INTRODUCTION TO COMPLEX SYSTEMS
2014 Winter

OU207 M-W-F 11:50AM - 01:05PM
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Topics: The discipline of 'Complex Systems' studies is how to analyze complex natural and social phenomena by rational thinking including 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 system research works. Understanding the course does not require high mathematical skills, but some concepts of dynamical systems and probability theory are going to be taught. 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 selected/assigned. Poster presentations on group tasks will be scheduled on March 5th.

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

Grades are calculated by your classroom activity (10%), results of midterm (20%), group tasks (25%) and final exams (45%).

Readings: P. Érdi - 'Complexity Explained' - Springer 2007 - (CE) should be used as a guide. **Other weekly readings/files etc. will be listed on Moodle.!!**

Weekly assignments (based on the suggestion of the TA; Aya: thanks!). Correspondence related to these assignments should be done with her!

1. Vocabularies

-Students will take notes in class, record 5 vocabularies that Dr. Erdi uses in his lecture AND they don't understand
-5 vocabs/lectures x 3lectures/week= 15vocabs/week
-If they understand every single vocabularies Dr. Erdi uses in the lecture, then they can pick five vocabs that are related to the main concepts of the lecture and expand them

-Every Monday, students will turn in vocabulary sheets from the previous week

2. Notebook check

1. Students will read sections, and take notes on important concepts
2. Students will write down question if they struggle while reading book
3. Students will staple notes for all the readings for the week, and turn them in to me on Fridays.

Computational Tools: Computer simulations with Netlogo will be required. NetLogo is a cross-platform multi-agent programmable modeling environment: http://ccl.northwestern.edu/netlogo/.

Personal remarks and requests. Use of laptops are discouraged. The consumption of chewing gum is discouraged. Please, be prepared physiologically for being able not to leave the classroom during the 75 minutes lecture time.

Topics:

I. COMPLEX SYSTEMS: THE INTELLECTUAL LANDSCAPE

1. Why complexity science is the science of the 21st century?
2. How to characterize simple and complex systems? (circular causality, feedback loops, logical paradoxes; self-referential systems, strange loops, butterfly effects, emergence and unpredictability)
3. Tipping points: small changes make big difference: dramatic changes in prices,

multistable perception. Wildfires. Avalanches
4. Extreme events: similarities and differences (epileptic seizures, earthquakes, stock market crashes)

II. THE DYNAMIC WORLD VIEW: THE CLOCKWORK UNIVERSE

1. Ancient and modern time concepts: cyclic universe versus linear time concepts
2. The mechanical clock
3. The beginning of modern science
4. Mechanics and determinism. Causes and effects.

III. THE IRREVERSIBLE UNIVERSE: THERMODYNAMICS

1. Systems: closed, open, isolated
2. Conservation of energy
3. Reversible and irreversible processes. The first and second laws of thermodynamics
4. Entropy and the Second Law
5. Heat conduction and irreversibility
6. The steam engine
7. Industrial revolution

IV. HISTORY OF COMPLEX SYSTEM RESEARCH

1. Reductionism and holism (philosophy of science, success stories of the twentieth century science: quantum physics and molecular biology)
2. Cybernetics, Systems theory, nonlinear science.
3. Dynamic structures: from being to becoming
4. New sciences and humanities

V-VI. DYNAMIC MODELS: BIOLOGICAL and SOCIAL COMPLEXITY

1.Growth models (population dynamics, economics etc.). Limits to growth
2. Attractors.
3. Oscillations: from physical via ecological to economic cycles (Lotka-Volterra models and many others)
4. Agent-based modeling and the NETLOGO platform

5. Propagation of biological and social epidemics
6. The dynamic laws behind rises and falls, periodic and irregular changes
7. From population models to dynamics of war and love
8. Direction of evolution
9. Segregation dynamics.
10. Opinion dynamics
11. Business Cycles
12. Looking into the past, predicting the future

VII. DETERMINISM AND RANDOMNESS: THE LIMITS OF PREDICTABILITY

One of the philosophical implications of the clockwork world-view 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 distributions. These distributions are skew, (skewness is a measure of asymmetry of a distribution).

1. Chaos and fractals in nature, society and art
2. Simple rules leads complex dynamics: the logistic map
3. Chaos everywhere: population dynamics, meteorology, economics ...
4. Fractal structures everywhere
5. Statistical laws: from symmetric to asymmetric
6. Normal (Gaussian) distribution
7. Long tail distributions. (power law distributions)
8. Skew distributions in social sciences (linguistics, economics): Zipf's law, Pareto distribution

9. Predictability of extreme events: scope and limits

VIII. 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:
1. Networks everywhere
2. Biological networks
3. Social networks
4. World wide web and the Internet
5. Statistical analysis of large networks
6. Development of networks: random evolution, rewiring, preferential attachment
7. Citation networks

IX. COMPLEXITY OF THE| BRAIN

1. Why neuoroscientists should learn complex systems theory?
2. Windows on the brain
3. Organizational principles of the brain
4. Even a single neuron is a complex device
5. The brain and the computer
6. Neural organization: structure, function and dynamics
7. Neural rhythms: normal and pathological
8. Towards a computational neuropharmacology, neurology and psychiatry

X. APPLICATIONS OF THE COMPLEX SYSTEMS PERSPECTIVE

1. History and dynamic systems
2. Game theory. Conflict, strategies, games. Social dilemmas. The tragedy of commons
3. How cooperation and social norms evolve? (Evolutionary game theory)
4. Computational social science