
The Use of Complexity Science
A Survey of Federal Departments and Agencies, Private Foundations, Universities, and Independent Education and Research Centers
October 2003
A Report to the U.S. Department of Education
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The Use of Complexity Science

I think the next century will be the century of complexity.

—Stephen Hawking
January 2000

Executive Summary

The challenges of the 21st century will require new ways of thinking about and understanding the complex, interconnected and rapidly changing world in which we live and work. And the new field of complexity science is providing the insights we need to push our thinking in new directions.

In the last twenty years, rapid advances in high-speed computing and computer graphics have created a revolution in the scientific understanding of complex systems. We now have the ability to move beyond the old reductionist paradigm; to look at whole systems; to study the interactions of many interdependent variables and to explore the underlying principles, structure and dynamics of complex physical, biological and social systems.

From health care to city planning to economics and international politics, the new science of complex systems is moving us away from a linear, mechanistic view of the world to one based on nonlinear dynamics, evolutionary development and systems thinking. It is laying the foundation for a fundamental shift in how we view the world, and with it the need for a shift in how we think about, organize, plan for, and lead 21st century organizations.

In 2002, the U. S. Department of Education asked the Washington Center for Complexity and Public Policy to look at how complexity science is being used — throughout the federal government, in private foundations, universities, and in independent education and research centers—with special attention to implications for its use in understanding and influencing the complexities of our educational system. In response to that request, this report provides a broad overview of the complexity science landscape in Washington, DC and around the country.

In conducting this survey, we identified three broad categories of complexity science activity.

Research Model**.** One of the new ways in which scientists are able to conduct research on complex systems is by using computer technology to develop "agent-based models," which simulate the likely real-life behavior of the system being studied. This exciting new technology has been called the "third" way of doing science with traditional experimentation and observation/description being the other two.

An agent-based model requires realistic knowledge of the "agents" or components of the system as well as the written and unwritten rules by which they operate, thus making it possible for the model to provide insights into the collective behavior of the agents when new information or changes are introduced into the system. After the model is built, it is possible to run simulations on many different aspects of the system to see how any given change will affect the interdependencies and overall dynamics of the whole system. This type of research model is being used to look at issues and options related to national security, infrastructure protection, forest ecosystems, climate change, ocean ecosystems, new diseases and disease patterns. It is also changing the ways in which research data is gathered and reported.

Business Model**.** Insights arising from the study of complex systems are being used to rethink and redesign business, industry and government organizations and systems so that they are more flexible, adaptable and able to respond quickly and more effectively to changes in the larger environment. In one of the most interesting and innovative examples of this, the Robert Wood Johnson Foundation provided funding to help establish a new organization, the Plexus Institute, for the purpose of using complexity-based approaches in rethinking our health care system. Because our health care system is in many ways analogous to our educational system, this project will be of special interest to the U.S. Department of Education.

Educational Model**.** Most university and college departments (across disciplines) have included complexity science in their curricula, and most have a range of complexity-related research underway. We also found a number of interdisciplinary university research centers focusing on specific types of complex systems and questions.

An interdisciplinary, whole systems approach is also being used to redesign college and university curricula in the sciences, humanities and social sciences. An interesting example of this is the UCLA Center for Human Complex Systems, http://www.hcs.ucla.edu.

Complexity as an Approach to the Educational System in the United States

Very little information was uncovered that relates directly to the use of complexity science as a framework for thinking about the U.S. educational system. Three projects, however, were found and are listed in Section I of this report, *Specific Complexity and Education-related Projects.*

One describes new computer software that allows teachers and students to study complex systems by creating a simulation, making-up the rules by which the system will operate and then watching as it evolves over time. Another identifies a special interest group on chaos and complexity science as it applies to education. And the third, describes a project funded by the National Science Foundation, specifically for the purpose of looking at the use of complexity science in our educational system.

Federal Departments and Agencies

Almost every federal department was found to have some type of complexity-related research underway. As an indication of the growing awareness of complexity as a cutting-edge approach, in July 2002 President Bush, along with House Speaker Dennis Hastert and (then) Homeland Security Advisor Tom Ridge, visited the Center for Complex Adaptive Systems Simulation at Argonne National Laboratory. While we uncovered many research projects using the principles and technologies of complexity science, very few organizations were found to be using complexity in a strategic sense to address broad system issues and challenges.

Private Foundations

While several major private foundations have complexity science initiatives, they are all struggling with reduced endowments and in many cases staff reductions due to the current economic climate. Overall, however, the field is growing rapidly as are its applications to broader societal issues and challenges.

Opportunities for the U.S. Department of Education

The survey findings provide an opportunity for the U.S. Department of Education to take the lead in developing ways to use this approach strategically—to create a new framework for transforming education in this country. Building on the ideas and models already underway, the Department could use this approach to push beyond incremental change and leverage its thinking and resources with transformative results.

Introduction

Background Context

Now, as never before, we have the knowledge and the tools to create a *21st century education delivery system* that prepares today's students and future generations of students to be lifetime learners, workers and citizens in a rapidly changing, complex and interconnected world. The children of today will be called upon to guide our country through the many challenges that lay ahead, and a well-educated and engaged citizenry is the foundation upon which an economically strong, moral and secure future will depend. The future will need every young mind developed to its fullest extent. The current generation of leaders, therefore, *must* do everything it can to leave as part of its legacy a strong and effective education delivery system.

In recent years, the use of complexity science and its state-of-the-art technologies for policy planning purposes have grown rapidly. Since September 11th, leaders at all levels have been pushed to quickly find new ways of thinking about and planning for the future, and complexity-based models are being used to provide insights on all types of important questions and policy issues.

As the first survey of its type*, it is not intended to present a comprehensive view of all that is taking place in this growing area. It will, however, give the reader a big picture sense, a broad sampling of how complexity science or a complex adaptive systems framework is being used, and what its potential applicability might be to the challenges facing the educational system in the United States.*

Complexity Science Overview

Stated simply, complexity can be defined as a situation where an "increasing number of independent variables are interacting in interdependent and unpredictable ways" (Ilachinski 2001: xxvii). Traffic is a good example of complexity as is the weather, the stock market and the United Nations.

In the last twenty years, a revolution has occurred in the scientific understanding of *complex systems*. And complexity science represents a growing body of interdisciplinary knowledge about structure, behavior and dynamics of change in a specific category of complex systems known as *complex adaptive systems (CAS).*

Most of the world is comprised of complex adaptive systems—open evolutionary systems such as a rain forest, a business, a society, your immune system, the World Wide Web and the rapidly globalizing world economy—where the components are strongly interrelated, self-organizing and dynamic. Each of these

systems evolves over time and in relationship to the larger environment in which it operates. The system *as a whole* must *adapt* to change in order to survive. Complexity science has moved science away from a linear mechanistic view of the world to one based on nonlinear dynamics, evolutionary development and systems thinking. It's a dramatic new way of looking at things; it's not just looking a more things at once.

Complexity science is truly an interdisciplinary science. Adopting a systems view of the world meant that the questions were too big for any one discipline alone to answer (Sanders 1998: 123). As scientists began looking for connections among different types of complex systems, the boundaries between disciplines began to open. As a result we are witnessing the integration of knowledge across disciplines—the physical sciences, social sciences and the humanities. Insights about complex systems are emerging across a broad spectrum of fields—from physics, mathematics and computer science, to biology oceanography, neuroscience, art and architecture (Turcotte and Rundle, 2002). From health care to city planning complexity science is creating a fundamental shift in the way we view the dynamics and interactions of complex systems.

Complex adaptive systems, and models thereof, are characterized by distributed organizations or networks, whose parts all influence each other, either directly or through feedback loops, which continually evolve and adapt to accomplish overarching goals (Sanders and Kadtke, 2001). This is in fundamental contrast to the conventional top-down, hierarchical management structures found in most government organizations and in much of corporate America, where local experimentation, innovation and adaptation are discouraged in favor of rigid bureaucratic rules and planning procedures. Simple cause-and-effect relationships do not characterize complex adaptive systems, and hence most of the conventional policy-planning tools currently used by decision-makers, both government and corporate, are often inappropriate and ineffective.

The structure and existence of complex adaptive systems depend on the constant flow of resources and new information. Widespread channels of information flow provide the critical feedback that makes the system complex. Operating rules defined at the level of each individual entity or network component and how they interact are typically more important than global directives. Constant adaptation of these rules, by sensing changes in the local environment and through widespread information flow, allow the whole system to evolve and effectively respond to and influence its environment.

Because the variables in the system are interacting constantly and changing in response to each other, the system is nonlinear. In nonlinear systems, small changes or inputs of resources at strategic leverage points can propagate in time and space to bring about significant shifts in the overall system (Lorenz, 1963; Bradley 1995).

Complexity science offers new ways of understanding, thinking about and designing organizational systems that are capable of responding to and influencing complex nonlinear relationships. Understanding the local dynamics in a complex system can provide great insight into the behavior of the overall system and help identify key leverage points of change and transformation.

Although individual business units, agencies and program offices may be quite effective, the system as a whole may experience a significant "failure to respond or adapt" to changes in the larger environment such as the one we witnessed in our intelligence-gathering organizations prior to September 11th. To be effective, an organization must learn to think and act as one coherent yet flexible system with a high degree of communication, cooperation and collaboration among its networks.

Complexity science is providing us with information about the underlying structure and patterns of interaction that create strong systems, support healthy adaptation and the ongoing evolution of a system over time. It has created a major shift in how we *must* think about, organize, plan for and lead 21st century organizations. You can no longer be an effective leader nor build an effective organization without understanding the basics of complexity science and developing the skills of complexity thinking.

Project Design

This project was designed to assess the current landscape of complexity-based research, models, methods, tools, technologies and applications being used in government agencies, universities, private foundations, and independent education and research centers. Emphasis was placed on identifying technology transfer options and potential collaborations that would be most useful to the U.S. Department of Education in implementing the *No Child Left Behind Act.*

The project staff used a variety of methods including surveys, interviews, the solicitation of documents and reports, as well as discussions with complexity science researchers, social scientists, and representatives of private foundations and independent education and research centers.

How This Report is Organized

The survey findings are organized by type of organization, whether government, university-based or private. Quotes and excerpts from interviews and documents are included to provide insights as to why and how various organizations are using complexity science, and to help facilitate the reader's understanding of the basic concepts being discussed. Contact information and an overview of the organization's mission are provided for each entry.

Examples: Complexity in Use

Agent-based models, one of the primary tools used to study the behavior of complex systems, are being used to explore a wide-range of issues and questions from climate change and customer preferences to manufacturing schedules and combat scenarios. When used to support real world decision-making, these interactive computer-based models enhance our thinking and lead to better responses, fewer unintended consequences and greater consensus on important policy decisions.

Agent-based modeling could be used to study the U.S. educational system. In this case the "agents" would represent school boards, superintendents, principals, teachers, students and parents as well as those organizations and policies that affect their behavior such as unions, federal policies and teacher preparation programs, etc. This type of model would then make it possible to explore the effects of various changes to the system such as standardized testing, student to teacher ratio, teacher preparation, parental involvement, school choice, funding levels, community involvement and the impact of technology on student-teacher interactions and performance. Agent-based models will often identify reforms and policy changes that are not intuitively obvious, but have the ability to *transform* the system.

These new technologies, however, can only take us so far. They cannot do the thinking for us, but they can help us learn to think more effectively. A linear, mechanistic view of the world based on a reductionist paradigm—breaking problems into component parts—no longer fits the realities of an interconnected, rapidly changing, multi-actor world.

Instead, complexity thinking—the ability to understand the dynamics of the big picture context in which your decisions are being made—has quickly become the most essential 21st century leadership skill. A basic understanding of complex systems combined with the ability to think broadly, to take a wide-angle big picture approach, will give you a deeper understanding of complex situations and lead to more effective questions, options and strategies.

