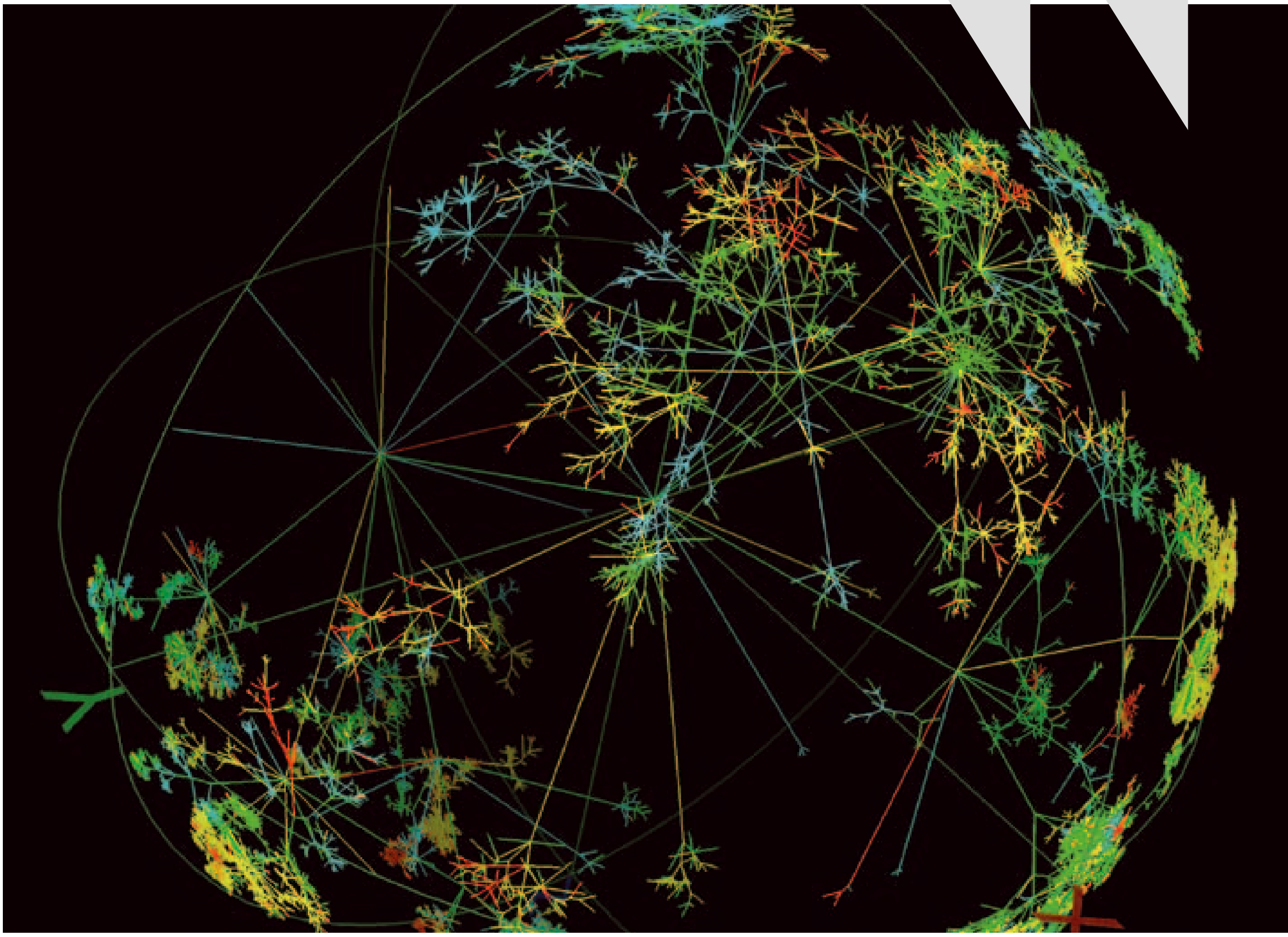
OECD Global Science Forum

Applications of Complexity Science for Public Policy

NEW TOOLS FOR FINDING UNANTICIPATED CONSEQUENCES AND UNREALIZED OPPORTUNITIES

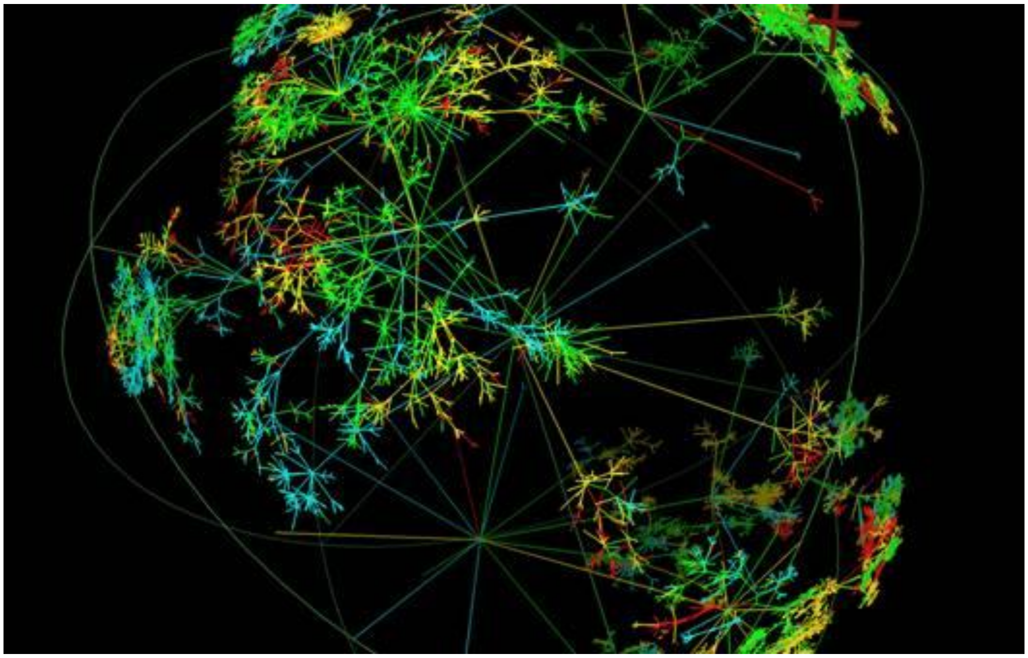


OECD

Organisation for Economic Co-operation
and Development (OECD)
Global Science Forum

Report on

Applications of Complexity Science for Public Policy: New Tools for Finding Unanticipated Consequences and Unrealized Opportunities



Based on a workshop convened on October 5-7, 2008
at the Ettore Majorana International Centre for Scientific Culture, Erice, Sicily

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Contents

Rationale

Government officials and other decision makers increasingly encounter a daunting class of problems that involve systems composed of very large numbers of diverse interacting parts. These systems are prone to surprising, large-scale, seemingly uncontrollable, behaviours. These traits are the hallmarks of what scientists call *complex systems.* This report is devoted to the proposition that the insights and results achieved through scientific analysis can be used to design and implement better governmental policies, programmes, regulations, treaties, and infrastructures for dealing with complex systems.

