Santa Fe Institute
Celebrating 20 years of Complexity Science

Innovation in Multi-Disciplinary Research: Experiences of the Santa Fe Institute

C. C. Wood
Vice President

Ministry of Economy, Trade and Industry
Tokyo, Japan
September 3, 2007

SANTA FE INSTITUTE

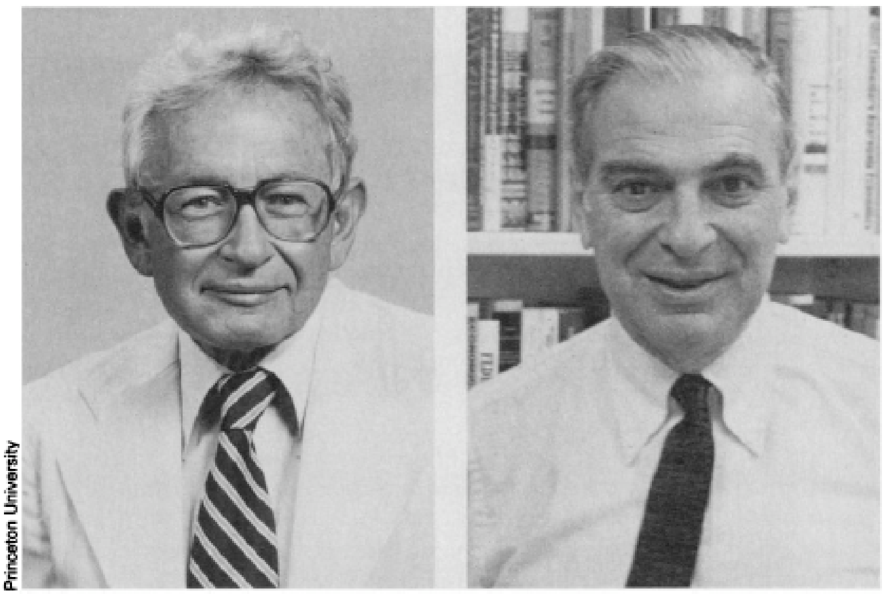
 Science, Aug 18, 1989

Strange Bedfellows

It is hard to think of a more unlikely collaboration than one between physicists and economists, but this is exactly what is going on at a former convent in Santa Fe, New Mexico

THEY MAKE AN ODD COUPLE, these two Nobel laureates. Philip Anderson is a condensed matter physicist who specializes in superconductivity; Kenneth Arrow is a theoretical economist who studies such things as how markets react to uncertainty. At first sight, you wouldn't expect them to have much in common, but you would be wrong.

Over the past 2 years, Anderson and Arrow have worked together in a venture that is one of the oddest couplings in the history of science—a marriage, or at least a serious affair, between economics and the physical sciences. If this unlikely liaison bears fruit, the result could be a hybrid theory that imparts to economics some of the tools and techniques developed for such fields as physics and biology.



Princeton University

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Physicist and economist. *Anderson (left) and Arrow kicked off an unusual collaboration by inviting ten physical scientists and ten economists to meet in Santa Fe.*

Although the project may seem somewhat quixotic, its roots are deep in the practical soil of the business world. In 1986, John Reed, chairman of Citicorp, found himself dissatisfied with state-of-the-art economic

best science and economics schools in the country—places such as Princeton, Caltech, Stanford, and Chicago.

As might be expected, the economists and scientists have found that things get rather interesting when two such different cultures collide.

Richard Palmer, a physicist at Duke University, recalls that first meeting in September 1987. "I used to think physicists were the most arrogant people in the world," he says. "The economists were, if anything, more arrogant." Both groups came into the meeting with skepticism and preconceived ideas, he recalls. The economists felt the physical scientists could not possibly help with their problems, and the physical scientists thought economics was a mess and there was not much you could do with it.

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SFI is a Private, Independent, Non-Profit Research Institute,
(not an accredited educational institution)

~12 Resident Faculty

~12 Postdocs

~60 External Faculty

~20 Staff

~300-400 Visitors per Year

~20-30 Workshops/WorkingGroups per Year

Yearly Budget: ~$9-10M (~$1.5M sub-awards):

~40% Federal and Foundation Grants; ~40% Private Donations; ~20% Corporate Affiliates / Business Network

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- *Rational Design of Vaccines*
- *Observed Quantum Systems*

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The Science Steering Committee (SSC) reviews and makes recommendations on all faculty appointments, workshops, ongoing research activities, and policy issues which affect how science is conducted at SFI. The SSC consists of a subset of the resident and off-site faculty as well as Science Board members.

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CHINA FOTOPRESS/GETTY

CULTURE CRASH

Some economists had hoped that physicists might shake up the rigid theories typical of mainstream economics. But so far, they're unimpressed by physicists' handling of the markets. **Philip Ball** reports.

For the past two decades, some physicists have been trying to apply their ideas and tools to an area that seems a long way from traditional physics. They are exploring the notion that there might be a kind of physics of the economy — an 'econophysics', as it has been dubbed[1]. Last year, some of these econophysicists even went as far as to suggest that economics might be "the next physical science"[2].

But now this unlikely marriage is showing signs of turning sour. Even those economists who at first welcomed econophysics are starting to wonder whether it is ever going to deliver on its initial promise. Early successes in modelling financial markets have not led to insights elsewhere, some complain. Matters came to a head at the Econophysics Colloquium, held at the Australian National University in Canberra last November. A group of economists attending the meeting were so dismayed with what they saw many physicists doing that they penned a forthcoming paper entitled 'Worrying trends in econophysics'[3].

In their critique, economist Paul Ormerod of the London-based consultancy Volterra and his co-authors accuse econophysicists of a litany of sins: applying inappropriate assumptions to economic systems, failing to do their homework properly, getting fixated on a small corner of the subject, and being sloppy with their statistics. At face value it is a damning indictment, and raises the question of whether econophysics will ever make a genuine contribution to economic theory, or whether it is doomed to remain a fringe interest.

Claim to blame

Some econophysicists admit that there are problems. "Econophysics is a field with very uneven quality," says Doyne Farmer, a physicist at the Santa Fe Institute in New Mexico, who made pioneering contributions to the study of chaos before moving into economics. Yi-Cheng Zhang of the University of Fribourg in Switzerland is even more ready with a *mea culpa*. "My economist friends are right. The literature is often littered with garbage. We can find gauge-field theories of finance, quantum options and so on. In short, anything goes."