As an example, in the last few years scientists have found that the sea otter population in Alaska has declined dramatically as a result of whaling practices off the coast of Japan! Without an understanding of complex systems and a big picture approach this connection would never have been made.

> In 1991, an Orca—a killer whale—was seen eating a sea otter. Orcas and otters usually coexist peacefully. So, what happened? Ecologists found that ocean perch and herring were also declining. Orcas don't eat those fish, but seals and sea lions do. And seals and sea lions are what Orcas usually eat and their population had also declined. So deprived of their natural prey— seals and sea lions—Orcas started turning to the playful sea otters for dinner.

> So otters have vanished because the fish, which they never ate in the first place, have vanished. Now, the ripple spreads, otters are no longer there to eat sea urchins, so the sea urchin population has exploded. But sea urchins live off seafloor kelp forests, so they're killing off the kelp. Kelp has been home to fish that feed seagulls and eagles. Like Orcas, seagulls can find other food, but bald eagles can't and they're in trouble.
>
> All this began with the decline of ocean perch and herring. Why? Well, Japanese whalers have been killing off the variety of whales that eat the same microscopic organisms that feed pollock. With more fish to eat, pollock flourish. They in turn attack the perch and herring that were food for the seals and sea lions. (Lienhard)
>
> Note: Excerpted and adapted from transcript of "Engines of Our Ingenuity," No. 1403: *Vanishing Sea Otters* by John H. Lienhard, University of Houston. http://www.uh.edu/engines/epi1403.htm

The August 14, 2003 blackout, the worst in U.S. history, is another example of how complexity thinking has become critical to our understanding of events and infrastructure interdependencies. On that day twenty percent of the North American power grid, including parts of the midwest and most of the northeastern United States and Ontario, Canada, went down. This happened in part because no one had a real time big picture view of the entire system, which could have alerted engineers to problems in time to prevent or minimize the blackout. (Iwata)
Source: Iwata, Edward. "Blackout Experts Struggle to Shed Light," USA Today, 10/13/03, p. A1.

As investigators work to sort out the causes and make recommendations, it seems clear that this enormous power outage was the result of many interacting and interdependent smaller events. That it didn't spread further, because engineers in Valley Forge, Pennsylvania were able to isolate other parts of the system from the cascading collapse, raises some interesting questions about the vulnerabilities of interdependent systems, including the rapidly globalizing world economy.

And finally, we hear the word "complexity" used daily to describe everything from the California election process to the "complexities" of nation-building in Iraq. Yet very few people, policy-makers included, have stopped to ask what the word really means, and what the new science of complex systems might contribute to our understanding of and responses to domestic and foreign policy issues.

The terrorists attacks on September 11, 2001 demonstrated clearly the urgent need to develop the skills of complexity thinking—to recognize changes in the larger context; to take a big picture approach to intelligence-gathering and national security; to develop a deeper understanding of the system dynamics influencing regional politics and conflicts; and, most importantly, to enhance our understanding of complex ***sociopolitical human*** systems. To successfully meet the challenges of the future, we will need leaders who are courageous enough to expand their thinking beyond the conventional wisdom, and smart enough to understand the importance of complex systems thinking.

The Use of Complexity Science
Survey Findings

I am convinced that the nations and the people who master the new sciences of complexity will become the economic, cultural and political superpowers of the next century.

—Heinz Pagels, physicist

A. United States Congress

1. The **Congressional Research Service (CRS**) reported that it had no information on these questions.

2. The **House Science Committee** reported that it had not explored these questions, but would be very interested in seeing this report.

B. Executive Office of the President

1. Office of Science and Technology Policy

John H. Marburger, PhD, Director
Executive Office of the President
Eisenhower Executive Office Building
1650 Pennsylvania Ave., NW, Room 424
Washington, DC 20502
Telephone: 202-456-7116
Email: info@ ostp.gov
Website: http://www.ostp.gov/html/

Mission Statement: OSTP, established in 1976, serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans and programs of the Federal Government.

Excerpt from Speech: "It seems to me—and I am not the first to point this out—that we are in the early stages of a revolution in science nearly as profound as the one that occurred early in the last century with the birth of quantum mechanics….This revolution is caused by two developments: one is the set of instruments such as electron microscopy, synchrotron x-ray sources, lasers, scanning microscopy, and nuclear magnetic resonance devices; the other is the availability of powerful computing and information technology. ***Together these have brought science finally within reach of a new frontier, the frontier of complexity.*** [at all scales]….Not only must we choose among the new opportunities in bio- and nano- technology, but we must also choose between

these and expanding investments at the traditional frontiers of science of large and small—or more generally between the issue-oriented sciences that clearly address societal needs, and the discovery-oriented sciences whose consequences are more a matter of conjecture."

—John Marburger, PhD, Director, OSTP
excerpt from, *Science Based Science Policy*
American Association for the Advancement of Science Conference
February 15, 2002, Boston, MA

a. Science and Technology Policy Institute **Rand Corporation**

Helga E. Rippen, PhD, Director
1200 South Hayes Street
Arlington, VA 22022
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Email: contact-st@rand.org
Website: http://www.rand.org/scitech/stpi/

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Background: The Science and Technology Policy Institute (S &TPI) is a federally funded research and development center (FFRDC) that provides analytic support to the White House Office of Science and Technology Policy (OSTP). It was chartered by Congress in 1991 and has been in operation since 1992. The National Science Foundation (NSF) is the sponsor of the FFRDC and awarded RAND Corporation, headquartered in Santa Monica, CA, the contract to manage S &TPI through a competitive selection process. NSF renewed Rand's contract in 1998 and in that same year it's charter was expanded to include work on science and technology policy and its name was changes from Critical Technologies Institute (CTI) to the Science and Technology Policy Institute.

Mission Statement: To help improve public policy by informing decisions through objective analysis.

Note: Congress has directed the Institute to consult widely with representatives from private industry, institutions of higher education, and nonprofit institutions; and to the maximum extent practicable, incorporate information and perspectives derived from such consultations in carrying out its mission.

Complexity-related Conference: September 27-28, 2000**, *Complex Systems and Policy Analysis: New Tools for a New Millennium***. The purpose of this conference was to investigate how state-of-the-art developments in chaos and complexity theory could be applied to public policy analysis and decision-making.

The conference attracted over 120 participants representing a wide-range of organizations including a number of government departments and agencies, university research centers, congressional staff, policy-related think tanks, consulting firms, and representatives from other complexity-related research institutes and educational organizations located outside the Washington, DC area.

C. Executive Departments

1. Department of Agriculture (USDA)

a. USDA Forest Service

Northern Global Change Research Program
Richard A. Birdsey, PhD, Program Manager
11 Campus Blvd., Suite 200
Newtown Square, PA 19073-3294
Telephone: 610-557-4091
Website: http://svinet2.fs.fed.us/ne/global/

Mission Statement: To study forest ecosystems in an effort to answer the following questions: 1) What processes in forest ecosystems are sensitive to physical and chemical changes in the atmospheres? 2) How future physical and chemical climate changes will influence the structure, function and productivity of forest and related ecosystems, and to what extent ecosystems will change in response to atmospheric changes? 3) What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health and diversity?

Complexity-Related Activities: The ***Complex Systems Research Center*** at the University of New Hampshire is a major research partner for the USDA Forest Service. Established in 1978, its major area of expertise is in predictive modeling for global climate change. In addition to USDA it receives federal funding from NASA and NOAA. It also receives contracts and grants from states, other universities, private foundations and the United Nations.

Contact: Karen Bushold, Assistant Director
Complex Systems Research Center
University of New Hampshire
39 College Road
Durham, NC 03824
Telephone: 603-862-1792
Email: karen.bushold@unh.edu
Website: http://www.csrc.sr.unh.edu

Complexity-related Conference: ***Modeling Complex Systems for Environmental Decision-Making***. May 19-22, 1997. Sponsored by the Ecosystem Management Analysis Center, USDA Forest Service, Fort Collins, Colorado.

b. Agricultural Research Service

Edward B. Kipling, Acting Administrator
5601 Sunnyside Ave
Beltsville, MD 20705-5134
Website: http://www.nps.ars.usda.gov

Overview: The Agricultural Research Service is the principal in-house research agency of the USDA. As one of the Research, Education and Economics (REE) agencies, it is charged with extending the Nation's scientific knowledge with 22 national programs, with research projects in agriculture, nutrition, technology, the environment and other topics that affect the American people on a daily basis.

Complexity-related Project: The ***Farming Systems Project*** of the Sustainable Agricultural Systems Laboratory is a long-term comparison of seven cropping systems established in 1993 to: study the basic biology and ecology of farming systems using a multidisciplinary, systems approach, and to address farmer-defined management and production barriers to the development and adoption of sustainable cropping systems in the mid-Atlantic.

Contact: Michel Cavigelli, PhD
Telephone: 301-504-8327
Email: cavigelm@ba.ars.usda.gov
Website:
http://www.nps.ars.usda.gov/publications/publications.htm?lognum=11073

2. Department of Commerce (DOC)

a. National Oceanic and Atmospheric Administration (NOAA)

National Geophysical Data Center
Christopher G. Fox, Acting Director
E/GC 325 Broadway
Boulder, CO 80305-3328
Telephone: 303-497-6826
Fax: 303-497-6513
Email: ngdc.info@noaa.gov
Website: http://www.ngdc.noaa.gov/ngdc.html

Mission Statement: NGDC provides leading-edge data management services for the development, integration and publication of biospheric data related to global systems and global change. It plays an integral role in NOAA's environmental research and stewardship, and provides data services to users worldwide.

Complexity-related Activities: ***A complex systems approach to research has dramatically changed the type of data and information needed and the ways in which that data need to be reported***.

Excerpt from NGDC website: "Living systems have properties that are unlike physical systems; they are "complex systems." In particular, living systems are characterized by the importance of their organization in determining system properties. Organization in a complex system cannot be reduced to the accumulated effects of its component interactions; whole system properties must also be considered. Living systems, and all data about living system components, are thus characterized by the importance of system organization and context.

Global ecosystem science today is driven by scientific frameworks, which have grown dramatically within the past 20-50 years. These include *global change, sustainable development, biodiversity, ecosystem health, adaptive management, Earth systems science, systems ecology, complexity and complex systems, systems science* and other organizing programs and concepts that are becoming closely related. *These perspectives shape our thinking and corresponding research programs, and in turn shape common needs for* data and information. *The nature of these programs can also affect the* form *in which data and information are needed."*

b. National Institute of Standards and Technology

Advanced Technology Program
Marc G. Stanley, Acting Director/Associate Dir. for Policy and Operations
100 Bureau Drive, MS 4710
Gaithersburg, MD 20899
Telephone: 1-800-287-3863
Email: atp@nist.gov
Website: http://www.atp.nist.gov

Mission Statement: The purpose of ATP is to benefit the U.S. economy by cost-sharing research with industry to foster, new, innovative technologies. The ATP invests in risky, challenging technologies that have the potential for a big pay-off for the nation's economy. The ATP does not fund companies to do product development. It funds R & D up to the point where it is feasible for companies to begin product development.

Complexity-related Project: ***Adaptive Learning Systems***. This purpose of this program is to support research designed to accelerate the development of a national learning infrastructure that permits education and training to be pervasive and precisely tailored to the needs of educators and learners. It's an example of how insights from complex systems research are being used to think about the development of new educational technology.

Excerpt from website: "The term *adaptive learning systems* best depicts the role that technology can play in correcting problems, that have stymied educational technology markets in the past. This program is designed to facilitate the development of technology that will adapt knowledge to the needs of learners. The term *adaptive* also relates to the flexibility and scalability of the envisioned learning system. In the future, context and courseware must be reusable, interoperable and easily organized at many levels of complexity through the on-line instructional environment."

