BIO-692

Symmetry and Conservation in the Cell

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Cursus	Sem.	Type
Computational and Quantitative Biology		Opt.
Neuroscience		Opt.

Language of teaching	English
Credits	3
Session	
Exam	Multiple
Workload	90h
Hours	**61**
Courses	21
Exercises	40
Number of positions	**20**

Remark

Next time: Spring 2021

Summary

This course instructs students in the use of advanced computational models and simulations in cell biology. The importance of dimensionality, symmetry and conservation in models of self-assembly, membranes, and polymer/filament scaling laws reveals how cells exploit these principles in life.

Content

This course aims to show how a living cell uses the principles of symmetry and conservation to carry out its functions. We will examine selected cellular structures and dynamical processes and construct computational models of them that are solved analytically, numerically or with computer simulations. The importance of dimensionality is illustrated by examining random walks in 1, 2 and 3 dimensions and two-dimensional fluid membranes that surround many cellular organelles and form the plasma membrane. The symmetry of a system usually changes when passing through a phase transition, and it is increasingly accepted that cells manipulate the phases of proteins in the cytosol to create membraneless organelles that are composed of intrinsically-disordered proteins (IDP). These organelles, which are also referred to as biomolecular condensates, carry out vital functions for the cell, but are implicated in neurodegenerative diseases such as Alzheimer's disease. They are three-dimensional, fluid networks formed by a process of liquid-liquid phase separation, and exhibit quite distinct structures and dynamics that are controlled by the thermodynamic properties of their constituent proteins within the crowded environment of the cytosol. We will construct models of IDPs and use simulations to quantitatively connect the structural properties of IDPs to the physical chemical properties of the condensates. Computer simulations are used to explore model systems in homework problems and a semester project. The primary goal of the course is to show students how nature uses symmetry and conservation to achieve specific cellular goals, and to understand how computer simulations can be used to study these processes.

Course content:
Overview of the biophysics of a cell on different length scales: a “day in the life of a cell”
Mathematical models in 1d: Random Walks and Langevin equations
Scaling laws for polymers, self-avoiding and phantom polymers, entropic spring, stiff asymmetric filaments and filament self-assembly and growth
Overview of computer simulations, fundamentals, coarse-graining, and simulations on multiple scales
Mathematical models in 2d: membranes, formation, material properties, and endo- and exocytosis
Molecular self-assembly on an axis from irreversible to reversible
Mathermatical models in 3d: Biomolecular condensates - a new phase of cellular matter

As part of the exercises and project, students will be expected to solve simplified models of diffusion processes in a cell using differential equations; set up and run a Dissipative Particle Dynamics simulation (the executable code and sample input files for modification will be provided), analyse the simulation output and present it in the form of time-averaged observables with an error estimation, and as time series plots.
Choose and justify which molecular simulation techniques are suitable for simulating selected cellular processes; set up and solve dynamical models relevant to a cell; and explain how the symmetry of molecules and aggregates influences cellular properties

Keywords

Membrane, organelle, random walk, diffusion equation, simulation, biomolecular condensate, phase separation

Learning Prerequisites

Required courses

BIO-205, MATH-106, PHYS-10