But others reject the accusations. In response to the Canberra critique, Joe McCauley, a physicist at the University of Houston, Texas, who now works mostly on economic problems, says, "Would one write an essay called 'Worrying trends in physics' simply because a few minor researchers put out bad papers? Bad papers, even wrong papers, appear in every issue of every scientific journal."

"Econophysics is a field with very uneven quality." — Doyne Farmer

It is tempting to interpret this as a mere academic turf war. But Ormerod and colleagues are among the few people in economics who have taken econophysics seriously. Most economists don't know the discipline exists — and if they did, they would probably heap derision on it.

The idea that physics might have something useful to contribute to economics arises because both fields are concerned with systems of many interacting components that obey specific rules. Statistical physics describes the behaviour of bulk matter based on the forces acting between atoms and molecules. Economics studies the interactions between economic 'agents' — market traders, say, or businesses.

Econophysicists have focused on the financial market because it offers a lot of good-quality data.

Arguably, deriving microeconomic principles from the behaviour of individual agents should pose similar problems to deriving thermodynamic laws from interatomic forces. The rules dictating how interactions play out between economic agents are admittedly more complex than the forces between atoms, but in conventional economics the rules have always been grossly simplified to make the models workable.

For example, the core theory of mainstream economics, the neoclassical model, argues that agents always act with perfect rationality to maximize their 'utility' (for example, profit), based on complete information about the state of the market as a whole. In this picture, an economic market quickly reaches an equilibrium state, in which commodities find the price that perfectly balances supply and demand.

Modelworld

Economists recognize that real human agents do not always act in such a coldly rational way, and that they generally have to manage with incomplete information. But although Nobel prizes in economics were awarded in 2001 and 2002 for work that recognizes these limitations, neoclassical theories — and particularly the idea of equilibrium — remain central to mainstream economics.

Ormerod and his colleagues, and other physics-friendly economists, had hoped that econophysics would help them create a new economics that is free from some of the dogmatic assumptions characterizing the mainstream discipline today. "Economics desperately needs econophysics," claims Ormerod's co-author Steve Keen, an economist at the University of Western Sydney in Australia. Keen had hoped in particular that econophysics might break his fellow economists' misconceived obsession with equilibrium. "Equilibrium thinking still has them in its unshakeable thrall," he says.

A glance at almost any plot of commodity prices over time belies the idea of market equilibrium: the values fluctuate wildly. But in neoclassical theory, these fluctuations are regarded as background 'noise' caused by unpredictable 'shocks' from outside the economic system, to which the market constantly and quickly adjusts. An attempt to explain such fluctuations using statistical physics was made as early as 1900 by Louis Bachelier; he proposed an explanation that introduced the theory of random walks, which was later developed independently by Einstein to explain brownian motion.

Bachelier's theory was deemed too strange to be taken seriously by economists. But the issue was revisited in the early 1960s, when mathematician Benoit Mandelbrot showed that fluctuations in cotton prices have a statistical distribution that differs from that expected of a typical gaussian process — where each event happens randomly and independently of all others. There were more large fluctuations than a gaussian distribution predicts[4]. This has significant implications for economic theories that assume market 'noise' to be gaussian — but more importantly, it suggests that big fluctuations, perhaps even market crashes, are not rare anomalies but intrinsic to normal market behaviour. Mandelbrot's 1963 paper on price fluctuations is now regarded as one of the key precursors to modern econophysics.

"Physicists suffer from a belief that there must be universal rules." — Paul Ormerod

Out of equilibrium

But it wasn't until the early 1980s, when an unusual mix of researchers got together at the Sante Fe Institute, that economists showed much interest in scientific ideas related to complex systems. They were helped by advances in computing. "Once we got desktop computers, we could model systems of many agents and allow them rules of behaviour and see how they evolved," says economist Brian Arthur, who worked at Santa Fe alongside physicists and evolutionary biologists to develop non-traditional approaches to economics[5]. Such computer simulations of the economy led to models of 'interacting agents'[6] that were influenced as much by work on cognition and evolutionary biology as by physics.

In these models, researchers could give the interacting agents any decision-making strategy they desired, and therefore study markets with different underlying behaviours. "What we found was quite surprising," recalls Arthur. "Under some restrictive conditions, you get market equilibrium, but under other conditions you get much more complicated outcomes." It seemed there was no good reason to believe that microeconomics always operates at equilibrium. "The economy is out of kilter most of the time," says Arthur. That, he says, accounts for one of the virtues of econophysics. "The core of economic theory is still built around equilibrium models, but most models in econophysics are non-equilibrium ones."

But those economists who have adopted new approaches such as agent-based modelling have become increasingly frustrated with the intransigence of main-stream economics. Some have even resorted to starting their own publication, the *Journal of Economic Interaction and Coordination*, the first issue of which appeared online in May. Zhang says that three of the four authors of the Canberra critique are victims of the intellectual exclusion imposed by mainstream economists. "That's why they had such high hopes when physicists offered what

Santa Fe Institute

How Life Began

by James Trefil

Some of the fundamental physical and chemical processes that were present early in the history of our planet still exist under the ocean. Here, images from the 2004 Submarine Ring of Fire exploration depict various aspects of volcanoes on the sea floor at Mariana Arc in the Pacific Ocean.

PHOTOS: NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

In the Beginning…

There are few phrases in the English language more freighted with meaning than this. Veteran lecturers know that there is nothing that evokes a sense of awe and majesty (and, in some people, insecurity) like a discussion of the origin of the universe or the origin of life. Now, a nationwide research effort spearheaded by Harold Morowitz of the Santa Fe Institute and George Mason University is forming to attack the ultimate question of how life began, to learn what might have happened— "In the beginning."

This new effort is being funded by a five year, $5 million grant from the National Science Foundation. The Foundation has funded a small number of research efforts in a program they call Frontiers in Integrative Biological Research (FIBR). The idea of this initiative is to identify research projects that, if successful, would result in major advances in our knowledge of living systems, but carry a high risk as well. Three awards were given in 2005. The SFI grant involves scientists at SFI and George Mason University, together with colleagues at the University of Colorado, the Carnegie Institution of Washington, the University of Illinois at Urbana-Champaign, and Arizona State University.