3. Department of Defense (DOD)

Donald H. Rumsfeld, Secretary
1000 Defense Pentagon
Washington, DC 20301-1000
Website: http://www.dod.gov

Background Context for this Section:

> "The topic today is an adversary that poses a threat, a serious threat, to the security of the United States of America. This adversary is one of the world's last bastions of central planning. It governs by dictating five-year plans. From a single capital, it attempts to impose its demands across time zones, continents, oceans and beyond. With brutal consistency, it stifles free thought and crushes new ideas. It disrupts the defense of the United States and places the lives of men and women in uniform at risk…It's the Pentagon bureaucracy. Not the people, but the processes. Not the civilians, but the systems. Not the men and women in uniform, but the uniformity of thought and action that we too often impose on them….Our challenge is to transform not just the way we deter and defend, but the way we conduct our daily business. Let's make no mistake… We must change for a simple reason—the world has—and we have not yet changed sufficiently. The clearest and most important transformation is from a bipolar Cold War world where threats were visible and predictable, to one in which they arise from multiple sources, most of which are difficult to anticipate, and many of which are impossible even to know today."
>
> —Secretary Rumsfeld
> Excerpt from Pentagon speech
> September 10, 2001

Note: Since the terrorist attacks the next morning, September 11, 2001, the language of transformation, using many terms from complex systems research and thinking, is familiar to anyone reading the morning newspapers—*we need an adaptable, flexible military capable of detecting and deterring threats against the U.S. at home and abroad; one that is capable of disrupting and destroying terrorist networks wherever they exist; and one that is capable of anticipating and responding to changing conditions on the battlefield and emerging targets of opportunity.*

Prior to 9/11 and since there have been many within the various parts of DoD who have used a complex adaptive systems approach to think about and describe the type of military capabilities, operational thinking and structure needed in the current and future national security environments. Among them are Marine General Paul Van Ripper, who took an early interest in complexity as a new way of thinking, and Admiral Art Cebrowski, who raised the idea "network centric warfare" to its current level of understanding and acceptance within DoD.

Complexity-related Activities: In the Department of Defense there are two broad research and development paths: service specific science and technology programs, which tend to focus on immediate and near-term requirements; and the Defense Advanced Research Projects Agency (DARPA), which pursues radical technological innovation and then serves as a bridge for its quick acceptance and integration into a service acquisition program.

a. Defense Advanced Research Projects Agency (DARPA)

Anthony J. Tether, PhD, Director
Website: http://www.darpa.mil

Mission**:** DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use.

Management Philosophy: "DARPA's mission implies on imperative for the Agency: radical innovation for national security. DARPA's management philosophy reflects this in a straightforward way: bring in expert, entrepreneurial program managers; empower them; protect them from red tape; and make decisions quickly about what projects to be started and what projects should stop…***DARPA has found that bringing together people with the same interests can lead to a non-linear generation of ideas***."

Strategic Plan: "Strategy can be described as the evolving pursuit of a central mission through changing circumstances. Consequently, over time, DARPA changes much of what it is doing in response to the different national security threats and technological opportunities facing the U.S." As of February 2003, DARPA has identified eight strategic thrusts, while at the same time maintaining its investments in what it calls "enduring foundations" i.e. fundamental new technologies that are critical to "quantum leaps in U.S. military capabilities," including materials, microsystems and information technology. Of the eight strategic thrusts there is one that is especially relevant to this report on complexity-related activities.

DARPA Critical Thrust, Section 3.4 of Strategic Plan:
Robust, Self-Forming Networks

"The Department is in the middle of a transformation to what is often termed 'Network Centric Warfare.' In simplest terms, the promise of network centric warfare is that networked military systems will change the terms of any conflict in the U.S. military's favor. Network Centric Warfare translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace." This type of linked information-decision-action network was used in the 2003 war with Iraq.

b. National Defense University

Vice Admiral Paul G. Gaffney II, USN, President
Fort Lesley J. McNair
Washington, DC 20319-5066
Telephone: 202-685-4700
Website: http://www.ndu.edu

Mission: NDU educates military and civilian leaders through teaching, research and outreach in national security strategy, national military strategy, and national resource strategy; joint and multinational operations; information strategies, operations and resources management; acquisition; and regional defense and security studies.

Industrial College of the Armed Forces (ICAF)
Major General Frances C. Wilson, USMC, Commandant
Website: http://www.ndu.edu/icaf

Mission: As one of the four colleges comprising NDU, the mission of the Industrial College of the Armed Forces is to prepare selected military officers and civilians for senior leadership and staff positions by conducting postgraduate, executive-level courses of study and associated research dealing with national security strategy and the resource component of national power, with special

emphasis on acquisition and joint logistics, and their integration into national security strategy for peace and war.

Complexity-related Activities: Professor Paul B. Davis Jr. has created a complexity hub within ICAF through his elective national security strategy courses based on nonlinear dynamics, and chaos and complexity theories. Through his interest in these topics, he has introduced ICAF and his students to a number of individuals, both military and civilian, working in complexity-related areas of research, strategy development and public policy. Through the years others have taught complexity-related courses at NDU, but Dr. Davis' are the most current.

4. Department of Education

Rod Paige, Secretary
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Washington, DC 20202-0498
Telephone: 1-800-872-5327
Website: http://www.ed.gov

Department initiating this study.

5. Department of Energy

a. Office of Science

Basic Energy Sciences
Patricia M. Dehmer, PhD, Associate Director
19901 Germantown Road
Germantown, MD 20874-1290
Telephone: 301-903-3081
Fax: 301-903-6594
Email: Patricia.Dehmer@science.doe.gov
Website: http://www.science.doe.gov/bes

Mission: The BES program supports fundamental research in materials sciences and engineering, chemistry, geosciences and molecular biosciences.

Overview: In 2001, BES funded research in more that 170 academic institutions located in 49 states and in 13 DOE laboratories located in 9 states. The BES program also supports world-class scientific user facilities, including four synchrotron radiation light sources, three neutron scattering facilities and four electron-beam micro characterization centers. Annually, 8,000 researchers from academia, industry and Federal laboratories perform experiments at these facilities. Under construction is the Spallation Neutron Source (SNS), a $1.4 billion next-generation, neutron-scattering facility. Basic research supported by

the BES program touches virtually every aspect of energy resources, production, conversion, efficiency and waste mitigation.

Complexity-related Conference: March 5-6, 1999 a BES-sponsored conference brought together more than 100 leading scientists to help define new scientific directions related to complex systems. The resulting report entitled, ***Complex Systems: Science for the 21st Century***, identifies five emerging themes around which research could be organized.

1. Collective Phenomena: *Can we achieve an understanding of collective phenomena to create materials with novel, useful properties?*

2. Materials by Design: *Can we design materials having predictable, and yet often unusual properties?*

3. Functional Systems: *Can we design and construct multicomponent molecular devices and machines?*

4. Nature's Mastery: *Can we harness, control or mimic the exquisite complexity of Nature to create new materials that repair themselves, respond to their environment and perhaps even evolve?*

5. New Tools: *Can we develop the characterization instruments and the theory to help us probe and exploit this world of complexity?*

Report Note: "The very nature of research on complexity makes it a "new millennium" program. Its foundations rest on four pillars: physics, chemistry, materials science and biology. Success will require an unprecedented level of interdisciplinary collaboration. Universities will need to break down barriers between established departments and encourage the development of teams across disciplinary lines. Interactions between universities and national laboratories will need to be increased, both in the use of the major facilities at the laboratories and also through collaborations among research programs. Finally, understanding the interactions among components depends on understanding the components themselves. Although a great deal has been accomplished in this area in the past few decades, far more remains to be done. A complexity program will complement the existing programs and will ensure the success of both. The benefits are, as they have been at the start of all previous scientific "revolutions," beyond anything we can now foresee."

b. National Laboratories

1. *Argonne National Laboratory*

Hermann A. Grunder, PhD, Director
9700 S. Cass Avenue (main site)
Argonne, IL 60439-4803
Telephone: 630-252-2000
Website: http://www.anl.gov

Mission: Conducting basic scientific research; operating national scientific facilities; enhancing the nation's energy resources; and developing better ways to manage environmental problems.

Overview: Chartered in 1946, Argonne was the first national laboratory. Argonne is a direct descendant of the University of Chicago's Metallurgical Lab, part of the WWII Manhattan Project to build the first atomic bomb. After the was, Argonne was given the mission of developing nuclear reactors for peaceful purposes. Argonne's research now includes many other areas of science, engineering and technology. It has 4,000 employees divided between its two sites; Chicago, the largest and which houses its main offices, and Idaho.

Complexity-related Projects: The ***Center for Complex Adaptive Systems Simulation (CCASS)*** is actively involved with agent-based modeling of physical, economic and social systems.

Charles Macal, PhD, PE
CCASS Director
Telephone: 630-252-3767
Fax: 630-252-6073
Email: macal@anl.gov
Website: http://www.dis.anl.gov

Fact Sheet Overview: "Complex systems are central to many national and global concerns—think of pipelines, electrical distribution systems, ecosystems and industrial supply chains, to name a few. Each of these systems consists of a highly complex network of interdependent by continually changing entities.

Dynamic networks such as these are termed "complex adaptive systems." In such systems, a slight change sometimes results in severe or widespread effects. To plan for growth or changing demands, decision makers in business and government need better ways to predict the behavior of these systems, particularly the conditions that could lead to instability or failure.

Conventional experimental and simulation methods often cannot capture the detailed and dynamic interactions that, cumulatively, make a complex adaptive system vulnerable to catastrophic effects. In particular, these methods often cannot reproduce the full range of behaviors inherent in such systems, especially the large-scale patterns that may emerge over time as parts of the system interact.

Argonne is combining new modeling theories and software tools to develop electronic laboratories, or "e-laboratories," for studying complex adaptive systems. The core technique is agent-based modeling, in which complex systems are modeled as collections of individual entities or "agents." This approach allows researchers to study complex adaptive systems under systematic, controlled conditions that elicit a wide-range of behaviors. The result is simulations that are far more realistic. Furthermore, these simulations allow decision-makers to:

- test alternative system configurations in a simulated world before implementing them in the real world,

- understand and predict conditions that could lead to system instability,

- anticipate system dynamics for various ways in which the might evolve."

Presidential Visit: On July 22, 2002, President Bush accompanied by (then) Homeland Security Advisor Tom Ridge (off camera), House of Representatives Speaker J. Dennis Hastert, Secretary of Energy Spencer Abraham and Department of Energy Office of Science Director Ray Orbach reviewed the work being conducted by the Center for Complex Adaptive Systems Simulation.

Center for Complex Adaptive Systems Simulation, Argonne National Laboratory, July 22, 2002.

2. Los Alamos National Laboratory

Peter Nanos, PhD, Interim Director
P.O. Box 1663
Los Alamos, NM 87545
Telephone: 505-667-7000 (public affairs)
Website: http://www.lanl.gov

Mission: To develop resources for the future.

Structure: Los Alamos National Laboratory is operated by the University of California for the National Nuclear Security Administration of the U.S. Department of Energy.

Complexity-related Projects:

The ***Complex Systems Group T-13*** develops new methods for solving complex problems and applies them to problems at the vanguard of technology. Computational modeling, quantum computers and nanotechnology are of great interest to researchers in this group. Current projects include models of gene regulation, analysis of protein and DNA sequences using neural nets and information theory, modeling of enhanced oil recovery processes and signal enhancement in chaotic processes.

