Modeling Complex Systems (CS/CSYS 6020), Fall 2024

Time: Tuesdays 14:50 - 16:05 and Thursdays 14:50 - 16:05
Place: Votey 207 and Zoom videoconference at `zoom.us/my/lsd.lhd`

Instructors: Dr. Giulio Burgio, Jonathan St-Onge & Grad. Asst. Prianka Bhattacharjee
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Office hours: After class (16:05 to 17:05, or by appointment) in E413 Innovation Hall
Course website: Support website and Brightspace
Textbook: Available in pdf (free) and hardcopies ($),
Hiroki Sayama, Introduction to the Modeling and Analysis of Complex Systems (2015)

What are models? What are complex systems?
How do we model complex systems in a way that respects and embraces their complexity?

Expectations: CSYS/CS 302 Modeling Complex Systems is designed as a hybrid, graduate level introduction to computational and mathematical modeling of complex systems. We use a breadth-first presentation of varied topics and methods, with hands-on experiences and mini-research problems with an emphasis on the relations and trade-offs between the different approaches. Undergraduates are held to the same expectations as graduate students.

Texts and resources:

1. Textbook: H. Sayama, *Introduction to the Modeling and Analysis of Complex Systems*, freely available from SUNY's Open Educational Resources.
2. LHD's video capsules and personal notes will be made available on the support website.
3. Additional readings, or Reading Group Papers, will be posted on support website.

Objectives:

1. To know the different definitions, types, and roles of *models* and *complex systems*.
2. To recognize the trade-offs between types of models.
3. To mathematically describe systems with differential equations.
4. To implement some computational models.
5. To formulate new questions, and identify relevant models and methods.

6. To collaborate, brainstorm and discuss.

Evaluation:

1. We will have 3 assignments, all done in teams of two or three. For the second assignment, you will have to discuss your results in short recorded presentations.

2. In addition, you are required to answer questions and provide a short-write up on each of our Reading Group Papers. The questions assess your understanding of the readings while the write-ups should provide your own summary or thoughts on the paper. These are shared on Blackboard through weekly quizzes.

3. You are also required to attend our discussions in person or by videoconference.

Software: The course is programming-intensive and will be taught mainly with pseudo-code or python notebooks. Lectures will emphasize how and why a model works rather than its formal implementation. Many python notebooks will be provided to help students new to programming. MOCS is not meant to be a crash course in programming, but the codes used will be user-friendly, readable and easy to learn.

Assignments and projects will often require you to write your own programs using Julia, C, MATLAB or octave, R, or Python.

Final project: Final project will be a stand-alone research project on a topic of your choice in teams. A list of potential ideas and topics will be discussed around week 8 or 9. There will be final recorded presentations on the final projects.

Grades: 24% for Reading Group Papers and weekly quizzes, 36% for assignments (12+12+12), 40% for the project. Extra points will be available for attending some relevant seminars and events (e.g. invited seminars of the Vermont Complex Systems Center).

Follow-up courses: For more coverage of specific topics,

- CSYS 6701 Principles of Complex Systems
- CSYS 5766 Chaos, Fractals and Dynamical Systems
- CSYS 6713 Complex Networks & STAT 6990 Statistical Network Analysis
- CSYS 6520 Evolutionary Computation & CS 3060 Evolutionary Robotics
- CSYS TBD: MOCS 2 coming soon...

Certificate of Graduate Study in Complex Systems & Data Science: Requires 15 graduate credits with a GPA of 3.0 or higher in these courses: CSYS 6701, CSYS 6020, CSYS 5970 plus 2 or 3 additional complex systems courses from a list of approved electives.

Comments:

- **Late assignments** will lose 20% for every calendar day past due, starting with an initial 20% after the start of class on due date.
- **Graduate students** are expected to use document preparation software for assignments, and are held to a higher standard for the final projects than undergraduates. We will judge their technical writing as we would a scientific paper.
- We reserve the right to deduce points on assignments and projects for failure to meet **basic academic standards**.
- **Class participation** can play a role in determining final grades in borderline situations.
- Students are expected to check the Blackboard page and their **UVM email** accounts regularly.
- Email communications/questions must include course number 6020 in the subject line.
- Any suspected violations of the **UVM policy on academic integrity** will not be tolerated and all allegations will be forwarded to the Center for Student Ethics & Standards.
- In keeping with University policy, any student with a documented disability interested in utilizing **accommodations** should contact SAS, the office of Disability Services on campus. SAS works with students and faculty in an interactive process to explore reasonable and appropriate accommodations, which are communicated to faculty in an accommodation letter. All students are strongly encouraged to meet with their faculty to discuss the accommodations they plan to use in each course. A student"s accommodation letter lists those accommodations that will not be implemented until the student meets with their faculty to create a plan. Contact SAS: A170 Living / Learning Center; or https://www.uvm.edu/access. If you need specific accommodations in this class, please bring your accommodation letter as early as possible (and at least 2 weeks prior to the final project presentation) so that we can make appropriate arrangements.
- **UVM Religious Holidays Policy:** Please submit in writing by the end of the second full week of classes your documented religious holiday schedule for the semester. Students who miss work for the purpose of religious observance will be permitted make up work within a mutually agreed-upon time.

Module 0: Model theory

- Model theory and Complex Systems (philosophy of science) — Sayama Chapter 2
- Model definition, assumptions, and sources of errors — Course notes and readings

Module 1: Dynamics

- Discrete-time models (difference equations) — Sayama Chapter 4-5
- Deterministic continuous-time models (differential equations) — Sayama Chapter 6-9
  - Compartmental models, mean-field approximations
  - Stability, chaos, and numerical errors
- Deterministic models in space — Sayama Chapter 11

Module 2: Structure, part 1

- Cellular Automata
- Stochastic models in space — Course notes and readings
  - Random walks, Brownian motion
  - Diffusion limited aggregation (fractals)
  - Percolation

Module 3: Structure, part 2

- Networks (infinite dimensional space) — Sayama Chapter 15-18
  - Network analysis
  - Directed or undirected networks, weighted or unweighted networks
  - Static or dynamical or adaptive networks

Module 4: Dynamics & Structure

- Agent-based models — Guest lectures and Sayama Chapter 19
- Evolutionary game theory

Module 0: Model theory (redux)

- Model validation and model selection — Guest lectures and readings
  - Model identifiably
  - Bayesian information criterion
  - Minimum description length

With applications including but not limited to: Collective behavior of humans and animals (swarms), contagion in humans and animals (public health), ecological systems (food webs and forest ecology), natural and engineered structures (fractals, power grids).