In a complex system, it is not uncommon for small changes to have big effects; big changes to have surprisingly small effects; and for effects to come from unanticipated causes. Thus, for example, a continent-wide electrical power grid can suffer massive cascading malfunctions after the breakdown of a single transformer in a small substation; an elaborate multi-year health education programmer may yield no discernable effect on health behaviours in one community while having a major impact in another; the emergence of a new pathogen in a remote village can sicken just a few individuals, or give rise to a devastating global epidemic; the adoption of an exotic new financial instrument can eventually contribute to a chain of stock market collapses and business failures. Clearly, any science-based insight into the behaviours of such systems would be of value to policymakers.

An exciting, interdisciplinary field called *complexity science* has emerged and evolved over the past several decades, devoted to understanding, predicting, and influencing the behaviours of complex systems. The field deals with issues that science has previously had difficulty addressing (and that are particularly common in human systems) such as: non-linearities and discontinuities; aggregate macroscopic patterns rather than causal microscopic events; probabilistic rather than deterministic outcomes and predictions; change rather than stasis.

Major advances in computational technologies have catalyzed complexity research, enabling scientists to create large numbers of virtual system components and set them to interact with each other in simulated worlds. By varying the parameters of these simulations, researchers can explore the spectrum of collective behaviours, validate theoretical models, and compare the virtual systems with their real-world counterparts. Computational advances are enabling scientists to cull regularities out of large, dense databases containing information about human interactions. Using these new methods, scientists are gaining insight into thorny complexities that characterise human and social entities such as brains, crowds, cities, communities and economies.

To understand what complexity science is about, it is helpful to draw a distinction between *complicated* and *complex* systems. Traditional science excels at the complicated, but encounters considerable limitations that make it ill-suited to the complex. An example of a *complicated* system is an automobile, composed of thousands of parts whose interactions obey precise, simple, known and unchanging cause-and-effect rules. The complicated car can be well understood using normal engineering analyses. An ensemble of cars travelling down a highway, by contrast, is a *complex* system. Drivers interact and mutually adjust their behaviours based on diverse factors such as perceptions, expectations, habits, even emotions. Excepting the constraints imposed by physical laws that apply to vehicular motions (and, possibly, collisions), actual traffic flow cannot be predicted with certainty. No one driver is in control and there is no single destination. To understand traffic, and to build better highways, set speed limits, install automatic radar systems, etc., it is helpful to have tools that can accommodate non-linear and collective patterns of behaviour, and varieties of driver types or rules that might be imposed. The tools of complexity science are needed in this case.

Given the accumulating scientific accomplishments of complexity scientists, the OECD Global Science Forum [1]asked an essential question: *How can the insights and methods of complexity science be applied to assist policymakers as they tackle difficult problems in policy areas such as health, environmental protection, economics, energy security, or public safety?*

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[1] A description of the OECD Global Science Forum can be found in the Workshop Agenda (Appendix).

Background

To address the above essential question, the OECD Global Science Forum convened a workshop on 5-7 October, 2008, on the topic of "Applications of Complexity Science for Public Policy: New Tools for Finding Unanticipated Consequences and Unrealized Opportunities." The convening of the workshop was formally proposed by the Delegation of the United States to the Global Science Forum at its meeting of 1/2 October, 2007. The preparations for the workshop were carried out by an international steering committee.[2] The workshop, held in Erice, Italy, was hosted by the Ettore Majorana Foundation and Centre for Scientific Culture, and was attended by thirty-three participants from twelve countries[3], plus five representatives of three international organizations[4].

Workshop participants included scientists, policymakers and science programme managers. The presentations and discussions were organized so as to explore (1) the extent to which complexity science can be useful to decision-makers today; and (2) how its utility might be enhanced by strengthening the research enterprise and promoting international cooperation.

The majority of the workshop sessions were devoted to problem domains that are of pressing concern to policymakers and to society, and where complexity science is considered promising: (1) epidemiology and contagion; (2) complex dynamics of technologically connected environments; (3) resilience and vulnerability to extreme events; and (4) societal implications of climate change. Two final sessions explored (1) how complexity science could be made more immediately useful to policymakers, and (2) what the international complexity science community needs in order to make longer-term progress, particularly in ways that are policy-relevant. The agenda for the workshop is included in the Appendix.

The following two sections of this report explore, first, the concepts and methods that characterize complexity science and, second, the implications of complexity science for public policy. The first section focuses on the definition of a complex system, and introduces key concepts and methods (illustrated with examples). The second section includes descriptions of existing applications in the policy domain, and concludes with an analysis of resources and arrangements that might be required to catalyze complexity sciences and make them even more useful for policy-relevant applications.

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[2] The list of members of the steering committee can be found in the Workshop Agenda (Appendix).

[3] Australia, France, Germany, Hungary, Italy, Japan, Netherlands, Norway, Portugal, Switzerland, United Kingdom, United States.

[4] European Commission, European Science Foundation, World Health Organization

Concepts and Methods of Complexity Science

A *complex system* is composed of many parts that interact with and adapt to each other and, in so doing, affect their own individual environments and, hence, their own futures. The combined system-level behaviour arises from the interactions of parts that are, in turn, influenced by the overall state of the system. Global patterns emerge from the autonomous but interdependent mutual adjustments of the components.

What are Complex Systems and Why Do They Matter?

Complexity science has been applied with success to the study of physical phenomena such as turbulent fluids or huge gravitating astronomical systems as well as to the intricate interactions of the components of living cells. Insights gained from the study of complex physical systems can be, and have been, applied to human ones.

A familiar example can help newcomers appreciate the basic traits of complex systems:

> A flock of birds swarming across a countryside is a complex system. No single bird is in charge, yet the flock's behaviour is organized and exhibits a kind of group intelligence. As they fly together, each member of the flock adjusts its location and speed based on the location and speed of others nearby. The collective produces beautifully non-uniform swarming motions that protect the members by frustrating predators that try to aim at individual birds.

A more speculative example involves the workings of the brain:

> The human brain is a complex system. The firing of certain neurons affects the firing of other neurons and the result in the whole-brain system can then influence the individual neurons. This dynamic ultimately produces some profoundly hard-to-predict phenomena of mind such as ideas, metaphors and dreams.
>
> Neither swarms nor dreams are predictable directly from the behaviour of individual birds or neurons. Neither system can be directly controlled. Yet there is hope that, some day, complexity science can yield significant insights into such phenomena and into many other systems that self-organize to develop rich, surprising patterns.

Complexity scientists seek and scrutinize patterns and tendencies in complex systems. When they succeed in identifying consistent tendencies, effective ways of positively influencing the systems may be derived from the scientific analysis. Some existing successes point the way to even more powerful future applications. For example:

- The movements in a crowd before it breaks into a stampede appear chaotic. When the stampede itself occurs, though, there is order: a strong, directional flow in which individuals can be trampled. Complexity scientists have identified patterns in crowd dynamics that are immediate precursors to stampedes (for example, stop-and-go waves and turbulent motions). Using these insights, public authorities and engineers have designed and organised public spaces so as to inhibit the precursor patterns and, thereby, prevent stampedes.

- Complexity scientists have identified persistent ordered patterns called Power Laws in several domains. For example, the relative population sizes of cities in a number of countries over the last century fit a particular mathematical relationship called Zipf's

Law[5]. This pattern is not predicted by a specific theory, but is associated with a well known feature of complex systems: positive feedback loops. This observation has successfully focused inquiry and enabled some strategic practical decisions in urban planning.

