "utterly featureless state" and then progressed step by step to its present condition of being "remarkably ordered on all scales...galaxies, stars and planets, the crystals and clouds, the living organisms." Alongside the degenerative entropy arrow of time (the second law of thermodynamics), there is also an "optimistic creative arrow" illustrated by the steady growth of structure, organization, and complexity in all of physical and biological Nature. Complex and highly organized unpredictable behavior can appear in open nonlinear systems far from equilibrium.

He regards the study of such systems as the third historical level in our classical analysis of matter, after Newtonian mechanics and equilibrium thermodynamics. These systems appear to have a tendency to naturally self-organize (spontaneously organize is perhaps a better phrase) into stable non-random collective patterns of activity. The behavior of these complex systems cannot be reduced to, or deduced from, a knowledge of their parts.

Davies agrees with those who argue that the origin of life and increasing biological complexity are difficult to explain using only the basic mechanisms of neo-Darwinism: variability due to random mutation and natural selection.

He argues that the reductionist program of explaining all phenomena by referring to general laws operating at the microlevel is simply irrelevant and often defines away the problem. Quoting Marvin Minsky: "To be sure, general laws apply to everything. But, for that very reason, they can rarely explain anything in particular." For example, the laws of physics don't tell us how to construct a computer—or a brain. Above a certain level of system complexity, new concepts, qualities, and laws emerge (generally consistent with lower level laws) that make no sense and have no applicability at other levels.

Higher Level Laws

Davies believes that to explain phenomena such as the origin of life, the progressive nature of evolution, purposeful behavior, and human consciousness will require higher-level laws—"software" laws as opposed to "hardware" laws—which cannot be derived from underlying physical laws. Discussing his view that "...matter and energy have innate self-organizing tendencies...," his belief is that "The general pattern of development is predestined, but the details are not." He also remarks that "...we will never fully understand the lower level processes (e.g., the collapse of the wave function in quantum mechanics) until we also understand the higher level laws."

Davies always retains his confidence in the rational program of science; he has little sympathy for "mystical or transcendent principles." "(I)t is one thing to expose the limitations of reductionism; it is quite another to use those limitations for an 'anything goes' policy." In a sense, Davies' book is an attempt to give a non-theistic account of facts that are often used to "prove" the existence of God (the "argument from design").

A Convincing Case?

Many scientific readers will feel (as I do) that he does not provide enough technical depth to make a convincing case. Most of his major points involve very active areas of current research. For example, I believe that a majority of modern evolutionary biologists would dispute his claim that Darwinism cannot explain the "richness of the biosphere." More controversial is the question of evo-

lutionary theory and the increasing organizational complexity that is observed. And here, as elsewhere in the discussion, we immediately recognize the critical need to have less subjective, more quantitative measures of system complexity, structure, and organization. Especially crucial to his argument is Davies' faith in the tendency of far-from-equilibrium open systems to form interesting complex structures. This claim requires a lot more experimental and theoretical support than is currently available. The study of non-equilibrium systems is a fascinating and difficult area, still in its infancy.

His criticisms of the reductionist program are compelling and express some of the reasons why many of us believe in the importance of—and have joined in—the study of nonlinear systems. It is exciting to realize that even reaching one primary goal of reductionism—finding the "lagrangian of everything"—would not end the task of science: explaining how the world is put together.

I also want to applaud Davies' focus on concepts rather than the personalities of science; it is refreshing in an age where the tendency is to reduce everything to the level of "who's hot today?" This informative, well-written, stimulating, bold, and passionate book is highly recommended.

—Harvey Shepard

Harvey Shepard is Professor of Physics at the University of New Hampshire. His research has been in elementary particle physics and nonlinear dynamical systems.

Educational Programs Grow

"An important aspect of the Institute's mission is providing research opportunities in the sciences of complexity for graduate students and postdoctoral fellows," says SFI Executive Vice President L. M. Simmons, Jr. "With few institutions in the nation devoted to the interdisciplinary study of complexity, we're providing a rare educational opportunity." True to its aim, in 1990, the Institute enlarged its postdoctoral fellow program to three full-time residential researchers, and it played host to a number of graduate workers.

Wentian Li

Postdoctoral Fellows

"The Institute's postdoctoral fellows are among its most productive researchers, and we're pleased by the superb caliber of young researchers we've attracted," Simmons adds. Postdoctoral Fellow Martin Casdagli's work, for example, focuses on nonlinear modeling and time series forecasting. In September, 1990, Casdagli, along with Los Alamos colleagues Stephen Eubank and Doyne Farmer, chaired an international workshop on this subject; proceedings from the meeting will appear this year. Casdagli's research is described elsewhere in this issue (see Nonlinear Modeling and Forecasting article on page 6).

Mats Nordahl

Wentian Li has been part of the SFI postdoctoral program since the fall of 1989. His research interests are broad: chaotic dynamics, edge of chaos dynamics, cellular automata and other spatially extended dynamical systems and the structure of their rule space, 1/f noise (1/f spectrum), both the observations and the models, statistical analysis of DNA sequences, and the measure of complexity and its relationship with entropy. As mentioned, a part of Li's research concentrates on 1/f noise, a theoretical problem in statistics. This phenomenon is quite widespread, which has lead to the speculation that it should be the result of a universal mechanism. During 1991 Li plans to write a major review article on the mathematical theories of 1/f noise. This should prove to be quite important; except for some review articles on the subject in solid state physics and a recent popular article, there is no recent general review of 1/f noise, especially the mathematical modes for 1/f spectra.

Kristian Lindgren

In September, the Institute's third Fellow, Mats Nordahl, joined the academic staff. Nordahl received his doctorate in Theoretical Physics from Chalmers University of Technology, Göteborg, Sweden. Before coming to SFI he was at NORDITA in Denmark. Nordahl's research interests are in the areas of dynamical systems with discrete spatial degrees of freedom.

