

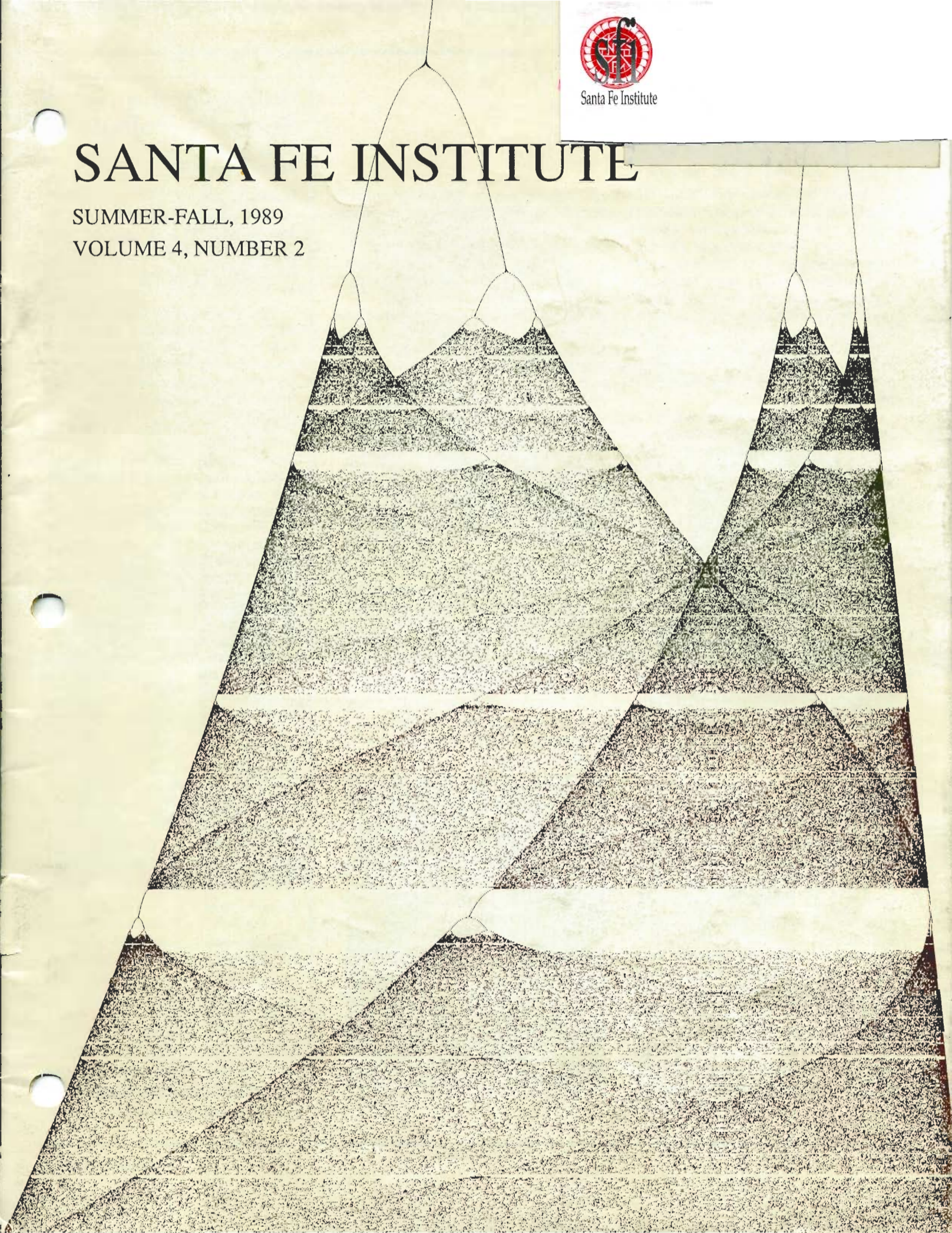


Santa Fe Institute

SANTA FE INSTITUTE

SUMMER-FALL, 1989

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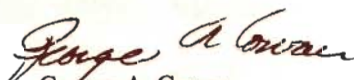
President's Message

During the past six months the calendar of SFI activities for workshops and research programs on a variety of complex, adaptive systems has expanded. The topics range across the entire spectrum of complexity, from the physical sciences, through the life sciences, and into the social sciences. As we have noted frequently, this breadth is necessary to help us identify the features that complex systems share. The commitments of time that are being made by our external faculty testify to the intellectual challenge and appeal of the approach we are taking to the study of complexity.

It is becoming increasingly clear that essentially all complex, adaptive systems are designed to process information. They are equipped to gather information from their external environments and to react to it or store it internally in a compressed form and to retrieve it when necessary. Their dynamics can differ greatly. Adaptive behavior can occur quickly in a given organism or it may evolve over generations by survival of the fittest.

As we have begun to examine the problems associated with sustaining a desirable human society, we find it useful to consider how this extremely complex system performs as an information-processor. There is an increasing torrent of information available worldwide in almost real time which appears to create a need for selection, processing, and response on a scale much grander and within times much shorter than anything we have experienced in the past. Where and how competently and how coherently are these functions presently being performed? Presumably the source and nature of our responses will affect the prospects for the continued survival of a desirable human world.

Perhaps we should take the rather forgiving view that an invisible hand can best guide the operation of a system that is so complex that it is essentially unknowable to the human mind and unmanageable by people. At SFI we prefer to favor a much more difficult view, that we can hope to speed the necessary processes and to shorten the path toward desirable change. The invisible hand may prove to be better designed to protect the planet than the human race. If we fail to achieve sufficient wisdom, we should not assume that nature will refrain from painful and even catastrophic remedies to protect itself from the threats posed by one of its less successful inventions.


George A. Cowan

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Bulletin of the Santa Fe Institute

Volume 4, No. 2
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The Bulletin of the Santa Fe Institute is published biannually by SFI to keep our friends and supporters informed about the scientific and administrative programs. The Bulletin is free of charge and may be obtained by writing to the Editor, 1120 Canyon Road, Santa Fe, New Mexico 87501.

The Santa Fe Institute is a multidisciplinary scientific center formed to nurture deeper examination of complex systems and their simpler elements. A private, independent institution, SFI was founded in 1984.

Its primary concern is to focus the tools of traditional disciplines and emerging new computer resources on the problems and opportunities that are involved in the multidisciplinary study of complex systems—those fundamental processes that shape almost every aspect of human life and experience.

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Our Common Future (Oxford University Press, 1987) is the title given to the final report to the United Nations of The World Commission on Environment and Development, an independent body created by the U.N. in 1983. The Commission was presented with a mandate to re-examine the critical issues of environment and development. These include the need to strengthen international cooperation; to formulate innovative, concrete, and realistic proposals to deal with the issues; and to raise the level of understanding and commitment on the part of all contributors to the implementation of constructive policies. The report was issued in 1987 and quickly became a best-seller. It has been reprinted eight times to date.

The Commission was organized a little over five years ago under the chairmanship of Mrs. Gro Harlem Brundtland of Norway and the vice-chairmanship of Mr. Mansour Khalid of the Sudan. Jim McNeil of Canada was appointed to serve as Secretary General. Twenty additional members were selected, their origins reflecting a stipulation by the United Nations that at least half would come from the third world. Extended meetings, site visits, and public hearings were held over a period of two years in Indonesia, Norway, Brazil, Canada, Zimbabwe, Kenya, Russia, and Japan. Funding was provided by the governments of Canada, Denmark, Finland, Japan, the Netherlands, Norway, Sweden, and Switzerland, all of them sponsors of the authorizing resolution. Additional funds were provided by Cameroon, Chile, the Federal Republic of Germany, Hungary, Oman, Portugal, Saudi Arabia, the Ford Foundation, and the John D. and Catherine T. MacArthur Foundation. The list of sponsors illustrates the nature and breadth of the international support of this study.

The Chairman's foreword emphasizes the importance of the Commission's responsibility to propose "long-term environmental strategies for achieving sustain-

able development by the year 2000 and beyond." The rest of its agenda is concerned with establishing the facts and exploring ways to make its views globally acceptable and implementing its recommendations. Thus, the report serves as a text on two rather different subjects, the one dealing with facts, problems, and suggested remedies, and the other with strategies to promote effective action at policy-making levels.

At the Santa Fe Institute, where the central theme is the study of the sciences of complexity, it is immediately evident that *Our Common Future* deals with one of the most complex topics in the hierarchy of complexity. Very complex systems are created of parts which are themselves complex and composed, in turn, of smaller parts. The immediately underlying and inextricably connected complex parts of the system that shapes the environmental future of our planet include the global economy and its energy and material needs; population growth and human health and behavior; political governance and the perceived security needs of nation-states, including the potential for and barriers against major wars; ecological and geophysical factors; cultural, ideological, and informational factors; the exponential growth of science and communication; and the erosion of national autonomy by a wealth of aggregative, dissipative, and homogenizing forces.

Although it is impossible to deal with such a topic in a truly comprehensive way, the scope of this report is probably greater than has been previously attempted. Obviously, it raises more questions than it can possibly answer and cannot avoid oversimplification and omission. It begins with the observation that sustainable development means "meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life. Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for

long-term sustainability. Yet many of us live beyond the world's ecological means, for instance in our patterns of energy use."

The global economy is given top billing. The report says "the ability of a government to control its national economy is reduced by growing international economic interactions...if economic interests and the benefits of trade were more equally distributed, common interests would be generally recognized.... The Commission's overall assessment is that the international economy must speed up growth while respecting the environmental constraints." It goes on to discuss how this might be done. The chapter on this subject ends with the statement that new dimensions of multilateralism are needed and that the mutual interests involved in the issues of environment and development can help secure the necessary international economic changes that will make it possible.

On population, the report states, "Present rates of population growth cannot continue." What solutions are offered? We are advised that sustainable economic growth and equitable access to resources are two of the more certain routes towards lower fertility rates. Following this statement is the observation that "giving people the means to choose the size of their families is not just a method of keeping population in balance with resources; it is also a way of assuring—especially for women—the basic human right of self-determination." It is interesting to speculate about the nature of the discussion that determined the order of these statements and the careful positioning of the sexes on the issue of population control.

Concerning human nutrition and food needs, it attacks the farm subsidy policies of the United States and Europe and favors new technology in developing countries, greater attention to the role of women farmers, particularly in sub-Saharan Africa, agricultural practices that preserve the soil, and a shifting of em-

phasis away from global distribution of food surpluses and toward greater production in food-deficit countries. With respect to government interventions, it points out that in most developing countries incentives favor the urban dweller and are limited to a few crops. The incentives must be restructured to promote farming practices that conserve and enhance the agricultural resource base.

