

FRONTIERS IN APPLICATIONS OF MATHEMATICS

EDITORS Philip K. Maini  
Hans G. Othmer

# Mathematical Models for Biological Pattern Formation



Springer

# Mathematical Models For Biological Pattern Formulation Frontiers In Biological Mathematics

**M Carnoy**



### **Mathematical Models For Biological Pattern Formation Frontiers In Biological Mathematics:**

*Mathematical Models for Biological Pattern Formation* Philip K. Maini, Hans G. Othmer, 2012-12-06 This 121st IMA volume entitled MATHEMATICAL MODELS FOR BIOLOGICAL PATTERN FORMATION is the first of a new series called FRONTIERS IN APPLICATION OF MATHEMATICS The FRONTIERS volumes are motivated by IMA programs and workshops but are specially planned and written to provide an entree to and assessment of exciting new areas for the application of mathematical tools and analysis The emphasis in FRONTIERS volumes is on surveys exposition and outlook to attract more mathematicians and other scientists to the study of these areas and to focus efforts on the most important issues rather than papers on the most recent research results aimed at an audience of specialists The present volume of peer reviewed papers grew out of the 1998-99 IMA program on Mathematics in Biology in particular the Fall 1998 emphasis on Theoretical Problems in Developmental Biology and Immunology During that period there were two workshops on Pattern Formation and Morphogenesis organized by Professors Murray Maini and Othmer James Murray was one of the principal organizers for the entire year program I am very grateful to James Murray for providing an introduction and to Philip Maini and Hans Othmer for their excellent work in planning and preparing this first FRONTIERS volume I also take this opportunity to thank the National Science Foundation whose financial support of the IMA made the Mathematics in Biology program possible

**Computational and Mathematical Models in Biology** Carla M.A. Pinto, Clara Mihaela Ionescu, 2023-12-08 This book provides the most valuable and updated research on computational and mathematical models in biological systems from influential researchers around the world and contributes to the development of future research guidelines in this topic Topics include but are not limited to modeling infectious and dynamic diseases regulation of cell function biological pattern formation biological networks tumor growth and angiogenesis complex biological systems Monte Carlo methods Control theory optimization and their applications

[Using the Mathematics Literature](#) Kristine K. Fowler, 2004-05-25 This reference serves as a reader friendly guide to every basic tool and skill required in the mathematical library and helps mathematicians find resources in any format in the mathematics literature It lists a wide range of standard texts journals review articles newsgroups and Internet and database tools for every major subfield in mathematics

**Mathematical Aspects of Pattern Formation in Biological Systems** Juncheng Wei, Matthias Winter, 2013-09-18 This monograph is concerned with the mathematical analysis of patterns which are encountered in biological systems It summarises expands and relates results obtained in the field during the last fifteen years It also links the results to biological applications and highlights their relevance to phenomena in nature Of particular concern are large amplitude patterns far from equilibrium in biologically relevant models The approach adopted in the monograph is based on the following paradigms Examine the existence of spiky steady states in reaction diffusion systems and select as observable patterns only the stable ones Begin by exploring spatially homogeneous two component activator inhibitor systems in one or two space dimensions

Extend the studies by considering extra effects or related systems each motivated by their specific roles in developmental biology such as spatial inhomogeneities large reaction rates altered boundary conditions saturation terms convection many component systems Mathematical Aspects of Pattern Formation in Biological Systems will be of interest to graduate students and researchers who are active in reaction diffusion systems pattern formation and mathematical biology Spatial Dynamics and Pattern Formation in Biological Populations Ranjit Kumar Upadhyay, Satteluri R. K. Iyengar, 2021 The book provides an introduction to deterministic and some stochastic modeling of spatiotemporal phenomena in ecology epidemiology and neural systems A survey of the classical models in the fields with up to date applications is given The book begins with detailed description of how spatial dynamics diffusive processes influence the dynamics of biological populations These processes play a key role in understanding the outbreak and spread of pandemics which help us in designing the control strategies from the public health perspective A brief discussion on the functional mechanism of the brain single neuron models and network level with classical models of neuronal dynamics in space and time is given Relevant phenomena and existing modeling approaches in ecology epidemiology and neuroscience are introduced which provide examples of pattern formation in these models The analysis of patterns enables us to study the dynamics of macroscopic and microscopic behaviour of underlying systems and travelling wave type patterns observed in dispersive systems Moving on to virus dynamics authors present a detailed analysis of different types models of infectious diseases including two models for influenza five models for Ebola virus and seven models for Zika virus with diffusion and time delay A Chapter is devoted for the study of Brain Dynamics Neural systems in space and time Significant advances made in modeling the reaction diffusion systems are presented and spatiotemporal patterning in the systems is reviewed Development of appropriate mathematical models and detailed analysis such as linear stability weakly nonlinear analysis bifurcation analysis control theory numerical simulation are presented Key Features Covers the fundamental concepts and mathematical skills required to analyse reaction diffusion models for biological populations Concepts are introduced in such a way that readers with a basic knowledge of differential equations and numerical methods can understand the analysis The results are also illustrated with figures Focuses on mathematical modeling and numerical simulations using basic conceptual and classic models of population dynamics Virus and Brain dynamics Covers wide range of models using spatial and non spatial approaches Covers single two and multispecies reaction diffusion models from ecology and models from bio chemistry Models are analysed for stability of equilibrium points Turing instability Hopf bifurcation and pattern formations Uses Mathematica for problem solving and MATLAB for pattern formations Contains solved Examples and Problems in Exercises The Book is suitable for advanced undergraduate graduate and research students For those who are working in the above areas it provides information from most of the recent works The text presents all the fundamental concepts and mathematical skills needed to build models and perform analyses **Mathematical Biology II** James D. Murray, 2006-05-31 It has been over a decade since the release

