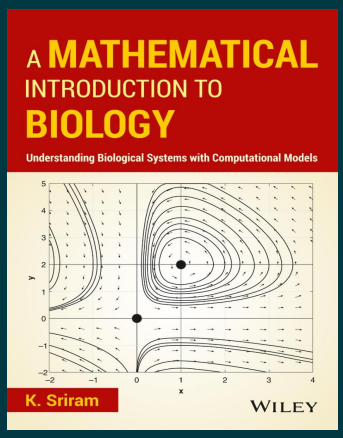
WILEY



A Mathematical Introduction to Biology: Understanding Biological Systems with Computational Models

By K. Sriram

Paperback 9789363867307 **₹1,379.00**

Pages: 560

Description

This book is perfect for a one-semester course called "Introduction to Mathematical Biology," which is a 4-credit winter course. It provides a well-organized and complete learning experience, making it great for both students and teachers in mathematical biology. Discover the dynamic intricacies of metabolic, signaling, and genetic network motifs with "A Mathematical Introduction to Biology: Understanding Biological Systems with Computational Models." This book elegantly intertwines mathematics and life sciences to reveal the roles of feedback and feedforward patterns embedded within network structures, uncovering the mechanisms that govern living systems. Customised for both students and instructors, it offers an engaging and accessible approach to bridging the gap between mathematics and biology.

Spanning 19 comprehensive chapters, this book covers essential topics such as constructing differential equation models based on the principles of mass-action kinetics and Michaelis-Menten kinetics. It delves deeply into the feedback and feedforward mechanisms that form the backbone of signaling, metabolic, and gene regulatory network motifs. By applying dynamical systems theory to adaptation models, MAPK signaling pathways, the cell division cycle, and circadian rhythms, this resource becomes indispensable for understanding biological complexity.

Problems, examples, and downloadable instructor resources—including programmable MATLAB codes and lecture slide decks for each chapter—make it an ideal companion for both independent study and classroom instruction. This book aims to the undergraduate and postgraduate students who are studying computational or mathematical biology courses and professionals working in the biotechnology and pharmaceutical industries who may find the foundational knowledge useful.

About the Author

K. Sriram

K. Sriram is an Associate Professor at IIIT-Delhi, where he has been a faculty member since 2012. Over the past 12 years, he has taught various courses in the Department of Computational Biology. He has developed courses like Systems Biology, Introduction to Mathematical Biology, Introduction to Quantitative Biology, Computational Neuroscience, Cell Biology, and Biochemistry tailored for undergraduate, postgraduate, and PhD students in the sciences and engineering disciplines. He is currently offering a course on Introduction to Mathematical Biology to master’s and PhD students of Computational Biology, and this book is the culmination of notes used in that course. His research interests lie in systems and mathematical biology, and he has published numerous papers in reputable international journals