PNAS

A mechanism for the association of amino acids with their codons and the origin of the genetic code

Shelley D. Copley*†, Eric Smith‡, and Harold J. Morowitz§

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Communicated by Gregory A. Petsko, Brandeis University, Waltham, MA, February 7, 2005 (received for review December 13, 2004)

The genetic code has certain regularities that have resisted mechanistic interpretation. These include strong correlations between the first base of codons and the precursor from which the encoded amino acid is synthesized and between the second base of codons and the hydrophobicity of the encoded amino acid. These regularities are even more striking in a projection of the modern code onto a simpler code consisting of doublet codons encoding a set of simple amino acids. These regularities can be explained if, before the emergence of macromolecules, simple amino acids were synthesized in covalent complexes of dinucleotides with α-keto acids originating from the reductive tricarboxylic acid cycle or reductive acetate pathway. The bases and phosphates of the dinucleotide are proposed to have enhanced the rates of synthetic reactions leading to amino acids in a small-molecule reaction network that preceded the RNA translation apparatus but created an association between amino acids and the first two bases of their codons that was retained when translation emerged later in evolution.

catalysis | origin of life

The genetic code has many regularities (1), of which only a subset have explanations in terms of tRNA function (2) or robustness against deleterious effects of mutation (3, 4) or errors in translation (3, 5). There is a strong correlation between the first bases of codons and the biosynthetic pathways of the amino acids they encode (1, 6). Codons beginning with C, A, and U encode amino acids synthesized from α-ketoglutarate (α-KG), oxaloacetate (OAA), and pyruvate, respectively.¶ These correlations are especially striking in light of the structural diversity of amino acids whose codons share a first base. For example, codons for Glu and Pro both begin with C, and those for Cys and Leu begin with U. Codons beginning with G encode amino acids that can be formed by direct reductive amination of a simple α-keto acid. These include glycine, alanine, aspartate, and glutamate, which can be formed by reductive amination of glyoxalate, pyruvate, OAA, and α-KG, respectively. There is also a long-recognized relationship between the hydrophobicity of the amino acid and the second base of its codon (1). Codons having U as the second base are associated with the most hydrophobic amino acids, and those having A as the second base are associated with the most hydrophilic amino acids.

We suggest that both correlations can be explained if, before the emergence of macromolecules, simple amino acids were synthesized from α-keto acid precursors covalently attached to dinucleotides that catalyzed the reactions required to synthesize specific amino acids (see Fig. 1). This is a significant departure from previous theories attempting to explain the regularities in the genetic code (3). The "stereochemical" hypothesis suggests that binding interactions between amino acids and their codons or anticodons dictated the structure of the genetic code (7–10). The "coevolution" hypothesis (6) suggests that the original genetic code specified a small number of simple amino acids, and that, as more complex amino acids were synthesized from these precursors, some codons that initially encoded a precursor were ceded to its more complex products. Finally, the genetic code has been proposed to be simply a "frozen accident" (11).

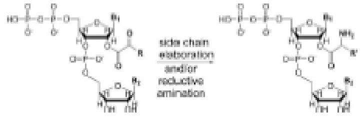


Fig. 1. Model for synthesis of amino acids from α-keto acid precursors covalently attached to dinucleotides. The dinucleotide that is capable of catalyzing synthesis of a particular amino acid is proposed to contain the first two bases of the codon specifying that amino acid.

Recent analysis suggests that the reductive tricarboxylic acid cycle could serve as a network-autocatalytic self-sufficient source for simple α-keto acids, including glyoxalate, pyruvate, OAA, and α-KG, as well as the carbon backbones of sugars and nucleobases (12). α-Keto acids can also be generated from the reductive acetyl CoA pathway (13). Most simple amino acids can be reached from an α-keto acid precursor by a small number of relatively simple chemical transformations, and the synthetic pathway that will be followed is determined within the first three steps. We propose that the positions of functional groups in a dinucleotide–α-keto acid complex determine what reactions can be effectively catalyzed for a given α-keto acid. An example of a series of reactions leading from α-KG to five amino acids, each attached to the first two bases of its codon, is shown in Fig. 2, which can be regarded as a "decision tree" in which the nature of the bases in the dinucleotide determines which types of reactions occur. The pathways proposed follow closely those in extant organisms (14), differing primarily in the timing of the reductive amination leading to the final amino acid. The motivation for this approach is that modern biosynthetic pathways likely emerged by gradual acquisition of enzymes capable of catalyzing reactions that had previously occurred in the absence of macromolecular catalysts. Thus, modern pathways are "metabolic fossils" that provide insight into prebiotic synthetic pathways, although some refinements and permutations are expected to have occurred.

The proposition that nucleotides might provide catalytic assistance during synthesis of amino acids is plausible. Catalytic RNAs are capable of catalyzing a wide range of chemical transformations (15–21). Because the amino acid building blocks of proteins can catalyze reactions such as aldol condensation (22, 23), it is reasonable to expect that the nucleotide building blocks of RNAs may also have catalytic abilities. Dinucleotides might catalyze reactions required for synthesis of amino acids by (*i*) orientation and polarization of reactants by hydrogen bonding interactions, (*ii*) use of

Abbreviations: α-KG, α-ketoglutarate; OAA, oxaloacetate.

†To whom correspondence should be addressed. E-mail: shelley@cires.colorado.edu.

¶Correlations between the first bases of codons and biosynthetic pathways were first pointed out by Wong (6) and later by Taylor and Coates (1). However, the earlier work focused on Glu, Asp, and Ala as the synthetic precursors rather than the α-keto acids α-KG, OAA, and pyr.

www.pnas.org/cgi/doi/10.1073/pnas.0501049102

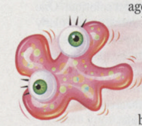
Geoffrey West -
Scaling in Biology

LIFE ON THE SCALES

Simple mathematical relationships underpin much of biology and ecology

BY ERICA KLARREICH

A mouse lives just a few years, while an elephant can make it to age 70. In a sense, however, both animals fit in the same amount of life experience. In its brief life, a mouse squeezes in, on average, as many heartbeats and breaths as an elephant does. Compared with those of an elephant, many aspects of a mouse's life—such as the rate at which its cells burn energy, the speed at which its muscles twitch, its gestation time, and the age at which it reaches maturity—are sped up by the same factor as its life span is. It's as if in designing a mouse, someone had simply pressed the fast-forward button on an elephant's life. This pattern relating life's speed to its length also holds for a sparrow, a gazelle, and a person—virtually any of the birds and mammals, in fact. Small animals live fast and die young, while big animals plod through much longer lives.



"It appears as if we've been gifted with just so much life," says Brian Enquist, an ecologist at the University of Arizona in Tucson. "You can spend it all at once or slowly dribble it out over a long time."