Occasionally the Institute hosts shorter research visits from postdoctoral fellows with appointments at other institutions. Such is the case with Kristian Lindgren, a postdoctoral fellow visiting from NORDITA in Denmark. Lindgren joined SFI researchers for three months this past fall, working on several projects, the main one focusing on "evolutionary dynamics." These are dynamical systems that are potentially infinite dimensional in the sense that new variables may enter due to "mutations" and variables may disappear in "extinction events." Within this context biological evolution can be viewed as a transient phenomenon in a potentially infinite-dimensional dynamical system. If the transients continue for ever, *open-ended* evolution occurs.

Martin Casdagli

Photo of Martin Casdagli taken by Cary Herz © 1990, all others taken by Nick Secor © 1990.

Graduate Students

A growing number of graduate students are working at the Institute. Students who have completed course work for their doctoral degree may, with the agreement of their home institution, conduct thesis research and writing in residence at SFI under the direction of a member of the SFI External Faculty.

(continued next page)

Rick Bagley

Francesca Chiaromonte

Piercesare Secchi

Jorge Muruzabal

Julie Rehmeyer

Their degree will be granted by their home institution. Less frequently, students at the pre-thesis graduate level conduct research at the SFI.

During the summer months, Jamie Taylor, Psychology Department, Harvard University, worked with Richard Herrnstein, Robin Cowan, and John Miller on designing human experiments to study economic and psychological issues. Scott Page and John Miller worked on mathematics of genetic algorithms and classifier systems to generate an adaptive model of voting. Pete Skordos from the Massachusetts Institute of Technology joined the staff as part of the Complexity, Entropy and Physics of Information research network. Skordos studied the relation beween information and thermodynamic entropy, inspired by Maxwell's Demon. Specifically he worked on building computer programs to simulate the motion of gas molecules in a box of two chambers connected by an "intelligent" trap door.

Melanie Mitchell, now an Assistant Professor at the University of Michigan, visited the Institute as a Maxwell visiting fellow to collaborate on the Adaptive Computation program with Maxwell Professor John Holland and External Faculty member Stephanie Forrest. She will return in the Spring of 1991 to continue the project.

Rick Bagley is a graduate student from the University of California, San Diego and a graduate research assistant at Los Alamos National Laboratory who has been in part-time residence at SFI throughout the past year. Bagley is interested in self-organization of systems when this process leads to greater degrees of interdependence and hierarchy, aspects which are characteristic of the evolution of life. An evolving system is often confronted with the dilemma that further development requires some ability which is not yet present. The solution involves "emergent functionality," or "self-organization." Bagley's work focuses on a particular model of self-organization, the transition to biogenesis at the origin of life. Science Board and External Faculty member J. Doyne Farmer is Bagley's thesis advisor, and SFI researchers Walter Fontana, Stephanie Forrest, and Stuart Kauffman have guided his work. Bagley will receive his Ph.D. in the Spring of 1991 and will joing Peter Schuster's group at Vienna as a postdoctoral fellow.

The Institute's Economics research program benefits from work by graduate students on a variety of projects. Francesca Chiaromonte, a graduate student from the University of Rome, joined the Economics program in December. As an undergraduate student, collaborating with advisors Giovanni Dosi and Luigi Orsenigo, Chiaromonte developed a model of a two-sector economy which is the basis of the computerized, microfounded model in the Technological Innovation project (see Economics article on page 10). Under the direction of Paul Tayler, she is currently working as the programmer on the learning model for the artificial economy. Support for Ms. Chiaromonte's residency is generously provided by a donation from Robert Dolan.

Piercesare Secchi from the Center for Population Analysis at the University of Minnesota spent the Fall, 1990 term at the Institute working on the problem of the "oldest old." On the one hand, the gerontological paradigm for aging states everyone over 70 years will die of "old age"; that is, maximum life span is genetically limited. The epidemiological model for aging, on the other hand, asserts that disease is the cause of death and that with progress against age and disease life expectancy can be greatly extended. Secchi's research synthesizes evidence from a wide variety of resources to determine which of the two paradigms is more plausible and what kinds of evidence will further clarify the question.

Jorge Muruzabal from the School of Statistics at the University of Minnesota also was in residence at the Institute this autumn working on his thesis which concerns the application of classifier schemes to problems of statistical prediction.

Undergraduates

Highly motivated undergraduates have also begun to discover the Santa Fe Institute. Currently Julie Rehmeyer, a junior at St. John's College in Santa Fe, is collaborating with External Faculty member Stephanie Forrest on developing genetic algorithms in the C programming language. Her work focuses on coding a stochastic iterated hillclimber for use as a contrast experiment for genetic algorithms, as well as designing a program to estimate the total number of hills in a function. Her next project will be experimentation with a distributed genetic algorithm. Julie is joined by fellow St. John's student Ann Boynton who is working with Stuart Kauffman.

Marc Lipsitch, a senior at Yale with broad interests in science philosophy and public affairs, joined the SFI undergraduate intern program for the summer of 1990, first as a participant in the Complex Systems Summer School and then in the Adaptive Computation Research program. Working with External Faculty member John Miller, he applied genetic algorithm techniques to search for optima on landscapes generated by cellular automata.

Alan Kaufman, a Yale undergraduate, will join SFI this Spring to work with Stuart Kauffman as a Maxwell intern. He will be using his background in mathematics and computing to implement Kauffman's ideas on evolutionary networks in computational models.

With intensified university collaborations such as the program at the University of Michigan, and with plans for a fourth Complex Systems Summer School and the addition of another Institute postdoctoral fellow, SFI looks forward to increased student participation in its programs throughout 1991.

—Ginger Richardson

Anatomy of a Corporate Grant

The Volvo North American Corporation joined SFI's growing list of corporate donors in 1990, a move that we believe demonstrates increased awareness of the Institute's activities among major corporations. Other corporate donors to date have included Citicorp, Public Service Company of New Mexico, the H. J. Heinz Company, IBM, Booz-Allen Hamilton, Sun Microsystems, and Fiduciary Trust International.