The report devotes three chapters to discussions of protection of the ecosystem and the diversity of species, to world energy needs (with the unqualified conclusion that a low energy path is the best way towards a sustainable future), and to an analysis of industrial practices and problems and the "urban revolution." These chapters underline the complexity of the problem of sustainability but are not among the book's strongest features. The energy problem is central. The examination of the various options for meeting the world's energy needs is reasonably comprehensive and provides the second longest chapter in the book. But, in the end, the analysis fails to deal with many important issues. On the major issue of nuclear energy, the discussion concludes with the assertion that the generation of nuclear energy can be justified only if there are solid solutions to its associated problems and that highest priority must be given to all economically and environmentally viable alternatives together with research and development on means to increase the safety of nuclear energy.

One of the most interesting parts of this report are its final three chapters on "Managing the Commons," "Peace and Security," and "Institutional and Legal Change." The recurring themes here are the increasing challenge to national sovereignty and the need for multilateral action by the international community. The problem is illustrated by a discussion of the management of the oceans, space, and Antarctica. The report notes that: "The nation state is insufficient to deal with

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threats to shared ecosystems. Threats to environmental security can only be dealt with by joint management and multilateral procedures and mechanisms."

Academic fact-finding groups are usually not particularly attentive to problems of implementation. This Commission was not highly academic.

It is clear throughout this book that it viewed its role more broadly. The responsibility to propose new policies is addressed in the final and longest chapter. It calls for focusing on the sources of policy change and displays the politician's awareness of the anatomy of power. It discusses the need to enlarge the statutory responsibility of agencies with money to include social responsibilities and enforcement duties rather than separating fiscal power from regulatory power. It proposes that the international legal framework be strengthened. It suggests that governments establish foreign policies for the environment and defines appropriate roles for the

many bilateral and multilateral bodies dedicated to an enormous variety of regional problems. It pays particular attention to the unique responsibilities of the United Nations and suggests an expanded role for the scientific community and non-governmental organizations (NGO's). Finally it turns its attention to contributions that might be made by industry, banks, and private investment. All of these topics might well be expanded into a fascinating new book. I feel that the authors are more authoritative on the paths to policy-making than on some of the earlier topics where the bare facts and political doctrine occasionally get entangled.

This book makes real contributions to a thinking person's insights into almost every conceivable global security issue, all subsumed under the rubric of a sustainable world. It is must reading for those concerned with global security and the world's future.

—George Cowan

Lectures in the Sciences of Complexity

"Complexity is almost a theological concept," observes Daniel Stein, editor of SFI's newest book *Lectures in the Sciences of Complexity* (SFI Studies in the Sciences of Complexity, Lectures Volume 1, Addison-Wesley, 1989), "but nobody knows what 'it' really is." Stein, Director of the 1988 Complex Systems Summer School, has pulled together lecture and seminar notes from the school, and while they don't presume to definitively identify the elusive "it," the contents shed much new light on the definition of this emergent discipline. The first of a series of annual summer school proceedings volumes, the book is pedagogical in nature, intended to provide an introduction to a broad range of topics. It may well become a standard reference in the sciences of complexity.

It is divided into lectures and seminars, reflecting the organization of the summer school itself. Lectures present a general treatment of a topic, and are accessible to non-experts in the field; seminar reports are more technical and address the writer/lecturer's specific research focus. The lectures range widely giving a general introduction to nonlinear science; a discussion of fluid mechanical systems away from equilibrium; an exploration of modeling in developmental biology in contributing to other complex adaptive systems; and the behavior of disordered many-body systems. In almost all of them there is discussion of how a particular area ties into complex systems research, and the reader will find a varied number of opinions as to what constitutes a complex system. The term has been loosely used to signify systems with numerous complex features including nonlinear interactions, chaotic dynamics, multiple equilibria, and so on. Cellular automata, neural networks, adaptive algorithms, and various pattern-forming systems all exhibit some aspects of complexity. In his introduction Stein suggests that we might begin our understanding of "complexity" by asking what properties these systems

share. He sees in them a kind of non-reducibility—the behavior we're interested in evaporates when we try to reduce the system to a simpler, better-understood one.

Fractals in the Desert

This June more than fifty graduate and postdoctoral students converged in Santa Fe to attend the second annual Complex Systems Summer School.

During four week of mini courses, seminars, computer sessions, and small group research meetings, the school covered subjects as diverse as nonlinear dynamics, algorithmic complexity, disordered systems, fluid dynamics, chemical oscillators, computational and experimental neurobiology, and pattern formation in biological systems. The common link of these systems lies in the emerging tools for studying them—methods which combine experimental observation, mathematical analysis, and numerical simulation, techniques which depend in large part on theoretical dynamics and rapidly developing computing power.

Student and faculty evaluations judged the month a major success. "I would rate the summer school's scientific content very high," wrote one student. "Of course, there were a few lectures I violently disagreed with. This was mostly a function of how close they were to my own work, about which I am opinionated. I think the raising of hackles is a favorable commentary on the school."

Dr. Erica Jen, Staff Member in the Mathematical Modeling and Analysis Group in the Theoretical Division at Los Alamos National Laboratory, directed the school. The program, which was held on the campus of St. John's College in Santa Fe, was supported by the U.S. Department of Energy, National Science Foundation, Office of Naval Re-

search, and Research Corporation and by several sponsoring institutions—Brandeis University, Los Alamos Center for Nonlinear Studies, the Universities of Arizona, California, Illinois, Maryland, and Texas, and the Santa Fe Institute, which acted as fiscal and administrative agent. The University of New Mexico, though not a co-sponsor, also provided support.

The Director of the inaugural 1988 complex systems school gleans two more generalizations when looking over the subjects chosen for discussion in the summer school, and thus in the book. First, complex systems abound in the real world,

search, and Research Corporation and by several sponsoring institutions—Brandeis University, Los Alamos Center for Nonlinear Studies, the Universities of Arizona, California, Illinois, Maryland, and Texas, and the Santa Fe Institute, which acted as fiscal and administrative agent. The University of New Mexico, though not a co-sponsor, also provided support.

Lectures in the Sciences of Complexity, notes from the first school in 1988, was published by Addison-Wesley just in time for this year's students. A book comprised of lectures and seminars from the 1989 school will follow early next year.

As intended, the school became a working community of scholars, comprised of both students and faculty. The last week of the four was given over to work on individual projects and research problems. "Students had the opportunity to do something with the ideas and techniques of complex systems. It was a time for absorbing, assessing and applying the material presented in the first three weeks," said Director Jen.

It's expected that some of collaborations and projects begun at the school will be the source of continuing work and may even ultimately affect participants' career decisions, actually bringing more young scientists into the field of complex systems. "This could not have happened at a more important time in my career," said one grad student. "The school has resulted in a research collaboration for me, although not strictly speaking with summer school personnel. I suspect future ones may lie in wait with people I met here. I've met my future colleagues."

Double Auction Tournament

If things go right both the organizers and players of the SFI-sponsored Double Auction Tournament should be happy. The organizers will gain new insights into the workings of markets like the New York Stock Exchange and the Chicago Board of Trade, and the tournament players have the opportunity to compete for reward money totalling \$10,000.

Double Auction

In a double auction, buyers and sellers are simultaneously able to call out bids (offers to buy) and asks (offers to sell), and can accept the lowest outstanding offer or highest outstanding bid at any point in the trading process. The fast flow of information combined with the ability of traders instantly to undercut an outstanding bid or ask makes the double auction perhaps the closest embodiment of a perfect "frictionless" market; friction being the market distortion caused by transaction costs. But the most provocative aspect of the double auction for theorists is the fact that, whatever the predetermined initial supply and demand curves within this trading institution, when actual experiments are run, prices and quantity converge very quickly to the *competitive equilibrium value*, the point where supply equals demand. This occurs despite the

fact that players have very little information.

The trouble is that economists don't know how or why this happens. Since the late 1960's experimental double auctions have been set up where human players are assigned game tokens with a fixed redemption value; this creates an artificial market with predetermined supply and demand curves. Players know only the redemption value of their tokens, and their economic sophistication ends with the obvious fact that more money is better than less. Yet, somehow in the process of trading the players learn enough about the redemption values of their opponents to determine what the market clearing price must be. Economists theorize that smart players use trading strategies that maximize their expected profits based on their beliefs about the token values and strategies of their opponents. But the theoreticians don't understand exactly how players form trading strategies, and so they lack a full understanding of this market's dynamics.

These questions are now more than merely academic. Today's economic theories, for instance, offer little guidance in predicting the impact of institutional changes such as the Chicago Board of Trade's new AURORA trading system which will ultimately replace the tradi-

tional oral double auction "pit" with a unified electronic pit that allows simultaneous trading by brokers who may be located virtually anywhere in the world.

Strategies Tournament

Enter the Santa Fe Institute's computerized Double Auction Tournament developed by John Miller, Richard Palmer, and John Rust. In this tournament each player will be represented by a separate computer program. A central monitor program will manage the game. Computerizing the game makes it intrinsically different from past trials involving human players working in "real time." First, because players must encode their trading within a computer program, this tournament isolates their strategic thoughts in a new way. "Encoded computer strategies are not perfect or even near perfect reflections of personal trading strategies," warns John Miller. "What we can learn, though, at some of the elements people build into their strategies, and how certain strategies perform, given different initial conditions and competing strategies." Using a computer, literally thousands of matches can be run, accelerating the co-evolution of competing strategies. With a computer, the gamemasters can also look at the dynamical effect of introducing slight variants into the market. "For instance," asks Miller, "what if one token value is changed, how much of an impact does that have on the market? How does the number of players affect it?"

The Game

The game itself is straightforward, but making it that way for players—both computer and human—using different computer languages and systems required a substantial amount of computer programming. Each player in a game is either a buyer or a seller of tokens. A seller tries to sell his tokens for as much as possible above token cost. A buyer tries to purchase tokens as cheaply as possible below

Lectures (continued)

and in some respects reflect the inherent "messiness" therein. Second, the problems chosen come from a large cross section of scientific endeavor. "New approaches and more sophisticated models have occurred in fields as diverse as computation, materials and condensed matter physics, cognitive science, neurobiology, climate, turbulence, and evolutionary biology," says Stein. "Some people are even looking ahead to new approaches to problems in the

social, political and cultural spheres. If this book successfully provokes the reader to contemplate these new interconnections, it will have achieved a large measure of its purpose."

The book is published and distributed by Addison-Wesley Publishing Company. It is available directly from the publisher by dialing 800-447-2226. Guests at SFI may purchase copies from the Program Coordinator.

their redemption value. Each seller's token costs and each buyer's redemption values are preassigned and differ from player to player. They are private information not known to the other players. Each auction proceeds in alternating bid/offer and buy/sell steps. In a bid/offer step each seller may offer to sell a token, and each buyer may make a bid to buy a token, each at prices they themselves specify. The lowest offer and highest bid determine the current offer and current bid prices. Then in the following buy/sell step the holder of the current bid may accept the current offer or vice-versa, thus completing a transaction.