Scientists have long known that most biological rates appear to bear a simple mathematical relationship to an animal's size: They are proportional to the animal's mass raised to a power that is a multiple of $1/4$. These relationships are known as quarter-power scaling laws. For instance, an animal's metabolic rate appears to be proportional to mass to the $3/4$ power, and its heart rate is proportional to mass to the $-1/4$ power.

The reasons behind these laws were a mystery until 8 years ago, when Enquist, together with ecologist James Brown of the University of New Mexico in Albuquerque and physicist Geoffrey West of Los Alamos (N.M.) National Laboratory proposed a model to explain quarter-power scaling in mammals (*SN: 10/16/99, p. 249*). They and their collaborators have since extended the model to encompass plants, birds, fish and other creatures. In 2001, Brown, West, and several of their colleagues distilled their model to a single formula, which they call the master equation, that predicts a species' metabolic rate in terms of its body size and temperature.

"They have identified the basic rate at which life proceeds," says Michael Kaspari, an ecologist at the University of Oklahoma in Norman.

In the July 2004 *Ecology*, Brown, West, and their colleagues proposed that their equation can shed light not just on individual animals' life processes but on every biological scale, from subcellular molecules to global ecosystems. In recent months, the investigators have applied their equation to a host of phenomena, from the mutation rate in cellular DNA to Earth's carbon cycle.

Carlos Martinez del Rio, an ecologist at the University of Wyoming in Laramie, hails the team's work as a major step forward. "I think they have provided us with a unified theory for ecology," he says.

THE BIOLOGICAL CLOCK In 1883, German physiologist Max Rubner proposed that an animal's metabolic rate is proportional to its mass raised to the $2/3$ power. This idea was rooted in simple geometry. If one animal is, say, twice as big as another animal in each linear dimension, then its total volume, or mass, is 2^3 times as large, but its skin surface is only 2^2 times as large. Since an animal must dissipate metabolic heat through its skin, Rubner reasoned that its metabolic rate should be proportional to its skin surface, which works out to mass to the $2/3$ power.

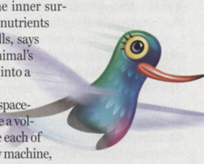
In 1932, however, animal scientist Max Kleiber of the University of California, Davis looked at a broad range of data and concluded that the correct exponent is $3/4$, not $2/3$. In subsequent decades, biologists have found that the $3/4$-power law appears to hold sway from microbes to whales, creatures of sizes ranging over a mind-boggling 21 orders of magnitude.

> "They have identified the basic rate at which life proceeds."
> — MICHAEL KASPARI, UNIVERSITY OF OKLAHOMA

For most of the past 70 years, ecologists had no explanation for the $3/4$ exponent. "One colleague told me in the early '90s that he took $3/4$-scaling as 'given by God,'" Brown recalls.

The beginnings of an explanation came in 1997, when Brown, West, and Enquist described metabolic scaling in mammals and birds in terms of the geometry of their circulatory systems. It turns out, West says, that Rubner was on the right track in comparing surface area with volume, but that an animal's metabolic rate is determined not by how efficiently it dissipates heat through its skin but by how efficiently it delivers fuel to its cells.

Rubner should have considered an animal's "effective surface area," which consists of all the inner surfaces across which energy and nutrients pass from blood vessels to cells, says West. These surfaces fill the animal's entire body, like linens stuffed into a laundry machine.



The idea, West says, is that a space-filling surface scales as if it were a volume, not an area. If you double each of the dimensions of your laundry machine, he observes, then the amount of linens you can fit into it scales up by 2^3, not 2^2. Thus, an animal's effective surface area scales as if it were a three-dimensional, not a two-dimensional, structure.

This creates a challenge for the network of blood vessels that must supply all these surfaces. In general, a network has one more dimension than the surfaces it supplies, since the network's tubes

D. MACADAM

Physics Today September 2004– Life's Universal Scaling Laws

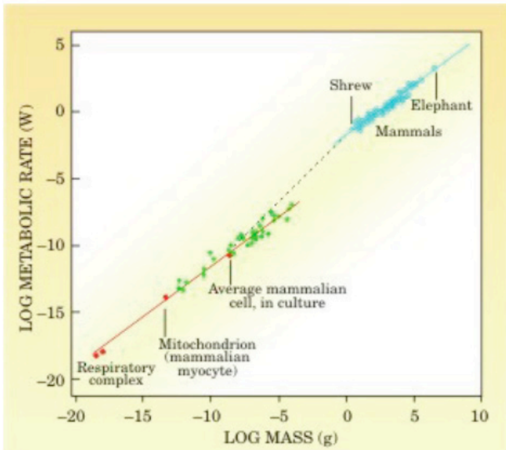


Figure 2. The 3/4–power law for the metabolic rate as a function of mass is observed over 27 orders of magnitude. The masses covered in this plot range from those of individual mammals (blue), to unicellular organisms (green), to uncoupled mammalian cells, mitochondria, and terminal oxidase molecules of the respiratory complex (red). The blue and red lines indicate 3/4–power scaling. The dashed line is a linear extrapolation that extends to masses below that of the shrew, the lightest mammal. In reference 6, it was predicted that the extrapolation would intersect the datum for an isolated cell in vitro, where the 3/4–power reemerges and extends to the cellular and intracellular levels. (Adapted from ref. 6.)

Growth, innovation, scaling, and the pace of life in cities

Luís M. A. Bettencourt*†, José Lobo‡, Dirk Helbing§, Christian Kühnert§, and Geoffrey B. West*¶

*Theoretical Division, MS B284, Los Alamos National Laboratory, Los Alamos, NM 87545; ‡Global Institute of Sustainability, Arizona State University, P.O. Box 873211, Tempe, AZ 85287-3211; §Institute for Transport and Economics, Dresden University of Technology, Andreas-Schubert-Strasse 23, D-01062 Dresden, Germany; and ¶Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501

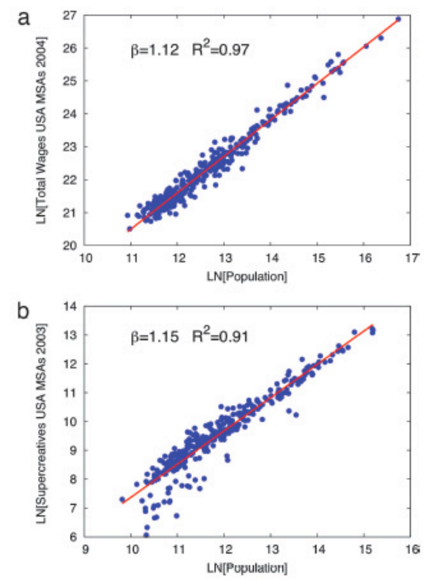


Fig. 1. Examples of scaling relationships. (*a*) Total wages per MSA in 2004 for the U.S. (blue points) vs. metropolitan population. (*b*) Supercreative employment per MSA in 2003, for the U.S. (blue points) vs. metropolitan population. Best-fit scaling relations are shown as solid lines.