- Two Nobel Prizes in Economics have been awarded for complex systems research. Thomas Schelling found that residential segregation tends to emerge in a system of independent citizens if they hold only a few simple, unobjectionable preferences for being near others like themselves (i.e., no hatred or racism is necessarily required). Paul Krugman has been able to explain the existence of clusters of economic activity and regional growth disparities by examining economies as complex adaptive systems. This work has already influenced city planners and economic geographers, among others.

Why do complex systems matter to policymakers?

Social, political, ecological and economic systems involve mutually adaptive interactions and produce characteristic patterns. The promise of complexity science for policy applications is, at its core, the hope that science can help anticipate and understand these key patterns in complex systems that involve or concern humans, thus enabling wiser decisions about policy interventions.

Some key characteristics of complex systems that are pertinent for policymakers are listed below. They were discovered in the course of mathematical investigations or through the study of fundamental physical/chemical/biological phenomena. But, given the nature of the OECD project, the examples below pertain to the social and behavioural domains[6]. Not all complex systems share all these traits, and some of the traits may overlap.

- Adaptability. Complex systems are formed by independent constituents that interact, changing their behaviours in reaction to those of others, thus adapting to a changing environment. The interactions need not be direct or physical; they can involve sharing of information, or even be indirect (e.g., as one agent changes an environment, another responds to the new environmental condition).

  Example: A city is a highly complex system, with individuals and organizations interacting on social, political, economic and physical levels, constantly changing and adjusting to one another.

- Emergence. Novel patterns that arise at a system level that are not predicted by the fundamental properties of the system's constituents or the system itself are called emergent properties. For example, hydrogen oxide is a simple, unexceptional three-atom molecule. But combining a large number of these molecules produces a liquid – water – whose intriguing and essential properties (e.g., transparency, role as universal solvent, capillary action, expansion upon freezing, etc.) have been the subject of numerous scientific studies. Similarly, weather is an emergent property of air, moisture and land interactions; global political dynamics are emergent from innumerable social, economic and political interactions. Emergent properties sometimes manifest themselves as

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[5] Thus, for the cities in any country, a graph can be generated with the logarithm of the population of each city on one axis, and the logarithm of the city's rank (most populous city has rank 1, second most populous has rank 2, etc.) Surprisingly, the resulting graph, with a point for each city, can be very accurately depicted by a straight line with slope -1.

[6] Experts will note that some of the descriptions are necessarily approximate and simplified for the purposes of this policy-level report.

unexpected surprises (e.g., cigarette taxes aimed at curtailing smoking that yielded unanticipated consequences such as cigarette smuggling and financing terrorism).

Example: In some communities, a web of healthy social and economic relations yields an emergent quality of *resilience*, such that the members are likely to remain essentially unaffected by significant adverse events (such as an economic slump, or a natural disaster); while in other communities the social and economic interactions yield an overall condition of *vulnerability* such that the members are likely to suffer seriously from even moderate or small perturbing events. In many policy domains, the complexity of systems is deliberately augmented in order to enhance resilience (for example by adding redundancy to a power grid or air traffic control network). But sometimes the reverse is inadvertently achieved: a greater vulnerability to single-point failures. Obviously, insights derived from complexity science could be of great benefit in such endeavours.

- Self-organization. A system that is formed and operates through many mutually adapting constituents is called self-organizing because no entity designs it or directly controls it. Self-organizing systems will adapt autonomously to changing conditions, including changes imposed by policymakers.

  Example: A market operates through all the independent decisions of buyers and sellers. Prices evolve through interactions. While markets can be influenced, they cannot be directly controlled. They will make their own – sometimes surprising and undesirable – responses to direct interventions.

- Attractors. Some complex systems spontaneously and consistently revert to recognizable dynamic states known as attractors. While they might, theoretically, be capable of exhibiting a huge variety of states, in fact they mostly exhibit the constrained attractor states. Periodic systems typically have prominent attractor states. Thus, if the pendulum of a grandfather clock is given a random nudge, it may move about erratically for a short time, but will soon settle back into its customary regular beat.

  Example: A society's norms and customs are persistent, hard to displace attractors. Married couples with more ties into a social network (i.e., more interactions in the social system) have been found to be far more likely to adopt and maintain a traditional segregation of husband and wife roles; those less connected are more likely to diverge from traditional divisions of responsibility.

- Self-organized Criticality. Referring to the concepts defined above, a complex system may possess a self-organising attractor state that has an inherent potential for abrupt transitions of a wide range of intensities. Because the state is an attractor, the system will, eventually, and spontaneously, return to it after each transition. Some scientists believe that a certain class of earthquake faults are characterised by such "self-organised criticality". They typically produce a large number of small tremors, with less frequent, more intense shocks, and rare catastrophic ruptures, but always returning to the same permanently unstable configuration as a result of the inexorable motion of tectonic plates. For a system that is in a self-organised critical state, the magnitude of the next transition is unpredictable, but the long-term probability distribution of event magnitudes is a very regular known distribution (a "power law" as described below).

Example: In a region of the world where strong, persistent, disruptive political, economic and social forces are at work, violent events can occur at any time. Small outbreaks are frequent, but more serious clashes are possible including, ultimately, war. Each event, whether big or small, can be precipitated by a seemingly insignificant perturbation (for example a personal quarrel). Unless fundamental change takes place in such a region, conflict will remain endemic and unavoidable.

- Chaos. One of the earliest known features of complex systems was chaotic dynamics, characterized by extreme sensitivity to initial conditions. Chaotic systems are not 100% predictable, yet they exhibit order due to an underlying attractor[7]. The weather is known to be chaotic, as illustrated by the proverbial "butterfly effect", in which a butterfly flapping its wings in one part of the world can, many days later, lead to the development of a hurricane elsewhere on the planet[8].

  Example: A healthy human heart actually beats in a slightly irregular chaotic fashion and, paradoxically, an overly regular heartbeat is more likely to lead to sudden death. The theory of chaotic dynamics has been used to develop treatments for this syndrome.

- Nonlinearity. When a system is linear, a change in one property produces a proportional change in others. A simple example is a mercury thermometer in which change in the height of the liquid in the tube is proportional to the change in temperature. However, if an attempt is made to measure a temperature that is less than -39C, the predictable regular behaviour of the device breaks down, since the now-frozen mercury will no longer respond at all to further cooling: a drastic form of nonlinearity. When relationships are nonlinear, prediction sometimes requires sophisticated forecasting algorithms that are probabilistic in nature. In some cases, small changes might have large effects on a nonlinear system, while large ones could have little or no effect.

  Example: In some instances, a single story in the media catalyzes vast societal interest and response (e.g., a child rescued after falling in a well) while in others it appears that all the messages in the world fail to raise public interest or awareness (e.g., the fate of children caught up in civil wars or genocide).

- Phase Transitions. System behaviour changes suddenly and dramatically (and, often, irreversibly) because a "tipping point", or phase transition point, is reached. Phase transitions are common in nature: boiling and freezing of liquids (for example, the freezing of mercury that is referred to above[9]), the onset of superconductivity in some materials when their temperature decreases beyond a fixed value, the transition between amorphous and crystalline configurations of certain glasses, the sudden triggering of an avalanche. Self-organized criticality is an example of a phase transition, but other classes of phase transitions exist.