David Sharp, PhD, Group Leader
Complex Systems Group T-13
Theoretical Division
Telephone: 505-667-2897
Fax: 505-665-3003
Email: dhs@lanl.gov
Website: http://t13web.lanl.gov

The **Center for Nonlinear Studies** coordinates a broad range of theoretical, experimental, and computational basic research programs in nonlinear science. Its mission is fourfold: 1) to identify and study fundamental nonlinear phenomena and promote their use in applied research; 2) to stimulate interdisciplinary research and information exchanges inside and outside the laboratory; 3) to provide a focal point for collaboration with academic and other scientific centers of excellence, and 4) to disseminate recent developments and introduce your researchers to the subject.

The Center operates by overseeing postdoctoral, student and visitor programs, organizing conferences and workshops, and acting as a focal point for laboratory research staff. The current CNLS research efforts are organized annually into

collaborative research projects divided into two broad "thrust" areas. Currently these are: *Structure and Dynamics of Self-Assembling Systems* and *Modeling Nonlinear Systems.*

These programs are complemented by ongoing CNLS support of research both in the traditional topics of nonlinear science (patterns and solitons, chaos, low-dimensional dynamical systems and turbulence), and in new exploratory areas (complex adaptive matters, predictability, nonlinear problems in environmental science and engineering). In each case analytical and computational tools are developed and/or applied toward furthering our understanding of structures and dynamics in strongly interacting many-degree-of-freedom nonlinear systems. Throughout the various directions run threads of common methods, paradigms, models and theories, which serve to bind the investigations together.

Hans Frauenfelder, PhD, Diredtor
CNLS
MS B358
Los Alamos National Laboratory
Los Alamos, NM 87545
Telephone: 505-667-1444
Fax: 505-665-2659
Email: office@cnls.lanl.gov
Website: http://cnls.lanl.gov

3. Idaho National Engineering and Environmental Laboratory

2525 Fremont Avenue
P.O. Box 1625
Idaho Falls, ID 83415
Telephone: 800-708-2680
Email: info@inel.gov
Website: http://www.inel.gov

Vision: To be a multi-purpose national laboratory that delivers science and engineering solutions to the world's environmental, energy and security challenges.

Mission: To deliver science-based, engineered solutions to the challenges of DOE's mission areas, other federal agencies and industrial clients; to complete environmental cleanup responsibility and cost-effectively using innovative science and engineering capabilities; provide leadership and support to optimize the value of EM investments and strategic partnerships throughout the DOE complex; and, enhance scientific and technical talent, facilities and equipment to best serve national and regional interests.

Overview: INEEL is positioned at the confluence of basic science and applied engineering. It builds on the potential and promise of the theoretical for the benefit of the real world.

Complexity-related Projects: Excerpt from website. "The attacks on September 11, 2001 opened the nation's eyes to a vulnerable United States. We now recognize that not only are our citizens threatened, but the very infrastructure that supports our society is also at risk….As new protective technologies are developed, we must conduct an extensive independent test and evaluation process to validate the capabilities and, ultimately, to define standards by which infrastructure protection technologies are certified. Computer modeling and simulation alone are not enough. ***The interdependencies of complex systems must be tested and validated on a scalable basis from bench-top to full-scale real-world conditions***. Using our complex infrastructure—itself a microcosm of the nation's critical systems—and our skilled scientific and engineering work force, we will develop, test, certify and deploy technologies that protect the nation's critical infrastructure, the environment and its citizens from terrorist threats, or any action or circumstance that makes us vulnerable."

4. Sandia National Laboratories

C. Paul Robinson, PhD, Director
PO Box 5800
Albuquerque, NM 87185
Telephone: 505 845-0011
E-mail: webmaster@sandia.gov
Website: http://www.sandia.gov

Vision: Helping our nation secure a peaceful and free world through technology. Our highest goal is to become the laboratory that the U.S. turns to first for technology solutions to the most challenging problems that threaten peace and freedom for our nation and the globe.

Structure: Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company for the Department of Energy; it is a government-owned/contractor-operated (GOCO) facility.

Overview: Sandia's precursor, Z Division, was created in 1945 as an ordnance arm of Los Alamos National Laboratory. In 1948, Z Division was renamed Sandia Laboratory. The next year AT&T agreed to manage the Lab as an independent entity. Sandia opened a new facility in Livermore, California in 1956 to support the nuclear weapons work of the new Lawrence Livermore Laboratory, and became a national laboratory in 1979. Today, Sandia has two primary facilities: a large laboratory and headquarters in Albuquerque (7400 employees) and a smaller laboratory in Livermore (about 900 employees).

Complexity-related Projects:

Complexity work at the Lab (often under the guise of being called something else) encompasses a broad spectrum of interdisciplinary activities relevant to the Lab's national security missions. These projects are often described in more traditional terms, like "modeling and simulation", "computer optimization", and "systems analysis studies". **Most efforts deal with dense interconnected phenomena with non-linear cause and effects (feedback) that are manifested in the real world as complex adaptive systems.** Agent-based modeling and simulation, network analysis, algorithm development, and data visualization are critical analytical tools that underpin individual efforts in Complexity Science at the Lab.

A key objective of this work is to identify and capitalize on the underlying synergies linking several of the Lab's differentiating or emerging capabilities that deal with **complexity applications**, specifically, robotics and networked sensor arrays; cognitive architectures; system-of-system applications; and self-organizing/self assembling computer software and microsystems. Other work at Sandia is focused on exploring strategies used in biologic systems to develop new types of micro/nano materials in which assembly, configuration, and disassembly can be programmed or self-regulated in artificial systems.

Multiagent models and tools are being applied to help solve numerous challenging technical problems for a diverse set of customers. Agent-based microsimulation computer models of the U.S. economy developed in the mid-1990's have been extended to modeling the impacts of terrorist events on confidence and the economy; infrastructure surety (the National Infrastructure and Simulation Analysis Center --- a joint effort with Los Alamos and Argonne National Labs); projects for DoD and the intelligence community; and a new initiative to develop physics-based global climate-change models using massively parallel computing architectures. In addition, several projects are using agent-based and related techniques including social network theory to model terrorist behavior and its consequences.

Additional Contact for Complexity-related Activities:
Robert J. Floran, PhD, RG
Planning and Executive Support
PO Box 5800
Telephone: 505 844-6268
Fax; 505 844-1218
Email: rjflora@sandia.gov
Website; http://www.sandia.gov

National Infrastructure Simulation and Analysis Center

Chartered by Congress in the 2001 Patriot Act to serve as source of research and information on our nation's critical infrastructures and infrastructure interdependencies. Funded and managed by the Department of Homeland Security, NISAC is based at Sandia National Laboratories with project operations at Los Alamos National Laboratory. Builds on the modeling, simulation and analysis capabilities of these two national laboratories. Assists government and industry with decision-making related to infrastructure protection, mitigation and response.

Steven M. Rinaldi, Joint Program Director
Telephone: 505-844-2153
Email: smrinal@sandia.gov

c. National Nuclear Security Administration

Linton F. Brooks, Administrator
Website: http://www.nnsa.doe.gov

NEW Complexity-related Project: The National Nuclear Security Administration will be the lead agency in a multi-agency counterterrorism and crisis management initiative that will be announced sometime in the summer of 2003. This project tentatively called, ***Project Alpha: Managing Complexity in the New Age of Knowledge***, will use a proprietary process developed by George Washington University to provide a "decision assessment environment" in which government officials at all levels, the private sector and universities will come together to consider a range of complex events and situations. This multi-year project will receive funding from the U.S. Congress.

Overview: Using the world's most advanced models and simulations of social dynamics presenting novel events, a decision assessment environment will be created to assist decision makers in the *a priori* development and testing of different policy options and processes as hypothetical complex event simulations evolve. The ***National Decision Assessment Immersion Center*** (proposed name) will be located in the national capital area.

6. Department of Health and Human Services (HHS)

Tommy G. Thompson, Secretary
200 Independence Blvd., SW
Washington, DC 20201
Telephone: 202-619-0257 or 877-696-6775
Website: http://www.hhs.gov

Mission: To protect the health of all Americans and provide essential human services, especially for those who are least able to help themselves.

Complexity-related Activities and Research: ***The use of complexity science or a complex adaptive systems framework*** for medical research, understanding and improving delivery systems, and policy development ***is widespread throughout the medical community and the programs of the National Institutes of Health (NIH).***

Elias A. Zerhouni, MD, Director
National Institutes of Health
9000 Rockville Pike
Rockville, MD 20893
Telephone: 301-496-4000
Website: http://www.nih.gov

Examples: In 2001 the National Institute of General Medial Sciences established a new program to fund academic ***Centers of Excellence in Complex Biomedical Systems Research*** to use and develop new computational approaches "to deepen our understanding of biological behavior." http://www.nigms.nih.gov;

Miller, WL; McDaniel, RR; Crabtree, BF; et al. ***Practice Jazz: Understanding Variation in Family Practices using Complexity Science.*** *Journal of Family Practice.* 2001 Oct*:* 50(10): 872-878. [Grant No. R01 HS08776].

Other examples:

Chaos Theory and Alcoholism. "Chaos theory may help scientists understand alcoholism's complex impacts on behavior, believe researchers at Ohio State University. Alcoholism is a complex, dynamic and oscillating set of patterns, much as weather systems and the stock market are, according to Keith Warren, an assistant professor of social work. 'Chaos theory is applicable to alcohol abuse because it can help us understand sudden changes in the behavior of a system, unpredictability, and irregular behavior,' he says. For example, behaviors that might indicate recovery could actually be part of a natural cycles in the disease, according to Warren, who suggests that most treatments for alcoholism

don't last long enough to ride these waves of recovery and relapse. Source: Ohio State University. http://www.osu.edu/researchnews/archive/alchaos.htm

Smallpox, Then and Now. By Robert Dorit, professor in the Department of Biology at Smith College. Book review found in *American Scientist,* March-April 2002. Writing in reference to *Pox Americana* by Elizabeth A. Fenn. (Hill and Wang, 2001). "Precisely because the author is a historian, she has captured the fundamental reality of all human epidemics: It's not the biology, stupid. Instead, it is the interactions between biology and socioeconomic variables (class, privilege, nutrition, crowding, access to medical care) and between biology and historical events (wars, migrations) that determine the real dynamics of infectious diseases."

Full review: http://www.americanscientist.org/template/AssetDetail/assetid/17780

7. Department of Homeland Security (DHS)

Tom Ridge, Secretary
Washington, DC 20528
Telephone: 202-282-8000
Website: http://www.dhs.gov

Mission: To protect the nation against further terrorist attacks; to reduce America's vulnerability to terrorism, and to minimize the damage from potential attacks and natural disasters.

Complexity-related Activities: Signed into law on November 25, 2002, H. R. 5005 the Homeland Security Act of 2002 established the Department of Homeland Security by bringing together, under one roof, twenty-two domestic agencies. During the course of its creation and the transition, ***a number of models and approaches have been used including using a complex adaptive systems framework*** for thinking about the organization and flow of information in the new Department.

8. Department of Housing and Urban Development (HUD)

Mel Martinez, Secretary
451 7th Street, SW
Washington, DC 20410
Telephone: 202-708-1112
Website: http://www.hud.gov

No specific complexity-related references found, although a number of books, periodicals and schools of urban planning are using a complex adaptive systems framework to study the history, evolution and future of cities.

9. Department of the Interior (DOI)

a. U.S. Geological Survey

Charles G. Groat, PhD, Director
913 National Center
Reston, VA. 20192
Telephone: 888-275=8747
Fax: 703-648-4888
Website: http://www.usgs.gov

Mission: To provide reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy and mineral resources; and enhance and protect our quality of life.

