Complex Systems 899: Theory of Complex Systems

Winter 2006

Room: 229 Dennison
Time: Tuesday/Thursday at 10–11:30am

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Course web page: `http://www-personal.umich.edu/~mejn/courses/2006/cmplxsys899/`

Description

This course is a math-based introduction to the theory and analysis of complex systems. Methods covered will include nonlinear dynamics, both discrete and continuous, chaos theory, stochastic processes, game theory, criticality and fractals, and numerical methods. Examples studied will include population dynamics, evolutionary theory, genetic algorithms, epidemiology, simple models of markets, opinion formation models, and cellular automata.

Text book

A good general book on the subject, which I've used in preparing the course, is *Modeling Complex Systems* by Nino Boccara. It's not required that you buy a copy of this book, but you may find it useful. There will also be some in-class handouts covering particular topics in greater depth. For the dynamical systems part of the course I have also made use of *Nonlinear Dynamics and Chaos* by Steve Strogatz, which is an excellent book. (Also not required, but very useful.)

Coursework

In addition to reading assignments, there will be weekly graded problem sets, consisting both of theory questions and of problems demonstrating applications of theory to example systems. There will be one mid-term and a final. The mid-term will be a take-home exam handed out on the Tuesday of the week after Winter break and due in two days later. The final will be on Monday, April 24 from 4pm till 6pm. Grade will be 40% on the homeworks, 25% on the mid-term, and 35% on the final.

Outline

As a special topics course, what we cover will, to some extent, depend on what you want to learn about and how well we advance with the material. However, here is a list of the topics I would like to cover, time permitting. It is virtually certain that we won't get to cover all of this. I have put things nearer the beginning that I think are more pressing and that I'd like to tackle first. Requests and suggestions for which of the later topics you'd like to work on are more than welcome.

Nonlinear dynamics

- Difference equations
- Population dynamics
- Opinion formation
- Differential equations
- Linear stability
- Population dynamics
- Epidemiology
- Chaos

Stochastic processes

- Random walks
- Gambler's ruin, the Kelly criterion
- First passage processes
- Rate equations
- Stochastic differential equations
- Population dynamics and epidemiology

Game theory

- Prisoner's dilemma and other simple games
- Opinion formation
- Markets
- Minority game

Criticality and SOC

- Percolation
- Continuous phase transitions
- The renormalization group
- Fractals
- Self-organized criticality
- Forest fires, sandpiles
- Power laws
- Yule process, wealth accumulation
- Other power-law processes

Computers

- Computational complexity
- Algorithms
- P and NP
- Numerical methods for ODEs and quadrature
- Simulation
- Importance sampling
- Agent-based methods

Entropy and related topics

- Information theory and data analysis
- Bayesian inversion
- Applications to model fitting for some of the earlier examples

Networks

- Internet, Web, social networks
- Random graphs
- Probability generating functions
- Growing networks
- Rate equations

Optimization

- Rugged landscapes, spin glasses, NK model, etc.
- Simulated annealing
- Multicanonical ensemble and entropic sampling
- Genetic algorithms
- No Free Lunch theorem