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[7] Interestingly, a system can be predictable and stable on one time scale, and complex/chaotic on another. Thus the Solar System is a well-known model of clockwork regularity on the time scale of years or decades, but its configuration is completely unpredictable millions of years into the future. Indeed, it is impossible to say with certainty that any planet will not someday collide with another one, or be ejected into deep space

[8] The concrete case of storms and butterflies has not been validated experimentally, but the point is that most large-scale phenomena in the natural and human worlds have a quasi-infinite number of contributing causes and are thus, for all practical purposes, unpredictable.

[9] For temperatures above 360C, the mercury in the tube would boil away – an instance of system behaviour going well beyond nonlinearity.

Example: The point at which public trust in a banking system collapses and withdrawals cascade catastrophically.

- Power Laws. Complex systems are sometimes characterized by probability distributions that are best described by a particular type of slowly decreasing mathematical function known as a power law (instead of the more familiar bell-shaped normal distribution). When power laws hold, it is possible to predict future states of even highly complex systems, albeit only in a probabilistic manner. In addition, rare events occur more frequently than expected based on conventional statistical prediction methods (or common-sense expectations). The power law distribution is also referred to as a "fat tail" distribution.

  Example: The likelihood of occurrence of many categories of natural threats – such as floods, earthquakes and storms – follows power laws. The fact that extreme catastrophes can occur at higher than expected rates is surely of concern to policymakers. Moreover, the presence of fat tailed distribution in the domain of finance is manifested in recurring huge market movements, breakdowns, and crises that occur with a higher probability than conventional economic theory would have us believe.

Tools and Techniques for Complexity Science

Some of the most important complexity tools being used in public policy domains at this time are:

- Agent-based or Multi-agent Models

  In computerized, agent-based simulations, a synthetic virtual "world" is populated by artificial agents who could be individuals, families, organizations, etc. Each agent is endowed with particular traits (e.g., it has certain physical characteristics and obeys particular decision rules). The agents interact adaptively with each other and also change with the overall conditions in the environment. The environment may include rules for selection, replication, and/or mutation of agents. The results can give insight into questions like: what are the stable characteristics of the system?; what are unstable or dangerous traits and conditions?; what rules tend to yield desirable states subject to various constraints?

- Network Analyses

  A common feature of many complex systems is that they are best represented by networks, which have defined structural features and follow specific dynamic laws. Network analyses are based on maps of relationships or linkages among constituents in systems. From these maps, scientists seek to identify configurations that are especially stable (or particularly fragile). For example, certain network patterns seem to characterize groups of collaborating scientists who are more successful and innovative than most. These are to be promoted, perhaps, by science policymakers. Other types of network patterns have been identified as predictors of catastrophic failures in real-life networks such as power-distribution or communication infrastructures. These insights are of obvious interest to responsible persons in government and industry.

Additional complexity-related techniques deserve special mention in this report, although their use is not unique to complexity science, but has been fruitful across a broad range of science-based endeavours:

- Data Mining

  Complexity scientists are developing techniques for finding patterns and relationships in large data sets with complex qualities. They are working at the cutting edges of mathematics, computer science, statistics, and visualization as they develop methods that are applicable to nonlinear and discontinuous phenomena.

- Scenario Modelling

  Scenario models are artificially constructed, hypothetical models of complex systems that reflect their key constituents and dynamics. Scenario modelling varies the conditions the systems face in order to anticipate the effects of various conditions and to identify policies that are robust to many likely futures. Corporations use scenario analyses as they make strategic decisions. Some governments also use scenario models to anticipate the effects of disasters, and then to develop plans for mitigating serious damage.

- Sensitivity Analysis

  Scientists have a great interest in how the behaviours of complex systems (for example, their evolution in time) depend on the many parameters which appear in models of the systems. They can make use of numerical techniques, largely developed by the engineering community, called sensitivity analyses. These methods allow the calculation of the degree to which outcomes would vary in response to changes in system parameters.

- Dynamical Systems Modeling

  Dynamical systems models are generally sets of differential equations or iterative discrete equations, used to describe the behaviour of interacting parts in a complex system, often including positive and negative feedback loops. They are used to enable simulation of, among other things, the results of alternative system interventions (for example, which incentives are most likely to yield adoption of alternative energies by consumers and power companies). They have also been used to anticipate unintended consequences of policies (for example, the impact of increased availability of health insurance on decreases in preventive health behaviours).

Existing and Potential Applications for Public Policy

Success Stories and Aspirations for the Future

Timely or even urgent policy domains for which a complex systems approach could inform decision-making include: medium-term weather prediction; long-term climate change; economic forecasting; environmental protection; energy security (including generation, distribution, storage and utilization of energy); the management of globally distributed computing networks; the dynamics of social alienation and conflict; the design of financial regulatory systems; and the epidemiology of diseases.
The participants in the workshop discussed a number of successful and promising applications of complexity principles and methods to public policy problems, including:

Epidemiology and Contagion

Traditional epidemiologic models assume homogeneous (so-called “well-mixed”) populations in which each person has the same probability of infection. Advanced research has improved on these techniques through the creation of agent-based models with heterogeneous populations interacting in alterable environments. The aim has been to develop more realistic predictions and to test potential new policies.

Agent-based models are already being used in the global public health domain. For example:

> - Complexity-science based sensitivity studies demonstrated that large, highly disruptive reductions in air traffic (20% or even 50%) would not dramatically slow spread of certain types of pathogens, leading policymakers to anticipate that restricting air travel was unlikely to be the most effective policy tool for dealing with Severe Acute Respiratory Syndrome (SARS).
>
> - Complexity-science based models of alternative anti-viral agent management policies indicated that massive stockpiling of smallpox vaccine could significantly reduce the number of cases in the event of a biological terror attack, but that combining smaller stockpiles with governmental agreements to cooperate by sharing parts of their stocks could be even more effective.

In addition to agent-based analyses, public health researchers are developing network-analysis models for improvements in predicting and managing epidemics by focusing on key actors and tipping points. They also engage in data mining activities of several kinds in efforts to develop more sophisticated models of epidemics, moving beyond homogeneous infection-rate curves.

U.S. public health officials are developing systems dynamics models as decision-support tools that examine the likely success of alternative health-promotion policies (e.g., is it more effective in a given population to increase the number of doctors, or to expand the availability of health insurance?).

Traffic

Besides public health, traffic safety is, according to workshop participants, the public policy domain to which complexity methods have been most extensively applied. Analytic techniques – often mirroring those used by physicists and engineers to study fluids – are now employed to anticipate the emergence of undesirable, even life-threatening, traffic phenomena, as well as to improve traffic flow to save time and fuel, and to reduce pollution.

An advanced modelling approach, which incorporates aspects of human cognition, is being used to predict, in real time, "surprises" (e.g., traffic jams) in traffic and to automatically alert drivers via a wireless communications network. Some experts believe that this "surprise modelling" will be generalisable to other types of situations, such as outbreaks of civil unrest in unstable countries or regions. Complexity visualization methods also have been successfully used to analyse human foot traffic. Precursor conditions to stampedes in crowded situations have been identified. This has led to practical insights into how to inhibit stampeding during the Hajj in Mecca.

Patterns in Other Complex Systems

The European Union uses complexity science methods to mine the contents of large numbers of web sites for patterns in news stories that may presage outbreaks of violence in regions that are prone to social or political instability.