Complexity-related Conference: November 20-21, 2002 the *U.S. Geological Survey* sponsored a conference at the University of Nevada entitled, ***Modeling Complex Systems*.** The focus of this workshop was on the application of complex-systems analysis in the Earth sciences, the life sciences, computer sciences and engineering. Preceding the conference was a one-day class on the basics of complex systems.

10. Department of Justice (DOJ)

a. Federal Bureau of Investigation (FBI)

Robert S. Mueller, Director
J. Edgar Hoover Building
935 Pennsylvania Ave., NW
Washington, DC 20535-0001
Telephone: 202-324-3000
Website: http://www2.fbi/gov

Overview: Founded on July 26, 1908, the FBI is the principal investigative arm of the U.S. Department of Justice. It has the authority and responsibility to investigate specific crimes assigned to it. The FBIU also is authorized to provide other law enforcement agencies with cooperative services, such as fingerprint identification, laboratory examinations and police training.

Mission: The mission of the FBI is to uphold the law through the investigation of violations of federal criminal law; to protect the United States from foreign intelligence and terrorist activities; to provide leadership and law enforcement assistance to federal, state, local and international agencies; and to perform these responsibilities in a manner that is responsive to the needs of the public and is faithful to the Constitution of the United States.

Note: The counterterrorism mandate was added after the terrorist attacks on September 11, 2001. This expanded the FBI's mission, which until then had been primarily focused on "after the crime" investigations. Since 9/11 the FBI has been required to make major adjustments in its structure, communication and interactions with other intelligence-gathering and law enforcement organizations.

Congressional Testimony: In reference to the FBI's ongoing reorganization Director Mueller said on June 18, 2003 in testimony before the House Committee on Appropriations, "Part of the FBI's legacy of success has been its ability to adapt to changes in the world in which it operates. That ability is now being tested under extreme circumstances."

Complexity-related Activities and Technologies: As with all agencies in the intelligence community, the FBI is making changes designed to make it more adaptable, flexible and more openly collaborative with other organizations in the intelligence community. It is also one of the key agencies supporting development of the new ***National Decision Assessment Immersion Center*** (see Department of Energy, section C).

11. Department of Labor (DOL)

Elaine L Chao, Secretary
Frances Perkins Building
200 Constitution Avenue
Washington, DC 20210
Telephone: 866-487-2365
Website: http://www.dol.gov

No specific references to complexity theory or complex adaptive systems were found. Although our research uncovered an interesting report, ***Learning a Living*** *(April 1992)*, which was based on a 1991 initial report, ***What Work Requires of Schools*** (1991), both produced by *The Secretary's Commission on Achieving Necessary Skills.* These reports looked at the skills need by the U.S. workforce 2000 and the role of schools in developing the skills and competencies needed for success. The report can be found at the following web address: http://wdr.doleta.gov/SCANS/lal/LAL.HTM

12. Department of State

a. Foreign Service Institute

Contact: Pat McArdle, Director
Public Diplomacy Training
4000 Arlington Blvd., Room F 3101
Arlington, VA 22204-1500
Telephone: 703-02-6870
Fax: 703-302-6866
Website: http://www.state.gov/
Email: mcarclepl@state.gov

Mission: To ensure that public diplomacy (engaging, informing and influencing key international audiences) is practiced in harmony with public affairs (outreach to Americans) and traditional diplomacy to advance U.S. interests and security and to provide the moral basis for U.S. leadership in the world.

Complexity-related Presentations:

Twice in 2002, the executive director of the Washington Center for Complexity and Public Policy was invited to make a two-hour presentation, as part of the Institute's weeklong course, ***New Trends in Public Diplomacy***. The purpose of these presentations was to discuss complexity and nonlinear thinking as new ways to think about the war on terrorism and the function of public diplomacy in a changing world.

Complexity as it relates to English Language Education: Article*: The Joy of Watching Others Learn: An Interview with Diane Larsen-Freeman.* By William P. Ancker, English Teaching Forum, Vol. 39, No. 4, October-December 2001. http://exchanges.state.gov/forum/vols/vol39/no4/p2.htm

Excerpt from the article: *Question*: "Looking ahead to the next ten years, where do you see the field [English Language Education] going? What do you think will be the issues that we are discussing and debating then? *Answer:* "I think the dominant metaphor in our field for language is changing. I think the field is struggling with the way it conceptualizes its subject matter. For many teachers, researchers, and students, language is seen as atomized, comprised of pieces, which are governed by some fairly rigid rules. Acquiring a language then is a matter of "getting" the pieces***. I have become interested in chaos/complexity science*** because it has helped me to realize that this description is not the only way of looking at language. …language can be seen as process …language is more organic than it is rigid and acquiring a language is more of a matter of participating than it is of "getting"…I can't think of anything more complex, nonlinear, and dynamic that language and its acquisition."

13. Department of Transportation (DOT)

Norman Y. Mineta, Secretary
400 7th Street, SW
Washington, DC 20590
Telephone: 202-366-4000
Website: http://www.dot.gov

Mission: To serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future.

Complexity-related Projects:

a. ***Planning in Air Traffic Control***. Prepared by the Office of Aerospace Medicine, October 2001. An experiment on the planning activities of en route air traffic controllers. "Research on planning has examined three different environments in which we plan: simple and static; complex and static; and complex and dynamic.…More germane to the present work are studies of planning in complex, dynamic domains. These include such domains as medicine, military operations, business among others…The results of the present study have implications for theories of planning and for the development of computer interfaces to aid planning." The full report is available from this website: http://www.hf.faa.gov/dics/508/docs/cami/0116.pdf

b. Application of Agent Technology to Traffic Simulation. 1998 report funded by the Research, Development and Technology Section of the Federal Highway Administration. A report on how agent-based modeling of traffic addresses the need for new traffic-control strategies. Excerpt: "Traffic is emergent behavior i.e. the result of the individual decisions of driver, pedestrians, traffic controllers and other individuals…The main focus is on identifying the components of a systems, discovering their local behaviors and the interactions among them. The global system behavior emerges from the local behaviors of the individual components and their interactions." The read the full report go to: http://.tfhre.gov/advanc/agent.htm

14. Department of Treasury

John Snow, Secretary
1500 Pennsylvania Avenue, NW
Washington, DC 20220
Telephone: 202-622-2000
Website: http://www.treas.gov

No complexity-related information found.

15. Department of Veterans Affairs

Anthony J. Principi, Secretary
Washington, DC
Website: http://www.va.gov

No complexity-related information found.

D. Independent Agencies and Government Corporations

1. Central Intelligence Agency (CIA)

a. Global Futures Partnership

Contact: Carol A. Dumaine
Sherman Kent School for Intelligence Analysis
Central Intelligence Agency
LF5 Room 2300
Washington, DC 20505
Telephone: 703-613-6319
Fax: 703-613-6314
Email: carolad1@ucia.gov

Background: The Global Futures Partnership is a small "outer node" organization within the CIA that grew out of an early 1990s internal grassroots effort to explore new ways of looking at "uncertainties" in the larger environment. Over the years it has invited innovative thinkers, researchers and other to speak in an effort to be "inside agitators," to stir things up, to introduce new ways of thinking about and approaching intelligence gathering and analysis. It maintains a network of contacts that extends beyond the United States.

Complexity-related Activities: Over the years, the Partnership has hosted a number of speakers involved in various aspects of complex systems research and its applications.

2. Federal Reserve System

Alan Greenspan, PhD
Chairman
Board of Governors
20th Street and Constitution Avenue, NW
Washington, DC 20551
Website: http://www.federalreserve.gov/

Background: The Federal Reserve, the central bank of the United States, was founded by Congress in 1913 to provide the nation with a safer, more flexible, and more stable monetary and financial system. Today the Federal Reserve's duties fall into four general areas: 1) conducting the nation's monetary policy; 2) supervising and regulating banking institutions and protecting the credit rights of consumers; 3) maintaining the stability of the financial system; and 4) providing certain financial services to the U.S. government, the public, financial institutions, and foreign official institutions.

Complexity-related activities: On August 29, 2003 at a symposium sponsored by the Federal Reserve Bank of Kansas City and held in Jackson Hole, WY, Chairman Greenspan gave a speech entitled, ***Monetary Policy Under Uncertainty***, in which he talked about risk management in a complex and rapidly changing global economy. "Every model, no matter how detailed or how well designed conceptually and empirically, is a vastly simplified representation of the world that we experience with all its intricacies on a day-to-day basis. Consequently, even with large advances in computational capabilities and greater comprehension of economic linkages, our knowledge base is barely able to keep pace with the ever-increasing complexity of our global economy. Given this state of flux, it is apparent that a prominent shortcoming of our structural models is that, for ease in parameter estimation, not only are economic responses presumed fixed through time, but they are generally assumed to be linear. An assumption of linearity may be adequate for estimating *average* relationships, but few expect that an economy will respond linearly to every aberration. Recent history has also reinforced the perception that the relationships underlying the economy's structure change over time in ways that are difficult to anticipate…."
Full text available:
http://www.federalreserve.gov/boarddocs/speeches/2003/20030829/default.htm

The Fine Arts Program of the Federal Reserve Board featured the exhibition, **COMPLEXITY**, September 26-November 28, 2003, which included 35 pieces of art representing the work of 25 artists. This first major museum exhibition on complexity science originated at the Samuel Dorsky Musuem of Art, State University of New York at New Paltz in October 2002 and is curated by Philip Galanter and Ellen K. Levy. The Washington exhibition at the Federal Reserve Board was cosponsored by the Washington Center for Complexity and Public Policy.

3. National Science Foundation (NSF)

Rita Colwell, PhD, Director
4201 Wilson Blvd.
Arlington, VA 22230
Telephone: 703-292-5111
Website: http://www.nsf.gov

Mission: To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; to foster the interchange of scientific and engineering information nationally and internationally; to support the development of computer and other methodologies; to maintain facilities in the Antarctic and promote the U.S. presence through research conducted there; and address issues of equal opportunity in science and engineering.

Complexity-related Activities: NSF is *the major funding source for university-based basic research in complexity-related areas*. At present, NSF is emphasizing the importance of various modeling technologies in order to understand the interactions within and among complex systems. In her speeches and congressional testimony, Dr. Colwell stresses the importance of research in the areas of biodiversity and biocomplexity.

In early 2003, NSF released ***Complex Environmental Systems: Synthesis for Earth, Life and Society in the 21st Century,*** a 10-year outlook report developed by the NSF Advisory Committee for Environmental Research and Education. This report emphasizes the importance of interdisciplinary dialogue and research in order to create a "synthesis of environmental knowledge and know-how, which depends on the development of a robust theoretical and empirical understanding of complex systems; including their capacity for self-organization, resilience, and adaptation."

Complexity and Education Projects: See Section I.3

4. Smithsonian Institution

a. Resident Associates Program

S. Dillon Ripley Center
1100 Jefferson Drive, SW
Washington, DC 20026-3293
Telephone: 202-357-3030
Fax: 202-786-2034
Email: rap@tsa.si.edu
Website: http://residentassociates.si.edu

Mission: The RAP provides educational and cultural programs for its members living in the national capital area. Programs are also open to nonmembers on a fee basis.

Complexity-related Courses:

1. 2002, May 11. ***Signs, Symptoms and Clues: Unraveling the Mystery of Nature and the Nature of Mystery through Semiotics and Complexity Theory.***

2. 2001, May 12. ***Gaia and Complexity***. A one-day lecture with four guest lecturers addressing questions related to learning more about our world and environment through complex adaptive systems thinking.

3. 2000, April – June. ***Complexity Science and Agent-based Modeling: Gaining Insight About Life through Discovery and Emergence***. An eight-week course of two-hour lectures.