Santa Fe Token Exchange

A central monitor program manages the game. Each player's program may be written in C, Fortran, or Pascal. Skeleton programs are provided in these languages so that participants only need develop the routine that makes the strategic decisions, such as how high to bid or when to accept an offer. Participants who have access to the worldwide Internet computer network will also be able to play against each other and against local SFI strategies in practice games by connecting to the Santa Fe Token Exchange. The Exchange is a monitor running regularly on computers at the Institute until just before the actual tournament.

By the end of this summer the organizers will have the word out in the form of posters, electronic bulletin boards, and software distribution; entries in the form of computer programs are expected from people in computer science and economics, as well as from traders on the exchanges. A maximum of one hundred entries will be accepted at the March 1990 deadline, and reward money totaling \$10,000 will be distributed among the participants in proportion to the total trading profit earned by their programs. Support is provided by IBM.

"The tournament is generating a lot of interest and excitement," notes Miller. "After we give out the prize money, we'll begin an analysis of the data. It really is a long-term project, and it's one of those things that has taken on a life of its own."

Auction Primer

Think about an auction. Someone owns a good that they would be willing to sell for, say, \$10. There might be a buyer who would be willing to pay up to \$20. If the agreed-upon price is in the \$10–20 range, both individuals would be happy to trade: the seller will be giving up the good and receiving more than her minimum value, and the buyer gets the good for less than the maximum he was willing to pay. The difference between the buyer's and seller's valuations is called *surplus*, and how it is divided (i.e., more to the seller or the buyer) is closely linked to the type of auction institution.

In an *English Auction*, which is the type of auction most people immediately think of, the winning bidder succeeds by offering a price just a bit above the bid offered by the person who values the good second most. This means that once the price exceeds the second buyer's value, the winning bidder can stop even though he may place a much greater value on the good (and might have been willing to pay a far greater price). In terms of the *surplus* an English auction favors the buyer, since all he need do is outbid the second highest bidder, not meet his highest valuation of the good. As long as the seller is willing to accept the bid, the buyer tends to get much of the surplus.

Note that in an English Auction bidders have an incentive to bid below their true value. One auction which tries to circumvent this problem is the *Vickery or Double Price Auction*. In this auction buyers submit sealed bids, and the highest bidder acquires the good, but pays a price equal to the second highest bid. At first glance, this may seem an odd way to run an auction, but by decoupling the price and the winner, a clever incentive is built into the bidding process. Suppose a buyer bids his true value and wins the auction. If he had bid higher, he still would

have won the auction, and he would have paid the same price—since that is determined by the second highest bid. If the buyer had bid lower, he would still pay the same price, unless the bid was so low that it becomes the second highest bid and thus he does not win the auction. In that case the bidder has given up a chance to acquire a good at a price below his true value. A similar argument holds for the case when one bids his true value and loses. The auction design builds in an incentive to be truthful.

A *Dutch Auction* works in the opposite way of an English Auction: the price starts high and is gradually lowered. The person who first accepts the lowering price gets the good. Since the competing buyers are unaware of each other's valuation of the good, there is an incentive to purchase the item at or just below one's true valuation of it; waiting for the price to drop lower would increase the buyer's surplus, but he might also lose the good. In this transaction, the seller receives more of the surplus, because the item is being sold closer to the buyer's maximum value.

A *Double Auction* combines elements of both the English and Dutch Auction formats. In a Double Auction buyers make bids against one another (similar to an English Auction) while simultaneously sellers make offers to sell (like a Dutch Auction). At any time a buyer can accept the lowest offer made by a seller, or a seller can accept the highest buyer's bid. This type of institution is particularly good when there are multiple buyers and sellers, and multiple units of identical goods to sell. Thus variants of the Double Auction are used to determine the prices of a major portion of the world's commodities and securities.

—John Miller

John Miller is a member of the SFI Economics Residential Research Program



Robert O. Anderson

Profile Robert O. Anderson

Robert Orville Anderson, the petroleum executive who for seventeen years headed the Atlantic Richfield Company (ARCO) in the dual role of Chairman of the Board and Chief Executive Officer, has been named Chairman of the Santa Fe Institute Board of Trustees.

A longtime New Mexico resident, Mr. Anderson was born in Chicago, Ill. He obtained a B.A. from the University of Chicago in 1939. After graduation, he launched his career in the oil industry. In 1941, he acquired a joint-venture interest in a small refinery in Artesia, N.M. That refinery eventually merged with the Atlantic Refining Company in Philadelphia; from that merger grew the present-day Atlantic Richfield Company. During the course of his career, Mr. Anderson bought and expanded several other refineries, one of which, Wilshire Oil Company of California, subsequently was sold to Gulf Oil Corporation. Today, he is President of Hondo Oil and Gas Company in Roswell, N.M., and Pauley Petroleum Inc. of Los Angeles, Calif. He has served on the National Petroleum Council since 1951.

In addition to his endeavors in the oil industry, Mr. Anderson has been involved in mining and milling, general manufacturing, and cattle raising and feeding operations. At its height, the Diamond A Cattle Company utilized more than a million acres of range land in such countries as Brazil, Australia, and Iran.

A past Chairman of the Republican National Committee, Mr. Anderson has an intense interest in public affairs, the humanities, and sciences, an interest reflected by his numerous honorary degrees and awards. He served for many years as Chairman of the Board of the Aspen Institute for Humanistic Studies, and played an important role in shaping the AIHS. There are important similarities between the activities of the AIHS in fostering interactions among the various fields of the humanities and public affairs and the activities of the Santa Fe Institute in fostering interactions among the sciences and on public policy. He is also Co-Chairman of the International Institute for Environment and Development in London, and serves as a trustee of the University of Chicago and the California Institute for Technology, and as a regent of the New Mexico Institute of Mining and Technology.

Here he confronts some of the issues involved in creating a "sustainable world," and the role of the Santa Fe Institute.

In your career, you've hit upon every important aspect of world survival—energy, agriculture.

Well, I've been involved in the environmental movement, too.

Can you tell me about that?

Sooner or later, all of these issues have to be resolved and seen as part of a single issue. I feel the resolution of environmental problems is absolutely essential to both agriculture and the world oil industry.

You probably have some solutions in mind. Can you go into some ideas you may have about the future of oil and the environment? Where does it go from here?

The world gas and oil resources are finite, and we are not too many years away from the time when this is going to be driven home very forcibly through periodic world shortages, in both oil and gas. And we should be using the intervening years to drastically improve and reduce our energy consumption, increase the efficiency of energy consumption. With the exception of coal, fossil fuel is not as abundant as we would like to think. The Middle East contains almost three-fourths of the world's

remaining oil, and given the political uncertainties of the area, this is not the most secure system of supply.

About how many years do you think we have left, if we continue to consume the way we are?

I think we could see some shortages develop in the next four, five years. As a matter of fact, I think it could be sooner. I would say with every likelihood that we'll see some trouble soon. With the exception of the OPEC countries, world oil production is currently on the decline. And the majority of the countries in OPEC are having difficulty maintaining production, or are facing declining levels themselves. There are only five countries in this world that have a reasonable surplus of production. Only four: Iraq, Kuwait, Saudi Arabia, and the United Arab Emirates. They probably represent 80 to 90 percent of the additional production that can be brought to bear in the next decade.

What about alternative sources of energy?

Well, the principal alternative is the unmentionable. Sooner or later I think that we will have to find an acceptable manner in which to utilize nuclear material.

What do you think about fusion?

Fusion is obviously the happy goal of the moment. We're so far from perfecting it that fusion is still very much in the realm of research. To make a major shift in the world energy spectrum, the supply spectrum, takes decades, not years; and for that reason, even if there were a breakthrough in fusion in the next few years, it would be a good many more before it would become a practical reality.

Expansion of knowledge in the last three or four decades has been an unbelievable phenomenon, and the transmission and the utilization of this knowledge is vital for the survival of this country and, perhaps, for the world community as well.

So you're seeing nuclear power, some sort of safe use of nuclear power, as perhaps the only viable alternative?

We (ARCO) had a very active (nuclear-energy) program and finally just dropped it, because we realized it was contrary to the national mood. We dropped the entire program.

Didn't you have a solar program, as well?

We had the leading solar program in the United States, which the company is currently interested in disposing of. The big drop in the price of oil set back solar energy in general by a tremendous degree. It had a tremendously negative impact on the devel-

opment of solar energy; and all other forms of energy were equally affected, because the economic advantages of new development were eliminated. And I'm sure the OPEC countries knew that. One of their goals is to eliminate competitive forms of fuel. And they were successful.

It seems like a very grim scene is being painted here. What's going to happen?

I think we'll wait and see. Solar energy, when it's perfected, will involve the type of equipment that will almost certainly be made overseas. This country has lost practically all of its manufacturing capability—radio, television, all kinds of consumer tech-

Practically all human activity is counter to the natural environment. It's just a question of how much and whether and who does it, but we have to recognize that man's activities are essentially in conflict with his environment.

nology. And my own theory is that if ARCO Solar had continued, we would've had to move its operations abroad, to take advantage of lower labor costs. It's going to be highly competitive. I think that solar energy today could become a reality if the cost of production could be reduced. My problem with the system is the cost of manufacturing. I think we're going to see a slow but steady expansion in solar energy. Higher oil prices will definitely accelerate the interest in it. Higher energy prices, put it that way.

I'd like to get back to the idea of environment, about making energy into an environmentally sound endeavor. Could you go into that?

Practically all human activity is counter to the natural environment. It's just a question of how much and whether and who does it, but we have to recognize that man's activities are essentially in conflict with his environment. This applies to agriculture. It applies to almost anything—hunting, fishing. Even primitive people, in a way, were in some conflict with their natural environment. You can see erosion—permanent damage to the soil—dating back four, five thousand years in the Middle East, due to overgrazing with goats. The Mediterranean Basin was a hardwood forest until the introduction of goats; that, and as a result of agriculture.

The latest corollary would be the reduction of the rain forests.

The odds are there will be some very, very serious reactions to the elimination of the rain forests. The problem with the elimination of the rain forests is, while they have luxuriant life, both

plant and animal life, they are based on a very delicate soil system. It deteriorates almost immediately after a deforestation. The recycling of the plant life is almost one-to-one. In other words, in our soils here, we get years of decomposed vegetable matter. In the soil there, it's gone just like that. It dies and it's immediately reabsorbed by vegetation, and reabsorbed and dies, and so on; so it's a cycle that's easy to interrupt.

In cattle ranching, is there a problem with that?

No, no problems if you use reasonable precautions in your grazing practices. Our Southwestern grasses are very tough. They have roots that extend seven or eight feet into the soil and can take a lot of abuse and trauma.

There's an equally great, almost urgent need for an organization such as the Santa Fe Institute, to try to pull together the broad spectrum of the scientific world and improve interdisciplinary exchange and communication.

Sort of like Southwesterners themselves.

Yes, it's the reason the country keeps coming back. But it can only stand so much abuse before you destroy it.

Can you tell me when you first became involved with the Santa Fe Institute?

