Systems Biology - an introduction for life scientists

2h lecture
2h seminar

General notes:

We learn in this course how to handle and use methods of Systems Biology in different biological systems. The lecture has 12 units in total, whereas 11 units are complemented with a seminar in which problem sets are solved together, e.g. in smaller group, where students help each other. Some parts of the problem sets have to be prepared at home. The lecture is finalized with an exam, which determines the grade for the lecture.

Required knowledge:

Only minor knowledge in math is assumed, but a certain affinity/tolerance for math is required. However, math will be needed in this lecture and the necessary knowledge will be introduced in the second lecture and extended throughout the course. A basic understanding of biology, especially molecular biology and microbiology is required, since basic concepts of biology will not be repeated (e.g. one should understand what are DNA, proteins and cell and how they are connected).

Content:

The course is divided into the following lectures.

1. Introduction
A general introduction into systems biology and its goals.

2. Math
An introduction into differential equations and why they are useful.

3. Interacting molecules, Enzymes, Genome-scale models
Describing interactions between molecules, enzyme kinetics and basics of modeling of whole cell metabolisms.

4. Gene Regulation 1
Auto-regulation: Genes regulate their own expression. They can either inhibit or facilitate themselves which allows them to react adequately to external stimuli.

5. Gene Regulation 2
Gene regulatory motifs and networks: Genes regulate each other and allow “smart” reactions to the environment. Gene networks are assembled as modules which may give them evolutionary flexibility.

6. Robustness
Cells/organisms can make reproducible decisions given an ever changing environment. Proteomes can adapt to growth conditions. Networks can be designed in very robust ways and chemotaxis always works.

7. Optimal Adaptation
Strategies how to deal with complex environment. Trade-off between different tasks. Bet-Hedging and stochastic switching between phenotypes to adapt for uncertain futures. Forecasting the future.

8. Population Dynamics
Growing populations can be described by simple laws. Negative interaction can limit growth and lead to oscillations and chaos. Positive interactions can cause bistable outcomes. Trade-off can cause a division of labor, where different cells do different things.

9. Evolutionary Game Theory
Evolution is a game and can be described as such. Prisoners dilemma and egoism. Group selection to enforce cooperation. Rock-paper-scissor games and biodiversity.

10. Spatial Systems and Pattern
Random walk as the most simple type of motion. Patterns during development: French flag model and Turing patterns. Range expansion and collective motion of organisms.

11. Species Interactions
Lotka-Volterra models to describe species interactions. Interaction determines if two species can coexist. Resource explicit models of species interaction. Limiting resources decides who wins competition.

12. Ecosystems
Lotka-Volterra equations for complex communities. Biodiversity lowers stability. In resource explicit models number of limiting resources sets biodiversity. Biodiversity can be increased by cross-feeding.