E-Dialogs on New Sciences

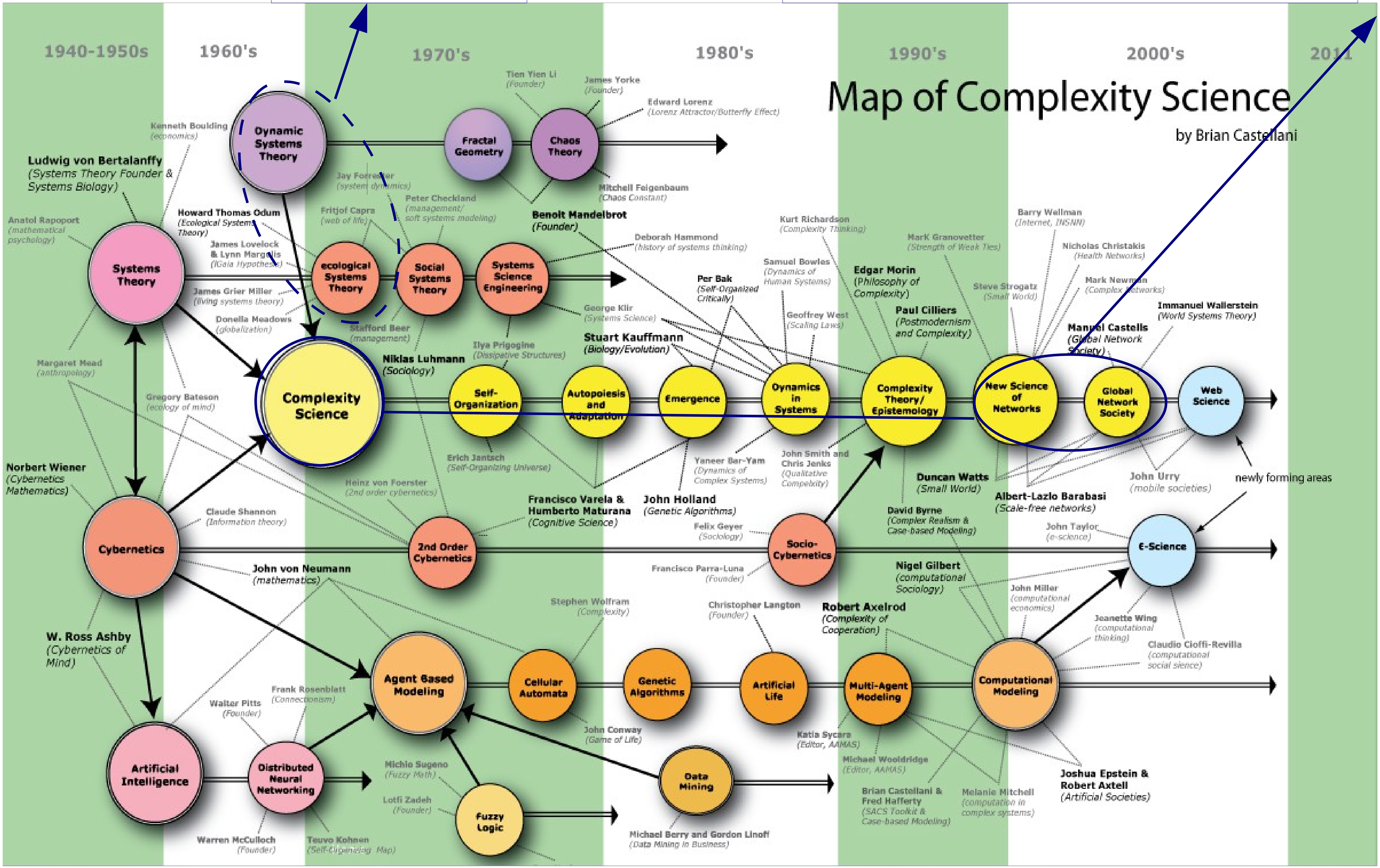
Science of Complexity [& Networks]

