INTRODUCTION TO COMPLEX SYSTEMS
2010 Winter

OU112 M-W-F- 1.15pm - 2.30pm
Instructor: Péter ノrdi, Henry R. Luce Professor of Complex Systems Studies
Office: OU 208/B. email: perdi@kzoo.edu
TA: Kinga Makovi
Email: kinga.makovi@gmail.com

Topics: The discipline of 'Complex Systems' studies how to analyze complex natural and social phenomena by rational thinking including by using mathematical models. You will learn about the basic concepts and methods of complex system research. It will be emphasized that since many systems of very different fields, such as physics, chemistry, biology, economics, psychology and sociology etc. have similar architecture, very different phenomena of nature and society can be analyzed and understood by using a common approach called 'systems thinking'.

Goal: The first goal is to teach WHY complex systems research is important in understanding the structure, function and dynamics of complex natural and social phenomena. The second goal is to give an introductory overview about HOW the fundamental methods of complex systems research works. The course is not highly technical mathematically, but teaches some concepts of dynamical systems and probability theory. Not only students of science majors, but social science students (with some mathematical interest and skill) are expected to take the class.

Group tasks will be assigned. Poster presentations on group tasks will be scheduled on March 12th.

Exam: There will be a one hour long written midterm and final examination.

Grades are calculated by your results in midterm (25%), group tasks (25%) and final exams (50%).

Readings: My book 'Complexity Explained' - Springer 2007 - (CE) should be used as a guide.. Don't worry (very much): the minimal necessary math will be explained.

Computational Tools:

Computer simulations with Netlogo will be required.

NetLogo is a cross-platform multi-agent programmable modeling environment: http://ccl.northwestern.edu/netlogo/.

Guest lecture: Christopher A. Klausmeier (W. K. Kellogg Biological Station, MSU) will speak about ecological modeling on February 17th.

Workshop on Computational Political Science and Legal Studies (March 5th): During class time participations is required.

1. COMPLEX SYSTEMS: THE INTELLECTUAL LANDSCAPE

Complex systems theory offers a unified perspective to understanding natural and social phenomena.

Topics:
The century of complexity
Characteristics of simple and complex systems
(circular causality, feedback loops, logical paradoxes; self-referential systems, strange loops, butterfly effects, emergence and unpredictability)

Readings:
CE 1
http://en.wikipedia.org/wiki/Complex_systems

2. HISTORY OF COMPLEX SYSTEMS RESEARCH

Topics:
Reductionist success stories versus the importance of Organization Principles
(Reductionism and holism in quantum physics, reductionism and complexity in molecular biology)
Ancestors of present day complex systems research
(Systems theory, cybernetics, nonlinear science.
Multistability: a general concept
Phase transition, synergetics and catastrophe theory: multistable perception and dramatic changes in oil prices)

Readings:
CE 2

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

http://geza.kzoo.edu/~erdi/2.pdf

3. THE CLOCK-WORK WORLD-VIEW versus IRREVERSIBILITY

The basis of the modern science is mechanics. The pioneers, such as Galileo, Kepler, Newton etc. established the 'scientific method' by integrating observations, reproducible experiments, data processing, and establishment and testing of mathematical models: the 'dynamical world view' emerged. The clock-work world view suggests that the Universe is cyclic. It is also known, however, that past evens don't return: physics, biology and maybe social development has a direction, an arrow of time.

Topics:
Ancient and modern time concepts: cyclic universe versus linear time concepts
The mechanical clock
From Kepler to Newton: The dynamic world view. States and processes
Reversibility versus irreversibility. Mechanics versus thermodynamics.

Readings
CE 3.1., 3.2.1, 3.2.2, 3.3,
http://geza.kzoo.edu/~erdi/1a.pdf
http://geza.kzoo.edu/~erdi/1b.pdf

4. DYNAMIC MODELS

Topics:
Growth models (population dynamics, economics etc.). Limits to growth,
Attractors
Oscillations: from physical to economic cycles (Lotka-Volterra models and many others)
Propagation of biological and social epidemics
The dynamic laws behind rises and falls, periodic and irregular changes
From population models to war dynamics
Direction of evolution

Readings:
Dynamical systems theoretical approach to civilization: rise, fall, competition, cooperation and self-organization http://geza.kzoo.edu/~erdi/civ-lec.pdf
nature.berkeley.edu/~bingxu/UU/geocomp/Week8/Predator-Prey%20Models.ppt

CE 4.4.2
CE 4.4.3
CE 4.8.1
CE 3.7.

5. DETERMINISM AND RANDOMNESS: THE LIMITS OF PREDICTABILITY

One of the philosophical implications of the clockwork worldview was the assumption of determinism related to the Laplace demon. It turned out that deterministic algorithms may lead to phenomena, which seem to be indistinguishable from the outcome of inherently random processes ('deterministic chaos'). Chaotic process and fractal structures proved to be very efficient mathematical concepts to understand temporal and spatial complexity.