Yes, it was two years ago this summer. And I've known George (Cowan, the president of the Institute). We started talking about it. I've been aware of the Institute since its inception, through some of the people who were involved. I've been aware of it for the last five years, but the last two really have been the strong years. Of course, the best thing that happened is that George Cowan decided to devote full time to it. That's the biggest break we've had.

And you became a board member....

After I retired from Atlantic Richfield, I decided I wanted to focus more of my time and energies on New Mexico, both as to its problems and its future; and I've made a conscious effort to do so in the last three years, four years. One of the activities that I was keenly interested in was the Santa Fe Institute, which I think is unique in its field and can do a great deal for both the state of New Mexico and the world community at large.

What specifically appeals to you about the Institute?

Well, the Institute has established a very successful interdisciplinary exchange, and it has created a very exciting, creative environment in the scientific community. And its location and the support that it has from many quarters virtually ensures that it will become a very successful, internationally recognized organization. The very nature of the Institute almost ensures that it will become a transnational endeavor.

What would you like to do as chairman?

My role as chairman is to do all I can to aid and abet whatever the Institute wants to do.

What do you envision bringing to the board?

I'm sure I can be helpful to the organization. I've got a broad background of experience and friends around the world. But mostly, my central role is simply to serve as chairman and do everything I can to assist and support the activities of our President, Dr. Cowan. I would say that the Institute has been an extraordinary success, and I speak having seen a large number of educational and non-profit organizations start up in various parts of the country.

Such as the Aspen Institute?

The Santa Fe Institute is fulfilling a function in the scientific community that the Aspen Institute undertook 40 years ago in the cultural and educational forum. I think that at the time the Aspen Institute was created, there was a very real need, postwar, for an institution like that. And I think today there's an equally great, almost urgent need for an organization such as the Santa Fe Institute, to try to pull together the broad spectrum of the scientific world and improve interdisciplinary exchange and communication. Expansion of knowledge in the last three or four decades has been an unbelievable phenomenon, and the transmission and the utilization of this knowledge is vital for the survival of this country and, perhaps, for the world community as well.

—Jocelyn Lieu

Jocelyn Lieu is a local freelance writer.

On the Cover

In the first chapter of *Lectures in the Sciences of Complexity* (Lectures Vol. 1, Santa Fe Institute Studies in the Sciences of Complexity, Addison-Wesley Pub. Co., copyright © 1989), the proceedings of the 1988 Complex Systems Summer School, David Campbell discusses in detail the, now classical, logistic map $x_{n+1} = rx_n(1-x_n)$, perhaps the simplest example of a discrete dissipative nonlinear dynamical. This model exhibits a series of bifurcations as the control parameter r is varied, leading to the famous period-doubling route to chaos. The cover illustration is from Campbell's lectures and appears courtesy of Roger Eckhardt.

Roger Eckhardt has a Ph.D. in Physical Chemistry. He worked in the Applied Photochemistry Department at Los Alamos National Laboratory before jumping at the chance to join the editing and writing staff of *Los Alamos Science* where he has exposure to a broad range of current scientific activities.

A Personal Statement

This year marks the sixtieth anniversary of the birth of Murray Gell-Mann, the first Chairman of the Board of the Institute and the Co-Chairman of the Science Board. In recognition of this milestone in the life of one of the nation's most distinguished and creative scientists, the Institute includes in this issue excerpts from a "Personal Statement" that he prepared for a recent conference on "Minds in History" at Arcosanti, Arizona.

Introduction

I am a theoretical physicist. Until recently I specialized in the theory of elementary particles, the building blocks of all matter. I found, among other things, that the neutron and proton, of which all atomic nuclei consist, are not elementary, as had been thought, but are composed of particles that I named "quarks," which are as elementary as the electron. The quarks are held together by forces arising from the exchange of quanta called "gluons." Those forces affect the gluons, too, and they are such that both quarks and gluons are permanently confined inside particles like the neutron and proton, and can never be extracted one at a time. Nevertheless, numerous experiments have confirmed the quark-gluon picture, and we constructed, around 1972, a real dynamical theory, called quantum chromodynamics, based on quarks and gluons, which seems to describe correctly the underlying mechanism of the nuclear forces, which were so mysterious when I was a student.

During the last few years, John Schwarz and other members of the Caltech research group (with my encouragement, but without much participation on my part) have played the leading role in finding the first viable candidate for a unified quantum field theory of all the elementary particles and all the forces of nature—superstring theory.

My interests extend to many other subjects, however, including natural history (especially bird study), historical linguistics, archeology, history, depth psychology, and creative thinking. All these

subjects are connected with biological evolution, cultural evolution, and learning and thinking—examples of adaptive complex systems.

I am also concerned about policy matters related to world environmental quality (including conservation of biological diversity), restraint in population growth, sustainable economic development, and stability of the world political system (including the strategic arms situation). These policy matters can all be summarized as the search for paths toward a more sustainable pattern of human activity on this planet.

My recent activities in science and in other domains have drawn to some extent on all these other interests as well as on my background in physics.

Elementary Particles

At the Institute for Advanced Study, collaborating with my friend Francis Low and encouraged by Robert Oppenheimer, who was then the Director, I began to contribute to elementary particle theory. In January, 1952, I joined the faculty of the University of Chicago, where I collaborated with "Murph" Goldberger, later President of Caltech and now Director of the Institute for Advanced Study; both of us interacted a great deal with Enrico Fermi. The work that Goldberger and I did on "dispersion theory" or "S-matrix theory" was ancestral to the superstring theory, which is causing so much excitement today as a possible unified field theory of all the particles and forces.

Meanwhile, I did research myself on symmetries of the elementary particle system, inventing the quantum number "strangeness" (with values like -2, -1, 0, +1, +2, etc.) and relating it to the known quantum number "isotopic spin" (which takes on values 0, 1/2, 1, 3/2, 2, etc.). The problem was to understand how the newly discovered "strange particles" could be copiously produced in high-energy nuclear collisions (as if strongly interacting) and yet decay slowly as if weakly interacting (for an elementary particle physicist, a



Murray Gell-Mann

half-life of a ten-billionth of a second is slow). I have recounted how I solved the problem by a slip of the tongue while giving a seminar on a visit to Princeton. In describing an approach I had tried, which did not work, I came to the point where I needed to say "isotopic spin 5/2"; instead I said "isotopic spin 1" and then stopped because I realized that the problem was solved.

Later on I learned that many scientists and artists (and, no doubt, other creative people) make advances by similar means; still later, I learned that Helmholtz and Poincaré had described the process about a century ago and that the psychologist Graham Wallas had included it in a textbook in 1926. The stages are "saturation," "incubation," "illumination," and "verification." First, immerse yourself in the contradiction between what needs to be done and what can be done with the existing methods and ideas, then allow what the shrinks call the "preconscious mind" to work on the problem (since further conscious effort seems useless), waiting for the brilliant inspiration that can come while cooking or shaving or cycling or lecturing or even sleeping and dreaming (if we are to believe what the chemist Kekulé wrote in his old age about the discovery of the benzene ring), and finally check whether the brilliant inspiration actually works.

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Still later, my friends Paul MacCready and Edward de Bono stimulated me to think about whether there may be something in the idea that special methods can be used to speed up the process of "illumination," so that we need not wait an indefinite time for the insight to appear. De Bono is one of the teachers of "thinking skills" who claim to have found such methods, and his ideas are reminiscent of phenomena that are known to occur in complex nonlinear systems, in which random effects can cause a transition from one "basin of attraction" to another.

To return to the elementary particles, I continued for many years to explore the symmetry properties of the elementary particles, first at the University of Chicago and, after 1955, at Caltech, where I had the pleasure of conversing with and sometimes collaborating with Richard Feynman.

During the middle fifties, Yang and Mills came up with their abstract idea of a new type of "gauge theory." As in electromagnetic theory and in Einstein's general-relativistic theory of gravitation, the Yang-Mills theory used the symmetries of a system of particles to construct the dynamics of that system. It became clear to some of us that the study of particle symmetries was not just a necessary preliminary to finding the real dynamics of the weak and strong interactions, but might give us the dynamics "free of charge" when we had sufficiently mastered the symmetries. That turned out indeed to be the case.

I have favored attention to the cultivation of thinking skills, including both critical and creative thinking, and the search for imaginative ways of testing various claims to teach thinking skills . . .

In 1963, I put forward (and so did a former student of mine, George Zweig, working independently) the idea that the fundamental or elementary constituents of the strongly interacting particles are quarks and gluons. As I worked out the properties of quarks, it became clear that the quark hypothesis summarized virtually all of the work that I had done on the symmetries of the weak and strong interactions of the strongly interacting particles. When, at the beginning of the seventies, a number of us had penetrated still

further into the symmetries of those interactions, the detailed dynamical theories indeed appeared, through the magic of the Yang-Mills gauge theory.

Some of the symmetries in physics, although exact in the equations, show up as broken symmetries in the resulting real world, because the equations describe a symmetrical set of unsymmetrical solutions, one of which appears in fact. A sort of example is provided by a magnet, which can point in any direction, but in actuality points in some particular direction. The description of nature in terms of these "spontaneous broken symmetries" is a profound property of theoretical science, which continues to supply important insights in numerous fields of study.

By the eighties, I had become "more of a swimming coach than a swimmer" in elementary particle theory, and I am very proud of the recent achievements of our Caltech particle theorists.

Some Adventures in Other Subjects

During the middle sixties, I considered the possibility of working on depth psychology. I had long been impressed by the achievements of psychoanalytic psychology in indicating the importance of mental processes out of awareness for the interpretation of much of human behavior, including certain repetitious patterns of maladaptive behavior that are listed as neuroses. However, there seemed to be little progress in incorporating those

insights into science, with a system of falsifiable propositions that could be compared with observation.

After studying a certain amount of literature, I had discussions with a number of academic psychologists and with some psychoanalysts. For opposite reasons, they were fairly united in their belief that it was stupid to undertake scientific research on mental processes out of awareness. More than fifteen years later, however, as one of the Directors of the John D. and Catherine T. MacArthur

Foundation, I was able to realize a portion of my ambition vicariously. I am a member of the Health Committee responsible for creating a sizeable program of research networks in the sciences relevant to mental health, and I was instrumental in persuading the Foundation to set up an adjunct research effort, based at the University of California, San Francisco, on "conscious and unconscious mental processes," involving cognitive psychologists, research-minded psychoanalysts, and some participants from other disciplines. Their work bears some resemblance to what I was hoping to try twenty-five years ago, and I hope that it bears fruit.

My principal activities with the Foundation have been connected with the Committee on World Environment and Resources, of which I am chairman. Our first achievement was the founding of the World Resources Institute, with headquarters in Washington and an international network of collaborators, to carry out policy studies on environmental issues and to suggest strategies for coping with such widespread phenomena as deforestation, loss of biological diversity, desertification, soil erosion, global warming, attenuation of the ozone layer, air pollution, fresh water pollution, pollution of the oceans, and so forth, while favoring relatively non-destructive economic development for those living in poverty and less destructive technology for the developed sector of the world economy. The World Resources Institute seems to be playing an increasingly useful role in shaping the thinking of decision makers in the U.S. and abroad. Our Foundation has also funded other organizations that have adopted a more strident tone in criticizing, for example, the policies of the World Bank.