The origin of the Volvo grant can be traced back to SFI's March 1989 Chairman's weekend, an intensive introduction to the Institute's agenda, planned for corporate and foundation heads. Joseph E. Slater, a member of the Board of Volvo North American Corporation and chairman of the grant-making Public Issues Review Committee, attended the weekend's presentations by Brian Arthur, Doyne Farmer, Marcus Feldman, Murray Gell-Mann, and John Holland. Intrigued and enthused by what he heard, Slater and SFI began an exchange of information until Slater was satisfied that the Institute's objectives were indeed in line with the foundation's goals.

In October, 1989, SFI made a formal proposal to the Volvo Board and the Institute received notification in early 1990 that it had been awarded a $40,000 grant. Bjorn Ahlstrom, Volvo's president, and Albert Dowden, their vice president, said they were impressed with SFI's "desire to work with other institutions and individuals" and encouraged SFI to use the grant to support the participation of scholars who "will introduce wider and more diverse perspectives, experiences, and insights into ... [SFI's] highly significant plans and programs."

The Volvo grant has had a substantial impact on SFI's 1990 programs, enabling the Institute to strengthen some of its most important new initiatives. This has been accomplished by drawing in non-scientists, one of the grant stipulations, and by involving more scholars from abroad in SFI's model building process in economics and in human sustainability and the environment.

The Volvo grant has had a substantial impact on SFI's 1990 programs, enabling the Institute to strengthen some of its most important new initiatives.

A portion of the grant supported participant costs for the "Paths Toward a Sustainable Human Society" workshop in May. The conference was very well received. Because of the leverage provided by Volvo funding in partial support of this workshop, SFI has been able to continue plans for a research program called "Visions of a Sustainable World."

Another portion of the grant supported ten foreign scholars who attended the "Nonlinear Modeling and Forecasting" workshop in September, 1990. The workshop brought together scholars from a variety of backgrounds and with a variety of different approaches to the problem of forecasting time-series data. The goal was to accelerate interdisciplinary research throughout the world in this extremely important subject area. Applications of improved techniques will range across economic, agricultural, and other forecasting problems.

Another portion of the grant has been applied to international visitor support within SFI's Economics Research Program. Paul Tayler, senior associate with the decision systems group of Coopers & Lybrand Deloitte in England, took part in the program in 1990. Tayler is building adaptive computational models of markets incorporating neural network and genetic algorithm methods. These models seek to distill essential features of market behavior and to model the evolution of trading rules with the goal of emulating the dynamics of real-world markets.

SFI is grateful for Volvo's support. We believe our use of this grant illustrates how important private contributions are to the strength of the overall program.

—Susan Wider

For Information

There are other opportunities at SFI for corporate support programs of this type. Firms interested in corporate involvement may contact:

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Director of Development
Santa Fe Institute
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Board/Staff News

Esther Dyson

Photo courtesy of Release 1.0.

David Lane

Photo by Nick Secor © 1990.

L. M. Simmons, Jr.

Photo by Cary Herz © 1990.

Boards

The Institute welcomes a new member to its Board of Trustees:

Esther Dyson is editor and publisher of the computer-industry monthly *Release 1.0*. The publication covers the computer business, focusing on new developments in software and software design, intellectual property issues, and the transformation of artificial intelligence into a commercial technology. Active in industry affairs, Dyson sits on the board of Adapso's Software Industry Division; she is also a member of the Software Publishers Association and the American Association for Artificial Intelligence. She serves on the advisory board of *AI Expert* magazine, Comdex, and PC Expo. Dyson graduated from Harvard with a B.A. in economics.

Two new members have been elected to the Science Board:

David A. Lane, Professor in the Department of Theoretical Statistics at the University of Minnesota, is currently Co-Director of the Institute's Economics Research program. For more information, please see page 13.

L. M. Simmons, Jr., is Executive Vice President of the Santa Fe Institute, a post he has held since 1988. As deputy to the president, he shares oversight of all Institute activities, but has particular responsibility for the research programs, computing, and publications. A Staff Member on leave from the Theoretical Division of Los Alamos National Laboratory, he has held a number of posts at LANL including Assistant and Associate Theoretical Division Leader and Deputy Associate Director for Physics and Mathematics. He is an Honorary Trustee, a member of the Advisory Board, a past Trustee, and past President of the Aspen Center for Physics. Simmons is the author of numerous articles on mathematical physics, elementary particle theory, and quantum theory.

External Faculty

Stephanie Forrest is Assistant Professor in the Department of Computer Science at the University of New Mexico; her areas of specialization within the field are machine learning, parallel processing, artificial intelligence, emergent computation, and real-time knowledge-based processing. Formerly a Director's Fellow at the Center for Nonlinear Studies and Computing Division at Los Alamos National Laboratory, Forrest is a member of the editorial board of the *Journal of Experimental and Theoretical Artificial Intelligence*. She was a member of the Logic of Computers Group at the University of Michigan and has been a visiting researcher at Bell Laboratories and USC's Information Sciences Institute.

Christopher Langton is a Staff Member in the Complex Systems Group in the Theoretical Division at Los Alamos National Laboratory and a former postdoctoral fellow at the LANL Center for Nonlinear Studies. A co-organizer of two international conferences on Artificial Life and editor of *Artificial Life: Proceedings of an Interdisciplinary Workshop on Synthesis and Simulation*, Langton's areas of technical specialization are cellular automata and artificial life. Langton received his Ph.D. in Electrical Engineering and Computer Science from the University of Michigan, where he held Graduate Research Assistant and Teaching Assistant appointments.

Staff News

Diane Banegas, Executive Assistant at the Institute, has taken a position as Public Information Specialist in the Public Affairs Office at Los Alamos National Laboratory.

Ronda Butler-Villa, Director of Publications at SFI, and her husband Roland have a new daughter, Sara Margaret, born in September, 1990.

