INTRODUCTION TO COMPLEX SYSTEMS
2019 Winter

Tuesday, Thursday 09:30AM - 11:20AM, Olds Upton Hall, Room 207
Instructor: Péter Érdi, Henry R. Luce Professor of Complex Systems Studies
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Office hours: by appointments
TA: Natalie Thompson <Natalie.Thompson15@kzoo.edu>
Office hours: TBA

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 projects will be selected/assigned. Poster presentations on group tasks will be scheduled on March 15th.

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

Grades are calculated by your classroom activity including assignments (20%), results of midterm (20%), group tasks (20%) and final exams (40%).

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


From your TA:

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**Vocabulary Assignment**
- Each student must record six vocabulary words that Dr. Erdi uses in class for each lecture, search the meaning of the words and type them on a sheet of paper. You must pick the words, with the intent to expand your complex systems vocabulary. **Every Tuesday,** you will turn in **hard copies** of the vocabulary sheets in class from the previous week. (6x2=12vocabs each week). Submissions via email are not accepted.

How your schedule will look like…

Week 2:
- Tuesday: Record 6 vocabulary words from lecture, type definitions of the words
- Thursday: Record 6 vocabulary words from lecture, type definitions of the words

*Turn in your vocab sheet from Week 2 on Tuesday of Week 3*

**Concepts Assignment**
- Pick two concepts (any of the two concepts Dr. Erdi talks in class) from each lecture and provide real life examples for them. Type a paragraph-long explanation for each concept. You need to complete this assignment for Tuesdays and Thursdays’ lectures. Turn in your concept assignments in the following lecture.

How your schedule will look like…

Week 2:
- Tuesday: Come up with examples of two concepts (you pick two) from Dr. Erdi’s lecture
- Thursday: Turn in your concept examples from Tuesday’s lecture. Record & come up with examples of concept from Dr. Erdi’s lecture on Thursday.

**NetLogo Project**
- There will be one group project for the class during the quarter. Dr. Erdi will provide details in the beginning of the 3rd week.

**It is your responsibility to turn in all the assignments required for this class. No late work will be accepted. Also, all the assignments must be typed.**

**Please turn in all the assignments in the black plastic box located by Dr. Erdi’s office on the due dates, prior to Complex Systems class period.**

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**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 strongly discouraged. The consumption of chewing gum is discouraged.

Schedule: There will be no classes during Week 1, since I attend a conference: https://efop362.itk.ppke.hu/conferences/bioinspired-networks.

The classes will be rescheduled for some evenings. (as a compensation, pizza will be served.)

However, on January 8th, you should meet with our TA, Natalie, say between 9:30 and 10.15am to have a chat about the general nature of the class, and about the group projects.

**Topics:**

**I. COMPLEX SYSTEMS: THE INTELLECTUAL LANDSCAPE**

1. Complex world problems: natural and social disasters; biological and social epidemics; financial and political crises
2. How to characterize simple and complex systems? (circular causality, feedback loops, logical paradoxes; self-referential systems, strange loops, butterfly effects, emergence and unpredictability)
4. Extreme events: similarities and differences (epileptic seizures, earthquakes, solar flares, stock market crashes).
5. Three revolutionary devices and their social roles: mechanical clock, steam engine, computer

**II. THE DYNAMIC WORLD VIEW: THE CLOCKWORK UNIVERSE**

“Looking into the past, predicting the future”
1. Ancient and modern time concepts: cyclic universe versus linear time concepts
2. The mechanical clock
3. The beginning of modern science

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
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. Basic concepts.
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 neuroscientists 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. Computational social science
2. Game theory. Conflict, strategies, games. Social dilemmas. The tragedy of commons
3. How cooperation and social norms evolve: