Monday, Wednesday, Friday 1:30-2:45pm ET
Course meets in Pierce 301

Instructor: Sarah Iams
Office: 316 Pierce Hall (at the end near MD)
Phone: 617-495-5935 (I check my office voicemail regularly)
Email: siams+am108@g.harvard.edu (message via Ed for questions about the course)
Office hours: See Canvas.
Course Team: Cyrus Asgari, Janice Nam, Emma Salafsky, Calliste Skouras

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Prerequisites. Multivariable calculus and linear algebra. Exposure to differential equations at the level of Math 1b + Math 21b (or willingness to self study the differential equations content of those courses).

Prerequisite topics to review:

- linear approximation for functions of one variable
- plotting functions of one variable
- single variable differentiation and integration
- vector fields
- gradient vectors
- computing eigenvalues and eigenvectors
- solving separable ordinary differential equations (ODEs)
- solutions to 2d linear systems of ODEs

Anti-requisite. In some years the curriculum of Math 118r has been similar to that of AM 108. In years when they are similar, it is unlikely to be interesting to take both courses.

What will you gain from this course?

The dynamical systems perspective is a productive perspective for analyzing differential-equation-based models of complex phenomena that occur across a wide range of application areas. Our emphasis is on developing an understanding of dynamical systems and of geometric methods for analyzing them. Numerical solution techniques are important for exploring the behaviors of solutions to these systems, so this course includes a computational component.

Learning goals:

- We will connect the dynamical systems framework to phenomena in the world, furthering a quantitative viewpoint.
- Working in teams, explicating your ideas for your peers, advocating for your own understanding, writing solutions to problem sets, and developing and presenting your final project contribute to the development of collaboration and communication skills within a technical context.
- This course will contribute to your knowledge of the discipline of mathematics, including your understanding of the power of mathematics.

- Learning to learn the material in the course creates an opportunity to develop new skills, as needed, to progress towards mastery of the material, and to engage in mathematical inquiry.

Learning objectives:
During the semester you will be asked to

1. describe differential equations as a way of encoding information about the evolution of a physical system, with the goal of identifying or constraining the long term behavior of a solution function to the equation
2. distinguish between analytic solution methods for differential equations and qualitative or numerical methods that provide only an estimate of the solution function
3. develop facility with geometrically-based qualitative solution techniques, including identifying critical points, assessing their stability, and using phase portraits to constrain our understanding of the long term behavior of a solution
4. identify bifurcations and describe their importance (by *bifurcation* we mean qualitative changes in system behavior that occur as a parameter is varied);
5. apply techniques, including nondimensionalization, linearization, and the use of recurrence maps, to analyze a dynamical system
6. describe the phenomenon of chaos and relate it to stretching and folding, as well as to example systems
7. justify the use of these methods as a valuable way to understand differential equations
8. visualize functions, compute quantities, produce bifurcation diagrams, and find numerical solutions of differential equations using Mathematica.
9. communicate mathematical reasoning in an organized, clear, and detailed way

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Course Materials:

- Course **text**: Steven Strogatz. Nonlinear Dynamics and Chaos, 2nd Edition (1st Edition is fine). 2015. Westview Press.

  Harvard has free online access to this text (via an interface that is a little clunky). Library link.
- A calculator app that can perform basic operations is helpful to have. Consider downloading Desmos to a phone or tablet for graphing.
- Consider installing Mathematica (and possibly Matlab) on your own computer. These are downloadable for free from `http://downloads.fas.harvard.edu/download`, by following their instructions. Instead of installing, you can use them in the cloud once you have made your Harvard account. You are also welcome to use Python if you prefer.

Course Components

- Pre-class preparation: Assigned videos (of up to 60 minutes in total) or readings should be watched/read by the morning of the day for which they are assigned. A short online "Check Yourself" quiz on the day's videos and readings is due before class, as are discussion board posts.

- Skill checks: Complete regular skill checks to support you in building the procedural skills associated with dynamical systems. These are completed in class.
- Problem sets: Eight or nine weekly problem sets containing questions based on textbook readings and class work will be posted on our course website and are due on Friday mornings. These will be marked for completion. The problem set has a problem component and a reflection component.
- Active participation: course meetings consist of collaborative activities and additional explanation around course content.
- There will be two quizzes and a 2d system analysis.
- A final project will be assigned, with **presentations during the final exam period at the end of the semester**. The project will typically be completed in teams of approximately three students. *This course has required presentations during the final exam timeslot that is assigned by the registrar for this course.*

Participation

I expect you to be present at course meetings, to participate in discussions and group work, and to make contributions that forward the learning of our whole class community.

Inclusion.

