University of Colorado
Department of Computer Science

Chaotic Dynamics
Spring 2019

General Information

Catalog Number:	CSCI 5446-001 CSCI 4446-001	grad undergrad
Time/Place:	Tuesdays & Thursdays 9:30-10:45am in ECCR 135	
Webpage:	`www.cs.colorado.edu/∼lizb/chaos-course.html`	
Instructor:	Liz Bradley `lizb@cs.colorado.edu`	ECOT 747 303-492-5355
Office Hours:	mondays from 1:30-3pm and at other times by appointment; please email me to set up a time. **Note!** it's a good idea to check my web page for changes before you come by.	
Texts:	*Nonlinear Dynamics and Chaos*, S. Strogatz, Addison-Wesley.	**[required]**
	Nonlinear Time-Series Analysis, H. Kantz and T. Schreiber	**[required]**

Description:

This course explores dynamical systems and the various ways to use a computer to investigate their behavior. It covers the standard computational and analytical tools used in nonlinear dynamics, together with their underlying theory, and concludes with a brief review of leading-edge chaos research. Examples of important topics and techniques are: state-space representation, interpretation, and surfaces of section; steady-state solutions and limit sets; numerical integration; time and frequency domain analysis; bifurcation diagrams; fractals, fractal dimension, and the link between fractals and chaos; etc. Students construct their own computational tools and use them to explore interesting chaotic systems, ranging from mechanical pendulums to biological populations to electronic circuits.

Strogatz's book will be the primary text. It is well-written and thorough, but gets mathematically dense now and then. The reading assignments at the beginning of each problem set will identify these places and lectures will guide you through them. The text will be supplemented by xeroxed material and current research papers, as well as a comprehensive reserve list from the Gemmill Engineering Library. A running bibliography of other interesting (but optional) material will be given in the problem sets. The Kantz/Schreiber book is a great source of both background material and algorithms for time-series analysis. Most of the algorithms described in that book are instantiated in the TISEAN package.

This year, we will also be using some online materials from a MOOC offered through the Santa Fe Institute's Complexity Explorer platform. This will include a couple of short videos for you to watch before each lecture, together with an (ungraded) online quiz about each one, and a series of ten "unit tests," which will be part of your grade for the course. You may take the unit tests whenever you wish—any time before the final exam—but previous students have found that they're useful in studying for the final. There are a couple of problems here & there on the unit tests that aren't applicable because our homework is different than the MOOC assignments (e.g., the question about the trapezoidal solver on unit test 6). Just skip those; I'll normalize that out of the grades.

> **Note:** this is an up-to-the-minute current-topics course, and a substantial percentage of the material that we will discuss is not covered in *any* textbook or paper. *Do not take this class unless you plan to attend all the lectures. Really. You won't be able to pass the final exam if you don't.* The MOOC videos can help, but they're at a much lower level than CSCI 4446/5446.

Assignments, workload, and expectations:

The heart of this course is a sequence of thirteen problem sets. People who are registered for CSCI 5446 will do a month-long final project instead of the last three homework sets. A cumulative exam will be held for everyone during the scheduled final exam period (Tuesday 8 May from 4:30-7pm). If you have three exams scheduled on May 8th, I need to know before the tenth week of the semester in order to make accomodations. You can find the exam schedules here:

`www.colorado.edu/registrar/calendars-schedules/final-exams-schedule`

There will also be one or two short videos due before each lecture, along with an online quiz about the material covered in those videos due at the end of every week. These will not be graded—there are solution videos online as well—but they will prepare you to absorb the in-class material more easily, and to pass the ten online "unit tests" that *are* part of your grade. All of these materials will be listed on the problem-set handouts and also on `www.cs.colorado.edu/~lizb/chaos/videos.html`.

You should expect to spend at least 8-10 hours per week of prep time—outside of lecture—on this class. Roughly a quarter of that time will be spent writing code, about half playing with your code and figuring out the results, and the other quarter reading source materials and thinking about the concepts that were presented in class.

An important point about the assignments: *each one builds upon the previous ones.* That means that you can't punt a problem set; you have to get the code for every assignment at least mostly working. The final project and the final exam will also depend upon successful completion of the assignments.

You are free to work together on homework during the initial problem-solving stages, but you should *finish, polish, interpret, and write up* your work on your own. You should also feel free to consult me or the other class members for clarifications, corroboration, suggestions, debugging help, etc., at *any* point in any assignment. Please do not carry this to the point where anyone avoids learning from the assignments. In particular, the final, turned-in version of all assignments should be your own work. That includes words, code, ideas, etc. Identical material will garner a zero grade for that assignment, and possibly a discussion with the Honor Code Council[1], for all of the people involved, regardless of who copied from whom. If you are in any doubt about where the academic honesty boundaries lie for this class, please ask me.

Computers:

The most critical of this course's prerequisites, besides independence and motivation, is functional computer literacy. If you are not totally comfortable hacking code, you may still enroll in this course, but be prepared to spend 15+ hours per week on it instead of the 8-10 hours cited above.

You may use any computer, language, and graphics package that you want. In the past, people have used PCs, Macs, and Unix machines; the graphics need not be whizzy, just good enough to plot a bunch of points on a scaled, labeled axis. Please come see me if you do not have access to adequate computer facilities and I will make arrangements.

Note that there is very little canned software for this course, and for a very important reason: I want you to understand the details of the algorithms, which only happens when you write them yourself from scratch. Almost all of what you turn in will be graphics output, sketches, and written analysis and interpretation of the patterns and trends you see in the pictures. I will not grade your code for style; I'm interested in what comes out of it, not how well-commented or well-written it is.