first edition of the now classic original edition of Murray's *Mathematical Biology*. Since then mathematical biology and medicine has grown at an astonishing rate and has established itself as a distinct discipline. Mathematical modelling is now being applied in every major discipline in the biomedical sciences. Though the field has become increasingly large and specialized, this book remains important as a text that introduces some of the exciting problems which arise in the biomedical sciences and gives some indication of the wide spectrum of questions that modelling can address. Due to the tremendous development in recent years, this new edition is being published in two volumes. This second volume covers spatial models and biomedical applications. For this new edition, Murray covers certain items in depth, introducing new applications such as modelling growth and control of brain tumours, bacterial patterns, wound healing, and wolf territoriality. In other areas, he discusses basic modelling concepts and provides further references as needed. He also provides even closer links between models and experimental data throughout the text. Graduate students and researchers will find this book invaluable as it gives an excellent background from which to begin genuinely practical interdisciplinary research in the biomedical sciences.

**Mathematical Modeling of Biological Systems, Volume II** Andreas Deutsch, Rafael Bravo de la Parra, Rob J. de Boer, Odo Diekmann, Peter Jagers, Eva Kisdi, Mirjam Kretzschmar, Petr Lansky, Hans Metz, 2007-10-12. Volume II of this two-volume interdisciplinary work is a unified presentation of a broad range of state-of-the-art topics in the rapidly growing field of mathematical modeling in the biological sciences. Highlighted throughout are mathematical and computational approaches to examine central problems in the life sciences, ranging from the organization principles of individual cells to the dynamics of large populations. The chapters are thematically organized into the following main areas: epidemiology, evolution, and ecology; immunology; neural systems and the brain; and innovative mathematical methods and education. The work will be an excellent reference text for a broad audience of researchers, practitioners, and advanced students in this rapidly growing field at the intersection of applied mathematics, experimental biology, and medicine; computational biology; biochemistry; computer science; and physics.

*Mathematical Modeling of Biological Systems, Volume I* Andreas Deutsch, Lutz Brusch, Helen Byrne, Gerda de Vries, Hanspeter Herzel, 2007-06-15. Volume I of this two-volume interdisciplinary work is a unified presentation of a broad range of state-of-the-art topics in the rapidly growing field of mathematical modeling in the biological sciences. The chapters are thematically organized into the following main areas: cellular biophysics; regulatory networks; developmental biology; biomedical applications; data analysis; and model validation. The work will be an excellent reference text for a broad audience of researchers, practitioners, and advanced students in this rapidly growing field at the intersection of applied mathematics, experimental biology, and medicine; computational biology; biochemistry; computer science; and physics.

**Mathematical Models in Biology** Valeria Zazzu, Maria Brigida Ferraro, Mario R. Guarracino, 2015-11-26. This book presents an exciting collection of contributions based on the workshop *Bringing Maths to Life* held October 27-29, 2014 in Naples, Italy. The state-of-the-art research in biology and the statistical and analytical challenges facing huge masses of data collection are

treated in this Work Specific topics explored in depth surround the sessions and special invited sessions of the workshop and include genetic variability via differential expression molecular dynamics and modeling complex biological systems viewed from quantitative models and microscopy images processing to name several In depth discussions of the mathematical analysis required to extract insights from complex bodies of biological datasets to aid development in the field novel algorithms methods and software tools for genetic variability molecular dynamics and complex biological systems are presented in this book Researchers and graduate students in biology life science and mathematics statistics will find the content useful as it addresses existing challenges in identifying the gaps between mathematical modeling and biological research The shared solutions will aid and promote further collaboration between life sciences and mathematics

