(18.353/12.006/2.050)j Nonlinear Dynamics: Chaos.

Tue and Thu 9:30-11:00 in room 2-131.

Quotes and anecdotes you should keep in mind.
Chinese proverb: *He who asks a question is a fool for five minutes; he who does not remains a fool forever.*
Chinese proverb: *The master leads you to the door, the rest is up to you.*
Anecdote involving Ernest Rutherford (1871-1937), a famous New Zealand physicist (Nobel 1908). The story is told that one student in his laboratory was extraordinarily hard-working. Having taken note of this, Rutherford asked him one evening, "Do you work in the mornings too?" The student (expecting commendation) proudly replied: "Yes!" Rutherford then looked puzzled, and asked in amazement: "But when do you think?"

Video: This course will be taught in person, but the lectures will be recorded and made accesible through the canvas page (check the Panopto link). A couple of lectures may be done via Zoom, because it is easier to show computer videos and such in this way. *Please do not plan to be on a plane on Tue Nov. 21 at lecture time,* since this lecture may be one of the zoom ones, and you will need a wi-fi connection.

Webpages: The course has two web pages: one public in the Math. site, and another in canvas [to upload problem set answers and get back graded sets, for announcements, to access piazza, to access class recordings or virtual lectures, etc.]. The **main page** is the public one, to which canvas is linked at various places. Please **check this webpage regularly.**
Main web page: https://math.mit.edu/classes/18.353J/index.html

Textbook: S. Strogatz, *Nonlinear Dynamics and Chaos*, Westview press [paperback]. Most of the course material is in the book [we will cover a good fraction of the book material]. But the lectures will not necessarily follow the book, and in some topics we may depart from it. We will also use notes posted in the (main) web page, as well as the notes in the MIT Open CourseWare web page from 2022 [when the course was taught by D. Rothman].

Pre-requisites: Physics II (GIR) and (18.03 or 18.032).

MatLab: I **urge you to become proficient in MatLab.** MatLab course scripts may be used in the lectures, and you should use them to reinforce the course materiel. MatLab will also be needed for the problem sets. See the course web page for more MatLab information. Some MatLab scrips will be provided, but you can use other software, as long as it does the job (e.g.: python or Julia).

Team work: I encourage you to form study groups. We will talk about this during the first lecture. PSet Partners https://psetpartners.mit.edu can be helpful to find study partners.
Please **read the POLICIES entry in the web page.**

Instructor: R. Rosales, rrr@math.mit.edu, room 2-337, x3-2784.
Off. Hours: TBA, **check the News UPDATES link in the web page.**
Easiest way to contact me is by email. If we need to meet, we can schedule a meeting.
Do not drop by my office (or call my office phone), I am not there very much.
For technical questions, use piazza, so everyone has access to the answer.

TA/grader: TBA, **check the News UPDATES link in the web page.**

Exams: None. Neither midterm, nor final. See **GRADING** below.

Problem sets: 8 (± 1) problem sets (one every ≈ 1.5 weeks). See **GRADING** below.
Do them all: *you need them to learn the material.* **You will need a computer, and MatLab.** Complete answers will be posted after their due date.

TPCP: You will need either a **Term Paper** or a **Course project**. See **GRADING** below.

GRADING: Each problem set will contain a buried mini-quiz within it (1-3 problems). Only the quiz will be

graded, but you need to do all the problems, since the quiz problems will not be identified. The course grade will be based on the cumulative quiz-grade, and a binary-grade for the TPCP.
TPCP grading: If you hand in an "acceptable" TPCP, then the grade is quiz-based, as explained above. Else the grade is F. **The TPCP is due the last day of November, and I its topic must be approved by November 9,** *but I strongly recommend that you start earlier than this!*

Term paper. On any topic relevant to the course materiel. It does not have to be original research, but it must be original work [e.g.: review the literature in some topic, and summarize the results in your own words].

