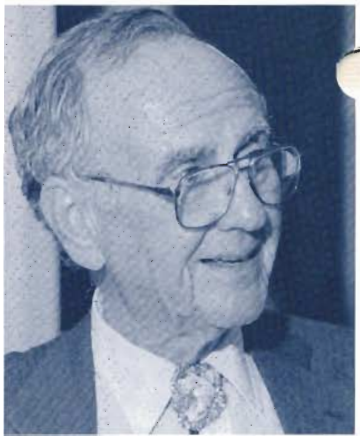
Origins and Visions:

George Cowan on the Concept of the Institute



George A. Cowan

George Cowan is retiring from the position of Senior Fellow at Los Alamos National Laboratory to become the full-time President of the Institute. A former member of the White House Science Council and a recipient of the E. O. Lawrence Award, Dr. Cowan is a Fellow of the American Physical Society and the American Association for the Advancement of Science. His special interests include high-technology transfer from government research laboratories to private enterprise; the development of econometrics based on nonlinear dynamic process modeling; research in physics; and new concepts in graduate education. His position as President of the Santa Fe Institute allows him to address all of these concerns.

The Santa Fe Institute became a reality in large part because of your efforts. What led you to envision such a place?

I've been directing research, starting with problems in radio chemistry and nuclear chemistry, since I was about thirty years old. I've dealt with physicists and theorists involved in the interpretation of diagnostic data, and research involving physical, nuclear, and organic chemistry, the life sciences and geosciences. In all of these experiences I was impressed with the fact that usually more than one person or set of people were working with parts of very similar problems. They sometimes spoke different jargons, but they needed to work more with one another. So I've been intrigued most of my life with how to put together a number of these different disciplines in a reasonable way. The only way I was ever able to do it was to get two good people in a room, people representative of different parts of the problem, and let them discuss it. If they agreed that it was a good and necessary interdisciplinary program, and if they more or less liked each other, then you brokered a marriage. And sometimes that was successful and sometimes it wasn't. After dealing with that problem for years I wouldn't know how to write a book about it. It's a black art.

The impression I had that research was too fragmented was reinforced when I went to the White House Science Council. I found even broader subjects, with a great deal of science and technology content, being decided without enough scientific input. Many issues that had decisive scientific considerations were probably being decided largely on the basis of political considerations and pressure—questions like Star Wars, the debate on AIDS, the supercollider, manned space stations, and so forth.

I talked a great deal with other members of the White House Science Council and Senior Fellows at Los Alamos about the need for a department of science and technology, which would draft national strategic science policy. People generally felt that such a department wouldn't be headed by a scientist because they aren't trained broadly enough and don't know their way through the jungle.

So that got me thinking about something like the Santa Fe Institute, how an institute might persuade some people to become generalists, to train people to range more broadly across the disciplines.

A kind of scientific Renaissance man?

Yeah, a twenty-first century Renaissance man, starting in science, but able to deal with the real messy world, which is not elegant, and which science doesn't really deal with. I talked about this man as almost surely able to use very large computers to do numerical simulations. So the Senior Fellows, led by Nick Metropolis, started discussing computational science in the very broadest sense. It's a big umbrella that covers all of these subjects—algorithms that somehow simulate what these systems do.

These discussions turned to topics like computer science, artificial intelligence, the cognitive sciences, neural networks, and so forth. And as we were joined by Murray Gell-Mann and David Pines and others, we began talking about emerging syntheses, interdisciplinary activities in which chemistry and physics were not enough by themselves.

Of course, the most obvious one of these is molecular biology, which has been a remarkably successful fusion of two conventional disciplines into a new discipline. It has resulted in all of the insights into the genetic code and much of what's happening in the huge ferment in the life sciences, from protein dynamics to more and more understanding of how life processes occur.

Then we proceeded from molecular biology to the resemblance of the social sciences to living systems, which is no accident because social sciences deal with people. And we began to define our theme as complexity. That's where the Santa Fe Institute is now, and it's obvious that this is where much of science is going.

What about those 'real world' problems you mentioned earlier. Can the Santa Fe Institute address them in a practical way?