Generally (continuous) biological variables (from heights, and weights to IQ) are characterized by the normal (or Gaussian) distribution ('Bell curve'). The Gaussian distribution is symmetric, so deviation from the average to both directions has similar properties.

Income distribution, occurrence of words, web hits, copies of books sold, frequency of family name have different statistical properties. They can be characterized by the family of “long tail” or ?”heavy tail” distributions. These distributions are skew, (skewness is a measure of asymmetry of a distribution).

Topics:
Chaos and fractals in nature, society and art
Simple rules leads complex dynamics: the logistic map
Chaos everywhere: population dynamics, meteorology, economics ...
Fractal dimension
Fractal structures everywhere
Statistical laws: from symmetric to asymmetric
Normal (Gaussian) distribution
Long tail distributions. (power law distributions)
Long tail in on-line business
Skew distributions in social sciences (linguistics, economics): Zipf's law, Pareto distribution
Black swans and dragon kings
Prediction of extreme events? Epileptics seizures, earthquake eruptions and stock market crashes

Readings:
http://www.pha.jhu.edu/~ldb/seminar/laplace.html
http://www.pha.jhu.edu/~ldb/seminar/
http://en.wikipedia.org/wiki/Chaos_theory
http://en.wikipedia.org/wiki/Logistic_map
http://hypertextbook.com/chaos/42.shtml
http://en.wikipedia.org/wiki/Fractal
CE 7.2.3
http://ccl.northwestern.edu/netlogo/models/KochCurve
http://ccl.northwestern.edu/netlogo/models/SierpinskiSimple
CE 6.1.1, CE Fig 6.2., 6.3, 6.4, CE 6.3.
http://en.wikipedia.org/wiki/The_Long_Tail
Chris Anderson: The Long Tail: http://www.wired.com/wired/archive/12.10/tail.html
http://www.nslij-genetics.org/wli/zipf/
CE 9.3.

6. COMPLEX ORGANIZATIONS: BIOLOGICAL AND SOCIAL NETWORKS

Real world systems in many cases can be represented by networks. Networks can be seen everywhere (neural networks of the brain, food webs and ecosystems, electric power networks, system of social connections, global financial network, the world-wide web). Since the social psychological experiment of Stanley Milgram, it is known that from a certain point of view we live in a 'small world'. Small world (and also scale-free) graphs are particular examples of complex networks: they are neither purely regular, nor purely random.

The performance of many biological, ecological, economical, sociological, communication and other networks can be illuminated by using new approaches coming from graph theory, statistical physics and nonlinear dynamics. Examples will be given to illustrate the power of the new approaches in the understanding of the organization of social structures. Specifically collaboration and citation networks will be analyzed.

Topics:
Networks everywhere
Biological networks
Social networks
World wide web and the internet
Statistical analysis of large networks

Development of networks: random evolution, rewiring, preferential attachment
Citation networks
Network science and defense

Readings:
CE 7.4
Péter ?rdi: Complex (not only neural) network
http://kzoo.edu.cneuro.rmki.kfki.hu/materials/network.pdf
http://en.wikipedia.org/wiki/Small_world_experiment
http://en.wikipedia.org/wiki/Erdős_number
http://en.wikipedia.org/wiki/Social_network
http://www.zangani.com/blog/2007-1030-networkingscience

7. COMPLEXITY OF THE| BRAIN

Why neuoroscientists should learn complex systems theory?

Topics:
Windows on the brain
Organizational principles of the brain
Even a single neuron is a complex device
Neural organization: structure, function and dynamics
Neural rhythms: normal and pathological
Towards a computational neuropharmacology, neurology and psychiatry

Readings:
http://neuroscientific.net/index.php?id=38
CE 8.1, 8.2, 8.3, 8.6

8. APPLICATIONS OF THE COMPLEX SYSTEMS PERSPECTIVE

Topics:

Segregation dynamics.
(The Schelling segregation model. Thomas Schelling, in 1971, showed that a small preference for one's neighbors to be of the same color could lead to total segregation. He

has been awarded by the Nobel prize in economics in 2005.)
History and dynamic systems
Game theory: The problem of fair division. Prisoner's Dilemma, The tragedy of commons.
How cooperation and of social norms evolve? (Evolutionary game theory)
Skew distribution and political science: Annual budget changes and institutional decision making

Readings:
CE 9.2
http://ccl.northwestern.edu/netlogo/models/Segregation
Turchin P: Can History Become an Analytical, Predictive Science?
from http://www.eeb.uconn.edu/people/turchin/Clio.htm
Brams SJ: Game theory and the Cuban missile crisis
http://plus.maths.org/issue13/features/brams/2pdf/index.html/op.pdf
http://dieoff.org/page95.htm
http://geza.kzoo.edu/~erdi/aaai-lec.pdf