Mathematics of Complexity

Biology 131

Stanford University, Fall Quarter 2012
Fridays, 2:15-4:05pm, Building 360, room 361A

Class Instructors:

Diamantis Sellis
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I. TOPICS: An exploration of mathematical formalisms associated with the study of complex systems.

II. READINGS: All required readings will be available on Coursework or Googledocs.

III. CLASS REQUIREMENTS: There are no prerequisites. This is a one credit satisfactory/no credit course. Credit will depend on attendance and class participation. One class absence is allowed; others must be excused. Each student will be responsible for a short (5-10 minute) presentation on one of our readings. Projects are encouraged.

IV. FORMAT: Classes will consist of lectures, discussion and hands-on exercises.

V. SCHEDULE:

Week 1: ***Introduction to Complexity*** - Mark D. Longo
- Lecture: "Complexity in Perspective"

Week 2: ***Modeling Complex Systems*** - Joel Thompson
- Discussion of Modeling, Simulation, and Reduction.
    - Types of mathematical models and techniques used for modeling.

Week 3: ***Dynamical systems*** - Oana Carja
- Introduction to linear and nonlinear dynamical systems.
- Reading(s): "Nonlinear dynamics and chaos", S. Strogatz, Chapter 5.

Week 4: ***Chaos*** - Oana Carja
- More on non-linear dynamics and chaos. Behavior and properties of chaotic systems. Examples of systems with chaotic behavior.
- Reading(s):
    - "Nonlinear dynamics and chaos", S. Strogatz, Chapter 9
    - James P. Crutchfield,]. Doyne Farmer, Norman H. Packard and Robert S. Shaw (1986), Chaos, Scientific American. http://www.nature.com/scientificamerican/journal/v255/n6/pdf/scientificamerican1286-46.pdf

Week 5: ***Fractals*** - Oana Carja

- Introduction to fractals. Fractals and chaos. Examples and exercises.
- Reading(s):
    - "Nonlinear dynamics and chaos", S. Strogatz, Chapter 11.
    - Hartmut Jurgens, Heinz-Otto Peitgen and Dietmar Saupe (1990) The language of fractals. Scientific American. http://www.nature.com/scientificamerican/journal/v263/n2/pdf/scientificamerican0890-60.pdf

Week 6: ***Power Laws*** - Joel Thompson

- What is a power law? What is the functional form?
- Discuss examples of power law distributions in real systems.
- Self similarity and fractal nature of power laws.
- What are mechanisms for obtaining power laws?
- Reading(s):
    - "Power laws, Pareto distributions and Zipf's law" by M. E. J. Newman

Week 7 : ***Networks I*** - Diamantis Sellis

- Networks statics: Intro to graph theory, network properties and structure.
- Hand's on exercise with network analysis software.
- Reading(s):
    - Newman, M. E. J. (2003). The structure and function of complex networks. Retrieved from http://arxiv.org/abs/cond-mat/0303516 (sections: I - III)

Week 8: ***Networks II*** - Diamantis Sellis

- Network dynamics: Network growth, processes on networks.
- Reading(s):
    - Newman, M. E. J. (2003). The structure and function of complex networks. Retrieved from http://arxiv.org/abs/cond-mat/0303516 (sections VI until end)
    - Kauffman, S. A., & Weinberger, E. D. (1989). The NK model of rugged fitness landscapes and its application to maturation of the immune response. Journal of Theoretical Biology, 141(2), 211–245. doi:10.1016/S0022-5193(89)80019-0

Week 9: ***Cellular Automata*** - Diamantis Sellis

- Cellular automata models
- Reading(s):
    - Chapter 3 from Wolfram, S., A New Kind of Science http://www.wolframscience.com/nksonline/toc.html
    - Wolfram, S. (1984, October). Cellular automata as models of complexity. Nature 311 (5985), 419-424.

Week 10: ***Collective Behavior and Phase Transitions*** - Joel Thompson

- Introduction to "self"-organizing systems
- Methods for modeling self-organization
- Phase transitions and critical phenomena
- NetLOGO tutorial.
- Reading(s):
    - "Self-Organization in Biological Systems" Camazine
    - "Phase Transitions" Ricard Sole, Ch.1 , Ch. 3