Table of Contents

Preface
About the Book
About the Author
Acknowledgment
Introduction to Cell Biology and Biochemistry
Introduction
Signalling Pathways in a Cell
Time Scales in Cellular Signalling
DNA, Promoters, Enhancers, and Silencers
Transcriptional Unit in a Cell
Translational Unit in a Cell
Post-Translation Modification
Metabolic Pathways
Homoeostasis and Adaptation
Motifs
Modules
ODEs are the Most Preferred Way of Modelling Biological Systems
Biochemical Modelling and Dynamical Systems Theory
Noise in Biological Systems
Role of Mathematical Models in Biology
Problems of Modelling Biological Systems
Broad Steps to Follow to Model the Biological Systems
Basic Requirements to Carry Out Mathematical Modelling in Biology
Summary
References
1 Basic Calculus and Algebra
1.1 Introduction
1.2 Types of Function
1.2.1 Power Function
1.2.2 Linear Function
1.2.3 Parabolic Function
1.2.4 Cubic Function
1.3 Exponential Function
1.3.1 Logarithm
1.3.2 Polynomial Function, Maxima, Minima, and the Inflexion Point
1.3.3 Extremum: Maxima, Minima, and an Inflection Point
1.3.4 Extrema of the Ratio of Polynomials
1.4 Rational Functions
1.4.1 Vertical and Horizontal Asymptotes
1.4.2 Hyperbolic and Sigmoidal Function
1.5 Zeros of a Function
1.5.1 Quadratic
1.5.2 Higher Order: Cubic Equation
1.6 Composite Functions
1.7 Important Integrals
Summary
Practice Zone
References
2 Mass Action Kinetics, Species Conservation Relationships, Steady State, and Equilibrium Approximations
2.1 Mass Action Kinetics
2.2 Mass Action Kinetics
2.2.1 Examples
2.3 Species Conservation Relationship
2.4 Stoichiometric Matrix
2.4.1 Brief Concepts from Linear Algebra to Identify Species Conservation Relationship
2.4.2 Linearly Dependent and Independent Vectors in a Matrix
2.4.3 Echelon and Row-Reduced Echelon Form
2.4.4 Rank of a Matrix
2.4.5 Gaussian Elimination
2.5 Species Conservation Relationship from the Gaussian Elimination
2.5.1 Conservation of Enzyme in MM Kinetics
2.6 Time Scales and Approximations
2.6.1 Steady-State Approximation (SSA)
2.7 Rapid-Equilibrium Approximation
2.7.1 Quasi-Steady-State Approximation (QSSA) of the Above Equation
2.8 Characteristic Time Scales
Summary
Practice Zone
References
3 Time-Scale Analysis of Enzyme Kinetics: Quasi-Steady-State, Rapid-Equilibrium, and Total Quasi-Steady-State Approximations
3.1 Enzyme Kinetics
3.2 Disparate Time Scales in ODE Models
3.3 Enzyme Kinetics and the Quasi-Steady-State Approximation (QSSA): Example of Time-Scale Separation
3.3.1 Assumptions
3.4 Validity of QSSA Over the Parameter Range: Time Scales in MM Kinetics
3.5 Total Quasi-Steady-State Approximation (tQSSA): When the Enzyme Exceeds the Substrate
3.6 Rapid-Equilibrium Approximation: Steps Involved in the Derivation of Enzyme Kinetic Equation
3.6.1 Rapid Approximation of Competitive Enzyme-Inhibition Dynamics
3.7 Allostery and Cooperativity
3.8 Modelling Cooperativity and Sigmoidal Dynamics: Hill's Equation
3.8.1 Parameters Affecting Threshold and Switching Response in Hill's Equation
3.9 Receptor-Ligand Interactions
3.9.1 kon, koff , and KD Values
Summary
Practice Zone
References
4 Linear and Nonlinear First-Order Differential Equations
4.1 Introduction
4.1.1 Linear First-Order Differential Equation
4.1.2 The Steady State is dx/dt = 0
4.1.3 Linear ODE with a Constant Input p
4.1.4 Linear, Non-Autonomous ODE: Time-Dependent Input S(t)
4.2 Example: S(t) = e−t
4.3 Nonlinear First-Order Differential Equations
4.3.1 Ricatti's Equation 110
4.3.2 Bernoulli's ODE 112
4.4 Quantitative Analysis of 1D Linear and Nonlinear Autonomous Differential Equations
4.5 Linear Stability Analysis
4.5.1 Example 1
4.5.2 Example 2
4.6 Qualitative Analysis of 1D-ODE: Slope Fields
Summary
Practice Zone
References
5 Rate-Balance Plot, Threshold, and Ultrasensitivity
5.1 Introduction
5.2 Rate-Balance Plot of Phosphorylation–Dephosphorylation Reaction with Mass Action Kinetics