Perhaps the most complex and important thing we should talk about is global security. By that, I mean a system that is almost failsafe. Military security fails catastrophically in one way or another. Military security based on large nuclear stockpiles fails utterly catastrophically. So when I talk about global security I mean something that eventually—and not too far in the future, in two or three or possibly four generations—is intrinsically stable with respect to going to war.

That's a wonderful and ambitious ideal. Is it possible within a handful of generations?

I think important things can be done in fifty to one hundred years. I don't think much can be done in ten years. But what you can do is to define a grand vision. A grand vision that has a broadly based consensus—within this country and internationally—of major changes in the way goods are distributed and the way social justice is dispensed and a recognition of the aspirations of everybody everywhere to have a significant role.

Specifically, how can the Santa Fe Institute study that problem?

The Institute can help by working closely with other people who look at global security as a large complex system, and who feel the same need to define this grand vision: what kind of a world will exist in peace and meet a large fraction of the needs of its population.

How has the Santa Fe Institute affected the study of complexity?

The issue of complexity has been popping up everywhere. The Santa Fe Institute has given it a little more credibility, I think, because the names attached to it are prestigious. We have a roster of National Academy types and Nobel winners, which suddenly did something very important for the whole notion, that is, to make it look more respectable. So we made waves. Other people are setting up centers to study complexity. We keep getting announcements from such centers—the University of Arizona, Illinois, a town outside of Vienna. And pretty soon there will probably be consortiums, councils, and it will become organized and start to look like one of the sciences. Or really, a science of science.

Do you see that kind of establishment as a potential problem?

Yeah, once it's established, it will start to develop its own specialties and will fragment again. Somehow or other we have to maintain the integrated parts of it. And I hope they're not brought into disrepute by a lack of rules. It's very easy when you generalize to become a scoundrel. Picasso did many great masterpieces but he also dashed things off in thirty seconds that sold for as much as anything else. That's the problem when you start painting in broad strokes. The temptation to be sloppy is always there. So you try to involve people with the specialized expertise that characterizes excellent science, but people who haven't been so brainwashed that they make a special virtue of their expertise and won't talk to people from other fields.

Are you saying that to study complexity legitimately you need a profound understanding of a particular discipline?

Right. You can't arrive at it as a generalist. Science is much too complicated for that. You have to arrive at it through rigor. The generalizations will emerge.You need directed, mutually supported collaborations and programs. And that means a certain amount of organization and willingness to communicate. And a certain security. Most people whose knowledge is limited simply don't do it, they feel vulnerable and they don't reveal their own inadequacies. Secure people do, of course. They revel in their ignorance and try to change it.

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There has to be wider recognition of the fact that science has reached the point where it can no longer simplify problems so that they don't resemble the real problem. As systems become complex they develop properties of their own. We have yet to successfully apply the reductionist technique in explaining complex systems in terms of their simpler subsystems. That's a profound and ongoing debate in science between the reductionist view, which says you can always find a shorter way to describe properties in the system in terms of its different parts, and the people who say you're going to run out of that capability the moment you challenge it against the real world, against life systems and social systems and so forth.

Nobody has yet been able to do a really good job of taking an even modestly complex system and describing it in terms of its subsystems and showing how all its properties arise from the interaction of all of its parts.

Ultimately, isn't that what the Santa Fe Institute is trying to do?

Well, it would like to define the general elements of the science of complexity, which would permit you to do that, at least to some extent. But it can't assert that one side is correct because the debate is ongoing and evenly matched with people who insist that some part of the properties of a complex system are in effect controlled by something external to the boundaries of the system. It's a religious issue because when you assert that a complex system will fail to be totally autonomous, that there will be some property derived from something external to the system, people will say you're talking about God or some aspect of nature that imposes order on complexity. Or does all the order arise internally? That's a very profound debate, one which I would like to avoid.

> "We can talk about global security . . . a system that is almost failsafe. Military security fails catastrophically in one way or another . . . I mean something that eventually . . . is intrinsically stable with respect to going to war."

I was just about to ask you not to avoid it.

