Physics 505: Topics in Physics
Chaos and Time-Series Analysis
Fall 1994 Course Description

Content and Level: This course is an introduction to the exciting new developments in chaos and related topics in nonlinear dynamics, including the detection and quantification of chaos in experimental data. Emphasis will be on the physical concepts rather than mathematical proofs and derivations. The course will be taught at a level that should be accessible to graduate and advanced undergraduate students in all fields of science and engineering.

Prerequisites: Consent of instructor (calculus and some programming experience will be assumed)

Materials Needed: Text: *Chaos and Nonlinear Dynamics: An Introduction for Scientists and Engineers*, by Robert C. Hilborn (Oxford University Press, 1994)

Computer: Any type will do, but you will need a compiler (or interpreter) for the machine in the language of your choice and a printer capable of printing graphics.

Lectures: 3:30-5:10 pm, Tuesdays, 1313 Sterling. Prof. Clint Sprott (3285 Chamberlin Hall, 263-4449, sprott@juno.physics.wisc.edu). The lectures supplement but do not substitute for the reading. They will be used mainly to motivate the material and to show demonstrations, computer animations, slides, and videos.

Homework: Homework will consist of weekly programming assignments that are due at the beginning of the lecture the following week. An elaborate writeup is not required, but you should provide evidence that you completed the assignment. In many cases, a screen print may be all that is required. You should fill out the cover sheet and turn it in with each assignment. You may work with others, but be sure the work you turn in is not simply copied from someone else.

Exams: There will be no exams in the course.

Grading: The grading will be based entirely on the homework. You will receive one point for each assignment that you complete, and one point for handing it in on time. With 15 assignments, your total possible score is thus 30. Letter grades will be assigned as follows: A = 26-30, AB = 21-25, B = 16-20, BC = 11-15, C = 6-10, D = 1-5, F = 0

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References are to Robert C. Hilborn, *Chaos and Nonlinear Dynamics: An Introduction for Scientists and Engineers* (Oxford University Press, 1994).

Week	Date	Reading	Topic
1	9/6	Ch 1	Introduction and Overview
2	9/13	Ch 2	One-Dimensional Maps
3	9/20	Ch 3	Dynamical Systems Theory
4	9/27	Ch 4	Chaotic Dissipative Flows
5	10/4	Ch 5	Iterated Maps
6	10/11	Ch 6	Strange Attractors
7	10/18	Ch 7	Stability and Bifurcations
8	10/25	Ch 8	Hamiltonian Chaos
9	11/1	Ch 9	Lyapunov Exponents and Entropy
10	11/8	Ch 9	Nonlinear Prediction and Noise Reduction
11	11/15	Ch 9	Fractals
12	11/22	Ch 9	Calculation of Fractal Dimension
13	11/29	Ch 10	Multifractals
14	12/6	Ch 11	Non-Attracting Chaotic Sets
15	12/13	Ch 12	Spatiotemporal Chaos and Pattern Formation

Bibliography

The following books will serve as useful outside reading for the serious student. They are all available in libraries on campus.

Barnsley, M. F., et. al., *The Science of Fractal Images* (Springer-Verlag, 1988). This is a very readable collection of articles describing the mathematics that underlies the computer generation of fractal patterns.

Devaney, R. L., *A First Course in Chaotic Dynamical Systems: Theory and Experiment* (Addison Wesley, 1992). This undergraduate mathematics book provides an excellent formal introduction to chaos and fractals. (See also the other books by Devaney.)

Gleick, J., *Chaos: Making a New Science* (Viking Penguin, 1987). Everyone should read this best-selling, historical, nontechnical account to understand why people are so excited about chaos.

Guckenheimer, J. and Holmes, P., *Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields* (Springer-Verlag, 1983). This is an advanced but standard text that's good for anyone who wants to dig deeper into the mathematics of the topics we are covering.

Gulick, D., *Encounters with Chaos* (McGraw-Hill, 1992). Here's a book that has all the theorems and proofs that we are omitting in our course.

Hilborn, R. C., *Chaos and Nonlinear Dynamics: An Introduction for Scientists and Engineers* (Oxford University Press, 1994). This book was chosen as our text because of its breadth and depth of coverage. It emphasizes the computer as a learning tool, and it has a thorough, up-to-date, annotated bibliography. It contains more material than we will cover, but you will be pleased to have it as a reference.

Jackson, E. A., *Perspectives of Nonlinear Dynamics* (Cambridge Univ. Press, 1991). This two-volume graduate-level text is a bit more advanced than our text, but covers all the essentials and includes many nice drawings.

Lorenz, E. N., *The Essence of Chaos* (Univ. of Washington Press, 1993). This series of popular lectures by one of the pioneers in the field attempts (with some success) to explain the mathematical ideas underlying chaos without using equations.

Mandelbrot, B. B., *The Fractal Geometry of Nature* (Freeman, 1982). This extended essay by the father of fractals was the seminal work that brought to the attention of the nonspecialist the ubiquity of fractals in nature. Read it if you're still not sure what fractals have to do with the real world.

Moon, F. C., *Chaotic and Fractal Dynamics: An Introduction for Applied Scientists and Engineers* (Wiley, 1992). Here's a book with more of an engineering flavor that includes many practical applications and examples of chaotic behavior. It's an update of an earlier (1987) edition.

