Engineering Tripos Part IIB, 4G7: Control and computation in living systems, 2025-26

Leader

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Second Assessor

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Timing and Structure

Michaelmas term, 12 Lectures + problems classes. 100% Exam

Prerequisites

Ability to program numerical simulations in MATLAB or Python. No formal prerequisites but 3G2 Mathematical Physiology and 3G3 Intro to Neuroscience would be very useful.

Aims

The aims of the course are to:

- Introduce students to formalisms for modelling biological systems at multiple levels, from molecules to organisms
- Provide tools for understanding how nonlinear computations arise in biological systems to enable decision making, timing, memory and control
- Develop an appreciation of current research in quantitative biology through case studies of recent and/or classic research papers

Objectives

As specific objectives, by the end of the course students should be able to:

- Introduce examples of biological computation and control: bacterial chemotaxis, circadian oscillators, motor pattern generators, biochemical
- Construct and analyse formal models of living systems, including biochemical networks, neural networks and populations of agents
- Provide a contextual introduction to key mathematical and computational tools: (nonlinear) feedback control, qualitative theory of ODEs, singular perturbation theory, stochastic dynamical systems, simulation methods.
- Develop ability to simulate and experiment with models of living systems and report results coherently and critically
- Develop ability to read, understand and appreciate/contextualise research papers in quantitative biology and mathematical biology

Content

Living systems, including single cells, nervous systems and animal/human populations, are increasingly well understood in terms of the computations they perform and the control principles they embody. This has enabled a paradigm shift in bioengineering, allowing us to pick apart and understand how living systems function and, crucially, manipulate and exploit these functions in a principled way.

This course will introduce students to current research in this field and provide tools and examples for analysing, modelling and designing biological and biologically-inspired systems. It therefore fills an important component of an up to date bioengineering curriculum and complements several courses on offer in Bioengineering (4G1 Mathematical Biology of the Cell, 4G3 Computational Neuroscience) and Information Engineering (4F2 Nonlinear and Robust Control, 4M7 Practical Optimization). It will naturally complement projects and modules in bioengineering and neuroscience.

Course content (individual lectures may vary)

1. Introduction to modelling formalisms with examples (mass action kinetics, agent/population dynamics, timescale separation)
2. Switches and hysteresis: the fundamental motif for decision making and memory
3. Introduction to phase plane analysis and qualitative theory of ODEs
4. Gradient following algorithms in nature, chemotaxis
5. From switches to pulses and nonlinear oscillations: the Fitzhugh Nagumo reduction of action potentials
6. Consensus and decision making in populations of cells and animals
7. Selected topics in biological control and computation and bio-inspired computation (e.g. brain machine interfaces, synthetic biochemical circuits, neuromorphic computing)

Coursework

Coding/simulation exercises with a short report (25%)

Booklists

The following textbooks are useful

Strogatz, S. H. (2018). Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering. CRC press.

Berg, H. C. (2008). E. coli in Motion. Springer Science & Business Media.

Alon, U. (2006). An introduction to systems biology: design principles of biological circuits. Chapman and Hall/CRC.

Examination Guidelines

Please refer to Form & conduct of the examinations [3].

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[3] https://teaching25-26.eng.cam.ac.uk/content/form-conduct-examinations