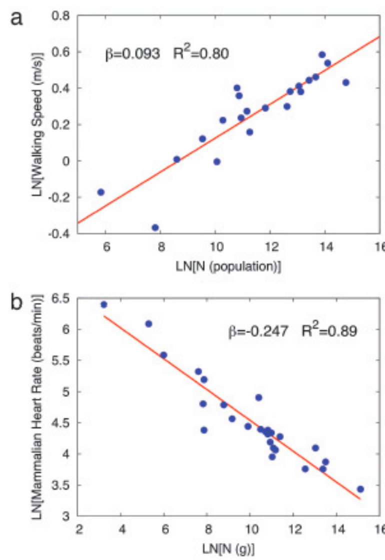


Fig. 2. The pace of urban life increases with city size in contrast to the pace of biological life, which decreases with organism size. (*a*) Scaling of walking speed vs. population for cities around the world. (*b*) Heart rate vs. the size (mass) of organisms.

TIME 100: The People Who Shape Our World

DAN PEEBLES FOR TIME

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May 8, 2006

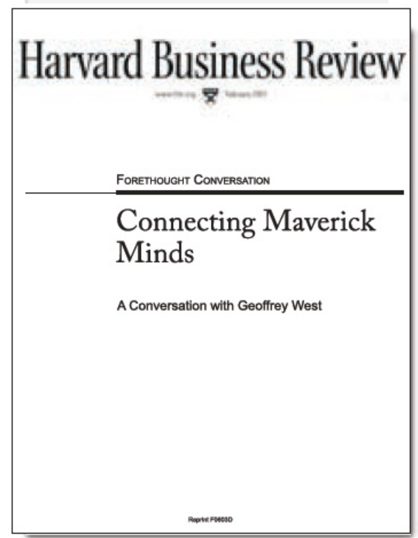
- Leaders & Revolutionaries

From the Magazine | Scientists & Thinkers

Geoffrey West

Master of Complexity

By MURRAY GELL-MANN



Harvard Business Review

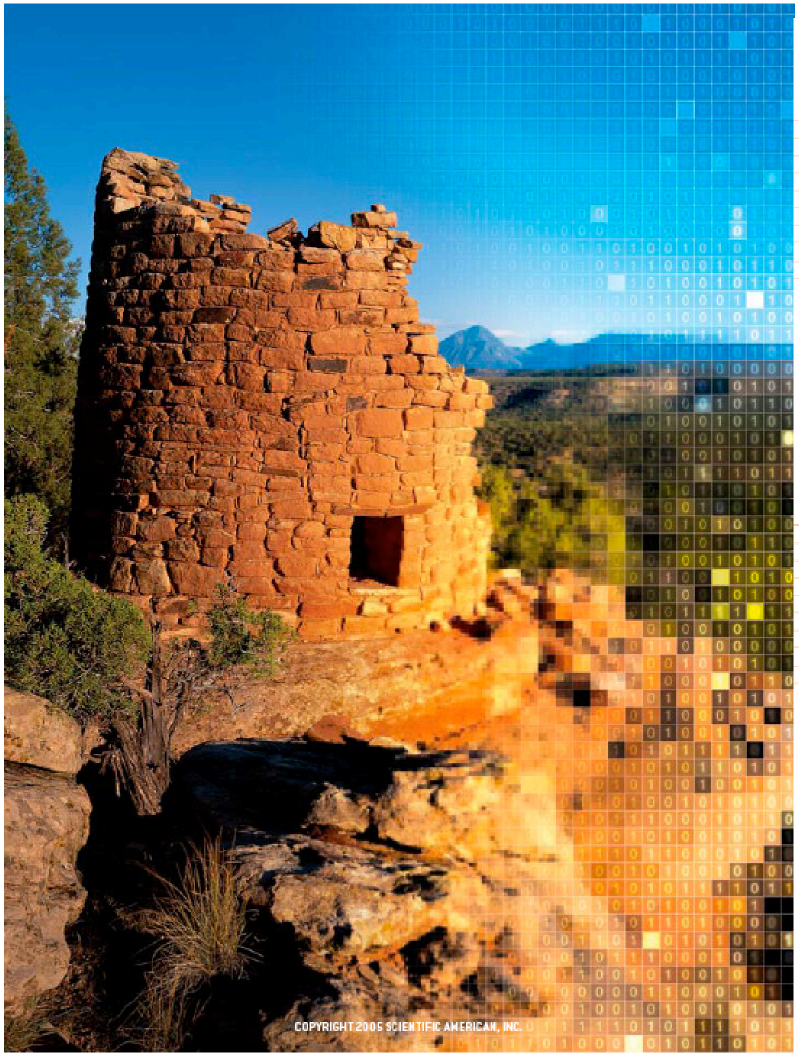
FORETHOUGHT CONVERSATION

Connecting Maverick Minds

A Conversation with Geoffrey West

Santa Fe Institute

Agent-Based Models in the Social Sciences



SIMULATING ANCIENT SOCIETIES

Computer modeling is helping unravel the archaeological mysteries of the American Southwest

By Timothy A. Kohler, George J. Gumerman and Robert G. Reynolds

PAINTED HAND, a 760-year-old ruin in the Mesa Verde region of southwestern Colorado, lies within a study area where researchers are using computer models to simulate the settlement and land-use patterns of the ancient Puebloan peoples.

Only a small fraction of human history is known through texts. For the rest, archaeology is the main source. By examining ruins, artifacts and remains, archaeologists have painstakingly constructed a series of pictures showing human societies as they existed thousands and even millions of years ago. It is much more difficult, however, to determine the processes that produced and changed these societies. Researchers are still struggling to understand the long chain of cause-and-effect (and chance events) stretching from our hominid ancestors of four million years ago—small bands of upright-walking primates with no stone tools and scarcely any conversation—to the communities and cultures we see around the world today.