Ott, E., *Chaos in Dynamical Systems* (Cambridge Univ. Press, 1993). This is a very insightful, graduate level text by one of the most prolific researchers in the field, using high-level mathematics only as necessary to elucidate the concepts and not as an end in itself.

Peitgen, H. O. and Richter, P. H., *The Beauty of Fractals: Images of Complex Dynamical Systems* (Springer-Verlag, 1986). Here's a book that will boggle your mind with beautiful images mainly from the Mandelbrot and Julia sets. It's computer art at its finest. (See also the other books co-authored by Peitgen.)

Pickover, C. A., *Computers, Pattern, Chaos and Beauty: Graphics from an Unseen World* (St. Martin's Press, 1990). This is a how-to book by the master of computer graphic art and visualization filled with original ideas for the computer generation of fractals and other artistic patterns. (See also the many other engaging books by Pickover.)

Schroeder, M., *Fractals, Chaos, and Power Laws: Minutes from an Infinite Paradise* (Freeman, 1991). This is a highly readable book packed with examples of temporal and spatial chaos in enormously diverse contexts (and a wealth of puns).

Sprott, J. C., *Strange Attractors: Creating Patterns in Chaos* (M&T Books, 1993). This is a popularization that uses computer art as a means for discussing the principles of chaos. It's included here on the strength of its author.

Sprott, J. C. and Rowlands, G. *Chaos Demonstrations* (Physics Academic Software, Box 8202, North Carolina State University, Raleigh, NC 27695, 800-955-TASL). This is the (IBM) computer software that will be used for most of the demonstrations in the course. It is on display in the Physics Museum (1328 Sterling). See also the *Chaos Data Analyzer* program by the same authors and publisher for time-series analysis.

Stewart, I., *Does God Play Dice?: The Mathematics of Chaos* (Blackwell, 1989). This is a charming little book that's basically a popularization but that doesn't shy away from using simple mathematics.

Thompson, J. M. T. and Stewart, H. B., *Nonlinear Dynamics and Chaos* (Wiley, 1986). This is a standard advanced undergraduate text aimed at physical science students. It's a bit uneven in the level of treatment of the various topics, but it might have served as a text for our course.

Tsonis, A. A., *Chaos: From Theory to Applications* (Plenum Press, 1992). This book is especially good on the time-series analysis topics that are largely missing from the other books. It might have been a text for our course except that it is less thorough, has fewer references, and costs a bit more than Hilborn.

Comments on Computers and Programming

You will need to approach the study of chaos differently from other math and science courses you have had. Although most of the phenomena we will be discussing are described by equations, the equations generally cannot be solved in the usual ways you have learned. The computer becomes a necessary and convenient tool for understanding chaos. Fortunately, the equations are usually very simple, and the programming requirements are minimal.

You have been given complete freedom to choose a computer and programming language. The best computer is one to which you have easy access. You will probably be happier using a primitive computer at home rather than a fancier one that you have to access by telephone (modem) or by going to one of the computer labs on campus, unless for some reason you prefer to work away from home. Most personal computers are either IBM PC compatibles or Apple Macintoshes. The IBM's are more common and tend to be easier to program, whereas the Macintoshes have a slick graphical user interface (GUI) that you may prefer. If you have no other access to a computer, you are welcome to use the Next machines in the Physics Department computer lab (2409 Sterling).

Just as the best language for speaking is the one most familiar to you, the best computer language is the one you are most comfortable using. If you are skilled in a language such as BASIC, C, Pascal, or FORTRAN, get a modern interactive compiler for that language and use it on your PC. Any language will suffice, and modern compilers in the various languages are so good that there is little reason to prefer one over another. If you have never done any serious programming, you might start by learning BASIC. It is easy to learn and more than adequate for the assignments you will be asked to do. My personal favorite is PowerBASIC for the IBM (Available for $137 from Programmer's Paradise, 1163 Shrewsbury Ave., Shrewsbury, NJ 07702, 800-445-7899). The closest thing for the Macintosh is Microsoft QuickBASIC ($63 from MACC), but it's not nearly as versatile, fast, or easy to use as PowerBASIC. You might visit the MACC Showroom (Room 1150) for advice, demonstrations, and information on how to purchase a suitable compiler.

Another possibility you may wish to consider is one of the algebraic manipulation tools such as Mathematica, Maple, Derive, or Theorist, or even a modern spreadsheet program such as Microsoft Excel. This option would be most sensible if you are already highly skilled in its use. You should be able to complete most if not all of the assignments in this way. In the long run, you will probably find a conventional programming language more versatile and useful, however.

In any case, I would advise you to develop your programs as modular subroutines and to document them so that they can be reused. There will be occasions during the semester where you will need something you did several weeks previous. Especially as we move into the time-series analysis part of the course, you will be developing routines that may be of use to you in analyzing experimental data after the course concludes.

Student Questionnaire

In an effort to construct the course to best meet your needs, I'd appreciate it if you would provide me with some information about yourself. You may turn this sheet in with your first homework set.

Name: ______________________________

E-mail or other address: ______________________________

Year/Major: ______________________________

Are you taking the course for credit? ______________________________

What type of computer do you have (if any)? ______________________________

What computer languages do you know? ______________________________

How much programming experience do you have? ______________________________

What do you hope to learn from the course? ______________________________

Comments: