MATH35032 - 2012/2013

General Information

- Title: Mathematical Biology
- Unit code: MATH35032
- Credits: 10
- Prerequisites: None
- Co-requisite units: None
- School responsible: Mathematics
- Members of staff responsible: Dr. Mark Muldoon

Specification

Aims

This module aims to engage students with the applications of mathematical methods to current questions in biology.

Brief Description of the unit

The life sciences are arguably the greatest scientific adventure of the age. Over the last few decades a series of revolutions in experimental technique have made it possible to ask very detailed questions about how life works, ranging from the smallest, sub-cellular scales up through the organisation of tissues and the functioning of the brain and, on the very largest scales, the evolution of species and ecosystems. Mathematics has so far played a small, but honourable part in this development, especially by providing simple models designed to illuminate principles and test broad hypotheses.

The mathematics required for biology is not generally all that hard or deep (though there are exceptions: some of the most exciting recent work in phylogenetics requires tools from algebraic geometry), but as the sketches above suggest the range of tools is extremely broad. The point is that modern mathematical biology is genuinely applied maths: its techniques are chosen to suit the biological problems, not the traditional disciplinary subdivisions. Although some previous acquaintance with graph theory and probability would be helpful, this course is meant to be self-contained and will only assume knowledge of differential equations.

Learning Outcomes

The main aim of this course is to see how mathematical ideas, techniques and habits of rigour can contribute to the understanding of questions about living things.

On completion of this unit successful students will be able to:

- Use simple ODE models to discuss questions in population dynamics
- Read, understand and analyse dynamical systems that describe networks of biochemical reactions.
- Read scientific papers that emphasize the application of mathematical ideas to biology.

Future topics requiring this course unit

No Fourth Year option requires this unit.

Syllabus

The course falls into two parts: for the first six weeks it is concerned mainly with standard ODE and PDE models and will rely strongly on the first volume of J. Murray's *Mathematical Biology*. The main topics will be:

• Population models & questions of ecological and evolutionary stability
    These topics are normally treated with ODEs or, when one wants to include spatial organisation, PDEs. This area is a good introduction to the “illustrative model” school of mathematical biology.
• Models of chemical reaction networks

The ODE models used here are formally very similar to those used for interacting populations, but the emphasis on chemical reactions prepares the way for the more detailed models of cellular signalling.

• Probabilistic simulation of chemical reaction networks

In the last part of the course we will be interested in models of genetic regulation, whihc naturally raise the question “Is it sensible to use ODE-based models when there are only a very few reactants?” Here we address this issue via a standard stochastic formulation, the Gillespie algorithm.

The latter part of the course is more directly connected to current questions in biology and the lectures will, in part, be designed to help the students read scientific papers, though some of the material is also covered in Uri Alon's book (see below).

• Pattern selection and development of body plan

This topic forms a bridge between the textbook study and the research literature. We will begin by reading a famous old paper, Alan Turing's *The Chemical Basis of Morphogenesis*, and then look at the sorts of things that modern work—both experimental and theoretical—has to say about related questions. The main tools here are, again, differential equations.

• Analysis of regulatory networks

This topic follows naturally from Turing's work and begins to bring in some new mathematical methods and ideas, especially from graph theory and probability. This is mathematical biology at its closest to experimental data (see the online materials for a more detailed list of topics and links to articles).

Textbooks

I studied the following—more or less mathematically-minded—books while preparing the course.

- James D. Murray, *Mathematical Biology I: An Introduction* 3rd edition, (Springer, 2002). ISBN 0-387-95223-3
  This book is available online through SpringerLink, a service to which the University subscribes.
- James D. Murray, *Mathematical Biology II: Spatial Models and Biomedical Applications* 3rd edition, (Springer, 2002). ISBN 0-387-95228-4
- Lee A. Segel, *Modeling dynamic phenomena in molecular and cellular biology* (Cambridge University Press, 1984). ISBN 0-521-27477-X
- Uri Alon, *An Introduction to Systems Biology: Design Principles of Biological Circuits* (Chapman & Hall/CRC, 2007). ISBN 1-58488-642-0
- Darren J. Wilkinson, *Stochastic Modelling for Systems Biology* (Chapman & Hall/CRC, 2006). ISBN 1-58488-540-8

For biological background one might also look at:

- Bernhard Ø. Palsson, *Systems Biology: Properties of Reconstructed Networks* (Cambridge University Press, 2006). ISBN 0-521-85903-4
- Eric H. Davidson, *Genomic Regulatory Systems* (Academic Press, 2001). ISBN 0-12-205351-6
- Eric H. Davidson, *The Regulatory Genome* (Academic Press, 2006). ISBN 0-12-088563-8
- Terry A. Brown, *Genomes 3* (Garland Science, 2007). ISBN 0-8153-4138-5
  The previous edition, *Genomes 2*, is available online from the National Center for Biotechnology Information (NCBI) Bookshelf, a service of the U.S.A's National Institutes of Health (NIH).
- Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts and Peter Walter, *Molecular Biology of the Cell* 4th edition, (Garland Science, 2002). ISBN 0-8153-4072-9

Teaching and learning methods

Two lectures and one problems class each week. In addition students should expect to do at least four hours private study each week for this course unit.

Assessment

Coursework: Homework, due in week 8, worth 20%
End of semester examination: two hours weighting 80%

Arrangements