5.3 Derivation of Goldbeter–Koshland Function for the PdP Reaction with Enzyme Kinetics
5.3.1 Rate-Balance Plot of GK Function: Zero-Order Ultrasensitivity
5.4 Quantifying Ultrasensitivity
5.4.1 Three-Tiered Signalling Cascade: Ultrasensitivity in Michaelis–Menten's or Hill's Equation Type of Models
5.5 Ultrasensitivity by Molecular Titration
5.5.1 Example: Molecular Titration in Mitotic Trigger: Entry from Interphase to Mitotic Phase
5.6 Example: Rate-Balance Plot for Reciprocal Regulation in Cell Cycle: Robustness of Mitotic Trigger
Summary
Practice Zone
References
6 Second-Order Linear and Nonlinear Differential Equations
6.1 Second-Order Linear Differential Equations
6.2 System of Linear Second-Order Differential Equation in a Matrix Form
6.3 Behaviour of the Solutions
6.3.1 Example 1: Decaying Solution–Stable Node
6.3.2 Plotting the Eigenvectors and the Trajectories for Different Initial Conditions
6.3.3 Example 2: Growing Solution–Unstable Node
6.3.4 Example 3: Eigenvalues have Opposite Sign: Growing–Saddle
6.3.5 Example 4: Eigenvalues are Complex and Oscillating
6.4 Trace–Determinant Method to Determine the Stability and the Dynamics of the Equilibrium Point
6.5 Mapping the Parameter Dynamics Based on the Trace–Determinant Equations
6.5.1 Example 1
6.5.2 Example 2
6.6 Nonlinear 2D-ODEs
6.7 Hyperbolic Equilibrium Point and Hartman–Grobman Theorem
6.8 Linearization of Nonlinear ODE
6.8.1 Example 1
6.8.2 Example 2
6.9 Higher-Dimensional ODEs
6.9.1 Routh–Hurwitz Criteria
6.9.2 Determination of Stability from the Hurwitz Matrix
6.9.3 Example 1
Summary
Practice Zone
References
7 Phase-Plane Analysis of Two-Dimensional Linear and Nonlinear Differential Equations
7.1 Phase Plane, Flow, Trajectories, and Portraits
7.2 Nullclines
7.3 General Points to Construct the Nullclines
7.4 Examples of Dynamics Through Phase-Plane Construction
7.4.1 Example 1: Stable Node
7.4.2 Example 2: Saddle
7.5 Coupled Linear ODEs
7.5.1 Example a = 2; b = 1; c = −1; d = 2
7.6 Phase-Plane Analysis of the 2D-Nonlinear ODEs
7.6.1 Example 1: Lotka–Volterra Model
7.6.2 Example 2: Bistability
Summary
Practice Zone
References
8 Scaling and Dimensionless Analysis of Differential Equations
8.1 Introduction
8.1.1 General Idea About Scaling
8.2 Examples
8.2.1 Dimensionless Logistic Equation
8.2.2 Variations of the Logistic Equation
8.3 Scaling and Dimensionless Analysis of Michaelis–Menten Equation
8.3.1 Short and Long Characteristic Time Scales of t0
8.4 Example-1: Dimensionless Analysis of Enzymatic Nonlinear Product Formation with Degradation
8.5 Example-2: Dimensionless Analysis of Substrate Inhibition by an Enzyme
8.5.1 Scaling and Dimensionless Analysis
8.6 Scaling and Dimensionless Analysis Problems from Gene Regulatory Networks
8.6.1 Scaling and Dimensionless Analysis of 2D-Model of GRN
Summary
Practice Zone
References
9 Bifurcation, Dynamical Analysis of Nonlinear Differential Equations, and Chemical Reaction Network Theory
9.1 Introduction
9.2 Bifurcation of the 1D Nonlinear ODE System
9.2.1 Transcritical Bifurcation
9.2.2 1D Directional Field Plot of yy
9.2.3 Bifurcation Diagram of the Transcritical Bifurcation with Etot as Bifurcation Parameter
9.2.4 Determination of Steady-State Stability
9.2.5 Conditions for a Nonlinear ODE Model to Exhibit Transcritical Bifurcation
9.3 Saddle–Node Bifurcation of 1D Nonlinear Model
9.4 Conditions for Saddle–Node Bifurcation
9.5 Determination of the Steady State and its Stability
9.5.1 Conditions for Schlögl Model to Exhibit Saddle–Node Bifurcation
9.5.2 Information from the Saddle–Node Bifurcation Diagram
9.6 Pitchfork Bifurcation
9.7 Chemical Reaction Network Theory (CRNT)
9.7.1 Structural Properties of Chemical Reaction Networks
9.8 Deficiency One and Advance Deficiency Algorithms: Use of the CRNT Toolbox
9.8.1 Example 1: Deficiency Zero Network Using CRNT Toolbox
