Universitat Pompeu Fabra Barcelona

Department of Experimental and Health Sciences
Parc de Recerca Biomèdica de Barcelona
Dr. Aiguader 88, 08003 Barcelona

SYSTEMS BIOLOGY

Degree: Bachelor's Degree in Biomedical Engineering
Course code: 22133
Year: 4th year, 1st term
Number of ECTS credits: 5
Class hours: 55
Department: Experimental and Health Sciences
Teachers: Jordi Garcia Ojalvo (coordinator), Marçal Gabaldà (labs), seminar speakers (Lucas Carey, James Sharpe, Ben Lehner)
Language in which the course is taught: English

1. Course presentation

The vast majority of cellular processes do not rely on the operation of a single component of the cell's machinery (e.g. a single gene or protein), but on the interplay between multiple components working together *as a system*. The goal of this course is to describe how this emerging behavior arises from the interaction between multiple cellular components, in the form of gene and protein circuits and networks. Given the presence of feedback loops in these circuits, their behavior cannot be predicted intuitively by tracking the state of the network components along their interaction paths. Due to these limitations, mathematical modeling is necessary to establish the range of possible behaviors that a cellular network can have, and the effect of perturbations (genetic or biochemical) on these behaviors. This course presents an overview of emerging phenomena that arise from cellular circuits and networks, emphasizing their mathematical description.

2. Contents

Lectures

Module 1. Oscillations. Design principles of biochemical oscillators. Classes of oscillatory motifs: delayed negative feedback and amplified negative feedback. Phase resetting. Examples: glycolysis, circadian rhythms, the cell cycle.

Module 2. Noise. Transcriptional noise. Master equation. Transcriptional bursting. Intrinsic and extrinsic noise. Noise spectra. Chemical Langevin equation. Stochastic simulations. Gillespie algorithm.

Module 3. Synchronization. Phase oscillators. The Kuramoto model. Synchronization order parameter. Synchronization transitions. Scaling laws. Examples: quorum sensing, glycolysis, circadian clocks.

Module 4. Patterns. Morphogens and positional information. Reaction-diffusion (Turing) mechanism. Linear stability analysis. General conditions for diffusion-driven instabilities. Lateral inhibition.

Module 5. Networks. Random graphs. Degree distribution. Clustering coefficient. Graph spectra. Percolation. Scale-free and small-world networks. Network motifs and modularity.

Seminars

The seminar classes will consist in both problem-solving sessions and presentations by invited professors, who will present their recent research results in the field of systems biology.

Practical sessions

During the first practical sessions we will implement computational approaches to solving the different models posed in the theoretical lectures. The final sessions will be devoted to developing a computational project, to be selected among several options, that will use the concepts introduced in the course, and that will be presented orally to all the class at the end of the course.

3. Grading

The final grade of the course will be distributed in the following way:

a) Theory (30%): the theoretical concepts will be assessed with a single exam at the end of the term, which may contain both multiple-choice questions and open-ended questions.

b) Problem solving (30%): the ability to solve problems analytically will be assessed with a single exam at the end of the term.

c) Practical knowledge (30%): half of this grade will correspond to reports of the practical sessions, which will have to be delivered periodically. The other half will be given by the computational project that will be carried out during the final practical sessions of the course.

d) Course participation (10%): this part of the grade will be determined by the active participation in the theoretical and seminar sessions (asking and answering questions, solving problems in the blackboard, answering the review questions at the beginning of each theoretical session, and active participation in the Q&A forum of the Campus Global).

Additional requirements and comments:

- It is compulsory to attend the practical sessions.
- Passing the course requires obtaining a minimum score of 3 (in a scale of 0 to 10) in each one of the grades (a-d) listed above.
- The students that do not pass the course in December will be able to take the final exam again in July. In that exam we will assess the theory and problem solving parts of the grade (a and b above), but not the practical knowledge and class participation scores.

Department of Experimental and Health Sciences
Parc de Recerca Biomèdica de Barcelona
Dr. Aiguader 88, 08003 Barcelona

4. Bibliography

4.1. Basic bibliography

- *An Introduction to Systems Biology*. Alon (Chapman and Hall, 2007)
- *Systems Biology*. Klipp, Liebermeister, Wierling, Kowald, Lehrach, Herwig (Wiley, 2009)
- *A First Course in Systems Biology.* Voit (Garland, 2012)
- *Mathematical Modeling in Systems Biology: An Introduction.* Ingalls (MIT Press, 2013)

4.2. Additional bibliography

- *Physical Biology of the Cell*, 2nd ed. Phillips, Kondev, Theriot, Garcia (Garland, 2012).
- *Biochemical Oscillations and Cellular Rhythms.* Goldbeter (Cambridge UP, 1997).
- *Computational Cell Biology*. Fall, Marland, Wagner and Tyson (Springer, 2005).
- *Mathematical Biology,* 3rd ed. Murray (Springer, 2003)
- *Stochastic Modelling for Systems Biology,* 2nd ed. Wilkinson (Chapman & Hall, 2011).
- *Computational Modelling Of Gene Regulatory Networks.* Bolouri (IC Press, 2008).