PHYS 615: Nonlinear Dynamics of Extended Systems

2:00 – 3:15 Tues. Thurs., Physics 1304

Instructor:

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Website:

https://sites.google.com/site/physics615/

Description:

This is a topics course in complex extended systems aimed at the level of first year graduate students. Broadly speaking, a complex system is a set of interacting elements that are nonlinearly coupled to give rise to emergent behavior. This course primarily focuses on how a physics perspective coupled with a computational approach can lend insights into complex systems. The course has no explicit prerequisites. A strong undergraduate math background that includes differential equations, linear algebra, and basic probability and statistics is assumed. A knowledge of statistical physics at the undergraduate level is also valuable, but the course is designed to be accessible to graduate students from non-physics disciplines. Some experience with computer programming is necessary. Problem sets will include numerical calculations and simple simulations, which means either writing code in a scientific programming language or using a standard software package such as Matlab or Mathematica. The course will work primarily from a series of research papers. Links to these papers will be posted to the website.

Grading:

Problem sets: 40% (4 problem sets, 10% each), literature presentation: 15% (Research papers will be assigned to students individually or in pairs. The task is to convey the main ideas in the assigned paper in a 35-40 minute presentation, including discussion), class discussion: 5%, final project: 40% (Students will identify a line of original research in the area of complex systems and write a report which includes: motivation of the problem, relevant background, an outline for the proposed work, and some preliminary investigations)

Topics and Schedule:

Course Overview*:* 8/31

Topic Area 1: A Physics Approach to Biological and Social Systems: Some Examples

- Scaling in biological systems: 9/2
- Econophysics: 9/7
- Physics of cancer (Guest lecturer: Wolfgang Losert): 9/9
- Two student literature presentations: 9/14
    - Scaling student literature presentation:
      J. F. Gillooly, J. H. Brown, G. B. West, V. M. Savage, and E. L. Charnov, "Effects of Size and Temperature on Metabolic Rate," Science 293, 2248 -2251 (2001).

- Econophysics student literature presentation:
  M. H. R. Stanley, L. A. N. Amaral, S. V. Buldyrev, S. Havlin, H. Leschhorn, P. Maass, M. A. Salinger, and H. E. Stanley, "Scaling Behavior in the Growth of Companies," Nature 379, 804-806 (1996).

Topic Area 2: Simple Models of Complex Systems

- Cellular automata. 9/16, 9/21
- Agent-based modeling. 9/26, 9/28
  - Agent-based modeling student literature presentation: 9/28
    Couzin, I.D., Krause, J., Franks, N.R. and Levin, S.A.(2005), "Effective leadership and decision making in animal groups on the move," Nature 433, 513-516 (2005)

Topic Area 3: Power Law Distributions in Natural Systems

- Simple mechanisms for generating power law distributions: 9/30, 10/5
  - Power law student literature presentation: 10/7
    A. Clauset, C.R. Shalizi, and M.E.J. Newman, "Power-law distributions in empirical data" SIAM (2009).
- Critical phenomena in percolation: 10/7, 10/12
- Self-organized criticality (SOC): 10/12, 10/14
  - SOC Student literature presentation: 10/19
    O. Peters and J. D. Neelin, "Critical phenomena in atmospheric precipitation," Nature Physics 2, 393 - 396 (2006)
- Highly-optimized tolerance (HOT): 10/19, 10/21
  - HOT student literature presentation: 10/21
    Zhou, T., Carlson, J.M., and Doyle, J., "Evolutionary Dynamics and Highly Optimized Tolerance," J. Theor. Bio. 236 , 438-447 (2005).

Topic Area 4: Complex Networks

- Network measures: 10/26
- Network models: 10/28
- Network algorithms: 11/2, 11/4
  - Student literature presentation: 11/17
    Watts, D. J, Dodds P.S., and Newman M.E.J., "Identity and search in social networks," Science 296:1302 (2002).
- Network dynamics: 11/9, 11/11

Topic Area 5: Computational Tools for Complex Systems

- Simulated Annealing and Genetic Algorithms: 11/16, 11/18
- Computational Mechanics: 11/16, 11/18, 11/23
  - Student literature presentation: 11/23
    D. P. Varn, G. S. Canright and J. P. Crutchfield, "Discovering planar disorder in close-packed structures from x-ray diffraction: Beyond the fault model," Physical Review B 66, 174110 (2002).

Due Dates:

10/5 - 1st problem set (on cellular automata) due
10/12 - 1 page description of proposed final project due
10/26 - 2nd problem set (on power laws) due
11/16 - 3rd problem set (on complex networks) due
12/2 - Final project report due. Presentations on 12/2, 12/7, 12/9
12/9 - 4th problem set (on computational tools) due

Suggested Readings:
(a more updated list including dates for the various readings will be kept on the website)

BOOKS:
Lectures on Complex Networks, S. N. Dorogovstev
Modeling Complex Systems by Nina Boccara,
Complex Systems Dynamics by Gerard Weisbuch

POWER LAWS:
http://www-personal.umich.edu/~mejn/courses/2006/cmplxsys899/powerlaws.pdf
by Mark Newman

SCALING IN BIOLOGICAL SYSTEMS: West *et al., Science* **276**, 122 (1997).

ECONOPHYSICS:
J. D. Farmer, M. Shubik, and E. Smith, *Phys. Today*, Sept 37-42 (2006) .
Daniels, *et al*., *PRL* **90**, 108102 (2003).
A. Dragulescu and V. M. Yakevenko, *Euro Phys J B* **17**, 723-729 (2000).

CELLULAR AUTOMATA: *Cellular Automata Modeling of Physical Systems* by Chopard and Droz

SIMULATED ANNEALING: S. Kirkpatrick *et al, Science*, **220**, 671-680 (1983)
see also Weisbuch

PERCOLATION THEORY: *Introduction to Percolation Theory* by Stauffer and Aharony

SELF-ORGANIZED CRITICALITY: *Self-Organized Criticality* by Jensen

HIGHLY OPTIMIZED TOLERANCE:
J.M. Carlson, J. Doyle*, PRE* **60**, 1412 - 1427 (1999)
J.M. Carlson, J. Doyle, *PRL* **84**, 2529 - 2532 (2000)

COMPLEX NETWORKS
S. H. Strogatz, *Nature* **410**, 268-276 (2001)
M. E. J. Newman, *SIAM Review* **45**, 167-256 (2003).
R. Albert and A.-L Barabasi, Rev. Mod. Phys. **74**, 47 –97 (2002)

COMPUTATIONAL MECHANICS:
http://hornacek.coa.edu/dave/Tutorial/notes.pdf by Dave Feldman
C. R. Shalizi and J. P. Crutchfield. *Journal Statistical Physics* **104**, 819-881 (2001)