Down the Old Pecos Trail

Since 1987 the former Cristo Rey Convent in the historic eastside of Santa Fe has been home to the Institute. This uniquely charming site has nearly perfectly suited the Institute's needs during its past three years of rapid growth. Now, however, due to its burgeoning residential research programs and flux of visitors, SFI is virtually bursting at the seams, with unstored cartons of books lining the corriders, and one makeshift staff office set up in a hallway between offices. These space contraints, along with the need of the Archdiocese of Santa Fe, the owners of the building at 1120 Canyon Road, to reoccupy the building because of their space needs, means that the Institute will have a new campus beginning in late June, 1991.

The Institute has leased former law offices at 1850 Old Pecos Trail and anticipates occupying a building in this compound for the next several years while plans for a permanent campus proceed. The new interim facilities will give SFI much-needed additional office space which is conveniently located between downtown Santa Fe and the St. Michael's Drive commercial district. Like our current arrangement, the new complex features both conference meeting space and research and staff offices; in addition there will be substantially more library space—and convenient parking. Look for an update on the move in the next issue of the Bulletin.

SFI Community News

Science Board member **Brian C. Goodwin** is 1990–1991 Academic Director of the International Honors Program at the Open University, United Kingdom. The program "Global Ecology: Integrating Nature and Society" involves research and travel in India, Thailand, Malaysia, New Zealand, Colombia, and Mexico.

Siegfried Hecker, Director of Los Alamos National Laboratory and SFI Science Board Member, has been awarded the prestigious AIME James O. Douglas Gold Medal Award.

External Faculty and Science Board member **John Holland**, Professor of Computer Science, Engineering, and Psychology at the University of Michigan recently delivered lectures at the Wharton School and at the Institute for Advanced Study at Princeton University. Holland during the past year has been instrumental in establishing the growing Santa Fe Institute/University of Michigan academic collaboration.

Christoph von der Malsburg, a member of the SFI Science Board, is in the process of establishing an institute for neuro-information at Ruhr University in Bochum, Germany. The Institute will stand as an independent research unit, separate from the established schools at the university.

Science Board member, **Theodore Puck,** Director of the Eleanor Roosevelt Cancer Institute, has received an "Honored Member" Appointment to *1990 Who's Who Worldwide* "for outstanding achievement in your profession and for the betterment of contemporary society."

Science Board member **Louis Rosen**, Senior Fellow Emeritus at Los Alamos National Laboratory, is at work planning another major international conference, this one to focus on the use of energy sources in ways to mitigate environmental problems. The program which will be sponsored by the laboratory will take place in Santa Fe in Fall, 1991.

Gérard Toulouse, Laboratoire de Physique de L'ENS, has been elected to the French Academy of Sciences. Toulouse is a member of the SFI Science Board.

Harry L. Swinney, Trull Centennial Professor at the University of Texas, Austin, and SFI Science Board member, has been appointed to the Third Sid W. Richardson Regents Chair in Physics at the University of Texas.

A note about publications: Aside from work appearing as Santa Fe Institute working papers, see page 24, members of the SFI community have, of course, authored many papers and books appearing in 1990. The list of such publications is too long to appear here.

1991 Scientific Meetings

JAN 11-17	**Learning in Economics, Psychology and Computer Science: An Exchange of Ideas** Brian Arthur, Stanford University Richard Herrnstein, Harvard University John Holland, University of Michigan
FEB 13-17	**New Technologies for Prediction and Pattern Recognition: Applications to Financial Markets** John Geanakoplos, Yale University David Lane, University of Minnesota
FEB 16-20	**DOE Human Genome Contractors and Grantees Markets** Sylvia Spengler, University of California at Berkeley
MAR 9	**Science Board Symposium**
APR 3-8	**Learning, Rationality, and Games** John Geanakoplos, Yale University David Lane, University of Minnesota
MAY 13-17	**Third Waddington Meeting on Theoretical Biology** Brian Goodwin, The Open University, England Stuart Kauffman, University of Pennsylvania Francisco Varela, CREA, Ecole Polytechnics, France Lewis Wolpert, The Middlesex Hospital Medical School, England
MID-MAY	**Increasing Returns** Brian Arthur, Stanford University David Lane, University of Minnesota
MID-MAY	**The Emergence of Market Structure** John Geanakoplos, Yale University David Lane, University of Minnesota Martin Shubik, Yale University
JUN 2-29	**Complex Systems Summer School** Lynn Nadel, University of Arizona Dan Stein, University of Arizona
JUN 8-9	**Price Dynamics and Trading Strategies in Double Auction Markets II** Dan Friedman, U.C. Santa Cruz John Geanakoplos, Yale University John Rust, University of Wisconsin
LATE SPRING	**Theoretical Computation in the Social Sciences** Michele Boldrin, Northwestern University John Miller, Carnegie Mellon University
AUG 19-23	**Society of Mathematical Biology Meeting** Stuart Kauffman, University of Pennsylvania
SEPT	**Neuron Model Complexity** Wilfred Rau, NIH Rall
OCT	**Theoretical Immunology Meeting** Alan Perelson, Los Alamos National Laboratory

See Summer School ad on page 27.

Interview

Order Out of Chaos

"In the beginning I did payroll and paid the light bill."

SFI Comptroller Marcella Austin remembers her job in 1985 when she worked one day a week to do a little clerical bookkeeping. The rest of the Institute's accounting functions were then managed in Albuquerque by SFI's former treasurer Arthur Spiegel.

Spiegel, who continues to serve on the Board of Trustees, and accounting consultant Tom Cook, formerly President of the Zia Company, donated their financial expertise in setting up SFI's accounting department.

Executive Vice President Mike Simmons says the founding scientists relied heavily on both men to transform their dream of a scientific institute into a functioning fiscal reality.

"I read a book on accounting for laymen and George Cowan had banking experience, but Tom, with Marcella's assistance, really got the day-to-day accounting operations running smoothly," Simmons says.