The United States Department of Defense uses network-analysis methods to attempt to identify associations of terrorists, including pinpointing the locations of key dangerous individuals.
Online "prediction markets" (in which individuals place bets on certain specified outcomes, for example, the results of national elections) are being studied in hopes of harnessing the power (and avoiding the limitations) of markets as distributed sources of useable intelligence and expertise. Prediction markets are, in essence, agent-based models in which the agents are real humans and the environmental conditions can be manipulated. In some domains, with some constraints, prediction markets significantly outperform expert forecasters. Understanding the range of applicability of this "wisdom of crowds" could shed light on the limits to healthy functioning in other types of markets.

Resilience and Vulnerability

Complex systems concepts have led disaster management officials in Japan to begin to adopt practices appropriate to self-organizing systems:

- Enabling bottom-up (rather than top-down) community-based disaster response capabilities.
- Enacting more proactive approaches to disaster preparation and planning, particularly employing "imagination-activating" policy simulations.

Climate Change

The most advanced climate change models are already based on complex systems concepts and methods, reflecting the complexity of the atmosphere, geosphere and biosphere. What is often missing, though, are the social and human aspects – the connections between economy, finance, energy, industry, and the natural world. These new degrees of sophistication can only be achieved using complexity science methods. An example of innovative work of this kind was presented at the OECD workshop: a complex systems model of the German economy, explicitly developed for policy-making, has been endorsed by the German government and Deutsche Bank. It has been used to identify mechanisms through which Germany could decrease greenhouse gas emissions by 40% by 2020 (compared with 1990 levels) and simultaneously increase GDP and jobs.

Complexity science techniques can be useful in identifying dangerous tipping points in the human-earth system, which can occur independently of purely geophysical transitions. Perhaps the most likely disruption of this type involves the management of water resources. Drought and water stresses occur regularly across large sections of Europe and the developing world. There are indications that a tipping point may be near, leading to massive long-term water shortages. More work in this area is warranted.

Financial Markets

A comprehensive strategy for restoring the health of financial systems could include decision support and analysis tools derived from complexity science. Specifically, new advanced methods and tools could allow the theoretical testing, via modelling and simulation, of the resilience of proposed financial regulations to the kinds of dramatic instabilities that have occurred recently. Since complexity models emphasize market qualities that traditional models do not (e.g., dynamism rather than equilibrium; real attractors rather than theoretically anticipated ones; positive feedback loops; phase transitions; power laws), they can offer an important supplement to traditional analyses.

Complexity Science: New Ways of Thinking for Policymakers

Beyond concepts, tools and methods, complex systems science offers some new ways to think about policy making. It focuses attention on dynamic connections and evolution, not just on designing and building fixed institutions, laws, regulations and other traditional policy instruments. In addition to control and causation, it highlights the importance of influence and likelihood, even irreducible randomness. Some conceptual implications for policymakers include:

- Predictability. Complex systems science focuses on identifying and analyzing trends and probabilities, rather than seeking to predict specific events. Traditionally, an inability to make a definitive prediction has been considered a scientific inadequacy (although, in the domain of fundamental physics, the advent of quantum indeterminacy banished this attitude nearly one hundred years ago). Today, researchers acknowledge that, for some classes of phenomena – notably, complex ones – the only alternative to probabilistic knowledge is none at all. It will be challenging, though necessary, for policymakers and scientists alike to move beyond strict determinism if they wish to effectively engage in decision making under conditions of uncertainty and complexity.

- Control. As with prediction, control is generally made possible by identifying cause-and-effect chains and then manipulating the causes. But cause and effect in complex systems are distributed, intermingled (e.g., an organism and its environment) and not directly controllable, so policymakers need to become more comfortable with strategies that aim to influence rather than control. Fortunately, complexity science offers many insights into finding and exploiting desirable attractors; identifying and avoiding dangerous tipping points; and recognising when a system is in a critical self-organizing state.

- Explanation. An advantage of traditional science that focuses on cause-effect relationships is that its findings provide a sense of surety and quantitative understanding of how things work, i.e., a satisfying explanation of phenomena in the natural world. When analyses are done using complexity science methods, insights about the underlying mechanisms that lead to complex behaviour are revealed. Although deterministic quantitative prediction is not generally achieved, the elucidation of the reasons for complex behaviour are often more important for comprehending what might otherwise be puzzling real-world events. Whether this constitutes an “explanation” in the traditional sense is not at all obvious, and could simply be a matter of taste or preference for individual scientists or policymakers.

Enabling Progress in Policy-Relevant Applications of Complexity Science

What will enable scientists to make progress with complexity techniques in policy-relevant ways?

Data Needs

Physicists and biologists have made great strides using complexity techniques when dense data sets have been available – that is, data whose completeness, diversity and precision match that of the phenomena that it describes. In particular, longitudinal data that enables analysis of trends over time is crucial to understanding complex system interactions and dynamics. Unfortunately, where human individual and societal matters are concerned, dense data is seldom available. Even when it exists, access to it, and its applications, are necessarily restricted by concerns over privacy, security, and ethics. Some of these concerns can be addressed via technical means (e.g., encryption); others require innovative policy measures (regulations or even laws, international agreements, etc.). There are ongoing discussions, in the OECD and elsewhere, about policies for access to data (especially the vast quantities of data that are compiled by public institutions). It would be useful to ensure that these discussions incorporate the special needs of researchers who use complexity-based techniques.

Validation of Models

Validation of social/behavioural models is critical if they are to be useful to policymakers. The model that can answer a policymaker's specific questions will be of the most use and will allow policymakers to make better decisions. Computer-based models (for example, simulations) are themselves extremely complex (or, rather, in the context of this report, complicated) artefacts, with hundreds of thousands of lines of code and a multiplicity of adjustable parameters. Often, many individuals contribute to various pieces of the computer program, and the complete documentation may not be provided. While the credibility of the results is clearly enhanced when they successfully reproduce known phenomena for which data is available (for example, in climate science, the observed evolution during the past century), caution is needed when interpreting projections into realms where measurements are not possible (typically, the future). Thus, two goals that would help complexity scientists contribute in ways useful to policy-makers are: making progress in the science of validation; and establishing internationally agreed-upon standards for the validation of complex models.

Decision-support Tools

Predictive models may not actually be as useful to policymakers as the existence of decision-support tools. Accordingly, researchers must take special care to formulate the results of their work in terms that policymakers can understand and utilize. Simulations that show what will happen in various scenarios and options are especially useful, particularly if they capture the essential complexity involved. Thus, organizations (such as funding agencies) that support research should also consider fostering events, fora and programmes that bring together scientists and policymakers.

Interoperability of Models

There is significant inefficiency in complexity science as independent scientists build separate models, even though the features of the systems they are studying may have similar attributes in complex systems terms. Furthermore the results of modelling are sometimes difficult to compare because they use incompatible descriptions, definitions and parameters. For non-experts, this type of heterogeneity can be an obstacle to choosing and applying models, as well as gauging their relevance and credibility. Model-building would be improved with the establishment of a mechanism to enable scientists to discuss and agree upon desired features of models.

Adaptation of the Institutions and Mechanisms of Science

Complexity science has its roots in pure mathematics but, today, it is a conspicuously interdisciplinary field, with an ever-widening spectrum of applications in the physical and life sciences, in engineering, and in the social and behavioural domains. As is the case for all interdisciplinary fields, there are special challenges associated with organising, funding, and evaluating the research. These are linked to the stubborn persistence of traditional patterns of categorization of knowledge (physics, biology, chemistry, etc.), the barriers that still separate pure and applied research, and difficulties of linking science with policymaking. The international community engaged with these problems is not well-connected, so it would be very fruitful to coordinate efforts.