Well, as a scientist my only choice is to say that we'll press for reductionism as far as it will go. But I would be agnostic to the extent that I will not be too surprised if I find that I've got to adopt Johnny von Neumann's pragmatic description of complexity. He avoids saying where the properties come from, and says that a truly complex system is best characterized by describing the system's properties. That's a shorter message than describing the subsystems, but you don't find any magic simplicity. Herb Simon calls it pragmatic holism.

Doesn't that undo the supposition that you can find laws that link all complex systems together?

I would like to believe that we'll find a general set of elements that indicate why complex systems behave the way they do, although we may never be able to use them in a predictively useful fashion. In fact, complex systems generally have many possible states, all of which look stable on some time scale. But they're all always metastable, far from equilibrium. If they are in true equilibrium, they're no longer complex, they're stable and probably have elegantly simple properties, and in fact they're dead. Complex systems usually imply a living system, something that's dynamic.

If you treat a complex system as many economists do, as a set of equilibria, it's no longer dynamic and it's of less interest. The Santa Fe Institute is attempting to bring an uncommon paradigm to economics. Economists tend to use the physical science paradigm and look for equilibria on some surface, possibly at some lowest, most stable state. But I think it's obvious that economics operates out of equilibrium. You shouldn't look for stable states, you should look for transitions and for the laws that govern them.

Is this the first time economics has been approached from this direction?

No. Economic texts usually pay attention to nonlinear dynamics, particularly in econometrics. You'll find a chapter somewhere in the book that says that this may be a more realistic way of looking at economics, then it gives up rather quickly because it gets into mathematics that most people don't deal with, except in a rather elementary way. And the consequences of nonlinear dynamics in economics are so awesome that nobody can pursue them very far.

The basic premise in neoclassical economics is that you will achieve an equilibrium. But change the time scale and that's not necessarily the case. You achieve punctuation points, transitions and hesitations. If you want to talk about it from minute to minute—and that's important in the stock market—it may have long plateaus. Of course, by sensing those plateaus you might make a lot of money. But on the other hand, changing the time scale, if you're a long-term trader, it may look totally devoid of any plateaus. So, in fact, the measure of complexity must have an element of time built into it. You always have hierarchy in the reductionist scheme. I suppose in any scheme you have to talk about complexity arising from simple parts that aggregate into more complex parts, which in turn aggregate into even more complex parts, and so forth. The time scale changes at every level.

That tendency to aggregate applies to any complex system, from subatomic phenomena on up?

In physical science, you start with quarks, which may be made up of simpler parts. With quarks you build protons and neutrons and so forth. And when you go from the nuclear interactions we're most familiar with, you go from let's say 10^{-20} seconds to atoms and orbital electrons interacting with each other, to a time scale of maybe 10^{-10} or 10^{-12} seconds. Then when those atoms interact with one another and become complex proteins, you start to talk about biological reactions and change the time scale again, usually by several orders of magnitude. In mental processes, a typical relaxation time is 10^{-3} seconds.

When you aggregate all of these things into cells and organisms the time scale changes again. Now you have circulation and other mechanisms. Even neural impulses from the brain to the toe—these things can change again by orders of magnitude. You have action at a distance, so to speak, both mechanical and electrical, conveyed in ways that take time. And then you have social structures that aggregate living species—for people, the aggregations of course are families that aggregate into communities, communities aggregate into nations, and so forth. In the economic structure you have offices and branches and corporations and working aggregations of corporations and global economies. The whole question of evolution deals with still another time scale.

The relationship of the time scales is fundamental to how a complex system works?

I suppose that one way to talk about complexity is to talk about characteristic relaxation times. At every level of complexity things interact with one another on about the same time scale. But they also see things happening below them, which essentially bias the system. They look like noise; they average out because they're operating so fast that they look like a DC signal. Above them, they see things that are operating so much more slowly than they do that they serve as parameters. So on every level in complexity you're living on a common time scale horizontally, looking at something that operates much faster below you and at something that operates much slower above you. A lot of that has to do with the size of the system and the length of time it takes to convey information, the bit rate, or the entropy if you know how to measure it.

Something important that's happening now is that modern technology is screwing it up by speeding up the bit rate. Information is being transmitted from large units to smaller units, and vice versa, much faster than ever before—TV and 24-hour global satellite communication and visual information. We're saturating social organizations that are geared to processing information at a much slower rate. We haven't invented the structures that can manage that very well.