By 1988, it seemed obvious to SFI's management and growing staff that an on-site bookkeeping office had become a necessity. So Austin joined the Institute as a full-time financial assistant and Cook continued to donate his consulting services, as he does to this day.

"Few people realize how much Tom has contributed to the Santa Fe Institute," Austin says. "He keeps a low profile, but he's always available if I have a question or need help on a project." She adds that those times are less frequent today than in 1988 and credits Cook with helping her achieve her present status as SFI's Comptroller. "I consider him my mentor," she says.

Austin's responsibilities have grown as dramatically as the Institute's yearly operating budget—from $77,259 in 1984 to more than $1.8 million in 1990. She illustrates her expanding duties another way: "The Institute had a one-page proposed budget for 1987 and a 25-page proposed budget for 1991."

SFI is currently funded by governmental grants, private foundations, corporations, and individuals. The paperwork that accompanies the money ranges from simple to exceedingly complex.

"A donation from an individual requires a letter from the donor stating how and when the money can be used," Austin notes. "A receipt and return letter from Susan Wider, Director of Development, acknowledges the gift."

Government grants, on the other hand, require a lot of monitoring on a lot of different levels. This monitoring includes quarterly and yearly reports, a final report when the grant ends, compliance with Federal regulations, and occasional visits from agency auditors. The tracking of funds is endless. For example, money designated for equipment and staff support cannot go above the designated ceiling. Also, money earmarked for a specific program cannot exceed the projected amount.

Austin says all restricted funds, government or otherwise, require tracking. She meets daily with Ginger Richardson, Director of Programs, to ensure that research goals are on track with available funding. When discrepancies arise—for instance, a workshop budget that exceeds allocated funding—George Cowan and Mike Simmons decide if and how the Institute should make up the difference.

"They make the decisions," Austin says. "It's my job to keep them informed and carry out their wishes." (The Science Board gives its funding recommendations during yearly board meetings. All budget decisions are made in compliance with board recommendations.)

All unrestricted funds go into a pool that supports SFI's overhead as well as research. "Unrestricted funds are the easiest to manage," she says. "They are also the hardest to solicit."

Marcella Austin. Photo by Randall West © 1991.

Unlike visiting researchers, who relish SFI's interdisciplinary focus and lack of bureaucratic red tape, Austin says her position is defined by red tape. Because of grant restrictions, IRS regulations, tracking requirements, and basic accounting procedures, the SFI accounting office is as structured and regimented as the budget office of any traditional university.

Red tape and other irritants aside, Austin says her position at the Institute has given her a rare opportunity for professional growth. "When I realize how much the job has evolved into and how much I've learned, I feel lucky to have been in the right place at the right time," she says.

Austin's pride in her work is validated by the reports of her colleagues. Santa Fe accounting firm Barraclough and Associates conducts a yearly audit of the Institute's books and prepares the financial statement for the Internal Revenue Service. No accounting errors were uncovered during last year's audit. The Institute also came through a recent audit by the National Science Foundation with flying colors.

Austin looks to the future of the Institute and welcomes the additional challenge that will certainly befall her position.

—Diane Banegas

Before taking a writing position in the Public Affairs Office at Los Alamos National Laboratory, Diane Banegas was the SFI Executive Assistant.

Bio-Matrix Society Forms

The Matrix of Biological Knowledge (Bio-Matrix) project, which began with a 1987 Santa Fe Institute workshop, addresses the pressing need to organize, intelligently access, and make available widely the wealth of biomedical information confronting researchers. At a minimum, this entails identifying and coordinating access to the proliferating biomedical databases. More prospectively, the Bio-Matrix project seeks to codify the laws, empirical generalizations, and physical foundations of biomedical knowledge; integrate analytical tools into knowledge-based management systems; and support reasoning mechanisms—in particular reasoning by analogy and homology—over the biological domain.

To date, the project—which has drawn interest from researchers across the country—has been loosely knit by means of the Bio-Matrix electronic bulletin board, by a BioMatrix newsletter, and by means of a series of nearly annual meetings and workshops focusing on various topics within the BioMatrix domain. The project has several nodes: George Mason University with BioMatrix founder Professsor Harold Morowitz (SFI Science Board); the University of Houston where Dan Davison runs the Biomatrix archive server; and the Santa Institute, fiscal and administrative home to the project.

During early 1991, the project anticipates the formal establishment of a national Biomatrix Society. To that end an Executive Committee has been appointed; members are Robert Bolender, University of Washington; Lindley Darden, University of Maryland; Dan Davison, University of Houston; Peter Karp, National Library of Medicine; Lawrence Hunter, National Library of Medicine; Harold Morowitz, George Mason University; and Christian Overton, Unisys, Paoli, Pennsylvania.

Additional information can be obtained through e-mail to Dan Davison davison@uh.edu.

Marcella at Home

Self-sufficiency, independence, and the undauntable willingness to take on any task are among the characteristics acquired by SFI Comptroller Marcella Austin from childhood. These traits have been essential to her career at SFI where she is a one-woman financial management department. Marcella grew up in southeastern Colorado and northern New Mexico in a totally self-sufficient, back-to-nature family where carrying water, chopping wood, growing vegetables and raising animals were a normal part of life. So were the recreations of a largely bygone era: reading, hunting, fishing, raising falcons, ice skating and sledding. It was an environment envied by school friends who were always eager to visit. In a home without electricity, television was not an option, so the monthly visits of the bookmobile were a cherished opportunity and all seven members of the family took the maximum number of books.

The independence learned in childhood continued. Marcella was financially independent at age 15, working fulltime to put herself through high school in Denver. By the time she graduated she had become an essential employee of the restaurant that employed her, keeping the books, ordering the wine, and running the wine bar. As those involved in the SFI finances know well, she is good at making herself indispensible.

Whatever the job may be, Austin is willing to take it on. At home she is equally adept at splitting firewood and using a hunting rifle in an elk hunt. At the SFI she deals with equal facility with IRS regulations, the details of the retirement program, and the arcane requirements of government funding regulations.