With the advent of computers, archaeologists began to experiment with simulation as an aid to exploring human prehistory. The logic is simple: you program the computer to mimic processes such as population growth and resource usage, then see how well the software's predictions coincide with the archaeological record. An early example is the well-known attempt in the late 1970s to examine the collapse of the Classic Maya civilization, which dominated a vast swath of Mexico and Central America from A.D. 300 to 900. Led by researchers at the Massachusetts

Santa Fe Institute

SFI Educational Activities

SFI Public Lecture Series and Ulam Lectures

SFI Prize for Scientific Excellence

"Adventures in Modeling" Project

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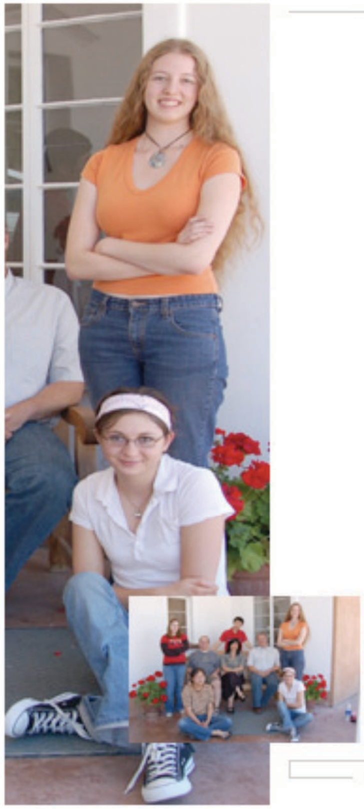
Computational Social Sciences
2007 Complex Systems Summer Schools
The annual Complex Systems Summer Schools provide an intensive introduction to complex behavior in mathematical, physical, living, and social systems for graduate students and postdoctoral fellows. It is open to students in all countries. Students are expected to attend for the full four weeks. No tuition is charged. Some support for housing and travel expenses may also be available. Enrollment is limited.
Partial support for these schools is provided by the National Science Foundation, the Santa Fe Institute, and The Chinese Academy of Sciences.
Santa Fe Program Information
Beijing Program Information
Santa Fe School
June 3 - 29, 2007
Santa Fe, NM, USA
China School
July 8 - August 4, 2007
Beijing, China
Santa Fe Wiki
Beijing Wiki
Previous Schools



K-12

SFI has a strong commitment to bring complexity science education to our next generation of scientists and scholars. We offer periodic workshops for local students and teachers. In addition, our secondary school program coordinators are available to present an on-site school-based introduction to computer modeling and inquiry-based science. SFI's approach to secondary school complexity science uses a hands-on approach featuring the computer-modeling tool StarLogo developed at MIT's Media Lab.

Summer Internship/Mentorship Program

A five-week program for high school students that focuses on the study of computer simulation and complex systems.

Project GUTS: Growing Up Thinking Scientifically

A year-long science, technology, math, and engineering (STEM) program for middle school students in Santa Fe, NM.

Secondary School Adventures in Modeling

"Exploring the World through Computer Models" is an annual summer and academic year program for Santa Fe high school students and teachers focusing on computer modeling.

Secondary Award for Scientific Excellence

Each year the Santa Fe Institute honors graduating seniors from area high schools with the Prize for Scientific Excellence.

International
PROGRAM

The International Program moved into a new phase in 2006 as it seeks to fully integrate the program into the research community at SF, the highlight of which was a meeting of all former and current International Fellows. Twenty-five researchers met at SFI in September to share research and explore collaborative and educational opportunities. The researchers came from every continent and some of the countries represented were Russia, South Africa, China, India, Argentina, Chile, Colombia, and Hungary.

Consistent with the program philosophy to encourage SFI-style research in developing countries the program supported a number of activities in target countries. For example, SFI researchers visited Budapest for a working group meeting convened by former International Fellow, Beáta Oborny, to explore "Ecological Borderlines" and the possibility of applying phase transitions to ecological systems. Former Fellow and Universidad de los Andes Professor Juan Camilo-Cardenas led a working group of SFI researchers, including two other former Fellows, entitled "The Evolution of Cooperation in the Commons," in Bogotá, Colombia.

Pablo Marquet received research support as "seed money" for his new EcoInformatics Lab in Santiago, Chile. SFI researchers Raissa D'Souza, Jim Crutchfield and Vice-President C.C. Wood traveled to Valparaiso, Chile to support the inaugural "Residency Month" held in the new complexity institute, ISCV.

For the third year, the Complex Systems Summer School (CSSS) was held in Beijing, China. Work on a new educational module series also commenced in 2006. Building on the successful model of the CSSS the modules break the components of complex systems analysis into smaller, mini-tutorials. The first module, on network theory, will be complete June 2007.

International
FELLOWS

The International Fellowship Program fosters the further development of academic and interdisciplinary research activities in targeted countries throughout the world. Two-year fellowships are awarded to outstanding graduate students, postdoctoral students, and junior or senior researchers, who are affiliated with, on a full-time basis, an academic institution within their country of origin. Fellows are invited for short-term visits to the Santa Fe Institute where they have the opportunity to participate in the Institute's many educational programs, workshops, and symposia. The fellowships can provide modest support for research activities in the Fellow's home institution, and Fellows also have the opportunity to organize workshops in their own country.

Miguel Fuentes,
(now SFI Postdoctoral Fellow), Center for Atomic Studies, Bariloche, Argentina Mathematical models in biological systems

Francisco Gutierrez,
National University of Colombia Political violence, microfoundations of civil wars

Jorge Velasco-Hernandez,
Mexican Institute of Petroleum Mathematical models of population dynamics, ecology and epidemiology