E. University-affiliated Research Centers

1. Boston University

The Frederick S. Pardee Center
for the Study of the Longer-Range Future

David Fromkin, JD, Director
Boston University
67 Bay State Road
Boston, MA 02215
Telephone: 617-358-4000
Fax: 617-358-4001
Website: http://www.bu.edu/pardee/

Mission: To advance scholarly dialogue and investigation into the longer-term future, identified as 35-200 years hence. The Center will serve as a leading academic nucleus for the study of the future and produce serious intellectual work that is interdisciplinary, international, non-ideological and of practical applicability.

Complexity-related Activities: Pardee Distinguished Lecture Series, ***Regularities and Randomness in the Past and the Future,*** Murray Gell-Mann, PhD, December 2 and 10, 2003. Dr. Gell-Mann is Professor and Co-Chairman of the Science Board of the Santa Fe Institute, and author of the popular science book, *The Quark and the Jaguar, Adventures in the Simple and the Complex.*

2. Brandeis University

The Benjamin & Mae Volen National Center for Complex Systems

Arthur Wingfiled, PhD, Director
415 South Street
Waltham, MA 02454-9110
Telephone: 781-736-4870
Fax: 781-736-2398
Website: http://www.bio.brandeis.edu/volen

Mission: To study the brain and intelligence. The center is an interdisciplinary group—artificial intelligence, cognitive science, linguistics, and a wide-range of topics in neuroscience including experimental psychology, computational neuroscience, and cellular and molecular neurobiology. The Center aims to increase knowledge within each of its individual component disciplines, as well as to foster interactions among the components, giving rise to new scientific initiatives.

3. California Institute of Technology

Control and Dynamical Systems (Research Group)
Division of Engineering and Applied Science

John Doyle, PhD
Professor of Control and Dynamical Systems, Electrical Engineering and Bioengineering
103 Steele, Mail Stop 107-81
1200 East California Blvd
Pasadena, CA 91125
Telephone: 626-395-4808
Fax: 626-796-8914
Email: doyle@cds.caltech.edu
Website: http://www.cds.caltech.edu

Description: This research group works on questions in the following areas: integrating modeling, ID, analysis and design of uncertain nonlinear systems, with applications throughout the aerospace and process control industries. Applications interests are motivated by the interplay between control, dynamical systems, and design and analysis of large, complex engineering systems. Computation in analysis and simulation, including complexity theory to guide algorithm development.

4. Duke University

Duke Center for Nonlinear and Complex Systems

Earl Dowell, PhD., Director
Room 069, Physics Building
Duke University
Durham, NC 27708
Telephone: 919-660-5321
Website: http://www.phy.duke.edu/cncs

Mission: To foster research and teaching of nonlinear dynamics and the mechanisms governing emergent phenomena in complex systems. The Center provides a regular seminar series and a Graduate Certificate Program, as well as numerous opportunities for undergraduate and graduate research through its associated faculty.

5. Florida Atlantic University

The Center for Complex Systems and Brain Sciences

J.A. Scott Kelso, PhD, Director
Florida Atlanta University
777 Glades Road
Boca Raton, FL 33431
Telephone: 561-297-2230
Website: http://www.ccs.fau.edu

Mission: To understand the principles and mechanism underlying complex behavior on all levels, from molecules and cells to whole brain functioning and even brains (people) working together. Since 1989, the Center has housed the National Institute of Mental Health's (NIMH) Training Program in Complex Systems and Brain Sciences, which provides fellowship support for graduate students and postdoctoral research and training.

6. George Mason University

a. *The Krasnow Institute for Advanced Studies*

Jim Olds, PhD, Director
Mail Stop 2A1
George Mason University
Fairfax, VA 22030
Telephone: 703-993-4333
Website: http://www.gmu.edu/departments/krasnow

Mission: To expand understanding of mind, brain and intelligence by encouraging research at the intersections of separate fields of cognitive psychology, neurobiology, and the computer-driven study of artificial intelligence and complex adaptive systems. The Institute also examines how new insights from cognitive science research can be applied for human benefit in the areas of mental health, neurobiological disease, education and computer design.

b. ***Center for Social Complexity***

Claudio Cioffi-Revilla, PhD, D.Sc.Pol, Director
237 Robinson Hall MS 3F4, George Mason University
Fairfax, VA 22030
Telephone: 703-993-1402
Fax: 703-993-1399
Website: http://www.gmu.edu/centers/complex

Mission: Established in 2002 to advance the knowledge frontiers of pure and applied social science, by using and developing computational and interdisciplinary approaches that yield new insights into the fundamental nature of social phenomena at all levels of social complexity—from cognitive networks to the world system.

7. Northeastern University

Center for Interdisciplinary Research on Complex Systems

Jorge V. José, PhD, Director
Dana Research Center, Physics Department
Northeastern University
Boston, MA 02115
Email: jjv@neu.edu
Website: http://www.circs.neu.edu

Mission: To conduct quantitative interdisciplinary research on many important problems in biology and materials science.

Complexity-related Focus: "The new global paradigm that we've identified as a promising director for future inquiry related to what has been termed complex systems. One characteristic of complex systems is that that involve many entities, or freedoms, which interact strongly and are usually modeled by nonlinear equations or by statistical models. Generally speaking, the solutions to these nonlinear equations behave regularly for some time. However, for extended periods of time, they often become irregular or deterministically chaotic. Chaotic behavior, however, is only part of the story when one attempts to explain the behavior observed in complex biological or mesoscopic material science

systems. Many other factors contribute to behavior, which requires an interdisciplinary effort to fully understand and model the myriad patterns of chaos."

8. Notre Dame

Department of Physics
Self-Organized Networks (Research Group)

Albert-László Barabási, PhD, Director
Hofman Professor, Theoretical Physics
Nieuwland Science Hall 203
Telephone: 574-631-5767
Fax: 674-631-5952
Email: Albert.L.Barabasi.1@nd.edu
Website: http://www.nd.edu/~alb

Description: The research focus is on networks. "…how they emerge, what they look like, how they evolve, and how networks impact on our understanding of complex systems." Barabási is author of, *Linked: The New Science of Networks*, 2002, Perseus Publishing.

9. Rensselaer Polytechnic Institute

Center for Ethics In Complex Systems:
Responding to Technological Change

John P. Harrington, PhD, Dean
School of Humanities and Social Sciences
110 8th Street
Troy, NY 12180
Telephone: 518-276-6575
Website: http://www.rpi.edu/dept/hss/research/cl/cecs.html

Mission: CECS conducts research to understand and address the ethical implications of new technologies.

Complexity-related Activities: "The effort to understand complex systems is particularly well suited to the CECS interdisciplinary research approach, which encourages attention to many variable, scales and interactions—between people with different kinds of expertise globally; between people and technology; and between social, technical and natural systems as they co-evolve. The Center aims to document and analyze the ethical dilemmas that emerge with the diffusion of new technologies in specific contexts, and the kinds of ethical action that can be mobilized in response—from the level of the individual to international policy—through laws and other institutional mechanisms as well as through new

social alliances, through new ways of designing and using technologies, and through efforts to bring about organizational and cultural change."

10. UCLA

Center for Human Complex Systems

Note: The Center is managed by a team of Executive Directors.

7285 Bunche Hall
Los Angeles, CA 90094
Telephone: 310-825-1750
Fax: 310-825-0778
Website: http://www.hcs.ucla.edu

Mission: To understand complex systems inhabited by human beings.

Background: "How does Social Science benefit from Complexity Theory and Computational Methods? We explore complex non-linear systems inhabited by human beings. These systems are biological, social, cultural, technological and creative. Our method is to analyze the behavior of the inhabitants of these systems and their interactions. Also, we construct computer models, synthesize virtual worlds and run simulation experiments….Results help us design better high-performing real-world systems with checks and balances. These systems are robust because they attend to: limited knowledge, distributed cognition, individual interaction, bounded rationality, subjective values, environmental change, and diverse world views….It [research] addresses questions faced everyday by decision-makers in business and government. We explore the implications of local actions for global patterns, and conversely, the influence of global structures on local behavior. Order and understanding come from chaos, competition, diversity, evolution and emergence."

11. University of Illinois

Center for Complex Systems Research

Alfred W. Hübler, PhD, Director
Department of Physics, UIUC
1110 W. Green Street
Urbana, IL 61801
Telephone: 217-244-5892
Email: hubler@uiuc.edu
Website: http://www.ccsr.uiuc.edu

Mission: Founded in 1986 by Stephen Wolfram, the Center studies systems that display adaptive, self-organizing behavior and systems that are usually

characterized by a large throughput, such a turbulent flow, lightning and the flow of information through the internet.

12. University of Michigan

Center for the Study of Complex Systems

John Holland, PhD
4477-4485 Randall Laboratory
Ann Arbor, MI 48109-1120
Telephone: 734-763-3301
Fax: 734-763-9267
Website: http://www.pscs.umich.edu/

Description: A broadly interdisciplinary program designed to encourage and facilitate research and education in the general area of nonlinear, dynamical and adaptive systems. Participating faculty represent nearly every college of the University. The Center is based on the recognition that many different kinds of systems which include self-regulation, feedback or adaptation in their dynamics, may have a common underlying structure despite their apparent differences. Moreover, these deep structural similarities can be explointed to transfer methods of analysis and understanding from one field to another. In addition to developing deeper understandings of specific systems, interdisciplinary approaches should help elucidate the general structure and behavior of complex systems, and move us toward a deeper appreciation of the general nature of such systems.

13. University of Texas

The Ilya Prigogine Center for Studies in Statistical Mechanics and Complex Systems

Professor Linda Reichl, Acting Director
Department of Physics, University of Texas at Austin
1 University Station, C1609
Austin, TX 78712
Telephone: 512-471-7253
Fax: 512-471-9621
Email: annie@physics.utexas.edu
Website: http://order.ph.utexas.edu

Mission: Based on Dr. Prigogine's work, the Center was established to conduct research and offer educational programs in the field of nonlinear dynamics, chaos and in other aspects of many-bodied systems.

Note: Dr. Prigogine died in Brussels, Belgium on May 28, 2003 at the age of 86.

14. University of Wisconsin-Madison

Human Performance in Complex Systems Consortium

Vicki M. Bier, Director
456 Mechanical Engineering Building
1513 University Avenue
Madison, WI 53706-1572
Telephone: 608-263-7546
Fax: 608-265-9094
Email: chpra@engr.wisc.edu
Website: http://www.engr.wisc.edu/consortia/hpcsc

Mission: This consortium conducts interdisciplinary research (both basic and applied) on human performance and decision-making processes in complex, advanced-technology systems.

F. Independent Education and Research Centers

1. Brookings Institution

Center on Social and Economic Dynamics
Robert Axtell, PhD, Scholar
Joshua M. Epstein, PhD, Scholar
1775 Massachusetts Ave, NW
Washington, DC 20036
Telephone: 202-797-6403
Email: csed@brookings.edu
Website: http://www.brook.edu/es/dynamics

Mission: The Center on Social and Economic Dynamics transcends disciplinary boundaries with innovative, unconventional research on economic and social issues. Research scholars Axtell and Epstein developed Ascape, a software tool designed to help users work with and explore agent-based simulations.

2. CNA Corporation (CNAC)

Honorable Robert J. Murray, President and CEO
4825 Mark Center Drive
Alexandria, VA 22311-1850
Telephone: 703-824-2000
Website: http://www.cna.org

Background: The Navy created the Center for Naval Analysis during World War II in order to bring scientific talent to bear on wartime operational problems.CNAC

has sustained and built upon that historical base, and extended its services to a wide-range of government clients outside its traditional national security base, while continuing to operate the Center for Naval Analysis.