June 18, 2013 via Webex

Content

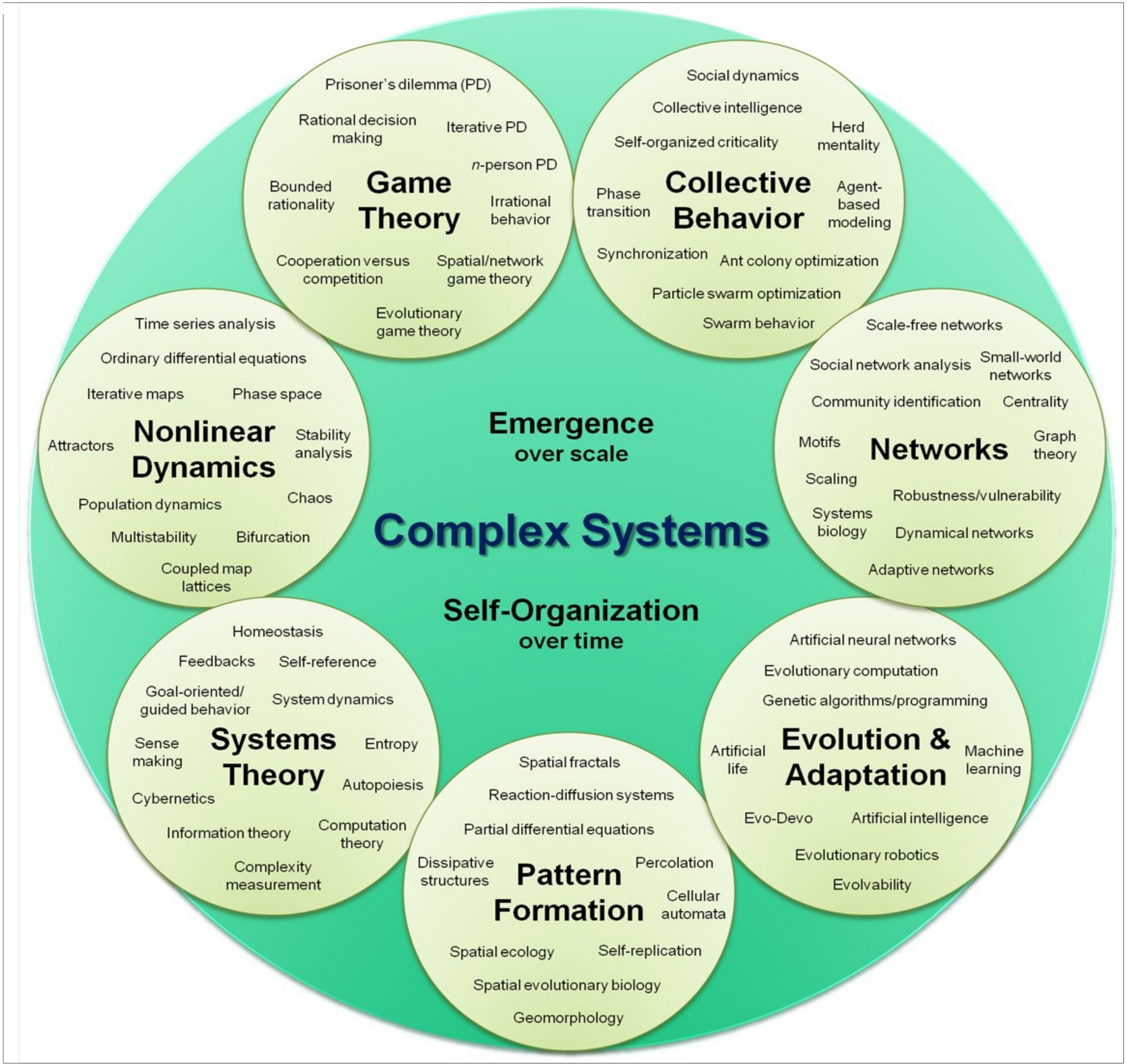
1972 Limits to Growth

2012 Towards Grand Unified Theory for Sustainability



http://wikipedia.org/wiki/Complexity

RW. Blue lines are add-ons



http://en.wikipedia.org/wiki/Complex_systems

Stephen Hawking has noted that the twenty first century will be the century of complexity.

For much of the twentieth century **social science** has emulated the **statistical methodologies** of the natural sciences. While this has enhanced social science it has **fallen short** of **capturing the complexity** of the social realm.

New models of adaptive agents may serve as a needed corrective that helps **integrate individual behavior and social interaction** in ways that improve social theory and inform public policy.