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How has that increased bit rate affected science?

It's permitted us to begin developing the science of complexity. You need large computers to do numerical simulations of high-dimensional problems. They don't have elegant solutions, and the larger the computer, the larger the ability to process information and acquire the data bases you need to do a numerical simulation that resembles reality. We still don't really know how to do it, but it's going to happen. Twenty years from now people will have really sophisticated means for handling large data bases and for letting the parts of highly complex systems interact with one another in ways that may resemble what actually happens. I suspect if we find general elements of a science of complexity, they'll emphasize feedback loops set up among the various parts, both amplifying and damping. Metastability can occur when these tend to balance out.

One of the most obvious loops is in economics—memory. People remember history and anticipate the future. If they feel that the future is going to be like the past, that's a negative feedback loop. They tend to retain the past history. If they feel for any reason the future is going to be different from the past, they behave in such a way as to affect the present. And that's positive feedback. They pop out of whatever basin or plateau they may be on. They may panic, they may become excessively greedy. If they become greedy you may have a boom, if they become panicky you have a crash.

How do you decide which loops to examine when you study a complex system?

When we talk about high levels of complexity we arbitrarily draw the boundaries. There's no natural boundary. Where you draw the boundaries of the system depends on how simple a view you want to take. You can keep enlarging the boundaries all the time. After drawing the boundaries, we usually say, well, we can't handle that, so let's constrain the system some more and see whether we can understand a simpler part of it. But when you reduce the boundaries, at least you know who your neighbors are. And if you start with a simple system you don't even know that. If you examine a larger system than the one you're eventually going to study, at least you know the neighborhood and you can hook up to it in an average way. But you shouldn't remain ignorant of the larger neighborhood, and you particularly shouldn't make a virtue of your ignorance of it, which is what a lot of people do.

Constraining the big picture to look at connections between particular neighbors seems like it would be tricky.

Well, that's why people don't generally do it well. We're talking about a whole new science and you don't achieve it by contemplating your navel overnight. What you try to do is define its general content, and then a lot of good people start to study it. If over the next fifty or hundred years it develops into something useful, it will be because of one hell of a lot of work. If anything I've said implies, "Eureka, we're going to understand complexity," that isn't so. What we're trying to do is establish complexity as a new science worth studying.

You've talked a lot about economics. Is that the most fruitful or promising topic for the study of complexity?

Well, I think it's possibly overly ambitious because if we stuck to the things that we know the most about, like fluid dynamics or cellular automata with fluctuations and errors or interactions with a stochastic external environment that pumps energy into them, they would represent the shortest extrapolations from what we think we know to what we don't know. And we would stop with simple protein dynamics, which is a reasonably well-thought-out, accepted field of research now, but not one people necessarily know much about.

And I suppose we should stop there. But the temptation to see in these life processes analogies with economic and social processes is very great. In fact once you start studying that kind of complexity you begin to see resemblances to larger organizations. And so very good economists are coming here, and we've begun to speculate together about economic processes.

There's a world out there which responds to the notion of new ideas about economics more quickly than to any of the other notions we're kicking around. So there are people who are prepared to support this new effort, and the Institute has moved more rapidly in that direction than caution might have indicated. It's a region in which we're all profoundly ignorant but one in which the payoffs could be big.

Also I have to admit I started out to be an economist so I have certain biases. As an undergraduate I paid more attention to those courses and less attention to physical science. I just found them in some ways more interesting, and I'm still kind of a closet economist.

"People will say you're talking about God or some aspect of nature that imposes order on complexity. Or does all the order arise internally?"

What's the relationship between complexity and the age-old attempts in physics to explain existence simply?

It's very interesting. If quantum fluctuations began the universe, it seems that rather than going to real simplicity, you re-enter a realm of complexity. I don't know whether you read the article by a Russian named Andrei Linde in Phys. Rev. last September called "Inflationary Cosmology." He says that there are many moments of beginning. The process can create a very large number of different universes. If, in fact, the expanding universe in that first moment can bifurcate many times and move into some part of an arbitrary, possibly infinite phase-space, you're back to the same philosophical question—what is the deep truth or is there any? So that's why I say I'm agnostic. It's not clear to me you can ever get back to a deep simplicity.