9.8.2 Example 2: Deficiency One Network
Summary
Practice Zone
References
10 Oscillations in Cell Biology
10.1 Introduction to Biological Oscillations
10.2 Limit Cycle Oscillations and Types
10.3 Conditions for Oscillations
10.4 Hopf Bifurcation
10.5 Poincaré–Bendixson Theorem and Other Methods
10.6 Example: Illustration of Conditions for Selkov's Two-Variable Oscillatory Models
10.7 Higgins' Multiple Template Circuits to Generate Oscillations in 2D-ODE
10.7.1 Example: Derivation of the Rate Equation Using Rapid-Equilibrium Approximation for One Specific Template Motif Backward Activation
10.7.2 Example 1: Regulation of Glycolytic Oscillatory Motif by Backward Activation
10.8 Three-Variable Model for Oscillations: Goodwin Model, Secant, and Routh–Hurwitz Conditions
10.9 Secant Condition
10.10 Routh–Hurwitz Condition and Linear Stability Analysis
10.11 Hopf Bifurcation Through Numerical Methods: Oscillations via Supercritical HB
10.12 Oscillations via Subcritical Hopf Bifurcation
10.13 Role of Positive Feedback in the Negative Feedback Loop in Sustained Oscillations: Fine-Tuning Frequency with a Near-Constant Amplitude
Summary
Practice Zone
References
11 Network Motifs: Modelling of Positive and Negative Feedback Loops, and Identifying Their Dynamics
11.1 Introduction
11.2 Feedback Loops: Important Recurrent Motifs in Biological Networks
11.3 Converting Abstract Biological Circuits into a Meaningful Mechanism
11.3.1 PdP Reaction with MM Kinetics
11.4 Template of Combining Two Case I Circuits Appropriately to Generate Perfect Adaptive Response
11.5 Template of Combining Case I Linear Circuit with Nonlinear Case II PdP Circuits to Generate Bistability
11.6 Coupling Bistable System to Activator–Inhibitor and Substrate Depletion Systems: Generation of Oscillations
11.7 Template for Gene Regulatory Networks: Hill's Equation
11.7.1 Reducing 2D to 1D ODE: Composite Function for Rate-Balance Plot
11.8 Example: Building a Minimal Model of G1-S Phase of Cell Using the Hill's and MM Equations as Templates
Summary
Practice Zone
References
12 Feedforward Loops: Templates for Modelling Biological Systems and Identifying Their Dynamics
12.1 Introduction
12.2 Threshold and Induction Time
12.2.1 Adding an Intermediate Step in the Conversion
12.2.2 Threshold from an Autocatalytic Reaction
12.3 Feedforward Loops
12.4 Modelling Feedforward Loops
12.4.1 C1-FFL–AND Logic
12.4.2 C1-FFL–OR Logic
12.5 Incoherent Feedback Loop and its Properties
12.5.1 Biphasic Dynamics in Incoherent FFLs
12.6 Example of the Role of Coherent and Incoherent Feedforward Motifs in Cell Cycle Regulation
12.6.1 Feedforward Loops in Cell Cycle
12.6.2 Mathematical Model of Eukaryotic Cell Cycle with Only Feedforward Loops
12.6.3 Dynamics of Cell Cycle with Only Feedforward Motifs
12.7 Long Signalling Cascade with Feedforward and Feedback Motifs
12.7.1 Case I: Positive Feedforward Cascade
12.7.2 Case II: Long Positive Feedback Loop Motif: A Permanent Response
12.7.3 Case III: Negative Feedforward Cascade and Positive Feedback Loop Motif
Summary
Practice Zone
References
13 Signalling Motifs and Networks: Templates for Modelling and Identifying the Dynamics
13.1 Introduction
13.2 Signal Amplification in the Three-Tiered Mono-Phosphorylation–Dephosphorylation Cascade
13.3 Modelling the Dynamics of Transient Responses in the Signalling Pathway
13.4 Increased Output Sensitivity and Conversion of Graded Inputs to Switch-Like Outputs in the Linear Signalling Cascade
13.5 Ultrasensitivity in the Cascade Reaction: Huang–Ferrell Model of Mitogen-Activated Protein Kinase (MAPK) Signalling Pathway
13.5.1 Comparison of MAPK Signalling Output Response with Hill's Equation for Ultrasensitivity
13.6 Bistability and Oscillations in Three-Tiered and One-Tiered MAPK Pathway
13.6.1 Markevich et al.'s Bistable Model of Single-Tiered Dual PdP Reactions
