CEE 6 / URBANST 109: PHYSICS OF CITIES
SPRING 2020

Course Overview:

We live in an urban world: more than half of the world's population currently lives in cities, and that number is expected to continue to increase for the foreseeable future. Cities often provide tremendous benefits to society: they are, for example, hotbeds of innovation, wealth generation, and opportunity. At the same time, large cities require massive investments in infrastructure and services, can have high crime rates and unhealthy living conditions, and can have significant and adverse environmental impacts. Thus, managing and planning for predicted urban growth in a sustainable way requires an understanding of how cities will evolve as they grow.

Historically, different aspects of cities have been studied by disparate communities: economists and social scientists have considered the social dimension of cities, while engineers have designed and built the technical infrastructure that supports urban populations. In this course, we will take a more holistic approach by conceptualizing cities and their residents as *complex systems* and exploring how methods developed by scientists to describe the physical world may be adapted to tell us something useful about urban structure and dynamics.

More broadly, this course will address the question of how scientists and engineers approach something as complicated and messy as a city, and what kinds of analytical tools and models are available and appropriate. We will be working from the overarching idea that the "scientific method" is a flexible intellectual approach that is applicable to a much broader range of questions than what is typically thought of as "science," and that the kinds of abstractions and analogies scientists make to describe the physical world can be used in many other contexts as well. The ideas we will introduce in this course are therefore transferrable to a wide range of other topics outside of urban systems.

We will discuss four broad topical areas that will allow us to describe different aspects of cities. Considering *Balances and Flows* will help us to understand the average behavior of a city and to make estimates of how cities interact with their surroundings. Thinking of cities as *Networks* will allow us to understand the sometimes hidden impact of (non-local) interactions in cities on their dynamics. Ideas of *Complexity and Scaling* will let us predict how cities will change as they grow, and will give us a meaningful way to compare cities of different sizes. And finally, treating cities as *Dynamical Systems* will let us describe the temporal dynamics of cities and think about questions of stability and collapse. In each of these topical areas, we will discuss both the scientific origins and context of the methods to be applied and how they can be adapted to an urban setting.

No particular scientific background is required for this course, but comfort with basic mathematics will be assumed. Prerequisites: MATH 19 and 20, or the equivalent.

Learning Goals:

By the end of this course, you should be able to:

- Articulate and explain
    - The ways scientists and engineers approach complicated problems.
    - The difference between reductionism and complexity.
    - The concept of a conservation law or balance equation.
    - The concept and consequences of a network model.
    - The concepts of scaling, complexity, and emergence.
    - The concepts of stability and bifurcation.
    - How these and other "scientific" methods may be applied to "non-scientific" questions.
- Estimate average properties of cities via balance equations.
- Compute simple measures of network structure.
- Estimate how urban indicators will change as city size increases.
- Qualitatively analyze simple dynamical systems.

Instructor:

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Virtual Office Hours: TBD (during the first week of the quarter), or by appointment

Course Support (TA):

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Virtual Office Hours: TBD (during the first week of the quarter), or by appointment

Course Meetings:

This quarter, all aspects of the class will run online only. The course will still meet, virtually but synchronously, during the originally scheduled time slot: T/Th, 1:30-2:50 PM Pacific Time. We will meet using Zoom, with links for each session provided on the Canvas site.

Required Texts:

None. A few supporting readings will be posted on Canvas.

Assignments and Grading:

The grade for this course will be based on a combination of three problem sets (20% in total) and four brief reflections (20%) over the course of the quarter, class participation and engagement (10%), and a final paper analyzing a problem or question of your choice related to cities using the methods we will cover (50%).

So that assignments can be returned promptly, they need to be turned in on time. Problem sets and writing assignments will be accepted one class period late at half of their full value; they will not be accepted after this. All work should be turned in via Canvas.

Note that for this quarter only, this course, like all other Stanford courses, will be graded on an S/NC basis **only**. Nevertheless, you are still expected to be engaged in the course and to complete the assigned work. Additionally, the Breadth Governance Board has determined that this course can still be counted for Ways credit despite the S/NC grading basis.

Problem Sets (20%)

Each section of the course will be accompanied by a problem set asking you to apply the technical material, since working problems is an essential way to practice and test your understanding of the ideas.

