EE 599: Systems Biology and Its Applications in the Real-World

Spring 2017

Course Information:
Time: Monday and Wednesday 10:00am-11:50am
Venue: TBD
Instructor: Paul Bogdan, pbogdan@usc.edu
Office Hours: EEB 304: MW 11:20am-12:30pm, or by appointment.
Webpage: http://ceng.usc.edu/cps/
TA: TBD.
Units: 3

Description: We love to think in terms of patterns, abstract the things around us, establish analogies and discover new knowledge. Mathematics, physics, chemistry and, more recently, computer sciences enable us to define the perspective from which we can detect patterns in biology and establish governing principles. This is systems biology. As engineers, we do not merely borrow these tools from mathematics and physics, but we also develop new theoretical foundations for the design and optimization of artificial systems. In this course, we aim to learn how we can employ our engineering theoretical foundation to model and optimize the computation, communication and control capabilities of biological systems. Special emphasis will be placed on reviewing existing models, identifying their limitations in relation to the actual characteristics of bio-physical processes and developing advanced mathematical models starting from actual measurements or observations of bio-physical/social phenomena. Students will become familiar with ongoing research in the field and will get a chance to apply their knowledge of theoretical concepts to the modeling, analysis and optimization of biological systems in the context of their major project.

Text:
There is no single textbook containing all subjects discussed in this class. Suggested readings are selected from the following scientific books:

- S. Redner, *A Guide to First-Passage Processes*, Cambridge Univ. Press, Business & Economics, 2007.
- D. Ben-Avraham and S. Havlin, *Diffusion and Reactions in Fractals and Disordered Systems*, Cambridge University Press, Science, 2005.
- U. Alon, *An Introduction to Systems Biology: Design Principles of Biological Circuits*, CRC Press, 2007.
- A. Barrat, M. Barthélemy, and A. Vespignani, *Dynamical Processes on Complex Networks*, Cambridge University Press, Science, 2012.
- R. Cohen and S. Havlin, *Complex Networks: Structure, Robustness and Function*, Cambridge University Press, Science, 2010.
- P.L. Krapivsky, S. Redner, and E. Ben-Naim, *A Kinetic View of Statistical Physics*, Cambridge University Press, 2010.
- P Meakin, *Fractals, Scaling and Growth Far from Equilibrium*, Cambridge University Press, Mathematics, 2011.
- J. Dubbeldam, K. Green, and D. Lenstra, *The Complexity of Dynamical Systems - A Multi-Disciplinary Perspective*, John Wiley & Sons, Science, 2011.
- R. Klages, W. Just, and C. Jarzynski, *Nonequilibrium Statistical Physics of Small Systems: Fluctuation Relations and Beyond*, John Wiley & Sons, Science, 2013.
- Piet van Mieghem, *Graph Spectra for Complex Networks*, Cambridge University Press, Dec 2, 2010.
- B. Palsson, *Systems Biology: Simulation of Dynamic Network States*, Cambridge University Press, 2014.
- S.Thiagalingam, *Systems Biology of Cancer*, Cambridge University Press, 2015.
- P. Luisi, *The Emergence of Life: From Chemical Origins to Synthetic Biology*, Cambridge Univ. Press, 2006.

However, the class material will be self-contained and I can help you with suggestions to which books and articles you should read if you are interested in a particular subject.

Pre-requisites:
Students enrolling in the course are expected to have prior exposure to matrix algebra, graph theory, basic probability theory, discrete optimization and algorithms / mathematical optimization, as well as have some knowledge of control and communication networks. Although the main concepts will be discussed in detail throughout the course, students are expected to read the recommended papers. Evaluation will be based on homework assignments, in class participation via paper presentation, and a semester-long project. Students should be prepared to put in enough effort to turn in a quality project.

Grading:
Paper presentation 10%
Quizzes 10%
Project 60%
Homework 20%

Course Outline (subject to change):

Week 1	Basic concepts in system biology.
Week 2	Basic concepts in networks and chemical reactions.
	Input function of a gene, Michaelis-Menten kinetics, and cooperativity.
Week 3	Stochastic modeling (Master equation, Fokker-Planck equation, Gillespie algorithm).
	Stochastic gene expression. Causes and consequences of stochastic gene expression.
Week 4	Mean field approximation modeling. Autoregulation, feedback and bistability.
Week 5	Life at low Reynold's number. Bacteria swimming and modeling techniques.
Week 6	Robustness and bacterial chemotaxis. Robustness in development and pattern formation.
Week 7	Complex Networks. Oscillatory genetic networks.
Week 8	Graph properties of transcription networks.
Week 9	Project presentations and mentoring.
Week 10	Fractals and their applications in biology.
Week 11	Microbial evolution and optimal gene circuit design.
	Interspecies interactions, the Lotka-Volterra model, and predator-prey oscillations
Week 12	Evolution in finite populations, genetic drift. Theory of neutral molecular evolution.
	Evolutionary games. Dynamics of populations in space.
Week 1 3	Entropy, free energy, self-organization, emergence and complexity in biology.
Week 14	Fluctuations and absence of detailed balance in biology.
Week 15	Project presentations.

Project:
The project is a major component of this course. Students can either choose their own project relevant to the course or pick one from the suggested topics. In both cases, the outcome of the project should be an original

research finding, well documented with regard to related work, well-supported by either theoretical proofs or experimental investigation. Students are encouraged to think big and develop out-of-the-box approaches that may lead to the development of significant solutions to problems in these areas of research. The project will count for 60% of the course grade. The project will consist of four milestones:

i) *Project definition*: Students are required to submit a 2 page report stating the motivation for a specific topic, outlining the problem statement, summarizing the main challenges, discussing the related work, and formulating a tentative work plan to address the anticipated challenges.

ii) *Project update*: Students are required to submit a 4-page report (which builds on their previous write-up) summarizing the proposed solution and some preliminary results.

iii) *Project evaluation*: Students are required to submit an 8-page report discussing the main results and contrasting the proposed solution with state-of-the-art solutions.

iv) *Project presentation*: Students are required to present their main project findings in an interactive session. Students will have approximately three weeks to work on each project milestone. Project teams of up to two students will be allowed, but a statement will have to be included detailing each student's contribution and assigning an agreed upon percentage contribution. The final project grade will be weighted accordingly.

Recommended Papers for Reading:
Recommended readings will be provided in class and via Blackboard throughout the entire semester.

Statement for Students with Disabilities:

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.–5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

Statement on Academic Integrity:

Throughout the course we will guide and obey the USC Academic Integrity and Honor Code:

"Engineering enables and empowers our ambitions and is integral to our identities.
In the Viterbi community, accountability is reflected in all our endeavors.
Engineering+ Integrity.
Engineering+ Responsibility.
Engineering+ Community.
Think good. Do better. Be great.
These are the pillars we stand upon as we address the challenges of society and enrich lives."

USC seeks to maintain an optimal learning environment. General principles of academic honesty include the concept of respect for the intellectual property of others, the expectation that individual work will be submitted unless otherwise allowed by an instructor, and the obligations both to protect one's own academic work from misuse by others as well as to avoid using another's work as one's own. All students are expected to understand and abide by these principles. If you have any questions or doubts you may direct them to the instructors. Furthermore the Student Guidebook, SCampus, contains the Student Conduct Code and sanctions: http://scampus.usc.edu/. Students will be referred to the Office of Student Judicial Affairs and Community Standards for further review, should there be any suspicion of academic dishonesty. The Review process can be found at: http://www.usc.edu/student-affairs/SJACS/.