MATH0100 (Quantitative Physiology: Mathematical Methods)

Year:	2020–2021
Code:	MATH0100
Level:	6 (UG)
Normal student group(s):	Biosciences students
Value:	15 credits (= 7.5 ECTS credits)
Term:	1
Structure:	3 hour lectures per week
Assessment:	90% examination, 10% coursework
Normal Pre-requisites:	A at A level Mathematics
Lecturer:	Dr Nuno R. Nené, Prof Alexey Zaikin

Course Description and Objectives

This module offers an introduction to mathematical modelling for biologists. Application of mathematical models is crucially important for modern systems biology for two simple reasons: solving mathematical models is much cheaper than running the experiments and it helps to understand the mechanisms behind complex biological phenomena. On the other hand, mathematical modelling of complex biological systems is a kind of art with many possible approaches. The module consists of reviewing the mathematical methods in biology, and solving different interesting examples illustrating application of these methods to the study of the normal function of living systems at all scales, starting with modelling gene expression and finishing with a consideration of blood dynamics.

The main aim is to teach students with a background in biology how to construct a mathematical model and solve it analytically in order to explain complex behaviours observed in living systems. In particular, this will include consideration of the following questions: i) Why is mathematical modelling so important right now in modern biology?; ii) What is the logic behind mathematical modelling, from the observed experimental results to the derivation of the model, its analytical solution and explanation of the data; iii) How do we apply differential equations, ordinary and partial, linear stability analysis, phase plane methodology and linearization to the solution of mathematical models?; iv) How do we apply mathematical equations when modelling expression dynamics and function of simple genetic networks, body and bone mechanics, activity of neurons, and different effects in blood dynamics?

Detailed Syllabus

The lectures will include a review of mathematical methods, including solving differential equations, integration, linear stability analysis, application of generalized functions in simple form, simple partial differential equations and exact or approximate solutions. All of these considerations will be focused on the simple examples whose solution will help to understand analytical derivations used in the following biological examples. The examples will include 5 topics, on a very different scale, each accompanied with the corresponding tutorial on mathematical methods:

– We will start with simple toy mathematical models using scaling arguments and discuss the questions: How high can an animal jump? How fast can we walk before breaking into run? What is the minimal nerve speed required to make it possible for an animal to balance? What is the simplest universal model for growth of a multicellular organism?

– This part is devoted to mathematical modelling of gene expression, an increasingly important branch because of the fast development of genetic medicine and synthetic biology. We will focus on how to write differential equations to describe gene expression. Additionally, we will consider how to model a simple bistable genetic switch to describe mechanisms of cell differentiation or a simple genetic clock. Finally, we will consider two very hot topics: the effect of stochasticity on genetic expression, manifesting itself in critical phenomena, and the possibility to use genetic networks for calculations.

– Next we consider a simple model of neural activity in the brain. We will study the FitzHugh-Nagumo model, its relation to the Hodgkin-Huxley model, and explain why a neuron can oscillate or wait in an excitable regime for an information transmission. Then we will consider neural networks and propagation of nerve impulses.

– Bone mechanics is the focus of this part. We will answer the questions: why is boxing with gloves safer than without? How much do our bones shorten when you stand? Why are long bones hollow? What is a simple model for bone's viscoelasticity? What is the simple model of breaking bones by bending?

– Finally, we will focus on blood dynamics and consider the main equations of blood movement. We will answer the questions: How can viscosity of the human blood be measured? Why is ESR increased in an illness? What is the model for pulse waves? What happened to the famous Arturo Toscanini in 1953 when he had a memory lapse? What are Korotkoff sounds and how can we use them to measure blood pressure?