The Hebrew University of Jerusalem

Syllabus

Modelling of Complex Systems - 55811

Last update 18-05-2024

HU Credits: 3

Degree/Cycle: 2nd degree (Master)

Responsible Department: Business Administration

Academic year: 0

Semester: 2nd Semester

Teaching Languages: Hebrew

Campus: Mt. Scopus

Course/Module Coordinator: Prof Lev Muchnik

Coordinator Email: lev.muchnik@huji.ac.il

Coordinator Office Hours: by appointment

Teaching Staff:

Prof Lev Muchnik

Course/Module description:

The world around us is abundant with complex phenomena and complex systems –containing numerous interacting parts. Many physical, biological, and social systems fall under that classification. Modelling is possibly the effective tool known to mankind for exploration of and gaining insight into such complex systems and phenomena. It allows us to deepen our understanding of the manner in which such systems operate and gain a better understanding of their dynamics. It also allows us to investigate effective ways of influencing a system and making it behave in a desirable way.

This course teaches how to model, explore, and understand systems of numerous interacting parts (agents). It utilizes mathematical and numerical techniques, including agent-based, discrete event simulations, and cellular automata, to reproduce phenomena that characterize complex systems such as synchronization, emergence of long-tailed distributions and spatial patterns, as well as the formation and change of collective behaviors. Students learn to recognize complex phenomena and phase transitions in complex systems, define and implement models, learn how to validate numerical simulations, and master techniques to analyze synthetic data they generate.

The course places an emphasis on socio-technical systems that underlie the phenomena we encounter in the realm of societies in general and businesses in particular, and develops the skills necessary to model and analyze them.

Course/Module aims:

Learning outcomes - On successful completion of this module, students should be able to:

recognize and characterize behavior of complex systems, model them using one of the studied techniques, validate and explore the models

Attendance requirements(%):

90

Teaching arrangement and method of instruction:

Course/Module Content:

The main concepts discussed in the course include

1. Heavy-Tailed Statistics
Social systems are frequently characterized by highly skewed fat-tailed distributions. We learn the general properties of these distributions, how they emerge, and what their presence implies from a business perspective. We also analyze the potentially catastrophic repercussions of failure to properly consider heavy-tailed distributions. We explore a number of analytical and agent-based models that can reproduce and explain such phenomena, study the characteristics of systems driven by fat-tailed distributions and learn when they can produce complex patterns, crash or explode.
2. Wisdom of crowds
People tried to find ways to solve complex problems collaboratively from the dawn of civilization. But only in the recent decades, with the maturation of communication, data storage and processing technologies, businesses, researchers and societies started to learn to exploit the collective mind systematically. We review various manifestations of crowdsourcing techniques including collaborative filtering and content creation, prediction (or information) markets, and games with a purpose, complementing the review with concrete examples such as Wikipedia, digg.com, the Amazon mechanical Turk, Threadless , TopCoder, the DARPA's red balloon challenge, SETI and bitcoin.
3. Stochastic modelling
3.1 Agent-based Modeling
Agent-based modeling is one of the most efficient tools capable of providing insight into socio-technical systems. We explore a number of analytical and agent-based models dealing with opinion formation and emergence of cooperation in multi-agent systems.
3.2 Discrete-Event Simulation
Discrete-event simulation is frequently used to model systems driven by sequences of events (or interactions) such that the system state either does not change or is easily predictable between such events. Discrete-event simulations are used to model business processes, production lines, stock markets, service queues and entire systems (e.g. healthcare).

The main topics covered during the course:
1. Opinion formation
Consumer behavior is increasingly driven by online product reviews. We discuss the research that evaluates the impact of online product reviews on consumer choice and whether the fraud is effective. Opinions, reviews and other forms of user generated content are frequently ranked by the web site users. We discuss the ways in which user votes can be weighted and the advantages and disadvantages of various opinion aggregation schemes. We also explore specific examples of content ranking and how arrangement of search results may influence user choice and consequent ranking.
2. Social media
Near-real-time one-to-many and many-to-many exchange of user generated content is changing the patterns in which information is consumed in our society. The effect of social media is so intense that some suggest that it could provoke a profound

social change (consider phenomena like “fake news” that already impact our society). Simultaneously, it offers an intimate insight into human behavior. We explore some of the computational approaches that help assessing such effects, harvest social media data valuable content, or be used by firms to manage social media. Pertinent examples include identification of topic trend dynamics, tracking of memes, roles of forum participants, emergence of social norms and distribution of activity within populations.

3. Crowds

This section deals with modeling of collective human behavior, such as crowds, traffic and evacuation. We review the use of mobile communication and ambient technology in this context and discuss subjects such as crowd-sensing and wireless ad hoc networks. We also explore several models of flock formation (of birds and fish).

4. Wealth distribution

Social inequality reflected in income and wealth distribution is one of the processes that effects economic development and could impact social stability. We examine historical and contemporary evidence of the phenomenon, model it, and study the impact of the tools (e.g. taxation) used to fight it.

5. Emergence of segregation

Aggregation of diverse populations in homogenous clustering is a phenomenon easily observed in any large city, country, or continent. It has dramatic social, political, economic (e.g. real estate) and business implications. We examine empirical evidence of segregation, characterize its spatial and behavioral patterns, then implement and explore Nobel laureate’s Schelling's Model of Segregation.