Course Project. A short report discussing any application of Dynamical Systems methods to a physical system that you find interesting. The topic or model does not need to be excessively complex. This can be an original topic, or a review of an existing application. Possible topics include specific applications to: aerodynamics and fluid flow, astrophysics, biological system models, chemical reactions, classical mechanics, ecosystem models, epidemiology, sports, and transportation. **I will post a pdf file with some suggestions in the web page.**

The TPCP must obey the following guidelines:

- Instructor pre-approval is required.
- Must be typed (font size 11-12) and submitted electronically in **pdf format**.
- Length should not exceed 15 pages (less is better, I suggest about 5), using standard page formatting. You can use more if you have many figures, but use judgement here!
- *The explanations must be clear, and accessible by someone with the level of an average student in the class.*
- *Be certain to give proper credit to your sources.*
- You **must have the topic approved** by November 9.

Failure to follow all these guidelines may result in a paper being classified as "not acceptable". Note that **the distinction between "term paper" and "course project" is fuzzy.** *This is intentional,* so you have freedom to be creative. Propose something somewhat "open ended", different from doing a problem set, and which requires you to plan and write a coherent exposition of some interesting topic . . . and I will probably approve it.

Problem set answers. The problem set answers **must be typed** and then uploaded to the Canvas web page. I will provide you with a "LaTeX template" that you can use for this purpose. Most science journals require papers to be submitted in LaTeX format; you should learn it.

OUTLINE of the Course: Some things may be covered in more detail than this implies, or the reverse.

- One-dimensional systems (flows on the line) and elementary bifurcations.
- Flows on the circle. More bifurcations.
- Review of linear systems. Classification of critical points.
- Two-dimensional systems; phase plane analysis, limit cycles. More bifurcations.
- Index theory. Poincaré-Bendixson theory (maybe).
- Nonlinear Oscillators, qualitative and approximate asymptotic techniques, Hopf bifurcations (maybe).
- Lorenz and Rossler equations, chaos, strange attractors and fractals.
- Iterated mappings, period-doubling, chaos, renormalization, universality.
- Hamiltonian systems; complete integrability and ergodicity (maybe).
- Area preserving mappings, KAM theory (maybe).
- Other: Floquet theory, Infinite Dimensional Hamiltonians, Dissipative-driven Systems, etc.

I will post in the web page a "schedule", which I will update to keep it more-or-less accurate. **Since there are no exams, the key thing to keep in mind is that there will be a problem set every 1.5 weeks (and you will have at least a week for each, from posting till due).** And, of course: **start working on the TPCP early!**

Additional references (in the library):

S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, Springer-Verlag. More "mathy" than Strogatz. Used for some topics.

P. G. Drazin, *Nonlinear Systems*, Cambridge U. P.

H-O Peitgen, H. Jurgens and D. Saupe, *Chaos and Fractals. New frontiers of science*, Springer-Verlag.

T. S. Parker and L. O. Chua, *Practical numerical algorithms for chaotic systems*, Springer-Verlag.

D. W. Jordan and P. Smith, *Nonlinear Ordinary Differential Equations*, Oxford U. P.

P. Berge, Y. Pomeau and C. Vidal, *Order Within Chaos*, Wiley.

S.W. McCuskey, *Introduction to Celestial Mechanics*, Addison Wesley.

J. Guckenheimer and P. Holmes, *Nonlinear Oscillations, Dynamical Systems and Bifurcations of Vector Fields*, Springer Verlag. Subject covered at a rigorous level, with proofs requiring knowledge beyond course pre-requisites (say, at the level of **Coddington & Levinson,** *Theory of Ordinary Differential Equations*, McGraw-Hill or Krieger).

A. J. Lichtenberg and M. A. Lieberman, *Regular and stochastic motion*, Applied Math. Sciences #38, Springer. New title: *Regular and chaotic dynamics.*

R. S. MacKay and J. D. Meiss, *Hamiltonian Dynamical Systems; a reprint selection*, CRC Press.

The End