LF305-12 Dynamics of Biological Systems

21/22

Department
Life Sciences
Level
Undergraduate Level 3
Module leader
Orkun Soyer
Credit value
12
Module duration
10 weeks
Assessment
30% coursework, 70% exam
Study location
University of Warwick main campus, Coventry

Description

Introductory description

This module will introduce students to the "systems dynamical" nature of cells. We will introduce the student to this system level view of the cell and explain the experimental and mathematical approaches used to achieve a system levels understanding of cellular function. The module will also outline how a detailed understanding of system dynamics enables researchers to engineer novel biological systems for the first time, in a synthetic biology approach.

Module aims

This module will introduce students to the fact that cells and cellular pathways are dynamical systems that can change their behaviour both in space and time. More particularly, we will highlight that regulatory, signalling, and metabolic pathways studied in biology and represented as static pictures in classic textbooks on biology, are indeed dynamical systems that can give rise to different behaviours that can change over time or under different environmental or cellular conditions. The module will introduce students to the key experimental and modelling approaches used to study biological systems, including computational models (e.g. differential equation models), techniques for acquisition of quantitative data (e.g. imaging, expression analysis, metabolomics, transcriptomics, and proteomics), analysis and interpretation of quantitative observations on system dynamics. The module will also outline how a detailed understanding of system dynamics allows researchers to engineer novel biological systems (synthetic biology).

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

Weeks 1-2: Analysing Cells as Interconnected Biological Systems (4 lectures)

Lecture 1 (Dr Orkun Soyer/Dr Miriam Gifford and the rest of the teaching team)
Introduction to Cellular Systems as Dynamical Systems

Lecture 2 (Dr Alex Jones), Identifying Protein Localisation and Interactions in Cellular Systems
This lecture will introduce high-throughput protein localisation methods and strategies and the identification of protein-protein interactions. The use of fusion proteins constructs in large-scale studies and the ways by which one tag can be used to obtain different measurements (localisation, quantification) will be discussed.

Lecture 3 (Dr Alex Jones), Analysing Cellular Systems using Quantitative Proteomics
This lecture will cover methods to quantify proteins by mass spectrometry. The advantages and limitations of such measurements in dynamic systems will be discussed, particularly regarding the functional role of protein modifications and localisation.

Lecture 4 (Dr Orkun Soyer), Understanding Cellular-level System Data using Graph Theory
This lecture will explore protein interaction networks, metabolic networks, graph theoretical analysis of networks and network motifs.

Weeks 3-5: Analysing cells as dynamical systems (5 lectures)

Lecture 5 (Dr Miriam Gifford), Temporal Acquisition and Analysis of Gene Expression Data
This lecture will look at experimental design for gene expression analysis experiments and discuss which technical methods are most effective. The lecture will also overview high-throughput sequencing methods and microarray technology relevant for analysing dynamic systems.

Lecture 6 (Dr Miriam Gifford), Analysis of Temporal Gene Expression Data
This lecture will cover data normalisation and analysis, including clustering, network inference and correlation vs. causation.

Lecture 7 (Dr Munehiro Asally), Temporal Acquisition and Analysis of Data using Time-lapse Microscopy
This lecture will introduce time-lapse microscopy, experiment design and data analysis using image/movie analysis.

Lecture 8 (Dr Orkun Soyer), Introduction to Modelling Cellular Systems as Dynamical Systems
This lecture will analyse systems dynamics concepts, using differential equations and look at writing differential equations for biochemical reactions, Michealis-Menten kinetics.

Lecture 9 (Dr Orkun Soyer), Understanding Dynamics of Cellular Systems Dynamics using Mathematical Models
This lecture will focus on writing models for signalling and gene-regulatory networks, numerical

simulation, analysis of stability. A case study in modelling/experiment.

Weeks 5-6:
Lecture 10 (Dr Orkun Soyer & all teaching team), Turning point Handset-based Revision

Weeks 6-7: Analysing Heterogeneity in Cellular System Dynamics (3 lectures)

Lecture 11 (Dr Munehiro Asally/Dr Orkun Soyer), Examples for Biological Noise in Physiological Processes
This lecture will examine antibiotic resistance, sporulation, population-level measurements, single-cell level measurements, cellular decision making and bacterial cell differentiation.

Lecture 12 (Dr Miriam Gifford), Acquisition of Single Cell Data and Measurement of Population -level Variance using Flow Cytometry
This lecture will introduce Flow cytometry, a technique that can analyse properties of cells such as cell size, density, ploidy, and expression of molecules tagged with fluorophores. After analysing individual cells within a mixture it can also be used to isolate those with properties of interest ‘cell sorting’ to understand dynamics in multicellular systems.