During the last few years, the World Environment and Resources Program has concentrated mainly on trying to work against the destruction of the many different kinds of tropical forests. We have funded organizations in Asia, Africa, and Latin America, as well as Pacific islands, the Caribbean, Hawaii, and South Florida, with an emphasis on the Western

Hemisphere. We have tried to help local conservation organizations to survive and flourish, and at present we are engaged in a tripartite program of aiding conservation action, conservation science, and truly sustainable rural economic development in the vicinity of crucial "hot spots" of biological diversity around the tropics.

The Foundation has also established a program of aiding local groups in tropical countries in their efforts to restrain population growth, especially by working, in culturally appropriate ways, for improvements in women's health and the position of women; by using mass communications; and by studying the local interaction of population and resources.

I have also been connected with our developing program in education, where I have favored attention to the cultivation of thinking skills, including both critical and creative thinking, and the search for imaginative ways of testing various claims to teach thinking skills, whether as special courses or as part of a general school curriculum. Recently the Foundation has announced an initiative called "Schools of Thought," intended to promote thinking (imagine that!) in American schools. We will see how that turns out.

Plectics and the Santa Fe Institute

If the dynamical theory of all the particles and forces is really at hand, it is still not a "theory of everything." In order to describe the universe, in principle, one requires, first of all, the boundary condition (initial condition) at or near the beginning of the expansion of the universe. James Hartle (my former student, now a professor at U.C. Santa Barbara) and Stephen Hawking have suggested that the initial condition may be derivable from the same formula that gives the dynamical theory of the particles. That is a startling suggestion and it may be quite a while before we know whether it is right. But suppose it is. Then what else is required for a description, in principle, of the universe?

The answer is a great deal, because the fundamental theory is quantum-mechanical and therefore yields only probabilities for an infinite number of different histories of the universe. If those are divided into equally probable classes, then only observation can establish which class of history we are dealing with. (The classical phenomenon of chaos, in which outcomes are infinitely sensitive to initial conditions, only compounds this quantum-mechanical indeterminacy.) Details of the world around us, such as the structure of our galaxy; the detailed properties of our star, the sun; the characteristics of our planet, the earth; special features of terrestrial life; the specific forms of life that have evolved; the characteristics of human beings; the detailed facts about par-

grammed so as to evolve new strategies for winning games can be regarded as complex adaptive systems. It is astonishing how all these subjects involve common problems and common ideas, and especially ideas related to the compression of information.

A complex adaptive system takes in certain kinds of information (inputs) from its surroundings and utilizes them to predict future inputs and how they may be affected by actions. The experience of interaction with the environment is not stored in "look-up tables," but encapsulated in compressed form in schemata or models such as DNA for biological evolution; institutions, customs, and myths for human societies; theories for the human scientific enterprise; or "person schemata"

It is astonishing how all these subjects involve common problems and common ideas, and especially ideas related to the compression of information.

ticular human beings and about human history—all of those are dependent on a large number of unpredictable accidents as well as on the fundamental laws of physics.

It is through thinking about that situation that I have come to work in a field that I call "plectics," the study of simplicity and complexity. (So far, hardly anyone else uses that word, but the situation may change.) Plectics includes understanding the interpretation of quantum mechanics in terms of alternative histories of the universe; learning about information, entropy, and complexity in the history of the universe; finding and comparing various definitions of simplicity and complexity; studying complex but apparently non-adaptive systems in physics and chemistry; and especially finding general principles that govern adaptive complex systems, including pre-biotic chemical evolution, biological evolution, cultural evolution, and possible offshoots of cultural evolution here on earth, as well as possible adaptive complex systems elsewhere in the universe. Biological evolution has given rise to many other adaptive complex systems, such as individual learning and thinking or mammalian immune systems. Also, computers that are pro-

for the human individual in interaction with other people. These models are relatively stable, but there is always a mechanism for altering them and a selection procedure that tends to favor more adaptive models, although, at any given time, many features may be maladaptive.

Working on complex, highly nonlinear systems, for which the behavior of the whole is not simply related to the behavior of the parts, requires the courage to look crudely at a whole situation instead of looking in detail at individual aspects, according to bureaucratic or academic specialties. That requires a revolution in our way of doing things, because we are accustomed to respect highly detailed analysis based on a specialty and not crude synthesis that covers many specialties. Yet top decision makers, such as presidents or kings or CEO's, have to behave as if they have taken into account, however crudely, the interactions among all the different factors affected by their decisions.

One requires, for the work of synthesis, teams of specialists, responsibly familiar with the facts and methods of various different fields, and also people (not necessarily the same people) who are capable of seeing unifying and integrating principles and of spotting key variables

(continued)

Murray Gell-Mann (continued)

that may govern to some extent the evolution of the system under study.

A great deal of institutional innovation is required to accommodate such work, and our great research universities, for example, will take a long time to adapt to the need. Some of us have responded by founding a new institution, the Santa Fe Institute, with headquarters in Santa Fe, New Mexico, and a worldwide associated "family" of scholars and scientists, most of whom have positions elsewhere but communicate with one another using the meetings, communication channels, and research networks of the Institute. Those networks are engaged in theoretical work on such diverse topics as immunology, the evolution of the human languages, the rise and fall of prehistoric cultures in the U.S. Southwest, the global economy as a complex system, using chaos theory to predict the structure of time series (from meteorology to futures markets!), understanding the role of complexity in the history of the universe, and training computers to evolve new strategies for games. We are even trying to see if we can somehow be helpful in the study of the approach to global sustainability.

To try to work on such a variety of transdisciplinary subjects sounds distinctly crackpot, but in fact it is not, because there are so many common threads and because we try to make use of real experts in the subject matter. As the chief recruiter of talent, I am astonished by the positive response from nearly all the busy, brilliant people that we contact—they seem to have been waiting all their lives for the Institute.

Meanwhile, most of us continue with our research work at our own home institutions, and try to bring about in each of those an awareness of the importance of the burgeoning sciences of complexity.

— Murray Gell-Mann

Workshops Focus on Man, Environment, and Society

The Santa Fe Institute is branching into new areas in its study of nonlinear systems with four workshops scheduled for the fall and spring. The workshops will focus on various problems in the fields of archaeology, environmental policy, language evolution, and the relationship between human cognition and emotion.

Public Policy Studies

The role of economics in public policy decisions concerning the environment will be the subject of a three-day workshop "Public Policy Studies," beginning November 15. "The question is whether scientists, economists, biologists, and policy analysts can somehow get together and figure out whether there's a better way to both understand environmental issues, analyze them, and advise governments to the better," says Brian Arthur of the Institute.

Discussion will focus on the destruction of the Brazilian rain forest as a key example of how local changes can affect global systems. "What's happening in Brazil in the tropical rain forest is a major consequence," says Arthur, "not just to the rain forest in Brazil, or in Central America, but to the entire global climate."

"It is now becoming clear that the biosphere—that is, the ecosystem and the climate system—is indeed a complex system. ...What look like localized changes, say in the tropical rain forests, could have very major consequences in 100 years for the earth's climate."

To prevent exponential damage caused by such localized occurrences, scientists and environmentalists must first understand the links between the whole biosphere and its various parts, and then determine how to use this knowledge to affect environmental policy.

The economic reasoning behind the elimination of the rain forest appears to be irrational, Arthur points out, because the serious long-term effects—such as global warming and a depleted ozone

layer—far outweigh the short-term gain of land for temporary agricultural use. "So one question we would have is why something that looks irrational like this is happening. What could science and policy analysis say about this?"

Prehistoric Southwestern Archaeology

Prehistoric southwestern archaeology as part of a complex system will be the subject of another workshop, conducted jointly by George Gumerman of the University of Southern Illinois, and Douglas Schwartz of the School for American Research in Santa Fe. The five-day workshop, to be held at the School beginning September 25, 1989, will be followed in March of 1990 by a conference at the Santa Fe Institute.

"What we're trying to do is to bring the talents of many different people, archaeologists and non-archaeologists, together to try to understand how (prehistoric southwestern) society changed through time and, more importantly, why it changed," says Gumerman.

Besides Southwest archaeologists, participants will be experts in the natural and physical sciences—including holocene geology, radiochemistry, dendroclimatology and paleobotany—who will address such questions as why did particular population shifts occur, why did certain areas become centers of population and later become abandoned, what role did diet and disease play, and what caused nomadic hunters and gatherers to develop agrarian societies.

"There's so much more data available now, that we're hoping to make some major breakthroughs in understanding how these cultures evolved and changed," says Gumerman.

Papers presented in the fall workshop will serve as the basis for discussion concerning the interrelationships between cultural systems and the natural environment. Institute experts in complex cultural and

natural systems will continue the discussion at the spring conference.

"Since you cannot understand, say, (geographic) abandonment without understanding the environment, and you cannot understand why people congregated in certain areas without understanding abandonment, it's at the Santa Fe Institute that we want to try to really connect these different topics together to understand how these cultures worked as a system," Gumerman says.

One impetus for the workshop is the availability of new technology, such as bone chemistry analysis, which makes it possible to tell what kinds of diets people had. "It's even possible to reconstruct DNA patterns now, so it's those kinds of technological things that we're interested in," Gumerman says.

"There's so much information, and we've been so involved in looking at our own river valley and mesa top—it's time we took a step back and looked at how the Southwest changed or didn't change and why."

Human Cognition and Emotion

A third workshop, co-chaired by Jerome Singer of Yale University and David Rumelhart of Stanford, will look at the relationship between human cognition and emotion.

"The general notion is that there are important links between the differentiated emotions and the information-processing systems of the human organism," says Singer. "The question is, how can the link between cognition, or information processing, and our emotional response to the information be tied together; and how can we make proposed theoretical models of how this linkage would operate."

We're going to present research data from personality and social psychology at the purely behavioral or experiential levels, and data from infancy and early childhood as well, and then try to relate these

data to what is being found in the area of psychophysiology and brain research."

In contrast to the Freudian idea that "people are motivated by instincts that burble up from somewhere inside them, like sex and aggression and so on, what we've come to recognize since the early '60's is that human beings are essentially information-processing creatures," says Singer. "So the information-processing system is really critical in motivating people."

At the same time, we recognize that people have very basic emotions...but there's increasing reason to believe that these emotions emerge in relation to the kinds of information we have to process. "What we don't understand yet is how this relates to the physical, bodily mechanisms that we also know are connected to emotion," such as parts of the brain, the glands, and the nervous system.

One area of focus will be the use of computer analogs to model the relationship between information-processing and emotional responses. Such an attempt "is really quite new," says Singer. "It's really at the cutting edge, I'd say."