Agent-based modeling raises serious questions concerning the application of the rational choice model to human economic actors.

http://www.nasonline.org/programs/sackler-colloquia/

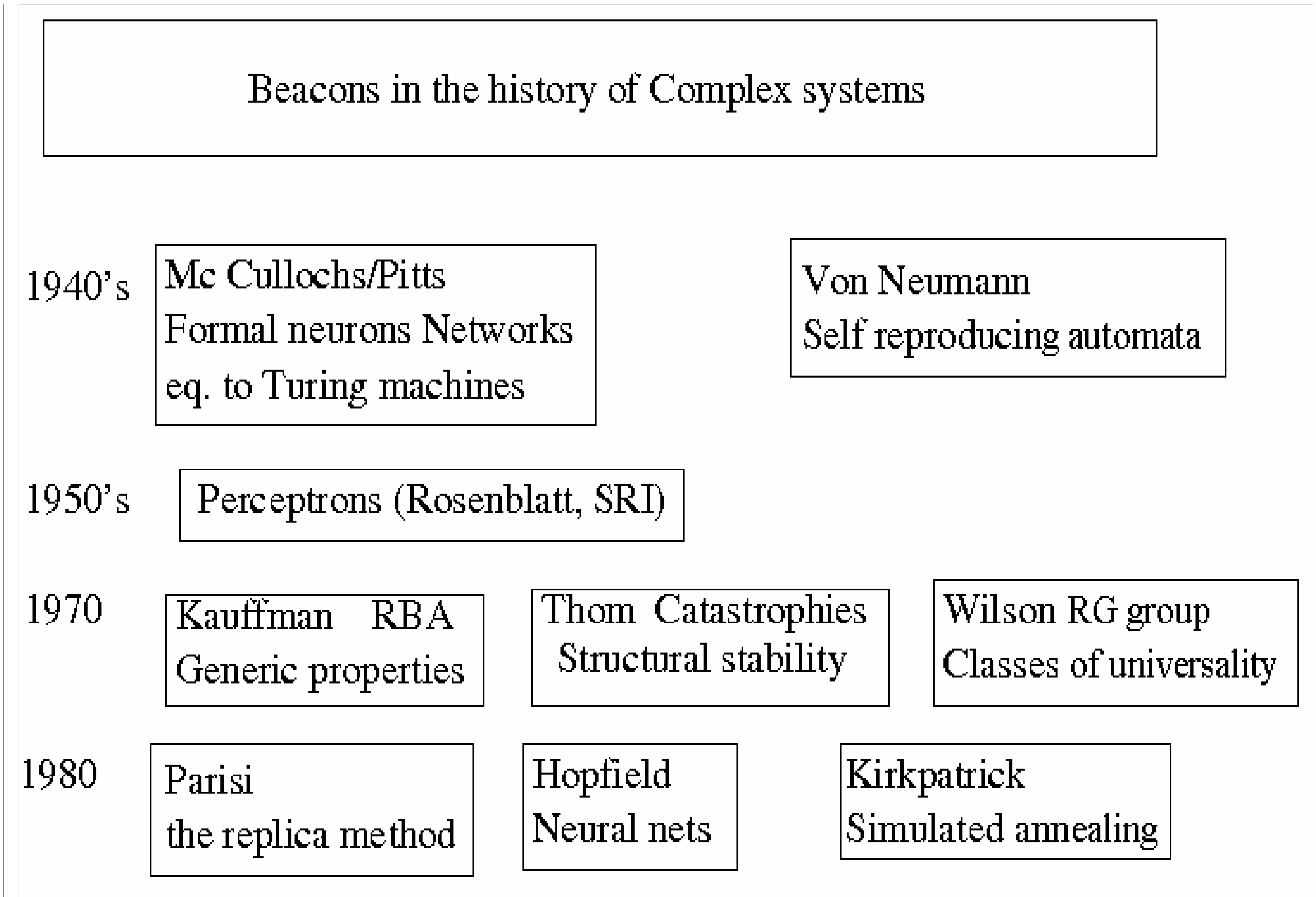
Definition :

***Complex systems is a new approach to science that studies* how *relationships* between parts give rise to the collective behaviors *of a system* and *how the system interacts* and forms relationships with its *environment*.**

The *equations* from which *complex system models* are developed generally derive from *statistical physics, information theory and non-linear dynamics*, and represent organized but *unpredictable behaviors of systems* of nature that are considered fundamentally complex.

[http://en.wikipedia.org/wiki/Complex_systems]

A short historical perspective in complex systems



G. Weisbuch & S. Solomon, (2007). Tackling Complexity in Science

III. Objectives of Complex Systems Science

Some caution should be used in keeping in mind the difference between real world complex systems and their models.

