BIO-369

Randomness and information in biological data

Bitbol Anne-Florence

Cursus	Sem.	Type
Computational and Quantitative Biology		Opt.
Computational biology minor	E	Opt.
Life Sciences Engineering	BA6, MA2, MA4	Opt.
Minor in life sciences engineering	E	Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	During the semester
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Biology is becoming more and more a data science, as illustrated by the explosion of available genome sequences. This course aims to show how we can make sense of such data and harness it in order to understand biological processes in a quantitative way.

Content

Recently, biology has become more and more a data science. For instance, progress in sequencing has caused an explosion of available genome sequences. How can we make sense of such data and harness it in order to understand biological processes in a quantitative way? In many cases, biological data can be understood as being sampled from distributions of random variables. This course will first show the importance of randomness in biology. Then it will introduce some ways of extracting information from biological data, of assessing models and of approximately inferring the probability distributions underlying biological data. Some notions of statistics, information theory and statistical physics will be introduced, always with concrete applications to biological data in mind. Problems and numerical projects will allow students to apply the methods to real biological data. The course will be organized as follows:

Part I: Randomness in biological processes and biological data

1. Randomness and random variables - Medical testing. Luria-Delbrück experiment.
2. Importance of thermal fluctuations at the cellular scale - Chemical bonds, biopolymers, biomembranes.
3. Random walks - Protein abundances in single cells. Population genetics. Other examples.

Part II: Extracting information from biological data

1. Quantifying randomness in data - Entropy and its interpretation. Entropy in neuroscience data.
2. Quantifying statistical dependence - Correlation. Mutual information. Coevolution in sequences of interacting proteins.
3. Inferring probability distributions from data - Maximum likelihood, model selection and parameter estimation. Introduction to maximum entropy inference. Prediction of protein structure from multiple sequence alignments (from maximum entropy models to transformers).
4. Finding relevant dimensions in data: dimension reduction - Principal component analysis. Introduction to nonlinear methods.

Keywords

Biological data, data science, sequencing data, neuroscience, population genetics, random variable, random walk, information theory, statistical physics, entropy, mutual information, inference, dimensionality reduction.

Learning Prerequisites

Required courses

Analysis; probability and statistics; linear algebra; general physics; programming.

Recommended courses

Introductory machine learning.

Learning Outcomes

By the end of the course, the student must be able to:

- Manipulate notions of statistics, information theory and statistical physics.
- Apply these notions to biological data.
- Propose strategies for biological data analysis.
- Assess / Evaluate proposed data analysis methods.

Teaching methods

Lectures, exercises, numerical mini-projects.

Assessment methods

Written mid-term exam and written final exam during the semester.

Supervision

Office hours	No
Assistant.e.s	Yes
Forum	Yes

Resources

Bibliography

Reference textbooks:

- P. Nelson, Physical Modeling of Living Systems, WH Freeman, 2014
- D. MacKay, Information Theory, Inference, and Learning Algorithms, Cambridge University Press, 2003

More advanced textbooks:

- W. Bialek, Biophysics: Searching for Principles, Princeton University Press, 2012
- T. Cover and J. Thomas, Elements of Information Theory, 2nd ed, Wiley Interscience, 2006
- S. Cocco, R. Monasson and F. Zamponi, From statistical physics to data-driven modelling, Oxford University Press, 2022

Ressources en bibliothèque

- Find the references at the Library

Moodle Link

- https://go.epfl.ch/BIO-369