Complexity-related Activities:

ISAAC/EINSTein =

Irreducible **S**emi-**A**utonomous **A**daptive **C**ombat/
Enhanced **I**SSAC **N**eural **S**imulation **T**oolkit

Andy Ilachinski, PhD, Director
Tactical Analysis Team/Operations Evaluation Group
Telephone: 703-824-2045
Fax: 703-824-2949
Email: ilachina@cna.org
Website: http://www.cna.org/isaac/

Mission: An artificial-life laboratory for exploring self-organized emergent behavior in land combat

Symposium: February 28, 2001. ***Complexity: An Important New Framework For Understanding Warfare?*** http://www.cna.org/isaac/complexity_conference.htm

Note: This website maintains an extensive list of links to complexity-related research centers and publications.

3. Chaordic Commons

Tom Hurley, Coordinating Director
1299 Fourth St., Suite 507
San Rafael, CA 94901
Telephone: 415-457-3670
Fax: 415-457-3625
Website: http://www.chaordic.org

Mission: Based on the work of Dee Hock, founder and CEO emeritus of Visa International, the Chaordic Commons is committed to creating the conditions for the formation of practical, innovative organizations that blend competition and cooperation to address critical societal issues..

4. Institute for the Study of Coherence and Emergence

Michael Lissack, PhD, Director
2338 Immokalee Road, Suite 113
Naples, FL 34110
Telephone: 941-254-9648
Email: kurt@isce.edu
Website: http://www.isce.edu

Mission: To promote pragmatic dialogue concerning the areas of networking, emergence and complexity studies with the aim of assisting practicing managers in the complex task of managing.

Note: ISCE has a number of locations and affiliations, and is the publisher of the journal, *Emergence.* http://www.emergence.org

5. New England Complex Systems Institute (NECSI)

Yaneer Bar-Yam, PhD, Director
23 Mt. Auburn Street
Cambridge, MA 02138
Telephone: 617-547-4100
Email: necsi@necsi.org
Website: http://www.necsi.org

Mission: NECSI is an independent educational and research institution dedicated to advancing the study of complex systems.

Note: See *Education and Complexity* project description in Section I.3

6. Plexus Institute

Curt Lindberg, President
The Olde Mill
P.O. Box 395
South Main Street
Allentown, NJ 08501
Telephone: 609-208-2930
Email: curt@plexusinstitute.org
Website: http://www.plexusinstitute.com

Mission: To foster the health of individuals, families, communities, organizations and our natural environment by helping people use concepts from the new science of complexity. Note: See also information in Section G 2.b

7. RAND Frederick S. Pardee Center for the Study of the Longer Range Global Policy and the Future Human Condition

James A. Dewar, PhD, Director, senior mathematician and Director of Research Quality Assurance at RAND.

1700 Main Street
P.O. Box 2138
Santa Monica, CA 90407-2138
Telephone: 310-393-0411 (main) 310-393-0411 (direct)
Email: dewar@rand.org
Website: http://www.rand.org/pardee

Background: Established in 2001 through a $5 million pledge from RAND alumnus Frederick S. Pardee.

Mission: To improve our ability to think about the longer range future—from 35 to as far as 200 years ahead—and to develop new methods of analyzing potential long-range, global effects of today's policy options in order to design sound policies that are sensitive to those effects.

Complexity-related Project: Beginning in January 2002, the Center and the Woodrow Wilson Foresight and Governance Project have sponsored an ongoing series of seminars, ***Complexity and Public Policy***, to explore how the emerging science of complex adaptive systems (CAS) is being applied to public policy issues and challenges. The various talks have highlighted the theory of complex adaptive systems and its application in areas such as budgeting, infrastructure planning and environment. http://www.complexityandpolicy.org/

8. Santa Fe Institute

Bob Eisenstein, PhD, President
1399 Hyde Park Road
Santa Fe, New Mexico 87501
Telephone: 505-984-8800
Email: eisenstein@santafe.edu
Website: http://www.santafe.edu

Mission: Founded in 1984, **the Santa Fe Institute is considered the formal birthplace of the interdisciplinary study of complex systems now known as "complexity science."** From website: "Since its inception, the Santa Fe Institute has devoted itself to the creation of a new kind of scientific research community pursuing emerging syntheses in science. The mission is to conduct and foster scientific research having four dominant, general properties: transdisciplinary, excellent, fresh and catalytic.

The current research agenda of SFI is simplicity, complexity, complex systems and particularly complex adaptive systems. Even as the concepts involved in the 'sciences of complexity' become well established elsewhere, this agenda, because of its breadth and because of the great variety of important scientific problems those concepts comprise, may endure for decades

Research at SFI has three primary attributes. The first is that the work is collaborative. SFI attracts researchers who are eager to interact with people from other fields and willing to go beyond the boundaries of academic disciplines or ideologies. A complementary attribute is that SFI research is accessible and open. That policy requires attitudes of hospitality and willingness to share ideas. In addition, it requires minimizing obstacles to broad participation, such as arcane jargon, rigid ideology, and solitary habits of work. Finally much of SFI's research is based on computation. The problem of validation of simulations by comparison of relevant data is an important focus."

9. Washington Center for Complexity and Public Policy

T. Irene Sanders, Executive Director
One Dupont Circle, NW, Suite 700
Washington, DC 20036
Telephone: 202-429-3733
Email: info@complexsys.org
Website: http://www.complexsys.org

Mission: To conduct research and educational programs that promote complexity science literacy and the development and implementation of new approaches to public policy-making.

10. Woodrow Wilson International Center for Scholars

Honorable Lee H. Hamilton, Director
Ronald Reagan Building and International Trade Center
One Woodrow Wilson Plaza
1300 Pennsylvania Avenue, NW
Washington, DC 20004-3027
Telephone: 202-691-4000 (main) 202-691-4204 (direct)
Website: http://wwics.si.edu

Background: The Center was established by Congress in 1961 as the official, national memorial to President Wilson. It is a living memorial whose work embodies President Wilson's belief that the scholar and the policymaker are "engaged in a common enterprise."

Mission Statement: To bridge the gap between the world of ideas and the world of policy, bringing them into creative contact, enriching the work of both and enabling each to learn from the other.

Complexity-related Project: Beginning in January 2002, the Foresight and Governance Project of the Center along with the RAND Pardee Center (see separate listing) have sponsored an ongoing series of seminars, ***Complexity and Public Policy***, to explore how the emerging science of complex adaptive systems (CAS) is being applied to public policy issues and challenges. The various talks have highlighted the theory of complex adaptive systems and its application in areas such as budgeting, infrastructure planning and the environment. http://www.complexityandpolicy.org/

David Rejeski, Director, Foresight and Governance Project
Telephone: 202-691-4276 (direct)
Email: foresight@wwic.si.edu

G. Private Foundations

1. John E. Fetzer Institute

Nonlinear Biodynamics
Paul C. Gailey, PhD, Vice President for Programs (interviewed)
9292 West KL Ave.
Kalamazoo, MI 49009-9398

Mission: The Fetzer Institute supports research, education and service programs exploring the integral relationships among body, mind and spirit in order to (new mission emphasis added post 9/11) foster awareness of the power of love and forgiveness in the emerging global community.

Complexity-related Activities:

> *The tools and ideas from nonlinear dynamics such as the concept of self-organization provide scientists with a powerful perspective for viewing living processes in a new light. As in the physical sciences before, the nonlinear dynamical systems approach promises to change scientific thinking in many areas of biomedical sciences. For example, two rapidly evolving branches of nonlinear dynamics, popularly known as chaos and complexity studies, which have opened up new vistas on the dynamics of the nonliving world, are also beginning to impact deeply on our view of the living world.*
>
> —Jan Walleczek, PhD
> from the preface to
> *Self-Organized Biological Dynamics & Nonlinear Control*

Recognizing the growing impact of nonlinear science on biomedicine, the Fetzer Institute sponsored a series of three conferences (the first in 1996 was sponsored jointly with the U.S. Department of Energy), which brought together research scientists representing a broad spectrum of scientific disciplines to review current know-ledge and to explore the most promising frontiers in this emerging new area of research. The excerpt above is taken from a book based on the first two conferences.

As a result of these three conferences the Fetzer Institute developed a research program, *Nonlinear Biodynamics,* designed to support research at the cutting-edge of this new frontier. In the last year, however, due to changes in the Institute's financial situation and a new emphasis in its mission statement, this program has been put back on the table for review and its future is uncertain.

2. Robert Wood Johnson Foundation

Risa Lavizzo-Mourey, MD, MBA, President and CEO
P.O. Box 2316
College Road East and Route 1
Princeton, NJ 08543-2316
Telephone: 888-631-9989
Website: http://www.rwjf.org

Mission: To improve the health and health care of all Americans.

Complexity-related Activities:

a. December 2-4, 1997. ***Leading From the Edge of Chaos: Complexity Theory and Health Care Leadership.*** This conference was the first national conference devoted to complexity and health-related topics. Support was provided by the Foundation to the organizer, VHA (formerly Voluntary Hospitals of America), and the purpose of the conference was to explore how complexity science can trigger fresh approaches to important health-related issues.

The conference brought leading thinkers on the science of complexity together with 103 representatives from various VHA facilities, including physicians, nurses, chief executives, and managers, many of whom were already engaged in various action research projects in their own facilities. Conference participants were exposed to the fundamental principles of the science of complexity and their application to organizational leadership, change and health care, and to examples of how these principles have be used by pioneering health care leaders.

In addition to underwriting a portion of the conference costs, the Foundation funded the development of teaching and learning materials called *Edgeware*, which were used to help conference participants introduce others from their organizations to the science of complexity and its implications for health care and management. The January 9, 1998 "Front Lines" column in the *Wall Street Journal* mentioned the conference in the context of a larger discussion of complexity science.

b. ***Developing a Complexity and Health Institute.*** Grants Results Brief, February 2003. The Deaconess Billings Clinic Foundation sponsored the implementation of a complexity and health institute, the *Plexus Institute*, located in Allentown, NJ. The Robert Wood Johnson Foundation provided a $50,000 grant to support the project.

Prior to the grant a group of scientists, organizational theorists, health practitioners and executives had developed basic plans for a complexity and health institute dedicated to the application and use of new scientific findings to advance the health of individuals, organizations, and communities. The grant was used for a series of meetings, on-line communications and support of several consultants to assist with the implementation of the institute. More information is available from: http://www.rwjf.org/reports/grr041253.htm and from http://www.plexusinstitute.org

3. W.K. Kellogg Foundation

William C. Richardson, PhD, President and CEO
1 Michigan Ave. E.
Battle Creek, MI 49017-4058
Telephone: 269-968-1611
Website: http://www.wkkf.org

Mission: To help people help themselves through the practical application of knowledge and resources to improve their quality of life and that of future generations.

Complexity-related Activities: ***Building Leadership: Findings from a Longitudinal Evaluation of the Kellogg National Fellowship Program.*** Prepared for the Foundation by Gregory B. Markus, PhD, University of Michigan, Ann Arbor.

Background: In 1980 the Kellogg Foundation launched an experiment, the Kellogg National Fellowship Program (later to become the Kellogg National Leadership Program) as its response to a major national challenge. "…the tumultuous times of the late 1960s and early 1970s cast in stark relief the mismatch between the complex challenges facing human society, on the one hand, and the trend toward narrowness and specialization within academia and

the professions, on the other. While respecting all the benefits that come from intense focus and specialization, the Foundation decided that something had to be done to help skilled specialists broaden their perspectives; reach out across disciplinary boundaries; comprehend the urgent need for socially oriented, effective leadership; and develop their capacities to provide such leadership." This initial experiment developed over twenty-one years (1980-2001) into a program regarded as one of premier leadership programs in the country.