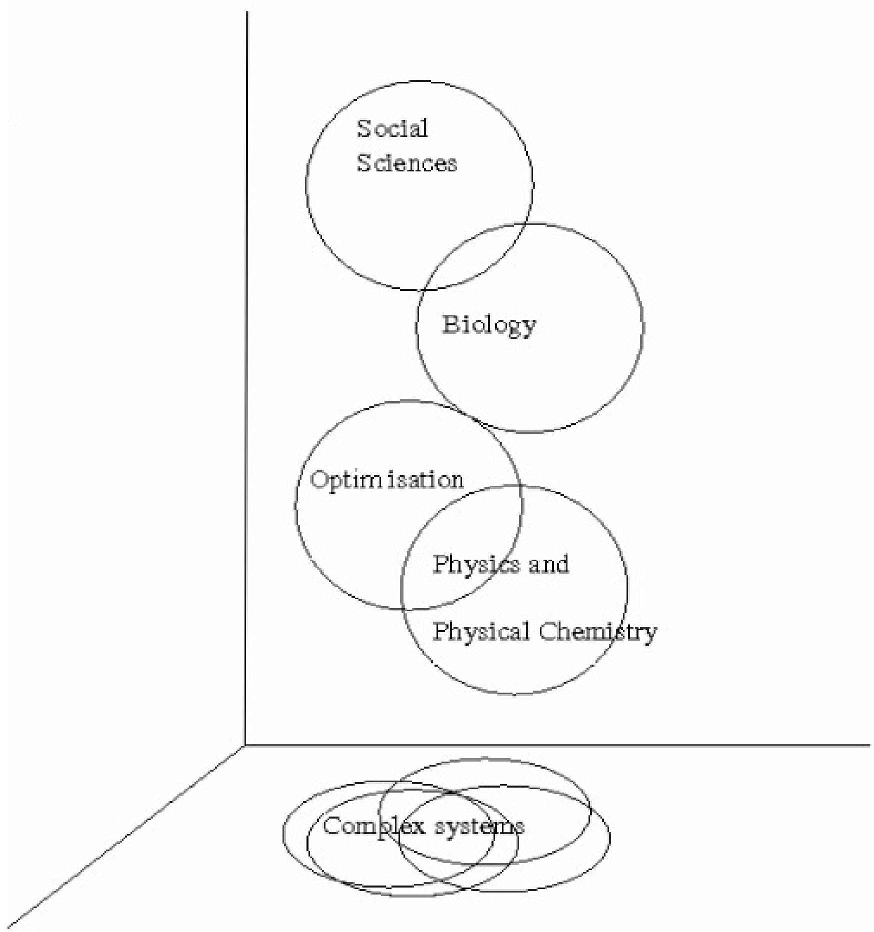
Models Complex systems are composed of a very large number of different elements with non-linear interactions; furthermore the interaction structure, a network, comprises many entangled loops.

Purpose of complex system research is to propose and solve models such that we can deduce the functional organization from the interaction of the components.
Complex system theory often addressed the issue by ***restricting predictions*** to ***generic properties***. (A recent shift in interests occurred with the availability of large data sets in biology or social sciences).

Thermodynamics is not only a theory about work and heat but it applies to all physical systems : gases, liquids, solids with electric, magnetic or elastic properties.
In fact statistical mechanics, the microscopic theory behind thermodynamics, ***is probably the closest theoretical analogue to complex systems theory*** : its purpose is to deduce the macroscopic properties of matter from those of its individual components, atoms, molecules, polymers.

G. Weisbuch & S. Solomon, (2007). Tackling Complexity in Science

The projection metaphor. Different fields of research, say biology, sociology, physical-chemistry, optimization, share many common traits when checked from a complex system perspective; this is illustrated by the large overlap of the two dimensional projections on the x,y plane of the four spheres in the 3d space. *G. Weisbuch & S. Solomon, (2007). Tackling Complexity in Science*



IV. Some Properties of Complexity Science.

Social, political, ecological and economic systems involve mutually adaptive interactions and produce characteristic patterns. The promise of complexity science for policy applications is the perspective that science can help ***anticipate and understand key patterns*** in complex systems and thus enabling ***wiser decisions about policy interventions***.

Adaptability. Complex systems are formed by ***independent constituents that interact***, changing their behaviors in reaction to those of others, thus ***adapting to a changing environment***.

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.

Example : Weather is an emergent property of air, moisture and land interactions; global political dynamics are emergent from innumerable social, economic and political interactions.

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.

OECD, 2009. Applications of Complexity Science for Public Policy: New Tools for finding Unanticipated Consequences and Unrealized Opportunities.