**Multiscale Modeling of Developmental Systems**, 2007-12-18 Mathematical and computational biology is playing an increasingly important role in the biological sciences This science brings forward unique challenges many of which are at the moment beyond the theoretical techniques available Developmental biology due to its complexity has lagged somewhat behind its sister disciplines such as molecular biology and population biology in making use of quantitative modeling to further biological understanding This volume comprises work that is among the best developmental modeling available and we feel it will do much to remedy this situation This book is aimed at all those with an interest in the interdisciplinary field of computer and mathematical modeling of multi cellular and developmental systems It is also a goal of the Editors to attract more developmental biologists to consider integrating modeling components into their research Most importantly this book is intended to serve as a portal into this research area for younger scientists especially graduate students and post docs from both biological and quantitative backgrounds Articles written by leading exponents in the field Provides techniques to address multiscale modeling Coverage includes a wide spectrum of modeling approaches Includes descriptions of the most recent advances in the field

**Pattern Formation in Morphogenesis** Vincenzo Capasso, Misha Gromov, Annick Harel-Bellan, Nadya Morozova, Linda Louise Pritchard, 2012-10-02 Pattern Formation in Morphogenesis is a rich source of interesting and challenging mathematical problems The volume aims at showing how a combination of new discoveries in developmental biology and associated modelling and computational techniques has stimulated or may stimulate relevant advances in the field Finally it aims at facilitating the process of unfolding a mutual recognition between Biologists and Mathematicians of their complementary skills to the point where the resulting synergy generates new and novel discoveries It offers an interdisciplinary interaction space between biologists from embryology genetics and molecular biology who present their own work in the perspective of the advancement of their specific fields and mathematicians who propose solutions based on the knowledge grasped from biologists

**Dynamical Models in Biology** Miklós Farkas, 2001-06-15 Dynamic Models in Biology offers an introduction to modern mathematical biology This book provides a short introduction to modern mathematical methods in modeling dynamical phenomena and treats the broad topics of population dynamics

epidemiology evolution immunology morphogenesis and pattern formation Primarily employing differential equations the author presents accessible descriptions of difficult mathematical models Recent mathematical results are included but the author's presentation gives intuitive meaning to all the main formulae Besides mathematicians who want to get acquainted with this relatively new field of applications this book is useful for physicians biologists agricultural engineers and environmentalists Key Topics Include Chaotic dynamics of populations The spread of sexually transmitted diseases Problems of the origin of life Models of immunology Formation of animal hide patterns The intuitive meaning of mathematical formulae explained with many figures Applying new mathematical results in modeling biological phenomena Miklos Farkas is a professor at Budapest University of Technology where he has researched and instructed mathematics for over thirty years He has taught at universities in the former Soviet Union Canada Australia Venezuela Nigeria India and Columbia Prof Farkas received the 1999 Bolyai Award of the Hungarian Academy of Science and the 2001 Albert Szentgyorgyi Award of the Hungarian Ministry of Education A down to earth introduction to the growing field of modern mathematical biology Also includes appendices which provide background material that goes beyond advanced calculus and linear algebra

*Mathematical Models of Cell-Based Morphogenesis* Hisao Honda, Tatsuzo Nagai, 2022-06-27 This book describes the shape formation of living organisms using mathematical models Genes are deeply related to the shape of living organisms and elucidation of a pathway of shape formation from genes is one of the fundamental problems in biology Mathematical cell models are indispensable tools to elucidate this problem The book introduces two mathematical cell models the cell center model and the vertex model with their applications The cell center model is applied to elucidate the formation of neat cell arrangements in epidermis cell patterns consisting of heterogeneous sized cells capillary networks and the branching patterns of blood vessels The vertex model is applied to elucidate the wound healing mechanisms of the epithelium and ordered pattern formation involving apoptosis Pattern formation with differential cell adhesion is also described The vertex model is then extended from a two dimensional 2D to a three dimensional 3D model A cell aggregate involving a large cavity is described to explain the development of the mammalian blastocyst or the formation of an epithelial vesicle Epithelial tissues and the polarity formation process of the epithelium are also explained The vertex model also recapitulates active remodeling of tissues and describes the twisting of tissue that contributes to understanding the cardiac loop formation of the embryonic tube The book showcases that mathematical cell models are indispensable tools to understand the shape formation of living organisms Successful contribution of the mathematical cell models means that the remodeling of collective cells is self construction Examining the successive iterations of self constructions leads to understanding the remarkable and mysterious morphogenesis that occurs during the development of living organisms The intended readers of this book are not only theoretical or mathematical biologists but also experimental and general biologists including undergraduate and postgraduate students who are interested in the relationship between genes and morphogenesis