Evolution of Human Languages

Finally, a workshop on the evolution of human languages will use an interdisciplinary approach to the subject, drawing on various branches of linguistics, including neurolinguistics and psycholinguistics, as well as cultural anthropology, human evolution, and biology. The workshop, chaired by John Hawkins of the University of Southern California, will address such questions as what properties are shared by all or most languages and why; and what general principles underlie language change.

In the 19th century, when the origin of language was studied extensively, explanation focused exclusively on its historical development; since then, much has been learned about the relationship of biology and function to language. "We're going to address the relationship between biology, function, and history to explain why languages are the way they are," Hawkins says, "and in order to do this we're bringing together a broad group of linguists and psycholinguists, people with

knowledge about the evolution of language, about language history, about the way language evolves when children acquire it or when adults acquire it as a second language...and people who speculate on the very beginnings of language."

Study of the interplay between biological, functional, and historical aspects of language in determining how it evolves reflects similar areas of study in other fields, Hawkins says, such as "the evolution of biological species: to what extent are biological species conditioned by the previous species out of which they've originated historically, and to what extent are they responding to functional pressures when they change—the whole Darwinian thing." The workshop will raise the same general explanatory questions in relation to languages: "What kinds of functions are out there to make them have the properties they do; and to what extent is the form of language biologically, innately conditioned—you know, monkeys don't get it but we do; and to what extent do we feel the connection of early historical stages in each language."

The workshop, which will be held at the Institute from August 21 to 26, will bring together about 15 scholars and scientists. Participants will include population geneticist and SFI Science Board member Marcus Feldman and Philip Lieberman, whose 1984 publication *Biology and Evolution of Language* revived serious interest in the subject.

"The study of universals is currently one of the hottest topics in linguistics," Hawkins says, "and we are making a contribution to it of a rather novel kind by the sheer breadth and number of contributors."

Not only is the subject of language universals increasingly important to linguists, Hawkins says—it also has "a lot of relevance for other disciplines...." He adds, "In the sense that language is a complex system, and as we watch this complex system evolving, it raises the same explanatory questions that other complex systems involve, and the answers we come up with can, I think, shed a lot of light on other scientific endeavors."

—Sara Tucker

Sara Tucker is a local freelance writer

Conferences, Schools and Workshops: The Year at a Glance

In March of this year the Santa Fe Institute Science Board met to review the year's academic program and to make funding allocations for the 1989-1990 academic year. What follows is a summary of conference activities for the 1989 calendar year, exploratory or other meetings which, taken as a whole, provide a provocative intellectual sampler of the sciences of complexity.

Spring/Summer

Integrative Workshop on Complexity and Adaptive Systems

In February about twenty-five scientists, participants in past SFI workshops plus some additional invitees, met to discuss the underlying themes of complexity and adaptation common to many of the Institute's activities. Among the topics discussed were various definitions of complexity including algorithmic complexity, computational depth and thermodynamic depth; the existence of complexity thresholds; the meaning of adaptation of modeling; measures of adaptive behavior; learning and model building; and evolution and learning analogies. Participants also grappled with issues of computation inherent in the study of complex systems ranging from the distinction between list processing and computation to the trade-offs between computational time versus storage capacity and available time. A volunteer editorial committee agreed to prepare a draft of the workshop's ideas for further discussion and possible publication. Another meeting will take place at SFI in September.

Planning for a Sustainable World

The Global Security Program Planning Committee met recently at SFI to discuss future directions for SFI research

in this field. Those present were George Cowan, Murray Gell-Mann, David Pines, and Frederic Wakeman. The committee considered whether the Institute should initiate a research program on the development of global society as a complex, adaptive system with particular

attention to present and future threats to its stability. It advised that the Institute should undertake a comprehensive survey of systems studies that have been completed or are presently underway which can provide a point of departure for its program, assess the quality of the various efforts, and further describe the nature of the unmet needs which might be usefully addressed by a long-term program. SFI should work in a mutually supportive relationship with one or more centers dedicated to the study of policy related to complex global security issues so that its program can be guided at the outset by the experience of people who think about needs and implementation at the policy-making level. Finally, a small group of people should be identified who will work partly at the Institute and partly at their home institutions over a period of several months to identify the significant interactive elements of the global security system and to help assemble the people necessary to the design of an ongoing research program with the necessary breadth. The planning process will include one or two workshops to be convened in 1990 to further develop the ongoing research program.



*Asher Peres and Carlton Caves during a quiet moment between sessions.
Photo by Cary Herz.*

Applied Molecular Evolution and Maturation of the Immune Response

More than forty molecular biologists, immunologists, physicists, and instrument designers from throughout the nation and Western Europe met at the SFI late in March for a five-day meeting, "Applied Molecular Evolution and Maturation of the Immune Response," organized by Science Board members Stuart Kauffman and Alan Perelson. The dual-themed workshop focussed on how the emerging synthesis of molecular biology and biotechnology can evolve useful new molecules, enzymes, vaccines and drugs, and on evolutionary processes, both within the immune systems and more globally. Participants discussed somatic mutation and the maturation of the immune response, evolution on fitness landscapes, protein structure and folding, rugged landscape theory, applied molecular evolution, and modeling the origin of life. The proceedings of this workshop will be available next Spring (proceedings volume IX, SFI Studies in the Sciences of Complexity, Addison-Wesley, 1990).

Parallel Computer Systems

In early May SFI co-sponsored with Los Alamos National Laboratory a "Workshop on Parallel Computer Systems: Performance Instrumentation and Visualization," chaired by Ingrid Bucher, Rebecca Koskela, and Margaret Simmons, all of Los Alamos National Laboratory. Performance evaluation of parallel computer systems is much more than mere benchmarking; rather it is an essential feedback mechanism for the design and implementation of hardware and software for the complex supercomputers of tomorrow. The complexity and quantity of data from measurements in the field of performance analysis is so overwhelming that new techniques are needed to allow efficient and timely analysis of data to take place. One such technique is visualization which transforms symbolic data into geometric form and thus allows researchers to observe their simulations and measurements. The program was supported by Los Alamos National Laboratory, SFI, Cray Research, Digital Equipment Corporation, IBM, and Thinking Machines Corporation.

Complexity, Entropy, and Physics of Information

In late May Wojciech Zurek, a staff member in the Theoretical Division at Los Alamos National Laboratory and an External Associate Professor at SFI, chaired an initial SFI workshop exploring complexity, entropy, and the physics of information. More than fifty scientists took part in the ten-day program which considered quantum measurements; the connections between general relativity, quantum and statistical mechanics; the physics of computation; algorithmic randomness; and the nature of the analogy between thermodynamic and information-theoretic entropy. The program was supported by the Center for Nonlinear Studies at Los Alamos, SFI, and by the Air Force Office of Scientific Research. A proceedings vol-

ume (volume VIII) will come out of the meeting, the first step in establishing SFI as the hub of a network facilitating collaboration between researchers working on different aspects of the "physics of information."

Glass, Macromolecules, and Evolution

Also in May a planning committee led by Hans Frauenfelder and Robert Young, University of Illinois, met at SFI to discuss plans for a full-scale 1990 workshop on Glasses, Macromolecules, and Evolution. The meeting, slated for late May, 1990, will meet with three aims: to identify rugged landscapes and characterize their properties in glasses, macromolecules, and evolution; to identify experimental and mathematical methods for exploring the landscapes; and to explore the relationships between these landscapes.

Fall/Winter

SFI fall meetings "Evolution of Human Language," "The Organization and

Evolution of Prehistoric Society," the September Economics workshop, "Human Cognition of Emotion," and "Public Policy Studies" are covered elsewhere in this issue. Other workshops are:

Coherency and Complexity in Homogeneous Stochastic Media

Homogeneous media—systems that have a degree of spatial uniformity—may nevertheless exhibit striking dynamical patterns, both spatially and temporally. Some of these phenomena such as equilibrium phase transitions and the freezing of water, are well understood. Other subtler collective phenomena in homogeneous media are less well understood and offer the prospect of storing data, performing computations in the presence of noise, and generating structures of unbounded size from simple initial conditions. Mathematical models of these systems include partial differential equations, coupled maps, cellular automata, etc.

Charles Bennett of the IBM Research Laboratories will convene at SFI in later



John Archibald Wheeler and Wojciech Zurek deep in discussion during the recent "Complexity, Entropy and the Physics of Information" workshop. Photo by Cary Herz.

October a small group of experts on various aspects of these problems. Questions to be discussed include the conditions for stable spatially coherent oscillations of an entire medium, the conditions for computational universality, how and on what scale does self-organization occur, how do

collective phenomena depend on symmetries, degeneracies, and initial conditions, and no doubt many others.

Participants will be drawn from computer science, statistical mechanics, condensed matter physics, dynamical systems theory, and other fields for an intense few

days of discussions with the hope that directions for significant new progress on these complex systems will emerge.

DNA and the Human Genome

Subsequent to the highly successful December, 1988, meeting in Santa Fe "The Interface between Computational Science and Nucleic Acid Sequencing," SFI will sponsor a small workshop (dates to be announced) focusing on the problems of completing physical maps of the human chromosomes. The program will be supported by U.S. Department of Energy funds. Several laboratories are busily constructing physical maps of the human chromosomes; for example, at the Center for Human Genome Studies at Los Alamos, researchers have isolated and begun to characterize 25,000 cosmid clones of human chromosome 16. Experience suggests that although one can make rapid progress in obtaining coverage of the "islands" along the chromosome, the end game will be much harder because of unclonable segments which make linkage difficult. Several strategies based on using other cloning systems are currently being discussed, and the small workshop will review the state of the art and establish further collaborations. The proceedings of last year's workshop will be available in November (*Computers and DNA*, SFI Studies in the Sciences of Complexity, edited by G. Bell and T. Marr, Addison-Wesley, 1989).

Public Lectures

SFI continues its popular community lectures with a talk on August 23 entitled "The Origin of Language" by Professor Philip Lieberman of the Linguistics Department at Brown University. The series continues in September with a presentation September 27 by Linda Cordell, Irvine Curator at the California Academy of Sciences. Ms. Cordell's talk is entitled "With Trowels, Lasers and Computers: A View of the Ancient Southwest." Both talks are scheduled in conjunction with SFI workshops. Lectures take place at St. John's College in Santa Fe, and admission is free. For further information call Andi Sutherland at 505-984-8800.