***Attractors.* -** A set of states of a dynamic physical system toward which that system tends to evolve, regardless of the starting conditions of the system.*[http://www.thefreedictionary.com/attractor]*

- Most complex systems exhibit what mathematicians call attractors, states to which the system eventually settles, depending on the properties of the system.*[Roger Lewin]*
- Some complex systems spontaneously and consistently revert to recognizable dynamic states known as attractors. *[OECD Report]*

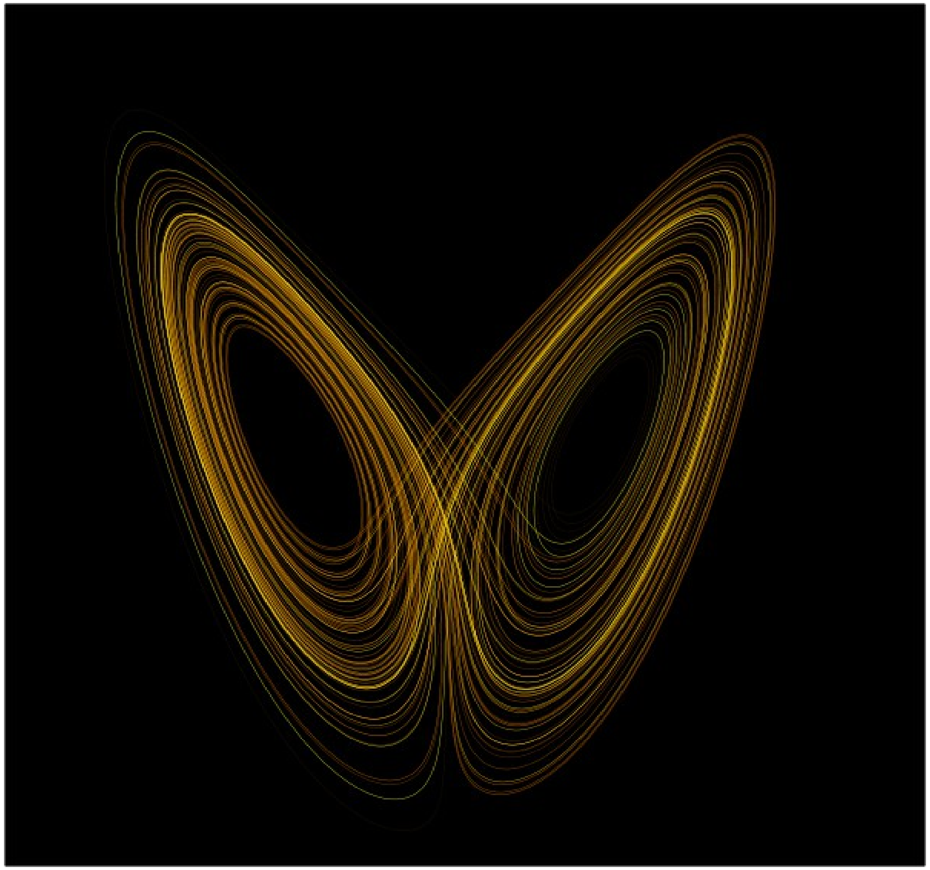
Self-organized Criticality. A complex system may possess a ***self-organizing attractor*** state that has an inherent potential for ***abrupt transitions of a wide range of intensities***.
For a system that is in a ***self-organized critical state,*** the magnitude of the next transition is unpredictable, but the long-term probability distribution of event magnitudes is a very regular known distribution (a "power law" as described below).

Chaos. One of the earliest known features of complex systems was ***chaotic dynamic***s, characterized by ***extreme sensitivity to initial conditions***. Chaotic systems are not 100% predictable, yet they exhibit order due to an underlying attractor.
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.

In ***chaos theory***, the ***butterfly effect*** is the sensitive dependence on ***initial conditions***, where a small change at one place in a deterministic nonlinear system can result in large differences to a later state.

The name of the effect, coined by ***Edward Lorenz***, is derived from the theoretical example of a hurricane's formation being contingent on whether or not a distant butterfly had flapped its wings several weeks before.

A plot of the Lorenz attractor. http://en.wikipedia.org/wiki/File:Lorenz_attractor_yb.svg



Non-linearity. When a system is linear, a change in one property produces a proportional change in others. When relationships are ***non-linear,*** 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.

Phase Transitions. System behavior 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, the onset of superconductivity in some materials when their temperature decreases beyond a fixed value, etc.
Self-organized criticality is an example of a phase transition.

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.

Example : The likelihood of occurrence of ***many categories of natural threats*** – such as floods, earth-quakes and storms – follows power laws.

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, geo-sphere and bio-sphere. 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 : cfr OECD and German Economic system: reducing GHG and increasing 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. Drought and water stresses occur regularly across large sections of Europe and the developing world.