Given that complexity science is still a relatively new field, the funding and organization of national research programs has, to date, been somewhat fragmented. During the OECD workshop, presentations were made regarding the situation in the United States[10], Japan[11], and the European Union (with emphasis on projects under the auspices of the European Commission[12]).

Further coordination of research and education efforts at a global, international level is needed if complex systems science is to meet the societal challenges of our day.

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[10] The United States does not have a coordinated approach to funding complexity science, but its main funding agency for basic research, the National Science Foundation, has had many initiatives in recent years to fund complex systems science. Examples include the Biocomplexity in the Environment programme, the Human and Social Dynamics programme and, most recently, the Cyber-Enabled Discovery and Innovation programme which includes complexity as one of its three focus areas.

[11] Japan has a "Basic Plan" for science and technology that emphasizes interdisciplinary research and encourages networking opportunities for scientists from different fields. This would definitely help further the goals of complex systems science. Similarly, Australia has initiated an "Emerging Science" programme and identified complex systems science as a key area to which the country is devoting considerable funding.

[12] Through its Framework Programmes for research, the EU has been funding research in complex systems via the Future and Emerging Technologies (FET) and Newly and Emerging S&T (NEST) actions. Between the two of them, they have invested close to 100 million euros over the last 5 years in dedicated complex systems research programmes (NEST terminated in 2006). Topics considered range from complex systems in IT to modelling of living and social systems. On a European national level there are various initiatives across Europe partially stimulated the FET and NEST initiatives. The Engineering and Physical Sciences Research Council (EPSRC) in the United Kingdom has funded dedicated programmes and centres of excellence (at the universities of Warwick and Bristol) in complex systems for some time now. In Italy, the "Lagrange Project", funded by the *Fondazione Lagrange* of the CRT - Cassa di Risparmio di Torino - finances research projects, Ph.D. grants, is funding a centre of excellence in Turin (ISI – *Institute for Scientific Interchange*) and provides a co-funding mechanism with industry.

Various small or medium-sized centres across Europe have formed over the last couple of years, for instance: ISC - *Institut des Systèmes Complexes* - in Paris, funded by CNRS and the region of Paris, an important CNR centre in Rome dedicated to complex systems research, and ECLT - *European Centre of Living Technologies* - in Venice. The *James Martin Institute for Science, Innovation and Society* in Oxford and a new institute for "system design" at ETH in Zurich focusing on social system dynamics are addressing complex systems ideas in the context of socio-economic systems. To facilitate collaborations between national programmes in complex systems, the European Commission implemented a European Research Area Network (ERA-NET) - *"Complexity-NET"*. This is a joint initiative of research funding and management agencies from eleven different partner countries in Europe, all with significant activities in the field of complexity science. Furthermore, the EU funded European **CO**operation in the field of **S**cientific and **T**echnical Research (COST) framework provides networking opportunities for complexity scientists across Europe.

Appendix

OECD Global Science Forum
Workshop on

Applications of Complexity Science for Public Policy:
New Tools for Finding Unanticipated Consequences and Unrealized Opportunities

Sunday, October 5 to Tuesday, October 7, 2008
Ettore Majorana International Centre for Scientific Culture, Erice, Sicily, Italy

Agenda

Sunday, October 5, 2008

Session 1	**09:00-10:30**	**Welcome and Introduction to the Workshop**
Session 2	**11:00-12:00**	**Complexity Science: Introduction to Key Concepts**
Session 3	**13:30-15:30**	**Epidemiology and Contagion**
Session 4	**16:00-18:00**	**Technologically-Connected Environments**

Monday, October 6, 2008

Session 5	**09:00-10:00**	**Resilience and Vulnerability to Extreme Events: Part 1**
Session 6	**11:00-12:00**	**Resilience and Vulnerability to Extreme Events: Part 2**
Session 7	**14:00-15:30**	**Climate Change, Predictions, Consequences, Solutions: Part 1**
Session 8	**16:00-17:00**	**Climate Change, Predictions, Consequences, Solutions: Part 2**

Tuesday, October 7, 2008

Session 9	**09:00-11:00**	**Challenges for Complexity Science as a Policy Tool** **Group Discussion -- Conclusions of the Workshop**
Session 10	**11:30-13:00**	**Organizing Science for Complexity**

Rationale and Goals

In today's challenging policy environment, government officials and other decision-makers are confronting daunting problems whose common feature is their *complexity*. That is, the problems involve large numbers of diverse interacting parts that produce behaviours that cannot be obviously derived from knowledge of their constituents. Examples include highly diverse, mobile human populations that can rapidly spread disease so as to yield pandemics; interactions of social, economic and political assets so as to yield communities that are either highly vulnerable to or resilient to disasters; sensitive political and economic systems that respond in complex ways to climate change; financial systems that exhibit instability when perturbed; and power or communications networks subject to unexpected, cascading malfunctions. Successful policy design depends on the ability to understand and predict the complex behaviours of such systems in order to design more effective governmental programmes, regulations, treaties, and infrastructures. As we come to understand how human actions can trigger bad dynamics in complex environments and societies, anticipating the consequences of policy choices becomes ever more important and more difficult.

Scientists from many different disciplines have been working for decades to extend their analytical and predictive abilities into the realm of complex phenomena. This quest has given birth to a new and exciting domain of research called *complexity science*. By developing sophisticated analytical and computational tools, scientists have discovered that, in many cases, very complex phenomena can be modelled and understood. Some of the principles and laws that have been discovered have a gratifying degree of universality, allowing them to be applied to large classes of complex systems, even ones that are seemingly unrelated. Recent advances in computational technologies are enabling a larger number and greater variety of scientists to conduct work on complex systems problems.

Given the accumulating scientific accomplishments of complexity scientists, the question naturally arises: *How can the insights and methods of complexity science be applied to assist policymakers as they tackle difficult problems in policy areas such as health, environmental protection, economics, energy security, or public safety?*

To address this question, the OECD workshop will bring together scientists, policymakers and science programme managers to explore the extent to which complexity science can be useful to decision-makers today, and how its utility could be further enhanced by strengthening the research enterprise and promoting international cooperation. The potential benefits to policymakers are reflected in the subtitle of the workshop: by applying the results of research to natural and human systems it may be possible to avoid unanticipated consequences of contemplated policy actions; through better appreciation and forecasting, it may be possible to undertake prudent interventions to avert unexpected negative developments, or to recognize opportunities for timely positive steps. A concise report conveying key findings about the promise of complexity sciences for policymakers and the needs of the research community will be produced and shared.