Business Network Members

AFOSR, *Arlington, VA*
Alidade Incorporated, *Newport, RI*
Amena, *Madrid, Spain*
Argonne National Laboratory, *Argonne, IL*
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Baillie Gifford, *Edinburgh, Scotland*
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Capital One, *McLean, VA*
Cisco Systems, *San Jose, CA*
CNO Strategic Studies Group, *Newport, RI*
Credit Suisse, *New York, NY*
CustomerSat Inc., *Mountain View, CA*
Davis Selected Advisers, L.P., *New York, NY*
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FX Palo Alto Laboratory, *Palo Alto, CA*
Hewlett-Packard, *Palo Alto, CA*
Honda R&D Americas, *Southfield, MI*
Insight Venture Partners, *Aspen, CO*
Intel Corporation, *Hillsboro, OR*
Lazard Asset Management, *New York, NY*
Legg Mason Capital Management, *Baltimore, MD*
Lockheed Martin Corporation, *Bethesda, MD*
Los Alamos National Bank, *Los Alamos, NM*
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The Mitre Corporation, *McLean, VA*
Morgan Stanley Investment Management, *New York, NY*
National Institute of Aerospace/NASA, *Hampton, VA*
Nativis, Inc., *La Jolla, CA*
NATS LLC, *San Francisco, CA*
Northrop Grumman Mission Systems, *Albuquerque, NM*
Office of Naval Research, *Arlington, VA*
OppenheimerFunds, *New York, NY*
Pioneer Hi-Bred International, *Johnston, IA*
Procter & Gamble, *Cincinnati, OH*
Sandia National Laboratories, *Albuquerque, NM*
Sente Corporation, *Orlando, FL*
Sherman Kent School for Intelligence Analysis, *Washington, DC*
State Farm Insurance Companies, *Bloomington, IL*
Steelcase, Inc., *Grand Rapids, MI*
Sun Microsystems, *Palo Alto, CA*
Susquehanna International Group, LLP, *New York, NY*
Swiss Re Investors, *New York, NY*
Thomson Scientific & Healthcare, *Philadelphia, PA*
Thornburg Mortgage Advisory, *Santa Fe, NM*
Toyota Motor Corporation, *Aichi, Japan*
Trust Company of the West, *Los Angeles, CA*
UBS AG, *Chicago, IL*
WCM Investment Management, *Lake Forest, CA*
Ziff Brothers Investments, *New York, NY*

"Agent-Based Modeling and Simulation Course"
April 16, 2007 to April 20, 2007
Argonne National Laboratory in Woodridge, IL hosts this sixth annual course from April 16th to April 20th, 2007. Company analyzes, software development and managerial topics will be covered.

"Diverse teams, Wise Crowds and Informed Experts"
March 16, 2007 by Scott Page and Michael Mauboussin
SFI External Faculty Member Scott Page (University of Michigan) and Business Network Member Michael Mauboussin (Legg Mason Capital Management) host this meeting in Chicago.

"Collective Intelligence in Synthetic Environments"
February 20, 2007 to February 21, 2007 by Leighton Read and Christian Renaud
Cisco Systems' Leighton Read and Christian Renaud present the first Topical Meeting of 2007, Feburary 20th and 21st on the San Jose, CA campus of Cisco Systems.

"Competitive Strategies in Complex Systems"
December 4, 2006 to December 6, 2006 by Alidade Inc. and Strategic Studies Group. Held in Newport, RI.

"Flows on Distributed Networks"
July 30, 2007 by David Krakauer (SFI)
"Flows on Distributed Networks"with SFI Researcher David Krakauer. Co-hosted by The Boeing Company, held in Seattle, WA

"Conflict, Robustness, and Creativity"
September 6, 2007 to September 7, 2007 by Jessica Flack (Research Fellow, Santa Fe Institute). This Topical Meeting is co-presented with CNO Strategic Studies Group and will be held in Washington, D.C.

"ARCS 2007 (Adaptive and Resilient Computer Security) Workshop"
September 27, 2007
ARCS 2007 is the sixth meeting of a workshop designed to bring together senior industrial researchers, policy makers and leading academics in the area of adaptive approaches to computer security. Co-hosted by the Santa Fe Institute, BT, and the British Computer Society and held at the Imperial War College, London.

"Diversity Collapse: When, Where, and What are the Consequences?"
November 2, 2007 to November 3, 2007 by Eric Smith (SFI)
Annual Business Network and Board of Trustees' Symposium "Diversity Collapse: When, Where, and What are the Consequences?" Co-organized by SFI Researcher D. Eric Smith, held in Santa Fe, NM

SFI Community Lectures

February 7, 2007

• Public Lecture—"More than Pretty Pictures: The Power of Images in Science," Felice Frankel (Senior Research Fellow in the Faculty of Arts and Sciences at Harvard University, where she heads the Envisioning Science program at Harvard's Initiative in Innovative Computing (IIC). She holds a concurrent appointment as a research scientist at the Massachusetts Institute of Technology. She is the author of Envisioning Science, The Design and Craft of the Science Image), 7:30 PM to 9:00 PM, James A. Little Theater.

March 14, 2007

• Public Lecture—"The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools and Societies," Scott E. Page (Professor of Complex Systems, Political Science, and Economics at the University of Michigan and External Faculty Member of the Santa Fe Institute. He is author of The Difference and coauthor of Complex Adaptive Social Systems (Princeton)), 7:30 PM to 9:00 PM, James A. Little Theater.

April 18, 2007

• Public Lecture—"Inevitable Life?," D. Eric Smith (Professor at the Santa Fe Institute and senior member of SFI's Frontiers in Integrative Biological Research (FIBR) program supported by the National Science Foundation), 7:30 PM to 9:00 PM, James A. Little Theater.

May 9, 2007

• Public Lecture—"New Mexico's Renewable Energy Future," Ben Luce (Physicist at Los Alamos National Laboratory, is Director of the New Mexico Coalition for Clean Affordable Energy), 7:30 PM to 9:00 PM, James A. Little Theater.

June 13, 2007

• Public Lecture—"Stylish Mathematics," Dan Rockmore (Professor of Mathematics at Dartmouth College and External Professor at the Santa Fe Institute. He is the author of Stalking the Riemann Hypothesis and co-author of Music and Computers: A Theoretical and Historical Approach. Rockmore is a semi-regular commentator for Vermont Public Radio; his essays and reviews appear in the New York Times, Dallas Morning News, and other media), 7:30 PM to 9:00 PM, James A. Little Theater, New Mexico School for the Deaf.

July 25, 2007

• Public Lecture—"Sexual Violence during War," Elisabeth Wood (Professor of Political Science at Yale University and Professor at the Santa Fe Institute. She is the author of Insurgent Collective Action and Civil War in El Salvador and Forging Democracy from Below: Insurgent Transitions in South Africa and El Salvador), 7:30 PM to 9:00 PM, James A. Little Theater, New Mexico School for the Deaf.

August 15, 2007

• Public Lecture—"Investor Behavior and Market Efficiency," Terrance Odean (Willis H. Booth Professor of Banking and Finance at the Haas School of Business, University of California at Berkeley), 7:30 PM to 9:00 PM, James A. Little Theater, New Mexico School for the Deaf.

October 17, 2007

• Public Lecture—"Borders and Gateways: Computer Networking in Everyday Life," Stephanie Forrest (Professor and Chairman of Computer Science at the University of New Mexico in Albuquerque and a Professor at the Santa Fe Institute. Professor Forrest is a member of the Adaptive Computation Group at UNM, where she studies adaptive systems, including genetic algorithms, computational immunology, biological modeling, and computer security), 7:30 PM to 9:00 PM, James A. Little Theater, New Mexico School for the Deaf.