Modelling the Dynamics of Biological Systems Erik Mosekilde, Ole G. Mouritsen, 2012-12-06 The development of a proper description of the living world today stands as one of the most significant challenges to physics. A variety of new experimental techniques in molecular biology, microbiology, physiology and other fields of biological research constantly expand our knowledge and enable us to make increasingly more detailed functional and structural descriptions. Over the past decades the amount and complexity of available information have multiplied dramatically while at the same time our basic understanding of the nature of regulation, behavior, morphogenesis and evolution in the living world has made only modest progress. A key obstacle is clearly the proper handling of the available data. This requires a stronger emphasis on mathematical modeling through which the consistency of the adopted explanations can be checked and general principles may be extracted. As an even more serious problem, however, it appears that the proper physical concepts for the development of a theoretically oriented biology have not hitherto been available. Classical mechanics and equilibrium thermodynamics, for instance, are inappropriate and useless in some of the most essential biological contexts. Fortunately, there is now convincing evidence that the concepts and methods of the newly developed fields of nonlinear dynamics and complex systems theory, combined with irreversible thermodynamics and far from equilibrium statistical mechanics, will enable us to move ahead with many of these problems.

Mathematical Models for Society and Biology Edward Beltrami, 2002 Mathematical Modeling for Society and Biology engagingly relates mathematics to compelling real life problems in biology and contemporary society. It shows how mathematical tools can be used to gain insight into these modern common problems to provide effective real solutions. Beltrami's creative, non-threatening approach draws on a wealth of interesting examples pertaining to current social and biological issues. Central ideas appear again in different contexts throughout the book, showing the general unity of the modeling process. The models are strikingly novel and based on issues of real concern. Most have never appeared in book form. Through the relevance of these models, mathematics becomes not just figures and numbers but a means to a more refined understanding of the world.

Fractal Modelling Jaap A. Kaandorp, 2012-12-06 In this book, methods from fractal geometry are applied to model growth forms, taking as a case study a type of growth process which can be found among various taxonomic classes such as sponges and corals. These models can be used, for example, to understand the amazing variety of forms to be found in a coral reef and to simulate their growth with 2D and 3D geometrical objects. Models which mimic the growth of forms and the environmental influence on the growth process are also useful for ecologists, as a combination of simulation models together with the actual growth forms can be used to detect the effects of slow changes in the environment.

Mathematical Models in Developmental Biology Jerome K. Percus, Stephen Childress, 2015-06-19 The path from relatively unstructured egg to full organism is one of the most fascinating trajectories in the biological sciences. Its complexity calls for a very high level of organization with an array of subprocesses in constant communication with each other. These notes introduce an interleaved set of mathematical models representative of research in the last few decades as

well as the techniques that have been developed for their solution. Such models offer an effective way of incorporating reliable data in a concise form, provide an approach complementary to the techniques of molecular biology, and help to inform and direct future research. Titles in this series are co-published with the Courant Institute of Mathematical Sciences at New York University.

How the Snake Lost its Legs Lewis I. Held, Jr., 2014-01-09. How did the zebra really get its stripes and the giraffe its long neck? What is the science behind camel humps, leopard spots, and other animal oddities? Such questions have fascinated us for centuries, but the expanding field of evo devo (evolutionary developmental biology) is now providing for the first time a wealth of insights and answers. Taking inspiration from Kipling's *Just So Stories*, this book weaves emerging insights from evo devo into a narrative that provides startling explanations for the origin and evolution of traits across the animal kingdom. Held's unique and engaging style makes this narrative both enlightening and entertaining, guiding students and researchers through even complex concepts and encouraging a fuller understanding of the latest developments in the field. The first five chapters cover the first bilaterally symmetric animals: flies, butterflies, snakes, and cheetahs. A final chapter surveys recent results about a menagerie of other animals.

**Introduction to Mathematical Biology** Ching-Shan Chou, Avner Friedman, 2016-04-27. This book is based on a one-semester course that the authors have been teaching for several years and includes two sets of case studies. The first includes chemostat models, predator-prey interaction, competition among species, the spread of infectious diseases, and oscillations arising from bifurcations. In developing these topics, readers will also be introduced to the basic theory of ordinary differential equations and how to work with MATLAB without having any prior programming experience. The second set of case studies were adapted from recent and current research papers to the level of the students. Topics have been selected based on public health interest. This includes the risk of atherosclerosis associated with high cholesterol levels, cancer, and immune interactions, cancer therapy, and tuberculosis. Readers will experience how mathematical models and their numerical simulations can provide explanations that guide biological and biomedical research. Considered to be the undergraduate companion to the more advanced book *Mathematical Modeling of Biological Processes* by Avner Friedman and C. Y. Kao (Springer, 2014), this book is geared towards undergraduate students with little background in mathematics and no biological background.

A Fully Explicit Optimal Two-stage Numerical Scheme for Solving Reaction-diffusion-chemotaxis Systems Jui-Ling Yu, 2005.

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