Workshop Agenda

Sunday, October 5, 2008

Session 1 **09:00-10:30** **Welcome and Introduction to the Workshop**
09:00-09:30 Raima Larter, Co-Chair, US National Science Foundation
Jacqueline Meszaros, Co-Chair, US National Science Foundation
09:30-10:00 Keynote: Carol Jaeger, Potsdam Institute for Climate Impact Research
10:00-10:30 Keynote: David Lightfoot, US National Science Foundation

Session 2 **11:00-12:00** **Complexity Science: Introduction to Key Concepts**
Moderator: Leonidas Karapiperis, European Commission
Speakers:
Guido Caldarelli, University of Rome La Sapienza
Roland Kupers, Shell Gas & Power

Session 3 **13:30-15:30** **Epidemiology and Contagion**
Moderator: Arne Skjeltorp, Norway Institute for Energy Technology
Panelists:
13:30-13:45 Dirk Helbing, Swiss Federal Institute of Technology
13:45-14:00 Alex Vespignani, Indiana University
14:00-14:15 Paul Halverson, Arkansas Department of Health
14:15-14:30 Cathy Roth, World Health Organization
14:30-15:30 **General Discussion**

Session 4 **16:00-18:00** **Technologically-Connected Environments**
Moderator: Ralph Dum, European Commission
Panelists:
16:00-16:15 Albrecht von Mueller, Parmenides Foundation
16:15-16:30 Jacqueline Meszaros, US National Science Fdn
16:30-16:45 Vittorio Loreto, University of Rome
16:45-18:00 **General Discussion**

Monday, October 6, 2008

Session 5 **09:00-10:00** **Resilience and Vulnerability to Extreme Events: Part 1**
Moderator: Jacqueline Meszaros, US National Science Foundation
Panelists:

09:00-09:15	Takashi Nanya, Japan
09:15-09:30	Imre Kondor, Eötvös Loránd University
09:30-09:45	Norio Okada, Japan
09:45-10:00	Robert Axtell, George Mason University
10:00-10:30	**General Discussion**

Session 6 **11:00-12:00** **Resilience and Vulnerability to Extreme Events Part 2**
Moderator: Jacqueline Meszaros, US National Science Foundation
General Discussion, continued

Session 7 **14:00-15:30** **Climate Change, Predictions, Consequences, Solutions: Part 1**
Moderator: Jean Vannimenus, French Ministry of Research
Panelists:

14:00-14:15	John Finnigan, Australian Commonwealth Scientific and Industrial Research Organisation
14:15-14:30	Christian Gollier, University of Toulouse
14:30-14:45	Michael Ghil, Ecole Normale Supérieure
14:45-15:00	
!5:00-15:30	**General Discussion**

Session 8 **16:00-17:00** **Climate Change, Predictions, Consequences, Solutions: Part 2**
Moderator: Jean Vannimenus, French Ministry of Research
General Discussion, continued

Tuesday, October 7, 2008

Session 9 **09:00-11:00** **Challenges for Complexity Science as a Policy Tool**
Group Discussion – Conclusions of the Workshop
Moderator: Jacqueline Meszaros, US National Science Foundation

Session 10 **11:30-13:00** **Organizing Science for Complexity**
Moderator: Raima Larter, US National Science Foundation
Group Discussion – Sharing Lessons from Recent Activities
Complexity Net, COST, NEST, etc.

Annotations to the Workshop Agenda

Session 1: Introductions and Keynote presentations

To orient attendees, the objectives for the workshop will be presented and discussed. The structure of the workshop and the roles of the participants pursuant to these objectives will be presented and discussed.

These Keynote talks will address complexity principally from a policy maker's perspective or from that of scientists experienced at working with policy makers. Experiences to date and hopes for the future will be highlighted. Complexity thinking as an approach to problems, not just complexity modelling, will be highlighted (e.g., how complexity thinking changes one's apprehension of problems and solutions, how it offers different ways of thinking about unpredictability).

Session 2: Complexity science: a nontechnical introduction to concepts, methods and results

Speakers will present and lead a discussion of key concepts in complexity science that are valuable for policy makers. The topics will draw on the material in the keynote talks and will prepare participants for discussions in the upcoming topical sessions. Participants will discuss, for example, emergence, nonlinearity, phase transitions, self-organization, scale invariance and other relevant topics. The goal of this part of the session is to ensure that all attendees are comfortable hearing and using the concepts, so that discussions throughout the workshop can be as productive as possible.

Session 3: Epidemiology and contagion

Background:

Complex epidemiological models are providing means to deal with the fact that infectious phenomena have the potential for sudden explosive (i.e., nonlinear) spread. Many of these models incorporate detailed information about how both people and diseases behave and interact in specific, realistic environments. These are levels of detail and specificity that traditional epidemiological models do not address and so complex contagion models promise to improve understanding of patterns of evolution of diseases, including emergence, suppression and re-emergence of disease vectors.

Contagion models pertain to, and can be informed by, study of a number of important social phenomena beyond disease. Spread of and tipping points for new social norms and attitudes, innovations and products, dangerous health fads such as smoking and overeating, computer viruses, and political trends are all being modelled and better understood by means of complexity methods.

Value for Policy Makers:

Complex contagion models are helpful for making better policies for inhibiting the spread of diseases and undesirable social phenomena. Complexity approaches are different from traditional approaches in that they are based on more realistic and detailed knowledge about the ways people and disease agents interact. The aim is to be able to tailor models to local conditions. Complex contagion models should yield better understanding of key points for policy intervention.

Discussion Questions for Both Presenters and Participants:

What is the potential for using complexity frameworks, approaches and theories to improve understanding of contagions?

- What do policy makers hope for?
- What do scientists hope for?

What is needed to make these frameworks, approaches and theories more useful?

- What will enable highly fruitful transfer of policy needs and scientific lessons back and forth between complexity scientists and policy makers?
- What is most needed from the point of view of the scientific community?
- What is most needed from the point of view of policy makers?

How best can we convey the potential value of complexity approaches to other policy makers?

- What can be done to enable them to make better use of information about potential explosions or tipping points when the predictions are necessarily probabilistic rather than deterministic?
- What are some of the most valuable examples of using complexity approaches to contagion and epidemiology to date?
- What are some of the most important public policy decisions, beyond public health, that could be affected by work of this nature?
- Which sorts of agencies/institutions could be affected/involved? On what time scale?

Session 4: Technologically connected environments

Background:

New virtual communities emerge as new information and communications technologies alter our patterns of connection. Complexity tools are being used to examine the capabilities and tendencies of emergent, technology-based communities like prediction markets; smart mobs; innovation networks; grass-roots disaster response efforts; and virtual worlds. Important new patterns of information flows, legitimacy sources, political power, influence and vulnerabilities are associated with these new connections. Trust has become a key and not-yet-fully-understood link in technologically mediated interactions involving finance, government, work and even play.

Value for Policy Makers:

Breakthroughs in understanding the dynamics of technologically connected communities can help policy makers find ways to better facilitate valuable community trends (e.g., the emergence of wisdom in a prediction market; the diffusion of valuable innovations in a technologically mediated world), dampen unhealthy tendencies (e.g., inhibit key nodes in teenage networks that promote cascades of dangerous fads) and avoid errors in designing policies when technologically mediated communities are key constituencies (e.g., diffusion and amplification of unrest among dispersed, disenfranchised political groups).

Discussion Questions for Both Presenters and Participants:

How might these tools and others like them be used?

- What do policy makers think/hope for?
- What do scientists think/hope?

What is needed to make these tools more useful?
  - What is needed from the point of view of the scientific community?
  - What is needed from the point of view of policy makers?

How best can we convey the value of these to other policy makers?
  - What is the best evidence of the value to date?
  - What types of public policy decisions could be affected by work of this nature?
  - Which sorts of agencies/institutions could be affected/involved? On what time scale?