Fall and Winter Events

1989

- August 21-26 "Evolution of Human Languages"
Co-Chaired by Murray Gell-Mann, California Institute of Technology, and Jack Hawkins, University of Southern California
- Aug. 23 Public Talk: "The Origin of Human Language"
Philip Lieberman, Linguistics, Brown University
- Sept. 5-10 "The Economy as an Envolving, Complex System"
Co-Chaired by Philip W. Anderson, Princeton University, and Kenneth J. Arrow, Stanford University
- Sept. 11-12: "Integrative Workshop on Complex Adaptive Systems"
Co-Chaired by Murray Gell-Mann, California Institute of Technology, and David Pines, University of Illinois, Urbana
- Sept. 25-30 "The Organization and Evolution of Prehistoric Southwestern Society"
Co-Chaired by George Gumerman, University of Southern Illinois, and Douglas Schwartz, School of American Research
- Sept. 27 Public Talk: "With Trowels, Computers and Lasers: A View of the Ancient Southwest"
Linda Cordell, California Academy of Sciences
- Oct. 13-15 "Modeling the Relationship of Human Cognition with Emotion"
Co-Chaired by David Rumelhart, Stanford University, and Jermonie Singer, Yale University
- Oct. 26-31 "Organization and Complexity in Stochastic Media"
Chaired by Charles Bennett, IBM
- Nov. 3-4 "Human Genome" Meeting
Chaired by George Bell, Los Alamos National Laboratory
- Nov. 5-9 "Foundations of Developmental Biology"
Co-Chaired by Stuart Kauffman, University of Pennsylvania; Richard Burian, Virginia Polytechnic Institute & State University; and William C. Wimsatt, University of Chicago
- Nov. 15-17 "Public Policy Studies"
Co-Chaired by W. Brian Arthur, Stanford University, and Murray Gell-Mann, California Institute of Technology

1990

- Feb. 5-9 "Artificial Life II"
Chaired by Christopher Langton, CNLS
- Feb. 27-Mar. 5 "Evolution of Prehistoric Southwestern Society"
Co-Chaired by George Gumerman, University of Southern Illinois, and Murray Gell-Mann, California Institute of Technology

Research

The SFI's Canyon Road neighbors have probably noticed few outward changes in the place over the past year. Their only clues might be late-burning lights, the fact that it's harder to find a parking place, and the occasional false alarm of the security system, tripped by a zealous researcher working overtime. Inside, however, things have changed: Several SFI research programs at first sustained by sporadic meetings and electronic networks are maturing into full-scale residential research programs. They are setting up shop at the former convent, and what was essentially a conference center is fast becoming a year-round research facility. Scientists involved in these projects, which include residencies by graduate students and postdocs, mix with the SFI External Faculty in the corridors of the "Research Wing," former dormitories now converted into offices and workstation areas. One of the main problems the SFI now faces is one of space; as editor John Maddox notes in a recent piece on SFI in *Nature*, "There is no place to sit." Things are going to get worse.

Residential Programs

The Economics Research program, directed by W. Brian Arthur of Stanford University, is the Institute's most mature residential research effort, in place for more than a year. It has been especially active this late Spring and Summer; a Summer Study Group involves more than twenty-five visitors for times ranging from one week to one month. The group meets in daily seminars, scheduled around informal collaborations and work on joint projects. Santa Fe researchers will have a chance to review their work and meet with non-residential members of the economics network at an annual workshop in September; the meeting will be chaired by Philip Anderson and Kenneth Arrow, leaders of the two highly successful workshops in 1987 and 1988 which mapped the initial direction of the residential program.

Physicist Gottfried Mayer-Kress has been at SFI this Spring and returns later this summer to continue research on ways to mathematically model socio-political problems of global security. Mayer-Kress' nonlinear models, which incorporate features of "multicausality," may shed light on the build-up of armaments between nations. When nation states are described mathematically as nonlinear and even "chaotic systems," even small disturbances—the bombing of a key communication link by terrorists, for instance—can trigger large and unpredictable consequences—such as nuclear war. "Even in the case where it turns out that a given situation cannot be accurately simulated by a mathematical model," says Mayer-Kress, "we think that the process of constructing a model can sharpen our perspective on a difficult socio-political problem."

J. Doyne Farmer, Group Leader of the Complex Systems Group and affiliate of the Center for Nonlinear Studies, heads a SFI project to develop new computer forecasting and modeling techniques which may be applicable in a variety of contexts. His Santa Fe group—Michael Angerman, Martin Casdagli, Stephen Eubank, John Gibson and Stephen Pope, all of SFI and the Theoretical Division at Los Alamos National Laboratory; Blake LeBaron, Wisconsin; Steven Omohundro, International Computer Science Institute; and David Umberger, Niels Bohr Institute—meet often at the SFI. The project has several purposes: to make better nonlinear models for generalization; to make better forecasting models for real-world data observed over time such as earthquakes and economic trends; and finally, to produce a comprehensive software package that can be used by different research groups on a variety of different applications. The group has come up with a new technique for forecasting fluid flow which gives predictions far superior to traditional models. It has also developed a menu-driven software package that allows researchers to perform many different tasks using a variety of nonlinear algorithms, or rules.

In the field of biology Alan Perelson has this year divided his time between Los Alamos National Laboratory and SFI

working on mathematical models of the immune system, in particular focusing on modeling the interaction of HIV with the immune system. Biophysicist Stuart Kauffman's work concerns evolutionary processes in the immune system, especially the relationship of those processes to our understanding of natural selection. During the past Spring, the two researchers have each hosted several collaborators as well as co-chairing the SFI workshop "Applied Molecular Evolution and Maturation of the Immune Response." In the Fall Kauffman will co-host with Richard Burian, Virginia Polytechnic and State University, and William Wimsatt, University of Chicago, a SFI conference on the foundations of developmental biology. Kauffman, who spent half the past academic year in residence at SFI and will be at SFI half-time in 1989–90, has also been actively involved in the economics research program and has just completed a book *Origins of Order: Self Organization and Selection in Evolution* (Oxford University Press, copyright © 1990), much of which was written in Santa Fe.

In May Wojciech Zurek, staff member in the Theoretical Division at Los Alamos National Laboratory and External Associate Professor at SFI, hosted in Santa Fe an international workshop on complexity, entropy and the physics of information. One outcome of the meeting was the establishment of SFI as the hub of a network fostering collaboration between researchers working on different aspects of the physics of information.

(continued)

Suspicious Confirmed Dept.

Dear Editor,

We would like to be on your mailing list. The bulletin that your organization sent out most recently has an article on chaos which particularly interested us. We would greatly appreciate receiving more news of the studies going on at the Santa Fe Institute.

David Albright
New Mexico Highway and
Transportation Department

Beginning in September Professor William Wootters, a physicist at Williams College with a background in quantum measurement theory, will spend a sabbatical year at SFI and Los Alamos National Laboratory, working with Zurek, Doyne Farmer and others.

Also at SFI beginning in September will be Science Board member John Holland, University of Michigan. John will continue his collaboration with researchers in the Economics program. He will also be working on setting up a SFI residential program in the area of adaptive computation. The initial efforts of this new venture will be on genetic algorithms and classifier systems with particular emphasis on the control of large systems.

Postdocs and Graduate Students

"An important aspect of the SFI residential program is providing research opportunities in the sciences of complexity for graduate and postdoctoral students," notes 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. We're gratified at the superb caliber of young researchers we have attracted."

SFI Economics postdoctoral fellow John Miller will be leaving in the fall for Carnegie-Mellon University, Los Alamos postdoc Stephanie Forrest and graduate students Luigi Marengo (University of Sussex) and Jasmina Arifovic (University of Chicago) have been at SFI for varying times during the past year, participating in the Economics program. Beginning later this summer, four more researchers will join SFI.

Graduate student David Cai, recent member of the Theoretical High-Energy Physics Group at Northwestern University, will be at SFI throughout the fall. He is slated to continue his research at Los Alamos National Laboratory next year, working primarily with Doyne Farmer. "The field (of nonlinear dynamics) is boldly crossing the traditional demarcation of physics into a new frontier of challenges," David writes. "My conviction has been growing that the study of nonlinear

systems will provide an insight into a variety of complicated systems and should eventually bring us to a new understanding of nature, life, and human society in a synthetic way."

Postdoc Wentian Li comes to Santa Fe with a Ph.D. from Columbia University and research experience at the Center for Complex Systems Research at the University of Illinois. He will be in Santa Fe for the 1989-1990 academic year continuing work on nonlinear dynamical systems with spatial degrees of freedom. It is expected that he'll collaborate both with the economics researchers as well as work with Stuart Kauffman on models of evolution.

Walter Fontana from the Institute of Theoretical Chemistry at the University of Vienna, has done outstanding work there with Peter Schuster on population flow on rugged molecular fitness landscapes. Fontana, a Research Fellow at the Center for Nonlinear Studies, has been appointed a Member of SFI and will work with Stuart Kauffman, Doyne Farmer, Steen Rasmussen, Chris Langton, and Rich Bagley to pursue origin of life, artificial life, and adaptation in complex systems.

Martin Casdagli will be in residence as an SFI postdoc for the academic year beginning in September working with Doyne Farmer on the Time Series Forecasting Project and pursuing other research interests in complex systems theory. An Assistant Professor of Mathematics at the University of Arizona, 1986, Casdagli comes to Los Alamos and Santa Fe from a Postdoctoral Fellowship in the School of Mathematical Sciences at Queen Mary College, London, England.

External Faculty

SFI's External Faculty program got under way earlier this year, and it too swells the ranks of in-house researchers: these "external" scholars—part-time SFI academic appointees—are expected to regularly spend a month or more at the Institute pursuing their own work as well as collaborating with graduate and postdoctoral students. In addition to the research directors mentioned above, External Faculty in residence for varying times this year include Murray Gell-Mann, Erica Jen, and Richard Palmer.

SFI External Faculty

External Professors

Philip Anderson, Physics, Princeton University
Kenneth Arrow, Economics, Stanford University
W. Brian Arthur, Food Research Institute, Stanford University
William Brock, Economics, University of Wisconsin, Madison
Jack Cowan, Applied Mathematics/Theoretical Biology, University of Chicago
J. Doyne Farmer, Theoretical Division, Los Alamos National Laboratory
Marcus Feldman, Biological Studies, Stanford University
Murray Gell-Mann, Physics/Astronomy, Caltech
John Holland, Computing Science/Engineering, University of Michigan
Stuart Kauffman, Biochemistry/Biophysics, University of Pennsylvania
Alan Perelson, Theoretical Biology, Los Alamos National Laboratory
David Pines, Physics, University of Illinois, Urbana-Champaign
José Scheinkman, Economics, University of Chicago

External Associate Professors

Jonathan Haas, School of American Research
Erica Jen, Theoretical Division, Los Alamos National Laboratory
Alan Lapedes, Theoretical Division, Los Alamos National Laboratory
Richard Palmer, Physics, Duke University
Daniel Stein, Physics, University of Arizona
Wojciech Zurek, Theoretical Division, Los Alamos National Laboratory

External Assistant Professors

Michele Boldrin, Economics, University of California, Los Angeles
Robert Farber, Theoretical Division, Los Alamos National Laboratory
Seth Lloyd, Physics/Astronomy, Caltech
Norman Packard, Center for Complex Systems Research, University of Illinois, Urbana

Fundraising as an Adaptive Complex System

In April, Susan Wider joined SFI's staff as Director of Development. She has crossed several disciplines to reach SFI. Previously with the Chamber of Commerce system in Normandy, France, and then with a subsidiary of the Public Service Company of New Mexico, Susan brings a world view to SFI's fundraising activities. She holds degrees from Colorado Women's College in Denver, Colorado and from the Monterey Institute for International Studies in Monterey, California where she chose to combine her self-described addiction to foreign languages and communications with management studies. She is a member of the National Society of Fundraising Executives and the American Literary Translators Association.