This class has many participatory components, and different students bring different perspectives, experiences, areas of expertise, and mathematical and subject area backgrounds. Every voice in our course community is important. I ask you to work to purposefully maintain a respectful environment during all interactions with your classmates.

Course Accessibility

I am committed to promoting your success in this course. If you have particular circumstances that might impact your work in this class, please contact me early in the term so that we can work to adapt assignments to meet your needs, within the context of the course requirements. A letter from the Disability Access Office is required for some accommodations or adaptations.

Collaborative Learning and Cooperation.

Our course will often be a collaborative learning environment. As a member of a collaborative team, you are responsible not only for your own learning, but for the learning of the other members of your team.

- Be prepared. Prior to meeting, do the readings, watch the lectures, and think about the problems.
- Contribute to assignment solutions.
- Listen carefully with respect to each other.
- Ask for help when you need it.
- Give help when it is requested.
- Criticize ideas, not people. Be tolerant, respectful, and caring.
- Never agree to something you don't understand when working in a group.

Assessment Schedule. Our course has two quizzes, a 2d system analysis, and a final project. The dates for these are:

- Quiz: Monday, February 26th
- Quiz: Monday, March 25th
- 2d system analysis: Week of April 8th
- Final Project Deadline and Presentations: Final presentations are during the registrar-assigned **final exam** time block and occur during the final exam period. Final projects are also due at that time. Find that time block on my.harvard.

Late Work Policy. Each problem sets can be submitted up to 8 hours late without penalty. In addition, all students have access to a late day of up to 24 hours for use on up to two of the problem sets.

Course Grade.

The standards for different grade categories are below.

Course component	A	B+, A-	B-, B	C-, C, C+
Skill checks	$\geq 90\%$ sat	$\geq 75\%$ sat	$\geq 60\%$ sat	$\geq 50\%$ sat
Problem sets (% complete)	$\geq 95\%$	$\geq 80\%$	$\geq 70\%$	$\geq 60\%$
Quiz 01	$\geq 75\%$	$\geq 60\%$	$\geq 50\%$	$\geq 50\%$
Quiz 02	$\geq 75\%$	$\geq 65\%$	$\geq 60\%$	$\geq 50\%$
2D system analysis (score)	$\geq 85\%$	$\geq 75\%$	$\geq 60\%$	$\geq 50\%$
Pre-class	complete + $\geq 90\%$ on time		$\geq 70\%$ complete + $\geq 50\%$ on time	
Final project	full math contribution		satisfactory work	

For your reference, the course activities are listed below:

- Skill Checks (and retakes)
- Problem sets (including problem set surveys)
- Preclass work (videos, readings, Check Yourself quizzes, discussion posts, and reflections)
- In-class work
- Quizzes
- 2d System Analysis
- Final Project (including project logs, a progress presentation, a final presentation, and an evaluation)

Academic Integrity.

I support and adhere to the principles of academic integrity described in Harvard's honor code. "We - the academic community of Harvard College, including the faculty and students - view integrity as the basis for intellectual discovery, artistic creation, independent scholarship, and meaningful collaboration.

We thus hold honesty in the representation of our work and in our interactions with teachers, advisers, peers, and students - as the foundation of our community."

At its core is an expectation that you will not take unfair advantage of your fellow community members. I will assume your trustworthiness in interactions with me, and with your fellow students. In the interest of fairness of those who adhere to this code of conduct, if a violation of this trust is discovered, it will be reported to the Honor Council. Your work for this class should be your own. You may not consult outside solutions, read the completed solutions of your classmates, or copy your solutions from common work.

Resources.

Using additional resources at Harvard can be important to your academic success.

- The Disability Access Office offers services related to course accessibility, including around mental health (this can include accommodations for test anxiety), illness, or unexpected disruptions to the semester.
- The Academic Resource Center (ARC) offers access to peer tutoring and other academic development resources.
- HU Counseling and Mental Health (CAMS) is a resource for stress or anxiety.
- The Office of Sexual Assault Prevention and Response and student groups such as Response or Room 13 offer information and support around sexual or relationship violence.

If it would be helpful to you, we are available to support you in your efforts to access campus resources.

Topic list:

- Introduction to dynamical systems
- 1d flows: phase portraits, stability, bifurcations, flows on a circle, dimension, parameters
- 2d flows: phase portraits, linear systems, nonlinear flows, population examples, Poincaré index, conservative systems, limit cycles, van der Pol oscillator, Poincaré maps, local bifurcations, global bifurcations
- 3d flows, 1d maps, chaos: Lorenz '63 model, Lorenz map, logistic map, tent map, orbit diagrams, geometry of an attractor