That reminds me of an ancient Hindu idea that the universe itself pulses, that it awakens and goes to sleep, and with every awakening there are new energies, forces, and natural laws, completely different from those of the previous awake state.

That's a theme that constantly recurs in philosophy. The major rationale of grand unification is that indeed you will grab the brass ring of simplicity. If that escapes people . . . in the end I don't know whether we'll find fundamental truth or have to admit that reality is a series of endless loops, that there's no bottom level in these hierarchal levels of complexity.

Meanwhile the physical scientist holds to the faith that simple components will be found at the bottom. And I don't think that's so bad. I mean everybody needs a working hypothesis.

Dan Tyler is a writer in the International Technology Division at Los Alamos National Laboratory.

Global Security

A World of Possibilities

SFI has scheduled an informal meeting possibly this fall as the first step in organizing an interdisciplinary research program on global security.

George A. Cowan, SFI President, said approximately 30 scholars, scientists, and public and corporate leaders would be brought together under the auspices of SFI and the Center for National Security Studies at Los Alamos.

"Our primary objective in this initial meeting," Cowan said, "is to create an agenda and to formulate a list of participants for a full-scale meeting on the dynamics of global security to be held next year."

"This is the start of a continuing research program designed to involve a number of different disciplines, at many existing centers, in all of the major elements of global security."

Cowan said that, for purposes of this discussion, the meeting would measure global security in terms of the avoidance of catastrophic war, consistent with preservation of widely held human values, and without primary dependence on deterrence by nuclear weapons or other military means of mass destruction.

The initial elements of such a global security system slated for discussion include: national and supranational governments, including their military components; economic and industrial organization and market and distribution mechanisms; environment, ecology, climate and exhaustible resources; human behavior and society; information and misinformation; and the contributions and problems stemming from science and technology.

Residential Research

Gottfried Mayer-Kress

Gottfried Mayer-Kress of the Center for Nonlinear Studies at Los Alamos National Laboratory and Psychiatry Department, University of California at San Diego, is a visitor at the Institute throughout the spring and summer of 1988. Dr. Mayer-Kress' broad research interests within the area of nonlinear dynamical systems are reflected in the variety of his current scientific collaborations which range from problems in visualization and model simulation, dimensional analysis of human electro encephalograms (EEG's), dimension distributions for different galaxy clusters, to work on speech recognition and nonlinear dynamics.

Here he describes his current work on global stability at SFI, along with some personal background about the pathway to his study of complex systems.

In my former life I worked in the relativistic quantum field theory of elementary particle physics, where all scales are incredibly remote from our own life. However, my Ph.D. work was in the field of synergetics (with H. Haken in Stuttgart) and there the situation was quite the opposite from the ivory tower of DESY (the German electron synchrotron accelerator). Although Haken's institute was an institute for theoretical physics, visitors often wondered why people were working on problems which ranged from galaxy formation, laser theory and fluid convection to problems of brain mappings and the evolution of public opinions. During that time, I gained an appreciation for the nonlinear paradigm and its universal (or at least planetary) manifestations. Today I enjoy working in interdisciplinary collaborations on problems in the natural sciences, medicine, and international security.

Global security is certainly one of the most important, fuzzy, soft, and complex problems we are facing today. It is very tempting to put this global system into a theoretical box and play with it on the computer. Yet there are many problems which have to be addressed if one doesn't want to repeat the mistakes of previous attempts.

Probably the first scientist who thought about deriving mathematical equations for modeling the interactions between nations involved in an arms race was L. F. Richardson, whose main scientific work was in atmospheric turbulence theory. He used ordinary differential equations of motion for describing the interaction between nations. This approach has been challenged. A mathematician would argue that decisions about armaments are not made every picosecond, so they do not constitute a continuous process in the strict mathematical sense. However, we physicists are never really bothered by what mathematicians tell us, especially when it is a proof that something is not allowed or does not exist. The question is, why does one want to make this idealization? Historically the answer is clear: Leibniz and Newton didn't have SUN workstations on their desks and so they had to (a) restrict themselves to simple

Gottfried Mayer-Kress