Fortunately, for the financial operation of the SFI, Marcella is also a fanatic about completing any task she takes on. Whether she is laying flagstones at night by spotlight as a home-improvement surprise for her husband or working late at the Institute to prepare a budget for presentation to the Board, Marcella spares no effort to complete the job.

Adaptive Molecular Evolution

(continued from page 5)

integration of symbiotic partners. In full mathematical rigor the *Co-Evolution Scenario* is compatible with the notion of fitness landscapes only in exceptional cases. Based on intuition and numerical simulation, Stuart Kauffman has suggested a model which visualizes co-evolution as a superposition of processes on different time scales: a dynamics of *slow change* of landscapes for individual species is superimposed to a *fast optimization* taking place on the landscapes. Together they formulated a research project on the dynamics of co-evolution with the goal of deriving precise expressions for the range of validity of the landscape concept. They plan to develop mathematical tools which allow to introduce realistic landscapes into the *Co-Evolution Scenario* wherever it proves useful and provides new insights into biology.

—Peter Schuster

Schuster was a Visiting Professor at SFI in 1990. He is Head of the Computer Center at University of Vienna. He will return to the Institute as Visiting Professor in the fall of 1991.

The Printed Word

Editorial Board Changes

Members of the Editorial Board are selected by the SFI President from the Board of Trustees, Science Board, and External Faculty. Nominations are made by these boards, the Editorial Board, and the publisher. The Editorial Board plays a vital role in the development of the publications program which has grown impressively over the last three years. Three new members were welcomed in late 1990:

Michele Boldrin, an External Assistant Professor since 1988, is currently Associate Professor at Managerial Economics and Decision Sciences, Northwestern University. He has also been Assistant Professor at the University of California at Los Angeles; Visiting Professor at the Universitat Autonoma de Barcelona and Universitá Commerciale "L. Bocconi"; and Instructor at the University of Chicago, Nazareth College, and the University of Rochester. A participant in the SFI Economics Research Program, Dr. Boldrin received his Ph.D. in Economics from the University of Rochester in 1987. He is an Associate Editor for *Cuadernos Economicos* (Madrid), and has authored two books and numerous articles. He was in residence at SFI in the Spring of 1990.

Harry Swinney, an SFI Science Board Member since 1987, is the Regents Chair for the Sid Richardson Foundation and Director of the Center for Nonlinear Dynamics at the University of Texas at Austin. He received his Ph.D. in Physics from Johns Hopkins University in 1968. Author of more than 80 scientific papers and presenter of more than 140 invited talks, he was Peyton Nalle Rhodes Lecturer at Rhodes College (1987); Halliburton Distinguished Lecturer, Texas Tech University (1987); Hudnall Lecturer, University of Chicago (1984); and Morris Loeb Lecturer, Harvard University (1982). Inducted into the Johns Hopkins Society of Scholars in 1984, he is also a Fellow of the American Physical Society. He was Editor of *Physica D–Nonlinear Dynamics* from 1982 to 1986.

We thank retiring Editorial Board members Robert McCormick Adams, Philip Anderson, and George Bell for their contributions during their terms on the board. They will continue in an advisory capacity, providing their professional expertise to review books in areas relevant to their own research.

New in Print

The first of our Lecture Notes Volumes, entitled *Introduction to the Theory of Neural Computation* was published in the fall of 1990. Drs. John Hertz, Anders Krogh, and Richard Palmer have written a comprehensive introduction to the neural network models currently under intensive study for computational applications. It is a detailed, logically developed treatment that covers the theory and uses of collective computational networks, including associative memory, feed forward networks, and unsupervised learning. It also provides coverage of neural network applications in a variety of problems of both theoretical and practical interest. The book is based on a course on advanced topics in statistical mechanics taught at Duke University.

Dr. Gérard Weisbuch wrote the second volume in this Lectures Notes series entitled *Complex Systems Dynamics*. This book introduces readers to a rich array of tools and concepts that are central to understanding and modeling complex systems. Its goal is to introduce this research field and provide an understanding of its methods and concepts as well as its many varied fields of application. Designed as a comprehensive introduction for all students, researchers, and professionals with an interest in the sciences of complexity, the book draws its examples from the physics of disordered systems, neural networks, theoretical immunology, origins of life, and signal processing and the design of parallel computers. This volume was originally published as *Dynamique des système complexes: Une introduction aux réseaux d'automates* (InterEditions/Editions du CNRS, 1989) and was translated into English by Sylvie Ryckebusch.

Augmenting our proceedings volume series, Alan S. Perelson and Stuart A. Kauffman have compiled the proceedings of the workshop on Applied Molecular Evolution and the Maturation of the Immune Response in a volume entitled *Molecular Evolution on Rugged Landscapes: Proteins, RNA and the Immune System.* Rugged fitness landscapes, an emerging concept in biological science, underlie both molecular and morphological evolution. Mathematical descriptions of such landscapes can be expected to lead to new experimental studies that actually test and establish their structure. In addition, current experimental techniques now allow one to carry out applied molecular evolution in the laboratory, opening up the possibility of evolving biomolecules for medical and industrial use. This volume is the first book to serve as a comprehensive introduction to these tools.

In Production

Lynn Nadel and Daniel Stein are editing the lectures from the third Complex Systems Summer School held in Santa Fe. This volume is entitled *1990 Lectures in Complex Systems*, available May 1991. In addition to faculty lectures, the volume will include student contributions from seminars presented at the school.

Artificial Life II is the proceedings of the second Artificial Life workshop held in New Mexico. Coordinators J. Doyne Farmer, Christopher Langton, Steen Rasmussen, and Chuck Taylor reviewed more than 50 papers and selected 27 containing mostly new and original research for inclusion in this proceedings volume, available May 1991. It will be a welcomed follow-up to the successful *Artificial Life* edited by Christopher Langton and published in 1989.