Financial Markets

A comprehensive strategy for restoring the ***health of financial systems*** could include decision support and analysis tools derived from complexity science. Specifically via ***modeling and simulation***, of the resilience of proposed financial regulations to the kinds of dramatic instabilities that have occurred recently.

For example. Dynamism rather than equilibrium; ***real attractors*** rather than theoretically anticipated ones; positive feedback loops; phase transitions; power laws.

Intermediate Synthesis : Agents & Complex Adaptive Systems.

The **agents** in the system are **all the components** of that system.

Complex adaptive systems**.** A theory that maintains that the universe is full of systems, weather systems, immune systems, social systems etc and that these systems are complex and constantly adapting to their environment.

Complex adaptive systems are all around us. Most things we take for granted are ***complex adaptive systems***, and the **agents** in every system exist and ***behave in total ignorance*** of the concept but that ***does not impede their contribution to the system***.

http://www.trojanmice.com/articles/complexadaptivesystems.htm

V. Tools & Techniques

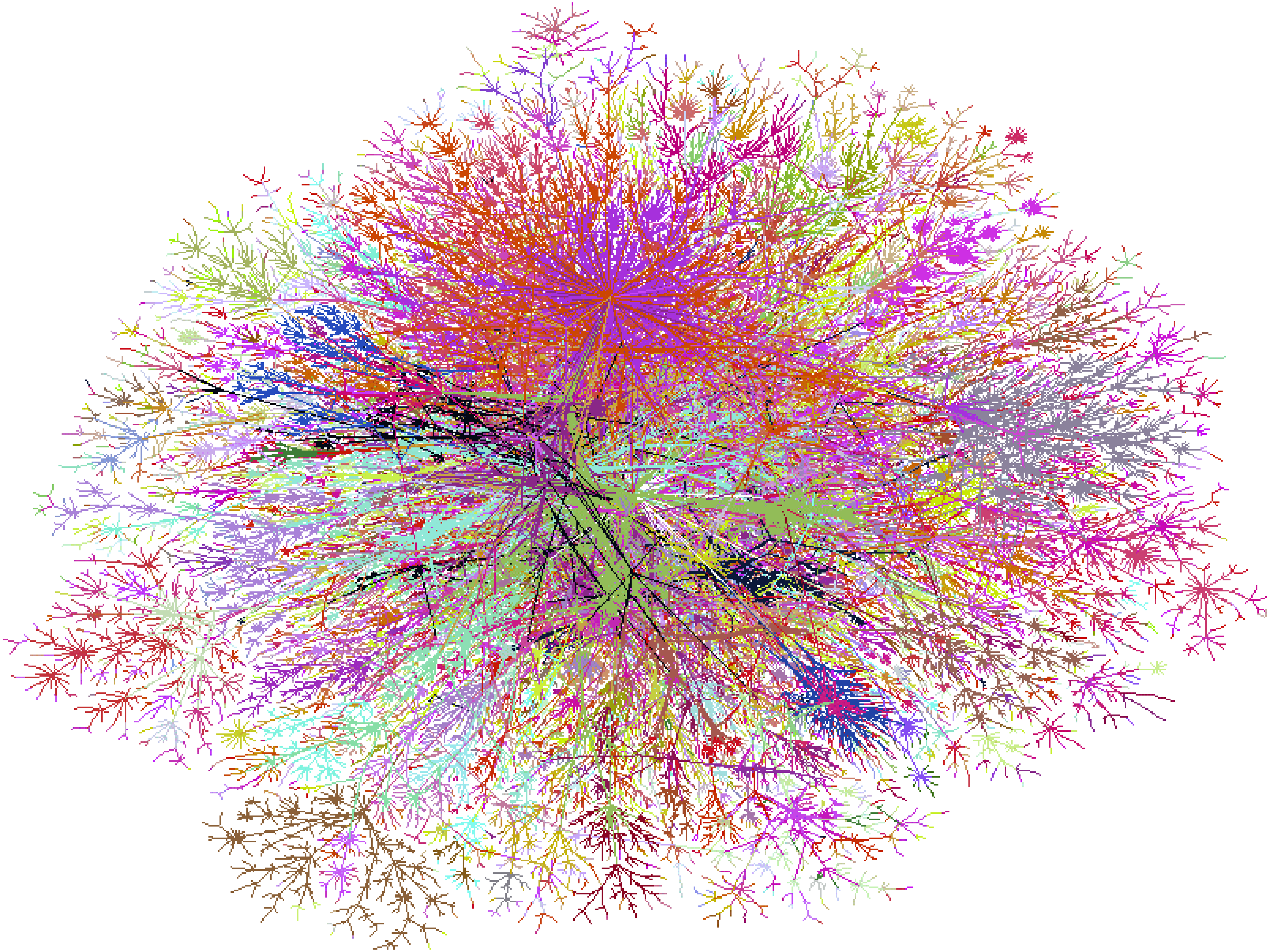
Agent-based or Multi-agent Models

Agents ***interact adaptively*** with each other and also change with the overall conditions in the environment.
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?