Grades:

Grades will be based on the homework, the online unit tests, and the final exam (for everyone) and the final project (for those enrolled in 5446). Here are the operative formulae:

CSCI 5446: 40% homework + 40% project + 15% final exam + 5% unit tests

CSCI 4446: 75% homework + 20% final exam + 5% unit tests

You must get all the programs to work at a basic level, understand and explain the results, and turn in all problem sets to pass this course. You must do so elegantly, thoughtfully, and in a timely fashion to get an A.

If you contribute actively to class discussions, I will bump your grade upwards, up to a full letter grade. This kicks in only above the passing threshold: I will not use class participation will not be used to change Fs into Ds. And note that "participation" does not just mean "attendance"—although, in my experience, there is a **very** strong correlation between attendance and final-exam performance.

[1] `http://www.colorado.edu/academics/honorcode/`

It is very difficult to pass this class, let alone do well, if you do not attend the lectures. Again, much of the course material is not in any textbook, webpage, video, or slide deck. Please plan accordingly.

Syllabus:

- General introduction to chaos (1 1/2 lectures)
- Dynamics of iterated maps (2 1/2 lectures)
- Fractals and fractal dimension (1-2 lectures)
- Continuous-time dynamics (3 lectures)
- Applications (1 lecture)
- Poincaré sections (2 lectures)
- Attractor characterization (6 lectures)
- Hamiltonian chaos (3 lectures)
- Prediction, modeling, and noise (1-2 lectures)
- Stability (2-3 lectures)
- Current topics (1 lecture)
- Project presentations (1-2 lectures)

Accomodations and other policies:

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, send me an email as soon as you can so we can figure out how to address your needs. (The "Temporary Medical Conditions" guidelines under the Students tab on the Disability Services website may also be useful in these situations.)

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. If you have religious obligations that will cause logistical issues in this class (e.g., with turning in an assignment or attending a lecture), please let me know at least two weeks in advance so that we can work out alternatives.

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline.

Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Class rosters are provided to me with the student's legal name, but I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior[2] and the Student Code of Conduct (`www.colorado.edu/osccr`.)

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website[3].

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. *Please note: "plagiarism" includes turning in code that you copied from somewhere on the web, even if you made some cosmetic changes in order to conceal that fact.* All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

Materials on Reserve in the Gemmill Engineering Library:

- H. Abarbanel, *Analysis of Observed Chaotic Data*, Springer, 1995.
- R. Abraham and C. Shaw, *Dynamics: The Geometry of Behavior*, 2nd edition, Addison Wesley, 1992.
- G. Baker and J. Gollub, *Chaotic Dynamics: An Introduction*, Cambridge, 1996.
- M. Barnsley, *Fractals Everywhere*, Academic Press, 1993.

[2] `www.colorado.edu/policies/student-classroom-and-course-related-behavior`
[3] `www.colorado.edu/institutionalequity/`

- T. Bass, *The Eudaemonic Pie*, Houghton-Mifflin, 1985.
- D. Campbell *et al.*, eds., *Nonlinear Science: The Next Decade*, M.I.T. Press, Cambridge MA, 1992.
- D. Campbell, ed., *Chaos/XAOC: Soviet-American perspectives on nonlinear science,* American Institute of Physics, New York, 1990.
- M. Casdagli and S. Eubank, eds., *Nonlinear Modeling and Forecasting*, Addison Wesley, 1992.
- P. Cvitanovic, *Universality in Chaos*, Adam Hilger, 1989.
- J. Danby, *Fundamentals of Celestial Mechanics*, Willmann-Bell, second edition, 1992.
- J. Gleick, *Chaos: Making a New Science*, Viking, 1987.
- H. Kantz and T. Schreiber, *Nonlinear Time Series Analysis*, Cambridge University Press, 1997
- G. Mayer-Kress ed., *Dimensions and Entropies in Chaotic Systems*, Springer-Verlag, Berlin, 1985.
- E. Ott, T. Sauer, and J. Yorke, eds., *Coping With Chaos*, Wiley, 1994.
- E. Ott, *Chaos in Dynamical Systems*, Cambridge, 1993.
- T. Parker and L. Chua, *Practical Numerical Algorithms for Chaotic Systems,* Springer-Verlag, 1989.
- I. Peterson, *Newton's Clock: Chaos in the Solar System*, Freeman, 1993.
- I. Stewart, *Does God Play Dice? The Mathematics of Chaos*, Blackwell, 1989.
- S. Strogatz, *Nonlinear Dynamics and Chaos*, Addison-Wesley, 1994.
- L. Taff, *Celestial Mechanics: A Computational Guide for the Practitioner*, Wiley, 1985.
- A. Weigend and N. Gershenfeld, eds., *Time Series Prediction: Forecasting the Future and Understanding the Past*, Santa Fe Institute Studies in the Sciences of Complexity, Santa Fe, NM, 1993.

In an ideal world, science and mathematics would be completely objective. In reality, however, these fields are to at least some extent subjective, and they are built on a small subset of privileged voices. I have made an effort to diversify the sources from which I draw, but the possibilities were limited and the material may contain overt or covert biases, even though the material is primarily scientific and/or mathematical. Please contact me (in person or electronically) or submit anonymous feedback if you have any suggestions as to how to improve the quality of the course materials.

I really want to create a learning environment for my students that supports a diversity of thought, perspectives, and experiences, and honors your identities (race, gender, class, sexuality, religion, ability, ...) As a participant in this class, you should strive to honor the diversity of your classmates. And if something was said in class—by anyone—that made you feel uncomfortable, please talk to me about it. Again, anonymous feedback is always an option.