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ijirset@gmail.com

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Application of Mathematics in Life Science

Manoj Kumar Tatwal

Assistant Professor, Government College, Bundi, Rajasthan, India

ABSTRACT: Mathematics reaches into almost every area of biology and medicine. Quantitative methods are increasingly valued by biologists seeking to make sense of complex systems, or seeking to extract useful information from large experimental datasets. The life science and healthcare arenas are also rich sources of challenging new mathematical and statistical questions.

Our interests span application areas such as biochemical and gene regulatory networks, biomechanics, cell migration and signalling, medical imaging, medical statistics, molecular evolution and population dynamics. These topics are pursued in collaboration with life science researchers in Manchester and beyond.

Mathematicians and biologists, including medical scientists, have a long history of working successfully together. Sophisticated mathematical results have been used in and have emerged from the life sciences. Examples are given by the development of stochastic processes and statistical methods to solve a variety of population problems in demography, ecology, genetics and epidemics, and most joint work between biologists, physicists, chemists and engineers involves synthesis and analysis of mathematical structures. Pythagoras, Aristotle, Fibonacci, Cardano, Bernoulli, Euler, Fourier, Laplace, Gauss, von Helmholtz, Riemann, Einstein, Thompson, Turing, Wiener, von Neumann, Thom, and Keller are names associated with both significant applications of mathematics to life science problems and significant developments in mathematics motivated by the life sciences.

KEYWORDS: mathematics, life science, developments, results, statistics, quantitative, dynamics

I. INTRODUCTION

Charles Darwin, the father of the modern theory of evolution through natural selection, once complained that “I have deeply regretted that I did not proceed far enough at least to understand something of the great leading principles of mathematics; for men thus endowed seem to have an extra sense.” While it is well appreciated the huge contribution of mathematics to physics, its role in biology is not so generally acknowledged.[1] However, mathematics has been of paramount importance in the understanding of life sciences, and this importance will even increase in the near future. This review provides an opinionated and biased appreciation of such a contribution from mathematics to biology and vice versa. If physics was the battlefield where mathematics was meeting the real world during the 19th century, biology became the area of greatest intellectual challenges and applications for mathematics in the 20th century.[1,2]

As nicely written by Joel E. Cohen, mathematics became to biology what the microscope represented a few centuries ago: A tool to approach and interpret a new and fascinating world. Certainly, it was not until the invention of the microscope in the late 17th century when a world invisible to the naked eye was suddenly discovered. Similarly, mathematics is a way to describe complex systems. Think for example in the complexity of the human brain, with its huge number of neurons and interactions, or in the thousands of species in a tropical forest interacting in complex ways. Biology represents challenges into the complex, and math may help us to approach such a complexity. Mathematics represents a way to extract straight forward consequences of a series of assumptions: If x is assumed, then y is derived. This does not only allow us to think clearly, but to perform mathematical experiments in systems in which real experiments are impossible.[1,3]

Arguably, the Hardy–Weinberg law in population genetics is equivalent with Newton's First Law: If no force is applied into a population (eg, natural selection, migration), the population will remain in a genetic equilibrium, that is gene frequencies will not change in a population from one generation to another. Population genetics is one of the fields with a highest mathematical development. Partly this is due to the extraordinary long time scale in which evolutionary forces take place. It is impossible to observe changes in gene frequencies through time.[2] Oftentimes, what we have is a temporal slice, and from these snapshots we are to infer a process. A rich mathematical development by the fathers of the modern evolutionary synthesis allowed us to merge Darwin's theory on natural selection with quantitative genetics. The resulting theory has been a fascinating intellectual contribution to understanding what forces shape life in this planet and why there is so much genetic variation in nature. Mathematics has thus been the glue bringing together evolution and genetics.[1,3]



Mathematics, in sum, provides useful approximations to the real world. This has the advantage of controlling all confounding factors, isolating the interesting variables, and allowing to perform experiments we would not be able to do in nature. And this exercise can ultimately shed some light into the complexities of biological systems.[4]

Simple models are the “perfect crystals” of biology, a kind of benchmark or reference where one can get straight-forward insight. As we walk through the challenging complexities of brain dynamics or the consequences of global change on ecological communities, mathematics will become an even more powerful language to speak about life.

II. DISCUSSION

Mathematical and theoretical biology, or biomathematics, is a branch of biology which employs theoretical analysis, mathematical models and abstractions of the living organisms to investigate the principles that govern the structure, development and behavior of the systems, as opposed to experimental biology which deals with the conduction of experiments to prove and validate the scientific theories.[1] The field is sometimes called mathematical biology or biomathematics to stress the mathematical side, or theoretical biology to stress the biological side.[2] Theoretical biology focuses more on the development of theoretical principles for biology while mathematical biology focuses on the use of mathematical tools to study biological systems, even though the two terms are sometimes interchanged.[3][4]

Mathematical biology aims at the mathematical representation and modeling of biological processes, using techniques and tools of applied mathematics. It can be useful in both theoretical and practical research. Describing systems in a quantitative manner means their behavior can be better simulated, and hence properties can be predicted that might not be evident to the experimenter. This requires precise mathematical models.

Because of the complexity of the living systems, theoretical biology employs several fields of mathematics,[5] and has contributed to the development of new techniques.