Lecture 13 (Dr Daniel Hebenstreit), Acquisition of Single Cell Data and Measurement of Population-level Variance using Gene Expression
This lecture will provide an overview of experimental technologies with single-cell and single-molecule resolution, including MS2 tagging, smRNA-FISH, single-cell RNA-seq, and molecular barcoding.

Weeks 7-8: From Understanding to Engineering Systems Dynamics (2 lectures)

Lecture 14 (Professor John McCarthy), Introduction to Synthetic Biology
This lecture will explore a relatively new field in which researchers use a detailed understanding of naturally evolved biological systems as the basis for engineering novel systems with specific functions.

Lecture 15 (Professor John McCarthy). Building and Testing Genetic and Biochemical Circuitry
This lecture will consider how building and testing genetic and biochemical circuitry can generate ground-breaking biotechnology.

Weeks 8-9: Revision (1 lecture)

Lecture 16 (whole teaching team), Re-summary of Material and Question & Answer Session with Students
The students will be provided with a few key concepts as an overview, after which they will be invited to participate in an open-floor discussion with questions.

Learning outcomes

By the end of the module, students should be able to:

- Module Specific Skills and Knowledge: 1. gather an appreciation of the systems view of cellular biology and the complexity of biological systems at the cellular level; 2. gather an appreciation for the role of quantitative data and mathematical modelling in understanding biological systems; 3. learn about experimental approaches to acquiring quantitative and single-cell data on biological systems 4. learn about building abstract computational/mathematical models that can allow explaining acquired quantitative data and guide further collection of it.

- Discipline Specific Skills and Knowledge: 5. apply a range of computational and mathematical methods to analyse biological data and model diverse biological phenomena; 6. combine experimental and theoretical concepts, literature and ideas.
- Personal and Key Transferable/ Employment Skills and Knowledge: 7. work in small groups to tackle complex problems; 8. communicate with scientists with experimental and/or theoretical backgrounds; 9. think creatively and beyond traditional discipline boundaries.

Indicative reading list

Essential Reading
Klipp, E, Liebermeister, E et al "Systems Biology: A Textbook", Wiley VCH Blackwell (2009), ISBN: 978-35273187742

Alon, Uri "An Introduction to Systems Biology: Design Principles of Biological Circuits", Taylor and Francis (2006), ISBN: 978-1584886426
Recommended Reading
Berg, Howard C "Random Walks in Biology", University Press of California (1993), ISBN: 978-0091000640
Strogatz, Steven H "Nonlinear Dynamics and Chaos", The Perseus Books Group (2000), ISBN: 978-0738204536

Ptashne, Mark "A Genetic Switch", Cold Spring Harbour Laboratory Press (2004), ISBN: 978-0879697167
Murray, James D "Mathematical Biology: An Introduction: Part 1" 3rd , Springer-Verlag (2002), ISBN: 978-0387952239
Britton, Nicholas F "Essential Mathematical Biology" , Springer (2005), ISBN: 978-1852335366
Kaneko, Kunihiko "Life: An introduction to complex systems Biology" , Springer-verlag (2006), ISBN: 978-364206
Additional reading material will be assigned for specific lecture and lab sections

Subject specific skills

1. Understanding protein dynamics in cellular systems
2. Understanding proteomics and synthetic biology
3. Understanding gene expression, genomic analysis and RNA-omics
4. Understanding dynamic modelling in cellular and physiological systems
5. Understanding population variations and population modelling

Transferable skills

1. Critical appraisal of source material
2. Self directed learning
3. Adult learning

Study

Study time

Type	Required
Lectures	16 sessions of 1 hour (13%)
Supervised practical classes	3 sessions of 6 hours (15%)
Private study	86 hours (72%)
Total	120 hours

Private study description

Independent learning, self directed learning and revision for exams.

Costs

No further costs have been identified for this module.

Assessment

You do not need to pass all assessment components to pass the module.

Assessment group D2

	Weighting	Study time
MCQ - Multi-Choice Questionnaire	30%	
Written Examination	70%	

Feedback on assessment

Feedback will be provided via Moodle on the practical element of the module.

[Past exam papers for LF305]

Availability

Courses

This module is Option list A for:

- UBSA-C1B9 Undergraduate Biomedical Science
    - Year 3 of C1B9 Biomedical Science
    - Year 3 of C1B9 Biomedical Science
    - Year 3 of C1B9 Biomedical Science
- ULFA-C1A3 Undergraduate Biomedical Science (MBio)
    - Year 3 of C1A3 Biomedical Science
    - Year 3 of C1B9 Biomedical Science