New Course for Winter 2006:

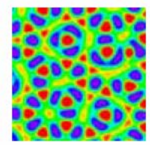
Computational Dynamics of Complex Systems: Phase Transitions

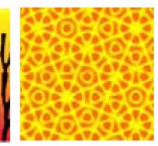
PHYS 250

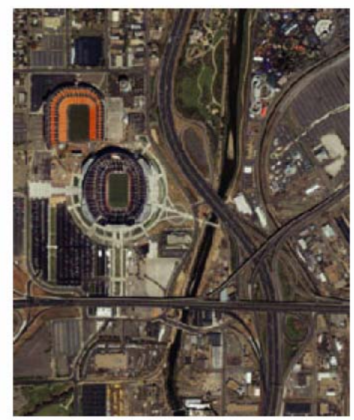
Professor John Rundle

The effects of nonlinearity and complexity represent the most critical constraint on systems throughout all areas of science and engineering, including neural networks, earthquakes, driven foams, magnetic de-pinning transitions in superconductors, and in engineered systems, which include the power grid, the World Wide Web, transportation systems, control systems, and human systems. The purpose of this course is to develop the knowledge and tools to understand the dynamics of these systems, and how system states and transitions can be described in terms of general (and possibly universal) organizing principles.

This course is targeted towards students who are interested in understanding and exploring phase transitions, nucleation, and critical phenomena in complex systems. We will discuss the emergent space-time patterns that are associated with the dynamics, and learn how to characterize these patterns and use the results for understanding natural and engineered systems.







Course Title: Computational Dynamics of Complex Systems: Phase Transitions
Units 3. Lectures 3 hours.

Course No: PHYS 250

Instructor: John Rundle, Professor of Physics and Engineering
Director, Center for Computational Science and Engineering

BACKGROUND AND RATIONALE:

The effects of nonlinearity and complexity represent the most critical constraint on systems throughout all areas of science and engineering, including neural networks, earthquakes, driven foams, magnetic de-pinning transitions in superconductors, and in engineered systems, which include the power grid, the World Wide Web, transportation systems, control systems, and human systems. The purpose of this course is to develop the knowledge and tools to understand the dynamics of these systems, and how system states and transitions can be described in terms of general (and possibly universal) organizing principles.

COURSE CONTENT:

Complex nonlinear systems typically undergo phase transitions, in which fluctuations become important in the dynamics of the system leading to a dramatic changes in the properties, parameters and dynamics of the system. Such phase transitions, which can be of either first or second order, have been studied in many other contexts, especially in liquid-gas-solid thermal systems, and in magnetic systems. This course is targeted towards students who are interested in exploring phase transitions, nucleation, and critical phenomena in complex systems. We will discuss scaling and show how scaling exponents can be calculated. We will place these ideas into a physical context and discuss the tools, both computational and theoretical, that have been developed to understand complexity. We will discuss the emergent space-time patterns that are associated with the dynamics, and learn how to characterize these patterns and use the results for applications. Grades will be based on homework (50%), a take-home exam (25%), and computational project (25%).

CATALOG DATA: PHYS 250. Units 3. Lectures 3 hours. Computational Dynamics of Complex Systems: Phase Transitions. Critical phenomena and scaling in thermal, magnetic, and other complex nonlinear systems. Applications to nonlinear systems encountered in science and engineering.

PREREQUISITES: PHYS 112 or equivalent; MATH 121 & MATH 167 or PHYS 104C or equivalent; ENG 5,6 or equivalent

COURSE TEXTS:

D. Stauffer and A. Aharony, *Introduction to Percolation Theory,* Taylor and Francis, London, 1994, ISBN 0-7484-0253-5.

N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*, Addison-Wesley, Reading, MA ISBN 0-201-55409-7.

Lecture notes on the nucleation and critical phenomena (to be handed out)

REFERENCES:

P. Papon, J. Leblond, P.H.E. Meijer, *The Physics of Phase Transitions, Concepts and Applications*, Springer, ISBN 3-540-43236-1.

H. Mori and Y. Kuramoto, *Dissipative Structures and Chaos*, Springer, ISBN3-540-62744-8

H. Eugene Stanley, *Introduction to Phase Transitions and Critical Phenomena*, Oxford, ISBN 0-19-505316-8

JJ Binney, NJ Dowrick, AJ Fisher, MEJ Newman, *The Theory of Critical Phenomena*, Oxford, ISBN 0-19-851393-3

PHYS 250: Computational Dynamics of Complex Systems: Phase Transitions
Proposed for Winter 2006

COURSE OUTLINE - TOPICS (30 Lectures):

I. INTRODUCTION & OVERVIEW

A. Administrative Trivia
B. Physical & Philosophical Motivation
C. Scaling, Fractals, Noise and Randomness
D. Statistical mechanics, phase transitions, complexity

II. PHASE TRANSITIONS AND SCALING IN COMPLEX SYSTEMS

A. What is a Complex System, and how do we understand them?
B. First and second order transitions
C. Role of numerical simulation
D. Clusters & diffusions, importance of spatial scales, scaling & scaling ideas
E. Scaling theories, cluster structure, Renormalization Group
F. Relation to thermal phase transitions (magnetism), resistor networks
G. Neural networks: Bistate models, Hopfield networks, Integrate-and-Fire networks, the problems of associated memory and learning
H. Self Organized Criticality and sandpiles
I. Earthquakes: First order transitions, nucleation, droplet models, spinodals
J. Ideas from thermodynamics: Free energy function, Lyapunov functions, and entropy
K. Applications to natural and engineered systems