UPDATED ***December 5, 2010*** http://www.cns.gatech.edu/~roman/phys4267/index.html

Introduction to Nonlinear Dynamics and Chaos

Instructor

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Office hours: Tuesday 1-2pm

Place and Times

Tuesdays and Thursdays, 9:35-10:55am
Room S107, Howey Physics Building

Course Description

The material covered includes differential equations, their stability and bifurcations, iterated maps, deterministic chaos, fractals, and strange attractors with applications to physical, chemical, and biological systems.

Textbook

Steven Strogatz: *Nonlinear Dynamics and Chaos* (Perseus Books, 1998). All chapter and exercise numbers refer to this book, unless stated otherwise.
Other books you might find useful:

- Maps:
  - H. Schuster, *Deterministic Chaos*, VCH, Weinheim.
  - K. Aligood, T. Sauer, J. Yorke, *Chaos: an Introduction to Dynamical Systems*, Springer-Verlag, New York.
- Hamiltonian Systems:
  - A. Lichtenberg, M. Liebermann, *Regular and Stochastic Motion*, Springer-Verlag, New York.
- Perturbation Theory:
  - C. M. Bender and S. A. Orszag, *Advanced Mathematical Methods for Scienists and Engineers: Asymptotic Methods and Perturbation Theory*, Springer, New York.

Homeworks

Homework assignments will be posted on the web every Thursday and will be due next Thursday in class. You can discuss problems with each other, but the solutions have to be executed and submitted individually. Some assignments will include problems (in blue font), which are mandatory for graduates and optional (for extra credit) for undergraduates. In general you are expected to comply with the academic honor code. Grades will based on the results of the homework assignments (50%), midterm (20%), and final exam (30%).

Course Schedule

August 24

1. Introduction

Reading: Chapter 1, lecture notes

August 26

2. Flows on the line

Reading: Chapter 2, lecture notes
Fun stuff: snowflakes and synchronization
Problem set #1: 2.1.5, 2.2.10, 2.3.3, 2.4.2, 2.4.9 (solutions)

August 31

3. Lyapunov function

Reading: Chapter 2, lecture notes

September 2

4. Numerical solution of nonlinear ODEs

Reading: Chapter 2, lecture notes, Sections 16.0-16.3 of *Numerical Recipies* by Press *et al.*
Problem set #2: 2.5.3, 2.7.6, 2.8.3 (solutions)
Note: There is a typo in 2.8.3 part (c): you are to plot ln(E) vs. ln(Delta t). Explain how the slope is related to the order of the method.

September 7

5. Bifurcations in one-dimensional systems

Reading: Chapter 3, lecture notes

September 9

6. Bifurcations in one-dimensional systems (continued)

Reading: Chapter 3, lecture notes
Problem set 3: 3.1.3, 3.2.6, 3.3.1, 3.4.8, 3.5.7 (solutions)

September 14

7. Flows on a circle

Reading: Chapter 4, lecture notes

September 16

8. Two-dimensional systems

Reading: Chapter 5, lecture notes
Problem set 4: 3.6.2, 3.7.6, 4.1.8, 4.3.7, 4.6.3 (solutions)

September 21
9. Phase plane analysis
Reading: Chapter 6, lecture notes

September 23
10. Conservative systems
Reading: Chapter 6, lecture notes
Problem set 5: 5.1.10, 5.2.13, 6.1.3, 6.2.1, 6.3.1, 6.4.7 (solutions)

September 28
11. Limit Cycles
Reading: Chapter 7, lecture notes

September 30
12. Perturbation theory
Reading: Chapter 7, lecture notes
Problem set 6: 6.5.10, 6.6.3, 6.7.2, 6.8.5, 6.8.7 (solutions)

October 5
13. Nonlinear oscillators and averaging
Reading: Chapter 7, lecture notes, Bender and Orszag

October 7
14. Bifurcations in two dimensions
Reading: Chapter 8, lecture notes
Problem set 7: 7.1.6, 7.2.9, 7.3.9, 7.4.1 (solutions)

October 12
Mid-term exam

October 14
15. Hopf bifurcation
Reading: Chapter 8, lecture notes

October 21
16. Global bifurcations of cycles
Reading: Chapter 8, lecture notes
Problem set 8: 7.5.4, 7.6.3, 7.6.6, 7.6.17 (solutions)

October 26
17. Quasiperiodicity and Poincare maps
Reading: Chapter 8, lecture notes

October 28
18. Floquet Theory
Reading: Chapter 8, lecture notes
Problem set 9: 8.1.8, 8.1.11, 8.2.1, 8.2.9, 8.3.1 (solutions)

November 2
19. Lorenz equations
Reading: Chapter 9, lecture notes
Numerical exploration of different dynamical regimes (Maple)

November 4
20. Lorenz equations
Reading: Chapter 9, lecture notes
Problem set 10: 8.4.2, 8.4.12, 8.5.2, 8.6.1, 8.7.5 (solutions)

November 9
21. One-dimensional maps
Reading: Chapter 10, lecture notes

November 11
22. Universality
Reading: Chapter 10, lecture notes
Matlab simulations of the Rossler system: reduction to 2D and 1D maps and stretching of phase space volumes
Problem set 11: assignment (solutions)

November 16
23. Statistical characterization of chaotic motion
Reading: Chapter 10, lecture notes, Schuster

November 18
24. Fractals
Reading: Chapter 11, lecture notes, Schuster
Fractals in nature, biology, and mathematics.
Problem set 12: 10.1.11, 10.2.6 (see comments for 10.2.3), 10.3.11, 10.4.1 (solutions)

November 23
No class

November 25
Holiday

November 30
25. Symbolic Dynamics
Reading: lecture notes, Aligood, Sauer, and Yorke

Problem set 13: assignment (solutions)

December 2

26. Strange Attractors

Reading: Chapter 12, lecture notes, Schuster

December 7

27. Hamiltonian chaos

Reading: lecture notes, Lichtenberg and Liebermann

December 9

28. Hamiltonian chaos

Reading: lecture notes, Lichtenberg and Liebermann

Final exam

Take home, see instructions

Course Instructor Opinion Survey

Please fill out the online Course Survey. This is your real opportunity to provide feedback regarding the contents of the course, the style and quality of the presentation, or any other subject related to the course. Tell us what you liked and what you did not like. Your input is very valuable and will benefit students taking this course in subsequent years.