6. Additional contexts

In this part, we explore additional models that demonstrate emergence of power law distribution (e.g. model of city growth and propagation of languages, to explain language speaker base), phase transition and self-organized criticality (model of sizes of forest fires, sandpile model), dependence of opinion formation dynamics on the way people interact, synchronization phenomena (firefly synchronization and the model explaining dynamics of ovation). We explore how game-theoretical models of pair-wise human interaction produce complex macroscopic phenomena when applied to populations (e.g. the prisoner’s dilemma on torus). The AB model is used to demonstrate how interaction of two types of agents may produce spatial discontinuities that cannot be explained by analytical analysis.

7. Optimization: Heuristic algorithms

Most business decisions boil down to optimization (under constraints), i.e. finding a set of parameters that maximizes the desired outcome. We introduce a classification of systems with respect to the approaches used to locate the maximum, study and apply heuristic-based algorithms (simulated annealing, genetic, and ant colony).

8. Causal inference

Identification of the factors capable of inducing change in behavior is essential for design of intervention strategies, whether these are marketing campaigns or governmental policies. In this section we demonstrate the need for making causal inferences from large-scale social systems, discuss ways to address such cases, and

review the recent research on the subject. Topics covered include social pressure, the reflection problem, observational data analysis and experiment design.

Required Reading:

Strogatz, Steven H. Sync: How order emerges from chaos in the universe, nature, and daily life. Hachette UK, 2012.

Hercock, Robert G. (2009), Cohesion - The Making of Society: Lulu Press.

Howe, Jeff (2008), Crowdsourcing: Why the Power of the Crowd Is Driving the Future of
Business: Crown Business.

Page SE. Diversity and complexity. Princeton University Press; 2010 Nov 8.

Gladwell, Malcolm (2000), Tipping Point: How Little Things can make a Big Difference. Boston, MA: Little, Brown and Company.

Miller, John H. and Scott E. Page (2007), Complex Adaptive Systems: An Introduction to Computational Models of Social Life (Princeton Studies in Complexity): Princeton University Press.

Additional Reading Material:

Clauset, Aaron, Cosma Rohilla Shalizi, and Mark EJ Newman. "Power-law distributions in empirical data." SIAM review 51.4 (2009): 661-703.
Souma, Wataru. "Physics of personal income." Empirical science of financial fluctuations. Springer, Tokyo, 2002. 343-352.
WICHMANN, S. (2005). On the power-law distribution of language family sizes. Journal of Linguistics, 41(1), 117–131.
Schulze, C., Stauffer, D., & Wichmann, S. (2007). Birth, survival and death of languages by Monte Carlo simulation, 24. Physics and Society.
De Oliveira, V. M., Campos, P. R. A., Gomes, M. A. F., & Tsang, I. R. (2006). Bounded fitness landscapes and the evolution of the linguistic diversity. Physica A, 368(1), 257–261.
Turcotte, D. L. (1999). Self-organized criticality. Reports on Progress in Physics, 62(10), 1377–1429.
Ben-Hur, Asa, and Ofer Biham. "Universality in sandpile models." Physical Review E 53.2 (1996): R1317.

Mirollo, R. E., & Strogatz, S. H. (1990). Synchronization of Pulse-Coupled Biological Oscillators. SIAM Journal on Applied Mathematics, 50(6), 1645–1662
Strogatz, S. H. (2004). Sync: How Order Emerges From Chaos In the Universe,

Nature, and Daily Life (p. 352).
Néda, Z., Ravasz, E., & Brechet, Y. (2000). Self-organizing processes: The sound of many hands clapping. Nature, 403, 849–850.

Solomon, S., Weisbuch, G., De Arcangelis, L., Jan, N., & Stauffer, D. (2000). Social percolation models. Physica A: Statistical Mechanics and its Applications, 277(1-2), 239–247. doi:10.1016/S0378-4371(99)00543-9
Sznajd-Weron, K. (2005). Sznajd model and its applications. Physics and Society.
Sznajd-Weron, K., & Sznajd, J. (2000). Opinion evolution in closed community. International Journal of Modern Physics C,
Sumpter, D. J. T. (2006). The principles of collective animal behaviour. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 361(1465), 5–22. doi:10.1098/rstb.2005.1733
Schelling, T.C., 1969. Models of Segregation. American Economic Review, Papers and Proceedings, 59, 488-493,
Schelling, T.C., 1971a. Dynamic Models of Segregation. Journal of Mathematical Sociology, 1 (2), 143–186,
Schelling, T.C., 1971b. On the Ecology of Micromotives. The Public Interest, 25, 61–98, Schelling, T.C., 1978. Micromotives and Macrobehavior. New York: Norton.

Wolfram, Stephen. "Statistical mechanics of cellular automata." Reviews of modern physics 55.3 (1983): 601.
Ermentrout, G. Bard, and Leah Edelstein-Keshet. "Cellular automata approaches to biological modeling." Journal of theoretical Biology 160.1 (1993): 97-133.
Conway, John. "The game of life." Scientific American 223.4 (1970): 4.
Martin Gardner, "On Cellular Automata, Self-reproduction, the Garden of Eden and the Game 'Life', Scientific American, 224 (2) (1971) 112-118.

E. Ben-Jacob, O. Schochet, A. Tenenbaum, I. Cohen, A. Czirók, and T. Vicsek, “Generic modelling of cooperative growth patterns in bacterial colonies.,” Nature, vol. 368, no. 6466, pp. 46–9, Mar. 1994.

Shnerb, N. M., Louzoun, Y., Bettelheim, E., & Solomon, S. (2000). The importance of being discrete: Life always wins on the surface. Proceedings of the National Academy of Science

Grading Scheme:
Essay / Project / Final Assignment / Home Exam / Referat 40 %
Submission assignments during the semester: Exercises / Essays / Audits / Reports / Forum / Simulation / others 45 %
Attendance / Participation in Field Excursion 15 %

Additional information: