

Biology and Medicine Editorial

Applications of Mathematics in Physics and Astronomy have a long history, reaching back to ancient civilisations in Egypt and Greece. By contrast, Biology and Medicine have only much more recently become the focus of mathematical investigation. Prominent early examples include Fibonacci's models of rabbit populations in the 12th century, Bernoulli's models of the impact of smallpox infections in the 18th century, and applications in evolutionarily biology in the 19th century. The beginning of the 20th century was a pivotal point, marked by the introduction of the terminology *theoretical biology* by Reinke in 1901, and D'Arcy Thompson's seminal book *On Growth and Form* in 1917.

For many years, the mathematical techniques developed and applied in Mathematical Biology were predominantly ODEs, PDEs, stochastic differential equations, difference equations and probability theory, and the majority of applications were in ecology and evolutionary biology. The spectrum of techniques used and the scope of areas in biology covered has since significantly broadened. Starting with Turing's seminal paper on 'The Chemical Basis of Morphogenesis' in 1952, spatial modelling techniques have become increasingly important, and have been used for a wide spectrum of applications, including travelling waves in wound-healing, agent based models of swarming behaviour, and pattern formation in many areas of biology. Later developments also included adapting mathematical techniques to investigate complex, non-linear dynamics in biology.

Stochasticity is inherent in many biological systems, and applications involving stochastic processes based on random variables and probability distributions, as well as Markovian and non-Markovian processes, jump processes and master equations, Monte Carlo methods and Gillespie algorithms have all become pillars of Mathematical Biology. These applications benefitted from developments in Computer Science and computing power since the late 20th century, enabling the computational analysis and simulation of complex dynamics described by large systems

of equations. Indeed, computational modelling has by now become a sub-discipline of Mathematical Biology in its own right.

Parallel developments in Biology and Medicine have also significantly impacted on the way Mathematical Biology has evolved. For example, through experimental developments in the Life Sciences biological data have become available that afford unprecedented insights into biological systems at the smallest scale.

This has spurred the area of Molecular Mathematical Biology, that is centred on mathematical investigations of RNA and DNA, the molecules storing genetic information, proteins and cells. Mathematical Virology, with its focus on the structures and functional roles of these components in the context of virology, is a subfield. Investigating biological entities at the microscale poses mathematical challenges that require the development of novel mathematical approaches. Two examples are covered in this special issue (Figure 1). Nataša Jonoska from the University of South Florida is reporting on her applications of graph and knot theory in the context of DNA recombination (see page 182). Reidun Twarock from the University of York describes her research programme in Mathematical Virology, covering applications of group, graph, and tiling theory to the modelling of viruses and its consequences for how viruses form, evolve and infect their hosts (see page 186).

In addition, the sheer amount of available data, also known as big data, requires the invention of novel mathematical techniques for their analysis. We have included two articles to showcase such developments (Figure 2). The contribution by Carola-Bibiane Schönlieb from the University of Cambridge, together with her collaborator Marta Betcke from the Computer Science Department at UCL, report on applications of optimisation problems and Fourier transforms in imaging data analysis with applications in healthcare (see page 202). Moreover, the contribution by Heather Harrington and her collaborators from the University of Oxford presents a novel data analysis method for large data sets routed in persistence homology (see page 206). The latter

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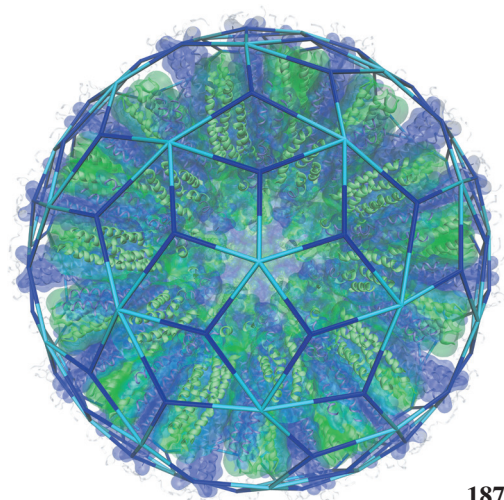


Figure 1: Graph theory reveals DNA recombination in ciliates, and tiling theory characterises protein containers for use in vaccines

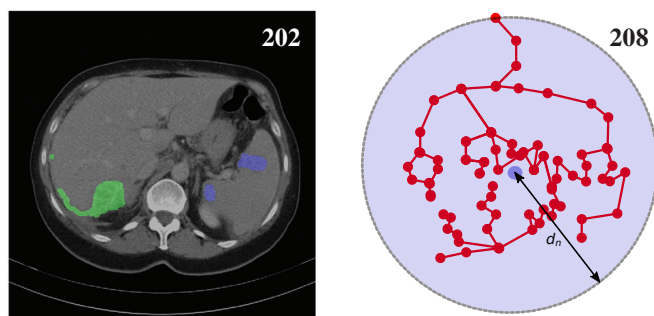


Figure 2: Examples of modelling cancer growth

also includes applications, in collaboration with Helen Byrne from Oxford, to cancer biology, which is an area in which mathematical and computational modelling have made important contributions.