Reflections (20%)

In addition to the technical content, this course is also designed to introduce you to a set of ideas that are broadly applicable both in science and beyond. During each section of the course you will be asked to write a **brief** (a few paragraphs) reflection summarizing the ideas we have introduced, thinking about what questions you may have about what we have discussed, and considering how the new concepts we have talked about can be applied to the question you will be addressing for your final paper. The goal of these assignments is both to help you reflect and organize your thoughts and to help you prepare for your final paper.

Class Participation and Engagement (10%)

You are expected to come to the online meetings prepared and ready to engage in classroom discussions.

Final Paper (50%)

Your task in the final paper for the course is to describe a problem or question of your choice related to cities (or urban systems more broadly) and discuss how you would analyze it using of one or more of the approaches we will discuss over the course of the quarter. Your aim should be to demonstrate your understanding of the strengths and weaknesses of the ideas we have discussed for studying different kinds of urban questions.

The paper should be about 10 pages long. It should be structured along the lines of a research proposal. You should begin by identifying the question or problem, explaining why it matters, and posing a hypothesis. Then, explain how you would evaluate your hypothesis. What kinds of methods would you use? What kinds of data would you need?

Since urban questions are typically quite complicated, you will likely want to consider *more than one* of the approaches we will discuss over the course of the quarter. If you feel that only one of these approaches is appropriate for your question, you should explicitly justify this choice.

To help you structure this assignment, we will develop the proposal over the course of the quarter via the reflections. Further details and potential topics will be given during class.

Special Considerations for Spring 2020:

The ongoing pandemic has required all of us to make significant changes to every aspect of our lives. This course is no different.

Virtual Classes

Even though classes will be held over Zoom, I am optimistic that most of what I do in a live classroom can be transitioned without too many sacrifices. Nevertheless, there are bound to be some unforeseen technical hiccups; please accept my apologies for these in advance.

Attendance

I expect everyone to "attend" classes at the scheduled time even though we will be meeting virtually. This will, of course, require you to have access to a computer and a good internet connection, as well as a quiet space to be in during class time. If you foresee that this will be a problem for you, please let me know as soon as possible so that we can discuss what kinds of accommodations can be made.

Even though I want everyone to attend each session, I will also be recording each lecture. Recordings will be accessible from the Canvas site. Note that *recordings may not be shared with anyone outside the class*.

Zoom Etiquette

Video: I would prefer you to keep your camera on if possible; the visual feedback I get from seeing everyone's reactions is invaluable for keeping lectures lively.

Audio: Please mute your microphone when not speaking. Note that your microphone will be muted when you enter the Zoom session, so you will need to unmute it to speak.

Speaking in turn: If you would like to ask a question, please use the *raise hand* icon in Zoom. Please only use the Zoom chat for technical issues, and please use the public rather than the private chat so that I am not distracted by messages no one else can see.

Multitasking: Please do not try to multitask during class! Use “Do Not Disturb” on Macs and “Quiet Hours” on PCs to avoid email and text notifications during class, and turn off unnecessary cell phone notifications.

Tentative Schedule

Week	Date	Topic	Assignment
1	April 7	Introduction and overview The scientist's approach Reductionism, complexity, and emergence	
	April 9	Lessons from the historical record Traditional approaches to urban studies	*Informational Survey due*
		Balances and Flows	
2	April 14	Introduction to conservation laws and balances	*Reflection 1 due*
	April 16	Urban heat islands	
3	April 21	Flows and traffic	*Final Paper topic due*
	April 23	Symmetries and constraints	
		Networks	
4	April 28	Introduction to network modeling	*Reflection 2 due*
	April 30	Network structure and communities Network modeling of air pollution	
5	May 5	Centrality and small worlds	*Problem Set 1 due*
	May 7	Scale-free networks Infrastructure and planar networks Network robustness	
		Complexity and Scaling	
6	May 12	Introduction to complexity theory	*Reflection 3 due*
	May 14	Power laws, scaling, self-similarity, and fractals	
7	May 19	Scaling in cities: empirical results and modeling	*Problem Set 2 due*

	May 21	Deviations from scaling Universality Self-organized criticality	
		Dynamical Systems	
8	May 26	Introduction to dynamical systems	*Reflection 4 due*
	May 28	Phase portraits, fixed points, and attractors	
9	June 2	Bifurcation and catastrophe	*Problem Set 3 due*
	June 4	Agent-based modeling and human behavior	
10	June 9	Summary and wrap-up	*Final Paper due*