Sessions 5, 6: Resilience, and vulnerability to extreme events

Background:

Interactions of natural and built environments with social and economic forces are what lead populations to be either self-organizing in a resilient way or vulnerable to failure in the face of shocks such as natural or man-made disasters. Complexity scientists are working to understand and characterize both vulnerability and resilience in human and natural systems. To the extent they succeed, better planning and policy in advance of disasters will be possible.

Nonlinear complexity analyses have revealed that the distributions of some types of rare events are different from what normal statistical analyses presume. Complexity methods suggest that some events are not as rare as commonly believed (or wished for) and that they may tend to occur in bunches, making their consequences even worse.

Complexity scientists are also working on nonlinear approaches to simulating catastrophes and modelling their consequences. The wild, dramatic and sometimes seemingly random swings that characterize complex disaster conditions are not amenable to traditional linear analyses but several complexity approaches show promise for better veracity in these domains. For example, cascading failures in critical infrastructures such as electricity, computing, transportation and financial systems are best understood by means of complexity analyses that can accommodate interactions among different types of assets and that can reveal key vulnerability conditions and tipping points.

Value for Policy Makers:

Complexity studies show promise to yield better models of the probabilities and likely effects of disasters on society and economies and, therefore, to enable better plans for mitigation measures and emergency response. The aim is to provide policy makers with maps of key vulnerabilities to mitigate, key qualities of resilience to promote, and early warning for developing disasters.

Discussion Questions for Both Presenters and Participants:

What is the potential for using complexity frameworks, approaches and theories to improve understanding of vulnerability and resilience?
  - What do policy makers hope for?
  - What do scientists hope for?

What is needed to make these frameworks, approaches and theories more useful?
  - What will enable highly fruitful transfer of policy needs and scientific lessons back and forth between complexity scientists and policy makers?
  - What is most needed from the point of view of the scientific community?

  - What is most needed from the point of view of policy makers?

How best can we convey the potential value of complexity approaches to other policy makers?

  - What can be done to enable them to make better use of cost-benefit information in low-probability, high-consequence domains?
  - What have been some highly fruitful approaches to using complexity approaches to address real-world vulnerability and resilience questions?
  - What types of public policy decisions could be affected by work of this nature?
  - Which sorts of agencies/institutions could be affected/involved? On what time scale?

Session 7, 8: Climate Change: predictions, consequences, solutions

Background:

Advances in nonlinear systems modelling are helping to improve forecasts of the impact of climate variability and change on storms, coasts and associated populations and economies. Although complex systems approaches are needed for meaningful modelling of the physical, chemical, atmospheric, etc. events which create climate and determine its dynamics, another urgent and difficult use of this approach involves the inclusion of the human component, especially the political, economic and social forces that impact climate change and will be affected by any policy decisions. This session will focus on the ways complex systems analysis can inform the potential social and economic effects of climate change.

Value for Policy Makers:

Complex systems models that include the connections between social and economic systems and a changing climate will allow policy makers to better predict and understand the consequences of potential interventions.

Discussion Questions for Both Presenters and Participants:

How might these tools and others like them be used?

  - What do policy makers think/hope for?
  - What do scientists think/hope?

What is needed to make these tools more useful?

  - What is needed from the point of view of the scientific community?
  - What is needed from the point of view of policy makers?

How best can we convey the value of these to other policy makers?

  - What is the best evidence of the value to date?
  - What types of public policy decisions could be affected by work of this nature?
  - Which sorts of agencies/institutions could be affected/involved? On what time scale?

Sessions 9, 10: Final sessions: Science for Policy and Policy for Science

In the final two sessions, overall findings and conclusions are to be extracted. Attendees will discuss important challenges in the use of complexity concepts and tools by policy makers (Session 9) and in ensuring that complexity science is nurtured internationally in ways that ensure its progress (Session 10).

Session 9 will be dedicated to **Science for Policy.**

Sample topics:
Hopes and Concerns for Policy guided by Complexity Frameworks
Aspirations for Validating Models: What Policy Makers Need
Grappling with Fundamental Sources of Uncertainty in Policy Contexts

Session 10 will be dedicated to **Policy for Science**

Sample Topics:
Aspirations for Validating Models: Needs for data to enable validation of models
Aspirations for Creating a Global Research Community
Means to engage scientists, policy makers and the wider public in fruitful dialogues

Background & Context

The convening of the workshop was authorized by delegates to the Seventeenth Meeting of the OECD Global Science Forum in October 2007, based on a proposal from the Delegation of the United States. The Delegation of Italy offered to host the event. Preparations were overseen by the International Steering Committee, whose members were appointed by national delegations:

Belgium	*Pierre Gaspard*	Norway	*Arne Skjeltorp*
European Commission	*Ralph Dum* *Leo Karapiperis*	United Kingdom	*Katherine Bowes* *Paul Williams*
France	*Jean Vannimenus*	Germany	*Siegfried Grossmann*
Italy	*Luciano Pietronero*	United States *(C0-Chairs)*	*Raima Larter* *Jacqueline Meszaros*
Japan	*Satoru Ohtake*	OECD	*Stefan Michalowski*

The Organisation for Economic Co-operation and Development (OECD) groups thirty Member countries committed to democratic government and the market economy, and provides a venue where governments can compare and exchange policy experiences, identify good practices and agree on decisions and action recommendations. Dialogue, consensus, peer review and peer pressure are at the very heart of the OECD's procedures. The Organisation's mission is essentially to help governments and society reap the full benefits of globalisation, while tackling the economic, social, environmental and governance challenges that can accompany it. It places a high priority on deciphering emerging issues and identifying policies that work in actual practice. In addition to the analysis and advice it provides on a vast range of economic issues, the OECD is one of the world's largest and most reliable sources of comparable statistical economic and social data. OECD databases span areas as diverse as national accounts, economic indicators, trade, employment, migration, education, energy, and health. The OECD produces internationally agreed instruments, decisions and recommendations in many areas, such as combating bribery in international business transactions, information and communications policy, taxation and environmental protection. Non-members are invited to subscribe to these agreements and treaties. Helping ensure development beyond the OECD's membership has been part of the Organisation's mission from the start. The Organisation maintains active relationships with some 70 non-member economies, along with businesses, labour organisations, civil society and parliaments. These stakeholders benefit from, and make valuable contributions to, the work of the OECD.

The Global Science Forum (GSF) is a venue for consultations among senior science policy officials of the OECD member and observer countries on matters relating to fundamental scientific research. The Forum's activities produce findings and recommendations for actions by governments, international organisations, and the scientific community. The GSF's mandate was adopted by OECD science ministers in 1999, and an extension until 2009 was endorsed by ministers in February 2004. The Forum serves its member delegations by exploring opportunities for new or enhanced international co-operation in selected scientific areas; by defining international frameworks for national or regional science policy decisions; and by addressing the scientific dimensions of issues of social concern.

The Global Science Forum meets twice each year. At these meetings, selected subsidiary activities are reviewed and approved, based on proposals from national governments. The activities may take the form of studies, working groups, task forces, and workshops. The normal duration of an activity is one or two years, and a public policy-level report is always issued. The Forum's reports are available at www.oecd.org/sti/gsf. The GSF staff are based at OECD headquarters in Paris, and can be contacted at gsforum@oecd.org.

OECD Global Science Forum

Applications of Complexity Science for Public Policy

NEW TOOLS FOR FINDING UNANTICIPATED CONSEQUENCES
AND UNREALIZED OPPORTUNITIES

www.oecd.org/sti/gsf