One of the modelling challenges in Mathematical Biology are multiscale models that combine different scales (Figure 3). Mariya Ptashnyk from Heriot-Watt University in Edinburgh is presenting multiscale models in plant science, using continuous models combined with numerical simulations and optimisation techniques (see page 197). Carmen Molina-Paris and her team of collaborators from the University of Leeds present multiscale models of bacterial infections, using Markov processes and ODE systems, that combine intra-cellular and within-host models (see page 194).

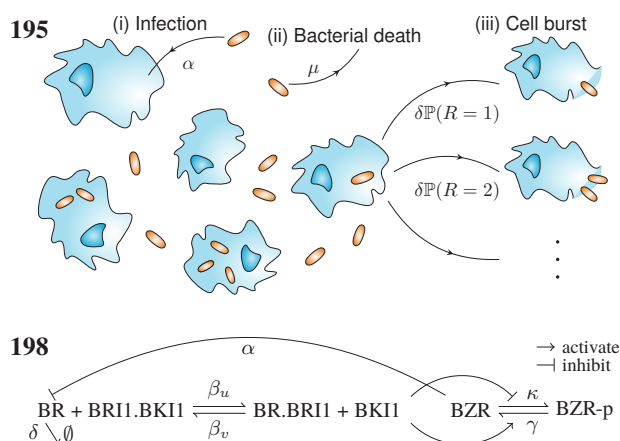


Figure 3: Multiscale modelling

A different perspective on the modelling of disease is provided by Emma L. Davis from the University of Warwick and Déirdre Hollingworth from the University of Oxford, who use probability theory, in particular branching processes and extinction probabilities, in order to develop mathematical models supporting disease control eradication programmes and prevention (see Figure 4 and page 190).

Many mathematicians working in Mathematical Biology have long-standing collaborations with experimentalists and medics, and these interactions have significantly impacted on their trajectories within Mathematical Biology. Many also work in close collaboration with colleagues from a wide range of theoretical disciplines, including bioinformatics, biophysics and computational chemistry. This high degree of interdisciplinarity in Mathematical Biology is also reflected by the diversity of the backgrounds of the people practising it. Take ourselves as

examples – Reidun Twarock has a background in Mathematical Physics and has a joint appointment at the University of York in the Departments of Mathematics and Biology; Ellen Brooks-Pollock has a maths background and is a lecturer in the Bristol Veterinary School and Bristol Medical School.

Many of the creative leaders in Mathematical Biology are women. A rare early example of a woman who shaped mathematical biology is Hilda Hudson who developed mathematical models of Malaria in the early part of the 20th century. Nowadays, women are comparatively well represented in this field. In order to celebrate the contributions of female mathematicians in Mathematical Biology, all lead authors have been chosen to be female, and indeed the vast majority of contributing authors and both guest editors are also women. We hope that this will encourage female students to embark on a career in Mathematical Biology. We had a long list of excellent female mathematical biologists and it was a challenge to choose just seven feature articles.

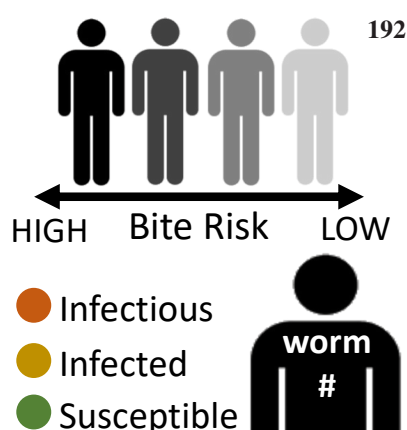


Figure 4: Model for disease control and eradication

Mathematical Biology has come of age within the last decade. This is not only reflected in the number of conferences, research programmes and doctoral training centres dedicated to topics in Mathematical Biology, but also by its classification as a discipline in its own right within the EPSRC Mathematical Sciences Portfolio. Its firm place on the map in the mathematical landscape was cemented last year when the community celebrated the Year of Mathematical Biology, as a joint venture of the European Mathematical Society and the European Society for Mathematical and Theoretical Biology.

In this special issue of *Mathematics Today* on Biology and Medicine, we are continuing this celebration by showcasing how versatile a research career in Mathematical Biology can be. Paraphrasing a colleague, ‘mathematical biology is more than being good at sums’; it relies on teams of people with different skills to capture the essence of a biological problem using mathematics. There are many opportunities to develop new mathematics, and apply mathematics in novel ways, inspired by – and indeed in tandem with – developments in Biology and Medicine. It is an exciting time to be working in Mathematical Biology, and to contribute to shaping a field that offers so much room for mathematical creativity.

The journey has really only just begun!

Ellen Brooks-Pollock FIMA, University of Bristol
Reidun Twarock FIMA, University of York