The Evolution of Human Languages proceedings volume is almost ready for printing. Edited by Jack Hawkins and Murray Gell-Mann, this volume aims within each chapter to first integrate the specialist material of each contributor's presentation with the themes of the workshop and with relevant material presented by others and then technically cover the topic in detail. Available next summer, this volume should be of interest to linguists as well as anyone interested in complex adaptive systems.

In the Queue

Edited by A. B. Baskin and J. E. Mittenthal, *Principles of Organization in Organisms* is the proceedings from last summer's workshop of the same title. Workshop participants sought principles of organization—compact summaries of structural patterns—and a dynamical theory, for the design and organization of adaptive systems, which should generate observed patterns of structure and should predict patterns not yet seen. This volume will present a status report on the search for natural pathways, principles of organization, and the theory of design and try to capture, as well as is possible in a linear sequence, the extraordinary richness of the web of ideas that the participants wove during the workshop. This volume should be available Fall, 1991.

Entitled *Nonlinear Modeling and Forecasting* and edited by Martin Casdagli and Steven Eubank, this proceedings volume will cover the September, 1990 workshop of the same title. For more information, see page 6 in the Program Review sections of this Bulletin.

—Ronda K. Butler-Villa

SFI Working Papers Series

Getting the Word Out

"A Double Auction Market for Computerized Traders," John Rust, Richard Palmer, and John H. Miller, 89-001.

"Communication, Computability and Common Interest Games," Luca Anderlini, 89-002.

"The Coevolution of Automata in the Repeated Prisoner's Dilemma," John H. Miller, 89-003.

"Money as a Medium of Exchange in an Economy with Artificially Intelligent Agents," Ramon Marimon, Ellen McGrattan, and Thomas J. Sargent, 89-004.

"The Dynamical Behavior of Classifier Systems," John H. Miller and Stephanie Forrest, 89-005.

"Nonlinearities in Economic Dynamics," José A. Scheinkman, 89-006.

"'Silicon Valley' Locational Clusters: When Do Increasing Returns Imply Monopoly?" W. Brian Arthur, 89-007.

"Mutual Information Functions of Natural Language Texts," Wentian Li, 89-008.

"Learning by Genetic Algorithms in Economic Environments," Jasmina Arifovic, 90-001.

"Optimal Detection of Nonlocal Quantum Information," Asher Peres and William K. Wootters, 90-002.

"Artificial Life: The Coming Evolution," J. Doyne Farmer and Alletta d'A. Belin, 90-003.

"A Rosetta Stone for Connectionism," J. Doyne Farmer, 90-004.

"Immune Network Theory," Alan S. Perelson, 90-005.

"Protein Evolution of Rugged Landscapes," Catherine A. Macken and Alan S. Perelson, 90-006.

"Evolutionary Walks on Rugged Landscapes," Catherine A. Macken, Patrick S. Hagan, and Alan S. Perelson, 90-007.

"Transition Phenomena in Cellular Automata Rule Space," Wentian Li, Norman H. Packard, and Chris Langton, 90-008.

"Absence of 1/f Spectra in Dow Jones Daily Price," Wentian Li, 90-009.

"Economic Life on a Lattice: Some Game Theoretic Results," R. A. Cowan and J. H. Miller, 90-010.

"Algorithmic Chemistry: A Model for Functional Self-Organization," Walter Fontana, 90-011.

"Expansion-Modification Systems: A Model for Spatial 1/f Spectra," Wentian Li, 90-012.

"Coevolution of the Edge of Chaos: Coupled Fitness Landscapes, Poised States, and Coevolutionary Avalanches," Stuart A. Kauffman and Sonke Johnsen, 90-013.

"A Short Summary of Remarks at the Meeting at the Santa Fe Institute on 'Paths Toward A Sustainable Human Society,'" George A. Cowan, 90-014.

"On The Application of Antiferromagnetic Fermi Liquid Theory to NMR Experiments on $YBa_2Cu_2O_{6.6,3}$. " H. Monien, D. Pines, and M. Takigawa, 90-015.

"On The Application of Antiferromagnetic Fermi Liquid Theory on NMR Experiments in $La_{1.85}Sr_{0.15}CuO_4$." H. Monien, P. Monthous, and D. Pines, 90-016.

"Size and Connectivity as Emergent Properties of a Developing Immune Network," Rob J. De Boer and Alan S. Perelson, 90-017.

"Game Theory Without Partitions, and Applications to Speculation and Consensus," John Geanakoplos, 90-018.

"*Drosophila* Segmentation: Supercomputer Simulation of Prepattern Hierarchy," Axel Hunding, Stuart A. Kauffman, and Brian C. Goodwin, 90-019.

"Random Grammars: A New Class of Models for Functional Integration and Transformation in the Biological, Neural, and Social Sciences," Stuart A. Kauffman, 90-020.

"Visions of a Sustainable World," Murray Gell-Mann, 90-021.

"Mutation in Autocatalytic Reaction Networks," Peter F. Stadler and Peter Schuster, 90-022.

"Novel Perturbation Expansion for the Langevin Equation," Carl Bender, Fred Cooper, Greg Kilcup, L. M. Simmons, Jr., and Pinaki Roy, 90-023.

"Mutual Information Functions versus Correlation Functions," Wentian Li, 90-024.

"A Relation Between Complexity and Entropy for Markov Chains and Regular Languages," Wentian Li, 90-025.

"A Learning Algorithm that Mimics Human Learning," W. Brian Arthur, 90-026.

"Localized Memories in Idiotypic Networks," Gérard Weisbuch, Rob J. De Boer, and Alan S. Perelson, 90-027.

"Pattern Formation in One- and Two-Dimensional Shape Space Models of the Immune System," Rob J. De Boer, Lee A. Segel, and Alan S. Perelson, 90-028.

"Phenomenology of Non-Local Cellular Automata," Wentian Li, 91-01-001.