Susan views each person associated with the Institute as a fundraiser, either active or passive. She defines "active" fundraisers as those individuals who actually solicit funds from qualified prospects or who personally introduce potential donors to the Chairman and the President. "Passive" fundraisers are those scholars and administrators who by their dedication to excellence carry out the mission of SFI.

"The Santa Fe Institute is in existence today because of its astonishing success in attracting the attention and support of corporations and foundations who understand the vital importance of our research and education innovations," says George Cowan, emphasizing the critical importance of SFI's fundraising program. "Our plans for growth are based on the conviction that we can expand and reach out to additional individuals and organizations who are inspired to support our commitment to scholarly excellence." When Dr. Cowan talks about inspiring support he goes directly to the heart of the SFI fundraising program. The Institute depends 100% on grants and gifts to finance its ambitious research and education program. Not only are funds re-

quired to support each academic initiative but also to support the ongoing core operations and the ever-increasing number of visiting scholars and external faculty. And we are ever looking ahead toward the establishment of endowments to build a campus and to underwrite permanent faculty appointments.

The Advocates

Current financial supporters of SFI include government agencies, foundations, corporations and individual donors. Their contributions may take one of two forms—monies designated for specific research programs or workshops and unrestricted funds for general support.

Our two major government funders are the National Science Foundation and the U.S. Department of Energy. Both organizations have offered consistent and generous support from the early years onward and our relationship with each continues to evolve. Their grant use specifications have now expanded to include both restricted and unrestricted funds. Foundations that have made commitments are the John D. and Catherine T. MacArthur Foundation, the Richard Lounsbery Foundation, the Joseph A. Klingenstein Foundation, and the Bay Foundation. Corporate supporters currently include Citicorp and the H. J. Heinz Company, among others, and an expanded membership program is under development to increase corporate participation. Individual gifts from Board members and other friends of SFI account for a substantial portion of the unrestricted income.

Program-Specific Funding

The Research Program in Economics is a striking example of our dependence on program-specific support from key donors. Citicorp currently provides one third of the support for this groundbreaking program. Representatives of



Susan Wider

their organization participate in the workshops and closely follow the planning and research activities. They have begun to assist us in bringing others from their industry on board.

Other program-specific funders include the Russell Sage Foundation for the Economics Program; Air Force Office of Scientific Research in support of the program on "Complexity, Entropy and the Physics of Information"; and the Center for Nonlinear Studies at Los Alamos National Laboratory to co-sponsor specific endeavors such as the Complex Systems Summer School.

General Support

In parallel with the program-specific gifts, we depend heavily on unrestricted gifts for core operating capital. The MacArthur Foundation is the major contributor in this category. The first MacArthur grant for \$250,000 in 1988-1989 was recently increased to \$300,000 for 1989-1990. Other supporters in this category include the H. J. Heinz Company Foundation and the Richard Lounsbery Foundation and numerous individuals whose generous gifts reflect their advocacy of SFI's activities and philosophy.

(continued)

History and Progress

As we look at the Institute's funding history, we see a steady, rapid increase in total contributions.

Total Private and Government Support 1984-1988

1984	\$77,259
1985	\$82,827
1986	\$221,077
1987	\$574,264
1988	\$1,027,924

In 1988 alone, one quarter of all support came from first-time givers—a clear indication of our ability to generate new interest and to broaden the funding base.

1989 Development Program

The Institute must constantly weigh and reevaluate the direction and strategy of its fundraising program and adapt it to ever-altering realities in the general economy, in the corporate and foundation world, and in its own needs. The current program calls for heavy solicitation of individuals and noted philanthropists. Because SFI's growth has been so fast-paced, and because we are still a low-budget organization with a small administrative staff, we must target our prospects in terms of our ability to reach them; the anticipated cultivation time; and the support potential.

In tandem with this personal approach to individuals, we continue to nurture our established relationships with foundations and corporations and to enlist the aid of additional, carefully targeted sponsors in these two sectors.

Implementation of the 1989 Development Program requires active involvement from the members of both Boards. The Members are eager to assist with Development activities and great care is taken to make efficient use of their time and valuable advice.

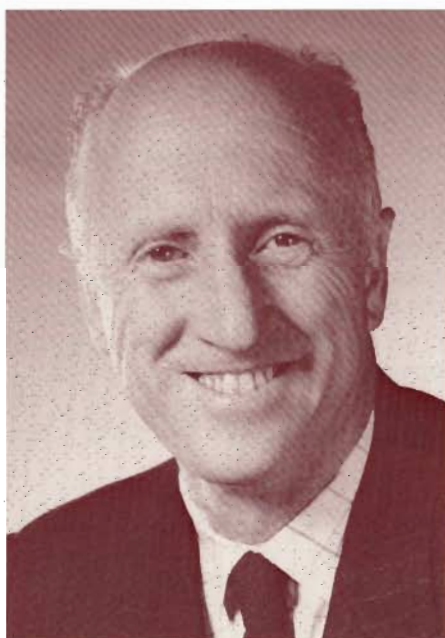
I was drawn to SFI, in part, by the discovery that the organization is peopled with inspired individuals. Our next step is to seek their counterpart among inspired financial supporters.

—Susan Wider

Board News

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

Stewart Brand is the Founder/Editor of *The Whole Earth Catalog*, *The Last Whole Earth Catalog* (winner of the National Book Award), *CoEvolution Quarterly*, and *The Whole Earth Software Catalog*. His books include *The Media Lab: Inventing the Future at MIT* and *Two Cybernetic Frontiers*. Mr. Brand has taught at the School of Management and Strategic Studies at the Western Behavioral Sciences Institute and at the College of Environmental Design at UC Berkeley (a seminar on "How Buildings Learn"); in 1986 he was a Visiting Scientist at The Media Laboratory, MIT. He is the Founder of "The WELL," a regional computer teleconference system for the San Francisco Bay Area, and Co-Founder, with Peter Schwartz and others, of the Global Business Network. Among his current projects, he is the organizer of a private conference series on "Learning in Complex Systems" sponsored by strategic planners at Royal Dutch/Shell, Volvo and AT&T.



Stewart Brand



J. Doyne Farmer

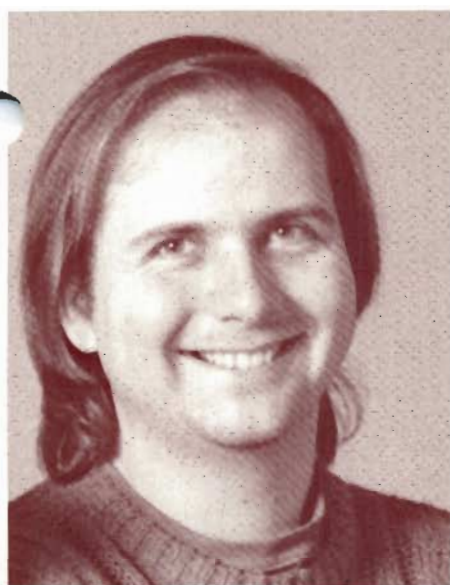
Four new members have been elected to the Science Board:

J. Doyne Farmer is the Group Leader of the Complex Systems Group, Theoretical Division, and an affiliate of the Center for Nonlinear Studies, Los Alamos National Laboratory. An Oppenheimer Fellow at Los Alamos from 1983 to 1986, Farmer is the co-editor (with A. Lapedes, N. Packard, and B. Wendroff) of *Evolution, Games and Learning: Models for Adaptation in Machines and Nature*. Author of numerous articles on chaos, Farmer has worked on several films and videos on the topic. He is co-author of a screenplay "The Eudaemonic Pie" (Warner Brothers).

W. Daniel Hillis is Founding Scientist at Thinking Machines Corporation in Cambridge, Massachusetts. In 1978, he received his Bachelor's degree from MIT in the field of mathematics. His Master's degree on "Active Touch Sensory" was awarded in 1981. Hillis is the architect of the parallel computer called the Connection Machine, which was the topic of his Ph.D. thesis. A book based on the thesis, *The Connection Machine*, was published by MIT Press in 1985. His Ph.D. was

awarded by MIT in 1988. Thinking Machines Corporation produces the Connection Machine as a commercial product. At the company Hillis has concentrated on parallel computers and computer architecture. His current research is on evolution and parallel-learning algorithms.

Leroy E. Hood is Bowles Professor of Biology and Chairman, Division of Biology and Director of the Cancer Center at the California Institute of Technology. His awards include California Scientist of the Year, 1985; Louis Pasteur Award for Medical Innovation, 1987; and Albert Lasker Basic Medical Research Award, 1987; Dickson Prize in Medicine, 1988. Dr. Hood is Fellow of the American Association for the Advancement of



W. Daniel Hillis

Science; Member, National Academy of Sciences; and Member, American Academy of Arts and Sciences.

Erica Jen, is a Staff Member in the Mathematical Modeling and Analysis Group in the Theoretical Division at Los Alamos National Laboratory. University Scholar and Assistant Professor of Mathematics at the University of Southern Cali-



Leroy E. Hood

fornia from 1983 to 1986, Dr. Jen is Director of the 1989 Complex Systems Summer School. Her research interests are in the areas of dynamical systems, cellular automata, and scientific computation.

Frederic E. Wakeman, Jr. is President of the Social Science Research Council, and Walter and Elise Haas Professor of Asian Studies, University of California



Erica Jen

Staff News

Deborah Magid joins the SFI staff as Executive Assistant. Deborah will be working closely with SFI President George Cowan and Executive Vice President L. M. Simmons, Jr. In addition to assisting Director of Development Susan Wider, she also handles receptionist duties at SFI. Deborah brings much editorial expertise to her job at SFI; her most recent position involved desktop publishing at the New York firm Kidder, Peabody & Co. She is currently editing the autobiography of cultural anthropologist Edward Twitchell Hall.



Frederic E. Wakeman

at Berkeley. Author of fiction, nonfiction, critical reviews, and scholarly works, his books include *History and Will: Philosophical Perspectives of the Thought of Mao Tse-Tung* (nominated for a National Book Award), and *The Great Enterprise: The Manchu Reconstruction of Imperial Order in Seventeenth-Century China*. He is a Member, Council on Foreign Relations; Member, U.S.-U.S.S.R. Binational Commission on the Social Sciences and Humanities; Advisor, Research Center for Social Development of Contemporary China at Peking University; Member, American Academy of Arts and Sciences, and Consultant on international relations, John D. and Catherine T. MacArthur Foundation.