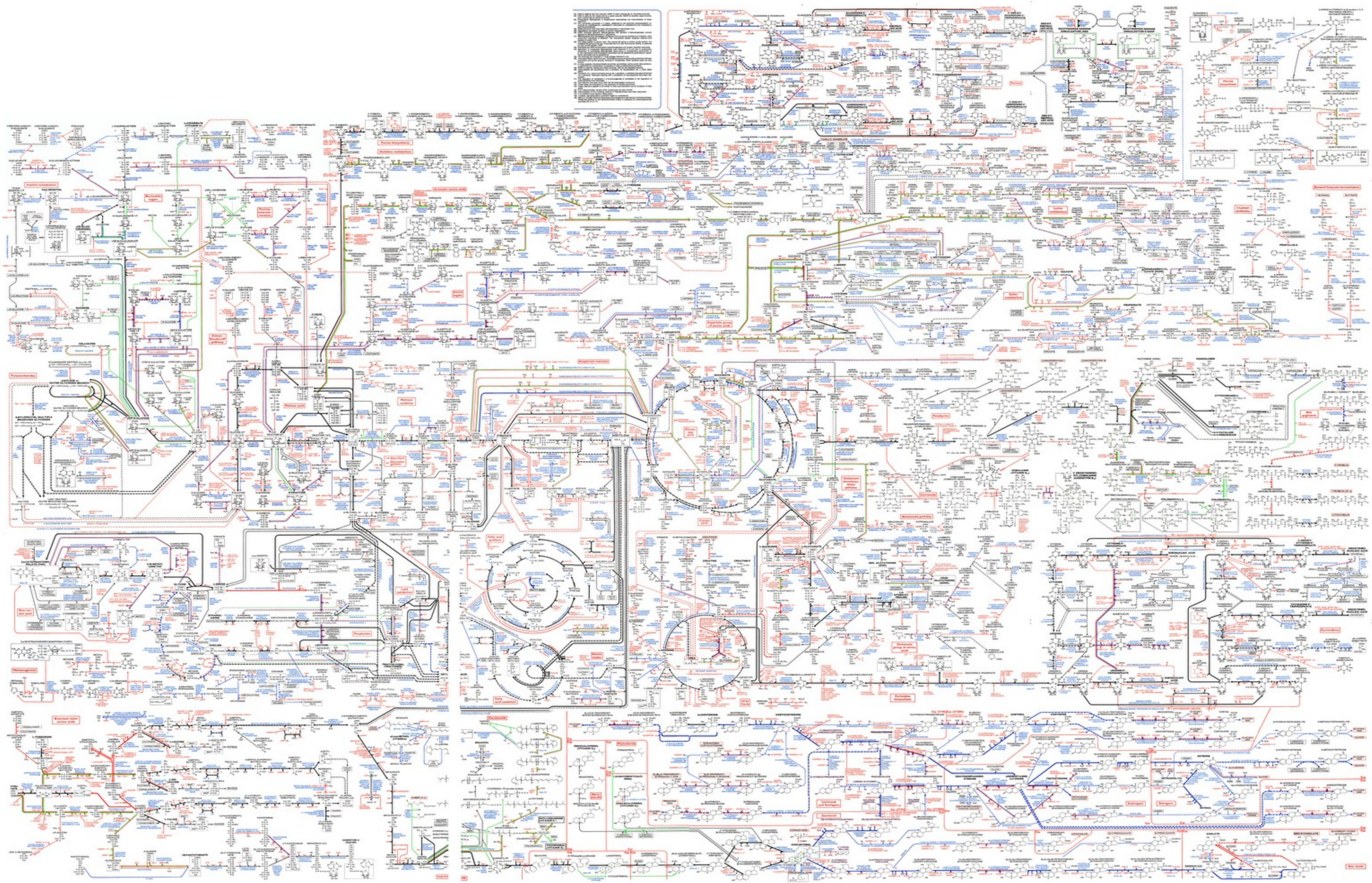
Network Analyses

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.