A model of a biological system is converted into a system of equations, although the word 'model' is often used synonymously with the system of corresponding equations. The solution of the equations, by either analytical or numerical means, describes how the biological system behaves either over time or at equilibrium. There are many different types of equations and the type of behavior that can occur is dependent on both the model and the equations used. The model often makes assumptions about the system. The equations may also make assumptions about the nature of what may occur.[5]

III. RESULTS

The life sciences deal with a vast array of problems at different spatial, temporal, and organizational scales. The mathematics necessary to describe, model, and analyze these problems is similarly diverse, incorporating quantitative techniques that are rarely taught in standard undergraduate courses. This textbook provides an accessible introduction to these critical mathematical concepts, linking them to biological observation and theory while also presenting the computational tools needed to address problems not readily investigated using mathematics alone.

Proven in the classroom and requiring only a background in high school math, *Mathematics for the Life Sciences* doesn't just focus on calculus as do most other textbooks on the subject. It covers deterministic methods and those that incorporate uncertainty, problems in discrete and continuous time, probability, graphing and data analysis, matrix modeling, difference equations, differential equations, and much more. The book uses MATLAB throughout, explaining how to use it, write code, and connect models to data in examples chosen from across the life sciences.[6]

- Provides undergraduate life science students with a succinct overview of major mathematical concepts that are essential for modern biology
- Covers all the major quantitative concepts that national reports have identified as the ideal components of an entry-level course for life science students
- Provides good background for the MCAT, which now includes data-based and statistical reasoning
- Explicitly links data and math modeling
- Includes end-of-chapter homework problems, end-of-unit student projects, and select answers to homework problems
- Uses MATLAB throughout, and MATLAB m-files with an R supplement are available online
- Prepares students to read with comprehension the growing quantitative literature across the life sciences
- A solutions manual for professors and an illustration package is available



Mathematics plays a key role in many disciplines of science, primarily as a mathematical modeling tool. New innovations and developments in physics are by the influence of mathematics. Calculus was invented entirely for the use of physics. The importance of the role of mathematics in physics is understood by the existing discipline "mathematical physics" or "theoretical physics". One can think is mathematics has that same important role or even lesser important role in the field of biology and is mathematics and biology could possibly have anything in common. Even though physics and biology are very different sciences, mathematicians and biologists developed the "mathematical biology" or "biomathematics" as a recent discipline for the mathematical representation in biology to the theoretical and practical applications in biological, biomedical and biotechnology researches. In this paper we study the role played by mathematics in biology and analysis whether a considerable amount of mathematics courses need to be taught for biological science graduates[7]

IV. CONCLUSIONS

Mathematical biology or biomathematics is a fast growing, well recognized and the most exciting modern application of mathematics. The use of mathematics in biology is important since biology becomes more quantitative. This new discipline has applications in biology, biomedical and biotechnology. The aim of this new discipline is the mathematical representations and modeling of the biological problems using a variety of mathematical theories and techniques. The mathematical biology has both theoretical and practical applications in research on biological, biomedical and biotechnological fields. One significant work is currently done by Dr. Aver Friedman, distinguished Professor of mathematics and his research team at the Oberlin center for computation and modeling in Ohio State university is to find a cure for cancer (Margaret Putney, 2005). The objective of the research is to use a virus that attacks just the tumor while leaving the healthy cells alone. The cancer which mostly affected by research is a particular type of brain tumor known as glioma. The researchers are trying to find a virus that reproduces fast enough is able to avoid enough of the immune system to reduce the tumor. The researchers of this center found some parameters that would cause the tumor to be reduced. They passed their result to the biologists to create a virus that matches such parameters.

Another contribution of mathematics to biology is a mathematical modeling to address the biological process. The Mathematical Biosciences Institute in Ohio State university works on this work. The institute works on the explosion of biological data which was created by the technology to study biological systems. The data created a need to develop many mathematical models, statistical methods and computational algorithms. The mathematical models needed to encompass the biological process such as neurological and cellular problems. In neurological process, Parkinson's disease is in the center of the modeling work. There are around 1012 neurons in the human brains. To understand properly their relationship with all of the other neurons they proved that the differential equations can be used for the models. Ecology and evolutionary biology are the dominant fields of mathematical biology. Evolutionary biology has been the subject of extensive mathematical theorizing. Hanna Kokko, theoretical biologist and the professor in the department of biological and environmental science at the University of Helsinki says that much of biology relies on mathematics [8]

Evolutionary ideas are often complex and the logic of hypothesis proposed should be tested not only empirically but also mathematically. Another area of specialized research in mathematical biology is the genetic models and various models of the spread of infections. Cancer modeling and simulation, modeling the movement of interacting cell populations, mathematical modeling of the cell cycles are some of the models developed in the discipline of mathematical biology. Molecular set theory was introduced by Anthony Bartholomay. Molecular set theory is a mathematical formulation of the chemical kinetics of bio-molecular reactions in terms of sets of molecules and their chemical transformations. Its applications were developed in mathematical biology and especially in mathematical medicine. Many universities in the western countries offer degrees in the field of biomathematics such as University of St Andrews offers B.Sc. (Hons) in Biology and Mathematics, University of Dundee offers B.Sc.(Hons) in Mathematical Biology, University of Leeds offers B.Sc. in Biology and Mathematics and University of York offers M.Sc. in Advanced Mathematical Biology. These courses consist both mathematics and biology subjects. There is a need to offer a considerable amount of mathematics courses for biology graduates and biology courses for mathematics graduates in Sri Lanka to work in the field of biomathematics.[9]



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