November 14, 2007

• Public Lecture—"Technology Creating Technology," W. Brian Arthur (External Professor at the Santa Fe Institute and Visiting Researcher, Intelligent Systems Lab, PARC. Formerly he was Dean and Virginia Morrison Professor of Economics and Population Studies at Stanford. He has been associated with SFI since 1987. He is currently writing a book: The Nature of Technology, to be published by Simon & Schuster), 7:30 PM to 9:00 PM, James A. Little Theater, New Mexico School for the Deaf.

Workshops and Working Groups are an "Engine" of SFI Science

2006

Meetings

An important component of the Institute's research programs is its workshops. In 2006 nearly 425 researchers participated in nearly two dozen workshops and working groups. These gatherings permit members of SFI's numerous offsite "virtual" collaborations to come together to update and synthesize ongoing work; as noted, founding workshops serve as a mechanism to catalyze new interdisciplinary networks of collaborative work.

January 6 - 8 "The Evolution of Gene Regulatory Logic," organized by David Krakauer (SFI) and Tanya Berger-Wolf (DIMACS and University of Illinois, Chicago)

January 21 - 22 "Adventures in Modeling," organized by Eric Klopfer (MIT) and Ginger Richardson (SFI)

February 8 – 11 "General Patterns of Migrations," organized by Ilia Peiros (SFI)

February 9 - 11 "Foundations of Cooperation in the Commons," organized by Juan Camilo Cardenas (Universidad de Los Andes, Bogota, Colombia), held in Bogota

February 17 - 19 "The Evolution of Inequality: The Long-Term Dynamics of Segmentation, Stratification, and Unequal Reward," organized by Samuel Bowles (SFI)

March 17 - 18 "Roadmap for Complex Adaptive Systems Science Education," organized by Ginger Richardson (SFI)

April 24 - 28 "Agent-Based Modeling and Simulation Course," co-hosted by SFI and Business Netowork Argonne National Laboratory

May 12 - 13 "Annual Science Board Meeting and Symposium," organized by Geoffrey West and C.C. Wood (SFI), David Campbell (Boston University), and Simon Levin (Princeton University)

May 23 "Annual Science Writers' Workshop," organized by Susan Ballati (SFI). Held at the Santa Fe Institute

May 29 - June 2 "From Vent Chemistry to Biochemistry," organized by Harold Morowitz (George Mason University/SFI) and D. Eric Smith (SFI)

June 4 - 30 "Complex Systems Summer School - Santa Fe," directed by Daniel Rockmore (Dartmouth College/SFI). Administered by SFI at St. John's College

June 28 "Scaling and Growth of Complex Networks," co-hosted by SFI and Business Network member The Boeing Company, held in Seattle

July 6 - 8 "Degeneracy and Complexity in the Immune System," organized by Eli Sercarz (Torrey Pines Institute), Alan Perelson (LANL/SFI), Irun Cohen (Weizmann Institute of Science)

July 9 - August 4 "Complex Systems Summer School - Beijing," co-directed by David P. Feldman (College of the Atlantic/SFI) and Chen Xiao-Song (Institute for Theoretical Physics, CAS). Sponsored by SFI in cooperation with the Institute of Theoretical Physics and the Graduate School, Chinese Academy of Sciences (CAS), held in Beijing

July 16 - 23 "Foundations of Theoretical Medicine," organized by David Krakauer (SFI)

July 18, 2006 "Evolving Software," co-hosted by SFI and Business Network member CISCO.

August 7 - 8 "Energy Futures Workshop Planning Meeting," organized by Doug Arent (National Renewable Energy Laboratory) and Geoffrey West (SFI)

August 14 "Cognition and Cosmology: New Models for Understanding Mesoamerican Southwestern and Southwestern Relations and Culture Change during the Prehistoric Era," organized by George Gumerman (School of American Research/SFI) and Tim Pauketat (University of Illinois, Champagne-Urbana)

September 10 - 12 "EARTHTIME III: Probing the Limits of Temporal Resolution in the Geological Record," organized by Doug Erwin (Smithsonian Institution/SFI)

September 15 - 19 "Global International Program Fellows Meeting," organized by Shannon Larsen (SFI)

September 28 - October 1 "Unifying Current Theories of Ecology," organized by Drew Allen (University of California, Santa Barbara), Jessica Green (University of California, Merced), Steve Hubbell (University of Georgia and Smithsonian Tropical Research Institute), and Pablo Marquet (Catholic University of Chile and former SFI International Fellow)

October 4, "Complex Adaptive Systems Applications," co-hosted by SFI and Business Network member BT, held in London

October 19 "New Perspectives on Risk," co-hosted by SFI and Business Network members Credit Suisse and Legg Mason Capital Management. Organized by Michael Mauboussin (Legg Mason Capital Management) and Eric Beinhocker (McKinsey Global Institute), held in New York City

October 23 - 27 "Robustness of Lowland Tropical Rainforests," organized by Lisa Curran (Yale University/SFI) and J. Stephen Lansing (University of Arizona/SFI)

October 31 - November 2 "Modern Malware: Underlying Causes and Potential Solutions," organized by Matt Williamson (Sana Security, Inc), Esther Dyson (Release 0.9/SFI), and Stephanie Forest (University of New Mexico/SFI)

November 1 - 2 "ARCS (Adaptive and Resilient Computer Security) Workshop," organized by Robert Ghanea-Hercock (BT) and Shannon Larsen (SFI)

November 3 - 4 "Business Network and Board of Trustees' Symposium – Infectivity" organized by Doug Erwin (Smithsonian Institution/SFI), C.C. Wood (SFI), and Shannon Larsen (SFI)

November 5 "Board of Trustees Meeting," organized by Bill Miller (Legg Mason Capital Management) and Geoffrey West (SFI)

December 4 - 6 "Competitive Strategies in Complex Systems," co-presented by SFI and Business Network members Alidade Inc. and CNO Strategic Studies Group, held in Newport

Informal Lessons from SFI's Experience as a "Continuously Evolving Experiment"

- Independence has both advantages and liabilities
- "Bottom-Up" rather than "Top-Down"
- Relatively small size allows nimbleness and flexibility
- Emphasis on small, high-risk/high-payoff investments that can grow upon initial successes or be quickly redirected
- Diversified sponsor/donor/funding portfolio
- Mulit- and Trans-disciplinarity are means not ends
- Most valuable collaborations arise from diversity
- Don't believe your own promotional materials!

Thank You

Questions?