Modeling Complex Systems (MTH3MCS/MTH5MCS)

Sachit Butail

Monsoon 2014, Mon (11:00a-12:30p) Wed (9:30a-11:00a), C03 lecture hall
Indraprastha Institute of Information Technology, Delhi (IIIT-D)

Description Synchronization in fireflies, schooling in fish, and formation of snowflakes are all examples of complex patterns that emerge from a large number of components interacting through simple rules. These patterns arise in the absence of a central control and continue to do so even if existing components are removed or new ones are added. In this course, we will use mathematical models to understand the rules that give rise to such patterns. Starting with the motivation on why we should model anyway, we will simulate examples of complex systems using methods from population dynamics, self-propelled particles, networks, and cellular automata. The course will consist of weekly lectures and labs, and a final project where you will get to model a system of your choice. Knowledge of undergraduate level calculus, linear algebra, and basic programming (preferably in MATLAB) is required. The objective of this course is to help the student better understand the emergence of complexity in nature and the intuition to take a first crack at modeling a complex system.

Pre-requisites Undergraduate level differential calculus and linear algebra. We will also touch upon these briefly in the beginning of the course.

Student capability after successfully completing the course (Post condition)

- Ability to simulate a complex system and suggest new tools for visualization and analysis
- Explain the global effects of individual and interaction parameters in group behavior
- Be aware of seminal works and popular models in complex systems
- Abstract a complex system into a simple mathematical form using meaningful assumptions

Text

There is no prescribed text for this course; we will be mainly using class notes and published papers. Material for this course has been borrowed with permission from Prof. David Sumpter at Uppsala University, Stockholm, Sweden and Prof. Vishwesha Guttal at Indian Institute of Science, Bangalore. In addition, some relevant references are listed below:

- Boccara N. Modeling complex systems. New York, New York, USA: Springer
- Strogatz S. H. Nonlinear dynamics and chaos: with applications to Physics, Biology, Chemistry and Engineering. Cambridge, Massachusetts, USA: Westview Press
- Sumpter D. J. T. Collective animal behavior. Princeton, New Jersey, USA: Princeton University Press

Homeworks

There will be four homework assignments as part of this course. Those who register for MTH5MCS will get an extra homework problem each time. You are encouraged to collaborate on these, however, the work you submit should be entirely your own. No collaboration is permitted during the mid-semester exam, which will be conducted during Week 8. Please refer to academic dishonesty section below. 10% of maximum marks will be docked for late homeworks for every additional day; After three days no marks will be awarded.

Project

The course will end with a final project where you are encouraged to either model and analyze a complex system of your choice, or, review and reproduce the results of a recent paper that models a complex system. The project topic or paper must be approved by the end of Week 10. At the end of the project you will be required to submit a 3 page report (including figures but excluding bibliography, and preferably in LaTeX) and present your findings before the class for 10 minutes.

Grading

- Homework Assignments (4): 40%
- Mid-semester exam: 20%
- Project (3 page report and presentation): 40%

Office hours

Thursdays: 12–2pm

Academic dishonesty

Please carefully read http://www.iiitd.ac.in/education/resources/academic-dishonesty. Please discuss with me if you have doubts about what constitutes dishonesty, plagiarism, and cheating. You are responsible for your work!

References

[1] D. Helbing, I. Farkas, and T. Vicsek, Simulating dynamical features of escape panic., Nature, vol. 407, no. 6803, pp. 48790, 2000.

[2] Millenium Bridge (http://youtu.be/eAXVa__XWZ8)

[3] Steven Strogatz: How things in nature tend to sync up (http://youtu.be/aSNrKS-sCE0)

[4] http://www.red3d.com/cwr/boids/

[5] http://youtu.be/CgOcEZinQ2I

[6] A. D. I. Kramer, J. E. Guillory, and J. T. Hancock, Experimental evidence of massive-scale emotional contagion through social networks., Proc. Natl. Acad. Sci. U. S. A., vol. 111, no. 24, pp. 878890, 2014.

[7] A. Tsoularis and J. Wallace, Analysis of logistic growth models, Math. Biosci., vol. 179, no. 1, pp. 2155, 2002.

[8] http://youtu.be/dcMa0djC7IM

[9] http://math.colgate.edu/~wweckesser/math312Spring05/handouts/Nondim.pdf

[10] https://www.math.duke.edu/education/ccp/materials/diffeq/logistic/logi1.html

[11] http://youtu.be/E8kUJL04ELA,http://youtu.be/R9Plq-D1gEk

[12] http://angel.elte.hu/~panic/

[13] https://courses.cit.cornell.edu/bionb441/CA/

Table 1: Schedule

Week	Learning outcomes	Readings/videos
4/8	Describe complexity; identify examples of complex systems;	[2]
11/8	Compute derivatives; solve simple differential equations; integrate in MATLAB using ode functions; hw 1 assigned	–
18/8	Population dynamics: Implement the logistic growth model on a real-world example of budworm populations; solve a two species system; simulate a two species system in MATLAB	[10]
25/8	Population dynamics: Determine one of two compartmental models to simulate a given disease; simulate the spread of an epidemic; simulate the spread of rumours; hw 1 due; hw 2 assigned	–
1/9	Self-propelled particle models: animate a set of particles in two dimensions according Vicsek's model; compute group observables; correlate group observables with particle density and uncertainty;	–
8/9	Self-propelled particle models: animate a set of particles according to a zonal model; distinguish between different topologies; hw 2 due; hw 3 assigned	–
15/9	Self-propelled particle models: simulate crowd panic using agent based model;	[1], [12]
22/9	Mid-semester exam;	–
29/9	Graph theory: construct graphs on a set of nodes based on criteria and weights; compute shortest path lengths, diameter, and betweenness of sample graphs; project topic due;	–
6/10	Networks: small-world network–compute Bacon number of some film personalities, compute Erdős number for academics; scale-free networks–random vs preferential connectivity; hw 3 due; hw 4 assigned	
13/10	Networks: what is synchronization; simulate fireflies sync using Kuramoto oscillator model;	[3, 2, 8]
27/10	Revisiting population dynamics: simulate the evolution of a network of individuals; simulate rumor spread in social networks	[6]
3/11	Cellular automata: design algorithms for generating patterns on seashells and snowflakes; hw 4 due	[13]
10/11	Cellular automata: design and play with the game of life; predict future patterns in the game of life; CA as models of complexity	[5], [11]
17/11	Decision making in groups; In-class presentations;	–
24/11	Project reports due	–