Excerpt from Evaluation Report, Section: ***Leadership and Complexity***. "The concepts with which students of complexity concern themselves are directly analogous to those of human organizations; adaptation, evolution, co-evolution, fitness, growth, order. What succeeds, they find, are robust systems that in spite of being incompletely understood and inherently unpredictable are flexible and adaptive…Fostering robust adaptiveness can mean de-emphasizing efficiency and emphasizing effectiveness instead…The moral of the story for leaders is that they should foster innovativeness and entrepreneurialism within their organizations—an ethic of constantly trying things our, keeping what works (for the time being) and discarding what doesn't." Full report: http://www.wkkf.org/pubs/CCT/Leadership/pub3676.pdf

Update: In 2002 the Foundation made a grant to the University of Maryland to continue working with the alumni network. For more information contact: Martha Lee, Executive Director, Kellogg Fellows Leadership Alliance, 1118 Taliaferro Hall, University of Maryland, College Park, MD 20742-7715. Telephone: 410-405-8064. Website: http://www.kelloggfellows.org

4. James S. McDonnell Foundation

John T. Bruer, PhD, President
Susan M. Fitzpatrick, PhD, Vice President (interviewed)
1034 South Brentwood Blvd, Suite 1850
St. Louis, MO 63117
Telephone: 314-721-1532
Fax: 314-721-7421
Website: www.jamf.org

Mission: To "improve the quality of life" by contributing to the generation of new knowledge through its support of research and scholarship.

Complexity-related Programs: ***Studying Complex Systems*** is a new program area for the foundation. The interest grew of its Centennial Fellows Program, where Global and Complex Systems research was one of its five fellowship areas. This program is guided by a nine person advisory panel of scientists.Its primary focus is on using and developing quantitative tools and models to address issues related to social issues and systems. Rather than seeing complexity as an overarching framework with many applications, the foundation's

perspective is that complexity is a research approach, which, may in ten years yield useful information about social systems.

5. David and Lucille Packard Foundation

Susan Packard Orr, Chairman
Barry D. Gold, Program Office, Sustainability Science (interviewed)
300 2nd Street, Suite 200
Los Altos, CA 94022
Telephone: 650-948-7658
Website: http://www.packfound.org

Mission: To focus on society's needs by supporting selected nonprofit organizations.

Complexity-related Activities: ***Sustainability Science,*** Conservation and Science Program. "In the last few years, the role of science and technology in addressing the challenge of sustainability has taken on a new urgency for scientists and policymakers worldwide. It requires new ways of doing science and new ways of linking research to policy, scientists to practitioners, and the developed world to the developing world." This is a new area of interest for the Foundation, which has not yet issued funding guidelines. It grew out of a series of experimental grant-making projects that ended in 2002. This program and many others at the Foundation are being reviewed as the Foundation reconsiders its funding priorities in light of a significantly reduced endowment and major staff reductions in the last year.

6. Pew Charitable Trusts

Rebecca W. Rimal, President
1 Commerce Square
2005 Market Street, Suite 1700
Philadelphia, PA 19103-7077
Telephone: 215-575-9050
Fax: 215-575-4939
Email: info@pewtrusts.com
Website: http://www.pewtrusts.com

Mission: The Pew Charitable Trusts support nonprofit activities in the areas of culture, education, the environment, health and human services, public policy and religion. The Trusts make strategic investments that encourage and support citizen participation in addressing critical issues and effecting social change.

Complexity-related Activities: While the Trusts do not have a specific emphasis or programmatic focus on complexity or complex systems research, many of its grantees are using this approach in their projects.

Example: May 2003, ***America's Living Oceans: Charting a Course for Sea Change.*** A report to the Nation. Recommendations for a New Ocean Policy. from the Pew Oceans Commission, chaired by Leon E. Panetta.

> Excerpt: "Our perspective on ocean resources and policy has also changed over 30 years. We are increasingly aware that development activities can change marine environments. We are learning more about complex interactions in marine ecosystems and the need to maintain the diversity and resilience of those complex adaptive natural systems."

H. Museums and Art Galleries

1. The Exploratorium

Goéry Delacôte, PhD, Director
3691 Lyon Street
San Francisco, CA 94123
Telephone: 415-563-0360
Website: http://www.exploratorium.edu

Background: The Exploratorium is a collage of over 600 interactive exhibits in the areas of science, art and human perception. It is at the forefront of the movement of the "museum as educational center." This unique museum was founded in 1979 by physicist and educator Frank Oppenheimer, PhD, who served as its director until his death in 1985. It's website now contains over 12,000 pages.

Complexity-related Exhibits: ***Turbulent Landscapes: The Natural Forces that Shape Our World.*** This 1996 exhibit featured the work of 13 artists exploring complexity in nature. http://www.exploratorium.edu/complexity/index.html
This exhibit was supported by a grant from the National Science Foundation. Development of the website was supported by the CoVis Project and the Making Sense of Information Project of the Association of Science Technology Centers.

2. The Fine Arts Program Federal Reserve Board

Mary Anne Goley, Director FAP
Federal Reserve Board
Washington, DC 20551
Telephone: 202-452-3778
Website:
http://www.federalreserve.gov/generalinfo/virtualtour/virtual.cfm?WhichSlide=2

Background: In 1975, Federal Reserve Board Chairman Arthur F. Burns founded the Board's Fine Arts Program in response to a May 26, 1971 memorandum from President Richard M. Nixon that encouraged all federal agencies to find ways to assist, and be assisted by "the arts and artists." The Board's program was conceived as a way to enhance the work environment for employees while providing visitors with a memorable experience of American artists and cultural values. In addition to its permanent collection, the Board presents three public exhibitions annually of loaned artworks. These exhibitions are displayed in the atrium of the Eccles Building. The entrance to the Eccles Building is on 20th Street NW, between Constitution Avenue and C Streets, NW.

Complexity-related Exhibit: September 22-November 28, 2003 the Fine Arts Program sponsored, **COMPLEXITY**, the first fine arts exhibit on complexity science. See section D.2 on Federal Reserve System.

3. Center for Art and Visual Culture
University of Maryland Baltimore County/UMBC

David Yager, PhD, Director
Center for Art and Visual Culture

Symmes Gardner, Director
Fine Arts Gallery

1000 Hilltop Circle
Fine Arts Building, Room 105
Baltimore, MD 21250
Telephone: 410-455-3188
Fax: 410-455-1596
Website:
http://www.umbc.edu/cavc/

Mission: CAVC is dedicated to the study of contemporary art and visual culture, critical theory, art and cultural history, criticism, and the relationship between society and the arts. The Center sponsors a variety of cultural programs including in-house and traveling exhibitions, a publication series, and community outreach and public arts projects. With a special emphasis placed on the role of education in the arts, the Center continues to present symposia, lecture series, conferences, film series, workshops, and visiting artists residencies to the university community, middle school and high school students and the general public.

Complexity-related Exhibits: Fall 2004 the Fine Arts Gallery will host an original exhibition on complexity. The exhibit will be the centerpiece for a conference and a film festival on complexity, ***The Art, Science and Societal Implications of Complex Systems Research,*** being produced jointly with the Washington Center for Complexity and Public Policy. This exhibit is part of an *art, science, technology and society* theme being carried through the year, starting in winter 2004 with, *Paradise Now: Picturing the Genetic Revolution.*

I. Specific Complexity and Education-related Projects

1. American Educational Research Association

Felice Levine, PhD, Executive Director
1230 17th Street, NW
Washington, DC 20036
Telephone: 202-223-9485
Fax: 202-775-1824
Website: http://www.aera.net

a. *Chaos and Complexity Theory Special Interest Group (SIG)*

Purpose: To apply, advance and extend chaos and complexity theories to inquiry, research and theory related to educational contexts. This SIG holds special workshops at the AERA meetings and has an active ongoing dialogue through its website.

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2. Center for Connected Learning and Computer-Based Modeling

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Mission: The Center for Connected Learning and Computer-based Modeling (CCL) is a research group dedicated to the creative use of technology to deepen learning. It also develops tools and curricula for use in both classrooms and informal learning settings.

Background: CCL was founded in 1995 at Tufts University and relocated to Northwestern University in 2000. The Center includes staff and students at Northwestern working together and in association with researchers here and at other universities. The group includes educational researchers, curriculum developers, software engineers, and model builders.

Educational Products: Tools developed at the CCL have been used with a wide-range of learners, ranging from young children to frontier level researchers in universities, businesses, and laboratories. Their technologies are designed to help learners to make deep connections between what they are learning and their personal experience of the world.

Recently CCL has been primarily engaged with developing computer-based modeling and simulation packages and associated materials. These packages enable learners to explore, construct and revise models across a wide variety of natural and social domains.

The NetLogo environment, for example, enables learners to give simple rules to individual "agents" in a simulation and observe the collective result of all agents' behavior. Using NetLogo language, students and researchers have constructed large numbers of models of complex phenomena in the natural and social worlds. The Models Library that comes with NetLogo covers phenomena in biology, chemistry, physics, earth science economies, history, sociology, business, medicine and a variety of other domains. These models can be explored and revised as part of model-based inquiry in middle, secondary and undergraduate classrooms as well as serving as the basis for research in more advanced settings.

They have also developed technologies that support Participatory Simulations. The HubNet technology built into NetLogo enables a network of learners to collaboratively explore and control a simulation. Students engaged in such a participatory simulation act out the roles of individual elements of a system and then observe how the behavior of the system as a whole can emerge from these individual behaviors. The emergent behavior of the system and its relation to individual participant actions and strategies can then become the object of collective discussion and analysis.

3. New England Complex Systems Institute (NECSI)

See Section F 5 for general information on NECSI.

Planning Meeting for a National Initiative on Complex Systems in K-16 Education

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Abstract: This initial phase of this project was funded with a grant (1999-2000) from the Education and Human Resources Directorate of the National Science Foundation, Award Number 9980241. The purpose of the overall project was "to create a long term public national agenda for incorporating new ideas of complexity, dynamical systems modeling of nonlinear phenomena and related ideas such as emergence and fractal descriptions into the mainstream education experience of American citizens."

The NSF grant funded an initial meeting, which produced reports from three working group collaborations of scholars, scientists and educators—*Complex Systems: Why and What?—Complex Systems and Education: Cognitive, Learning and Pedagogical Perspectives*—and *Toward Systemic Educational Change: Questions from a Complex Systems Perspective.* These were intended to be the conceptual building blocks for the overall project.

Full report available at: http://www.fastlane.nsf.gov/servlet/showaward?award=9980241

Update: In February 2003, current NSF staff were not aware of this project nor were staff at the U.S. Department of Education. According to the Yaneer Bar-Yam, PhD, principal investigator, the results of this initial planning phase and the follow-up recommendations were never pursued by NSF. The most likely scenario explaining this is that the program manager, Nora Sabelli, left NSF and the report was lost in the transition.

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L. Washington Center for Complexity and Public Policy

The Washington Center for Complexity and Public Policy is a private, non-profit organization that was established in 2001 in response to the growing interest in complexity science as a framework for thinking about and planning for the future. The mission of the Center is to conduct research and educational programs that promote complexity science literacy, and the development and implementation of new approaches to public policy-making. http://www.complexsys.org

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Ms. Sanders, author of *Strategic Thinking and the New Science: Planning in the Midst of Chaos, Complexity and Change* (The Free Press, 1998.), pioneered the application of chaos theory and complexity to the much-needed skill of strategic thinking and the process of strategic planning.

In 1989-90, she developed and directed an executive education program on the applications of complexity to business for the Colorado Center for Chaos and Complexity at the University of Colorado at Boulder. She developed the first online MBA and M.Ed courses on the new science. Ms. Sanders originated and

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This report was developed under a grant to the Washington Center for Complexity and Public Policy from the Fund for the Improvement of Education, U.S. Department of Education, Grant Number R215U02000402. The contents do not necessarily represent the policy of the Department of Education and should not be viewed as endorsed by the Federal Government.