> For example, certain network patterns seem to characterize groups of collaborating scientists who are more successful and innovative than most.
> 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.***



https://www.google.be/search?q=communication+networks&hl=en&client=firefox-a&hs=uK0&rls=org.mozilla:nl:official&prmd=imvnsb&tbm=isch&tbo=u&s



http://biochemicalpathwayswallchart.blogspot.be/2010/10/roche-biochemical-pathways-wall-chart.html

Additional complexity-related tools

Although their use is not unique to complexity science, but have been fruitful across a broad range of **science-based endeavors :**

Data Mining. Complexity scientists are developing techniques for finding patterns and relationships in large data sets with complex qualities.

Scenario Modeling. Scenario models are artificially constructed, hypothetical models of complex systems that reflect their key constituents and dynamics. 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 behaviors 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 called ***sensitivity analyses***.

Dynamical Systems Modeling. ***Dynamical systems models*** are generally sets of differential equations or iterative discrete equations, used to describe the ***behavior of interacting parts*** in a complex system, often including positive and negative ***feedback loops***.

Example. Which incentives are most likely to yield adoption of alternative energies by consumers and power companies.

VI. Examples application domains.

✱ Traffic

An advanced modeling 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 modeling"*** will be generalizable 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 analyze human foot traffic.

✱ 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.***

The ***US Department of Defense*** uses network-analysis methods to attempt to identify ***associations of terrorists***, including pinpointing the locations of key dangerous individuals.

On line ***"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.

✱ Some Other topics

Complex Adaptive systems and the challenge of sustainability.
Simon Levin, Lecture Portugal, 2012,

Nonlinear detection of paleoclimate-variability transitions possibly related to human evolution.
Donges et al. PNAS, PIK, 2011

The Network of Driving Forces of Global Environmental Change.
J.C. Rocha, Stockholm, 2012

Growth, innovation,scaling, and the pace of life in cities.
L.M.A. Bettencourt et al, PNAS, 2007. Los Alamos, Santa Fe Institute.

Complexity and the Limits of Ecological Engineering.
L. Parrot, 2002. ASAE

✱ The Food Crises and Political Instability in North Africa and the Middle East

Social unrest may reflect a variety of factors such as poverty, unemployment, and social injustice. Despite the many possible contributing factors, the **timing of violent protests** in North Africa and the Middle East in 2011 as well as earlier riots in 2008 **coincides with large peaks in global food prices.**

Identifying **specific food price threshold** above which protests become likely. These observations suggest that protests may reflect not only long-standing political failings of governments, but also the **sudden desperate straits of vulnerable populations**.

Underlying the food price peaks one also finds an ongoing trend of increasing prices. We extrapolate these trends and identify a crossing point to the domain of high impacts, even without price peaks, in 2012-2013. This implies that avoiding global food crises and associated social unrest requires rapid and concerted action.

Marco Lagi, Karla Z. Bertrand and Yaneer Bar-Yam. **New England Complex Systems Institute**

✱ Santa Fe Institute, US

SFI's complexity research led to efforts to create artificial life modeling real organisms and ecosystems in the 1980s and 1990s.

Contributions to the field of **chaos theory**.

Contributions to the field of **genetic algorithms**.

Contributions to the complexity **economics school of thought**.

Contributions to the field of **econophysics**.

Contributions to the field of **complex networks**.

Contributions to the field of **systems biology**.

a.o.

http://en.wikipedia.org/wiki/Santa_Fe_Institute

VII. Challenge. 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.*** 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. It will be challenging ***to move beyond strict determinism***, 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. Complexity science offers many insights into finding and exploiting ***desirable attractors;*** identifying and ***avoiding dangerous tipping points***; and ***recognizing when a system is in a critical self-organizing state***.

Anyone aiming to engage in modeling should keep in mind the *Box–Draper dictum* *(Box and Draper 1987, p. 424)* :

Essentially, all models are wrong, but some are useful.

http://www.dtc.umn.edu/~odlyzko/doc/ecra.westland.pdf

VIII. *Some References*

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Albert-Laszlo Barabasi & Eric Bonabeau. ***Scale-Free Networks.*** **Scientific American, May 2003**

M.E.J. Newman. ***Networks. An Introduction.*** **Oxford Univ. Press, 2010**

OECD. ***Report on Applications of Complex Science for Public Policy : New tools for finding unanticipated Consequences and Unrealized Opportunities.*** **September 2009**

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Stuart Kauffman. ***At home in the universe The Search for Laws of Complexity*****. Penguin, 1995**

M. Mitchell Waldrop. ***Complexity. The emerging Science at the Edge of Order and Chaos*****. A Touchstone Book, 1992**

Roger Lewin. ***Complexity. Life at the Edge of Chaos.*** **A Phoenix Paperback, 1993**