"Generating Non-Trivial Long-Range Correlations and 1/f Spectra by Replication and Mutation," Wentian Li, 91-01-002.

"Can Evolutionary Dynamics Explain Free Riding in Experiments?" John H. Miller and James Andreoni, 91-01-003.

"Auctions with Adaptive Artificially Intelligent Agents," James Andreoni and John H. Miller, 91-01-004.

"A Comparison of Some Variational Strategies used in Field Theory," Fred Cooper, H. F. Jones, and L. M. Simmons, Jr, 91-01-005.

"Simple Technical Trading Rules and the Stochastic Properties of Stock Returns," William Brock, Josef Lakonishok, and Blake LeBaron, 91-01-006.

"Attractor Reconstruction from Event-Related Multi-Electrode EEG-Data," Gottfried Mayer-Kress, Cathleen Barczys, and Walter J. Freeman, 91-01-007.

"Embedology," Tim Sauer, James A. Yorke, and Martin Casdagli, 91-01-008.

"Some Theory for Statistical Inference for Nonlinear Science," William A. Brock and Ehung G. Baek, 91-02-009.

"Dynamic Externalities, Multiple Equilibria and Growth," Michele Boldrin, 91-02-010.

"Adaptation on Rugged Landscapes Generated by Local Interactions of Neighboring Genes," Marc Lipsitch, 91-02-011.

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Tom Ainsworth	*Texas A&M University*
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Arthur H. and Libby Spiegel, Albuquerque, NM
J. I. Staley, Wichita Falls, TX
The Estate of Paul Stein, Los Alamos, NM
Anthony Turkevich, Chicago, IL
Philip F. and Mimi Voegelin, Santa Fe, NM
Henry and Mary C. Wider, Albuquerque, NM
Susan Wider, Albuquerque, NM

Announcements

In addition to the summer school ad, the SFI publishes two announcements on this page as a courtesy to the organizers or publisher. SFI is not a co-sponsor of these projects.

See page 19 for a list of 1991 SFI Scientific Meetings.

Call for Papers

Journal of Social and Biological Structures

Under new editorialship and publisher

The *Journal of Social and Biological Structures* is an interdisciplinary quarterly concerned with the unity, analogy, and relationships, theoretical and practical, between biological dynamics and mechanisms such as evolution, natural selection, and individual development, and social activities including technology, economics, politics, ideologies, literature, art, customs, and culture. As such, the *Journal* seeks to help elucidate the human place in the cosmos.

Your contribution must be submitted on an MS-Dos or MAC disk, in ASCII (unformatted) form, as well as on three copies of double-spaced paper with one-inch margins. Queries regarding style, contact:

Elias L. Khalil
Assistant Editor
Economics Department
Ohio State University
1680 University Drive
Mansfield, OH 44906.

Please send submissions to:

Paul Levinson
Editor-in-Chief
Connected Education, Inc.
92 Van Cortlandt Park South #6f
Bronx, NY 10463.

Call for Papers

1st Workshop of the Principia Cybernetica Project:

Computer-supported cooperative development of an evolutionary-systemic philosophy

July 2-5, 1991,
Free University of Brussels, Belgium

Organized by: The Principia Cybernetica Editorial Board of the Transdisciplinary Research Group

Workshop Topics

- Supporting Technology
- Semantic and Conversational Systems
- Constructive Epistemology
- Evolutionary Ethics
- Process Metaphysics

Submission of Papers

For submissions of abstracts, or further information, contact:

- Francis HEYLIGHEN
  PESP, V.U.B., Pleinlaan 2
  B-1050 Brussels, Belgium.
  Tel. +32-2-641 25 25
  Fax +32-2-641 22 82
  Email:
  Z09302@BBRBFUOI.BITNET
- Cliff JOSLYN
  Systems Science, SUNY Binghamton
  6 Garfield Ave. # 2
  Binghamton, NY 13905, USA.
  Email:
  cjoslyn@bingvaxu.cc.binghamton.edu

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Gordon Pask (London)

School

1991 Complex Systems Summer School

June 2–29, 1991 in Santa Fe, New Mexico

The school is intended to provide graduate students and postdoctoral scientists with an introduction to the study of "complex" behavior in mathematical, physical, and living systems. The four-week program includes course lectures together with seminars and computer workshops. Individual/group research projects are encouraged. Students are expected to have graduate-level training in one of the mathematical, physical, biological, or information sciences.

Course Lectures

Gail Carpenter, *Center for Adaptive Systems, Boston University:* neural networks for adaptive pattern recognition
Predrag Cvitanovic, *NORDITA:* chaos
Bernardo Huberman, *Xerox Palo Alto Research Center:* the ecology of computation
Christopher Langton, *Los Alamos National Laboratory:* artificial life
George Mpitsos, *Mark O. Hatfield Marine Science Center:* chaos and other forms of variability in self-organizing adaptive systems
Fred Nijhout, *Zoology, Duke University:* pattern formation in animals; reaction diffusion simulations
James Sethna, *Physics, Cornell University:* complex liquids and solids
Carla Shatz, *Neurobiology, Stanford University:* neural activity and pattern formation during visual system development
Michael Shlesinger, *Office of Naval Research:* noise, fractals, and scaling
Sara Solla, *AT&T Bell Laboratories, Holmdel:* statistical mechanics of neural networks
Nicholas Strausfeld, *Arizona Research Laboratory Division of Neurobiology, University of Arizona:* neural basis of vision in insects
David Tank, *AT&T Bell Laboratories, Murray Hill:* oscillations in invertebrate and vertebrate olfactory systems

Co-Directors

Lynn Nadel and Daniel Stein, *University of Arizona*

Support

Students will be supported with housing, meals and travel funds as necessary, subject to funding availability. No tuition fees.

Contact

Andi Sutherland, Santa Fe Institute, 1120 Canyon Road Santa Fe, NM 87501; (505)984-8800; (505)982-0565 fax

summerschool@sfi.santafe.edu

Extended Deadline: Mar. 1, 1991

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