13.7 Death Receptor-Mediated Apoptosis
13.7.1 Law of Mass Action Kinetics and Mathematical Model for the Apoptosis Network
Summary
Practice Zone
References
14 Signalling Motifs in Adaptation, Homoeostasis, and Two-Component Systems
14.1 Adaptation in Bacterial Chemotaxis
14.2 Molecular Mechanism of Perfect Adaptation
14.2.1 BL Model of Chemotaxis
14.2.2 Two-State Barkai–Leibler Model for Chemotaxis
14.3 Examples of Perfect and Near-Perfect Adaptation
14.4 Sensitivity and Precision Characterize Different Types of Adaptive Response
14.5 A Simple Example of Robust, Perfect Adaptation
14.6 Negative Feedback Circuit without a Buffer: Near-Perfect Adaptation
14.7 Negative Feedback Circuit with a Buffer: Robust, Perfect Adaptation
14.8 State-Dependent Activation and Inactivation for Perfect Adaptation
14.9 Integral Feedback Control as a Mechanism for Perfect Adaptation
14.10 Dynamics of Bacterial Two-Component System
14.10.1 Igoshin's Model for Bistability in EnvZ/OmpR System
Summary
Practice Zone
References
15 Circadian Oscillations
15.1 Circadian Oscillations
15.2 Terminologies
15.2.1 Free Running Period and Endogenous Oscillations
15.2.2 What is a Circadian Time (CT)?
15.2.3 What is a Zeitgeber Time (ZT)?
15.2.4 What is an Entrainment?
15.2.5 What is a Phase-Response Curve (PRC)?
15.2.6 What Characteristic Features a Circadian Mathematical Model Should Capture?
15.3 Circadian Models: General Ideas
15.4 Mathematical Model of the Circadian Rhythms of Neurospora crassa
15.5 Mathematical Model of Mammalian Circadian Rhythms: KF Model for Circadian Rhythms
15.6 Circadian Model for Cyanobacteria: A Case of Autocatalysis
15.6.1 Chemical Steps in Positive Autocatalytic Reaction
15.6.2 Two-Parameter Bifurcation Diagram in the k3 − k6 Plane
15.7 Temperature Compensation
15.7.1 Temperature Compensation in Brusselator, the Chemical Oscillator
15.8 Example of Temperature Compensation in Circadian Rhythms of Neurospora crassa
15.8.1 FRQ Stability and Temperature Compensation
15.8.2 Temperature Compensation in FRQ Mutants
15.8.3 Loss of Temperature Compensation in the Mutants
Summary
Practice Zone
References
16 Cell Division Cycle
16.1 Introduction
16.2 Molecular Controls in Cell Cycle: Cyclin-Dependent Kinases (CDKs) and Cyclins
16.2.1 Three Modes Broadly Control Cyclins
16.3 Mitotic Oscillations
16.4 Model-1: Norel and Agur's Model of Embryonic Cell Cycle Oscillations
16.5 Model-2: Goldbeter Model of Embryonic Cell Cycle Oscillations
16.6 Model-3: Tyson's Model of for MPF Oscillations
16.7 General Principles of Cell Division Cycle and Dynamical Systems Theory
16.7.1 Detour: Writing a GK Function
16.8 A Two-Variable Toy Model of Eukaryotic Cell Division Cycle
16.9 Adding Controls-1: Transition from S-G2-M → G1 Phases – Role of APC Auxiliary Protein Cdc20 in Allowing G1 Control and Exit from Mitosis
16.10 Adding Controls-2: Transition from G1 → S-G2-M Phases – Role of Starter Kinase (SK) and Cyclin Kinase Inhibitor
16.11 Can the Novak and Tyson Model Undergo Oscillations without a Checkpoint?
16.12 Activator–Inhibitor Models of Cell Cycle Checkpoint Dynamics
16.12.1 SIMM: Substrate-Inhibitor Multiply Modified
16.13 SMMs: MDTIF
16.14 Sic as Inhibitor Checkpoint and CycB as Activator: G1-S Checkpoint Engagement
Summary
Practice Zone
References
17 Probability
17.1 Introduction
17.1.1 Examples
17.2 Density and Distribution Function
17.3 Probability Distributions
17.3.1 Probability Mass Function
17.3.2 Bernoulli and Binomial Discrete Distributions
17.3.3 Expectation and Variance of a Discrete Distribution
17.3.4 Geometric Distribution
17.3.5 Expectation and Variance of a Geometric Distribution
17.4 Poisson Distribution
17.4.1 Mean and Variance of the Poisson Distribution
17.5 Exponential Distribution and Inter-Arrival Time
17.5.1 Expectation and Variance of the Exponential Distribution
17.5.2 Example: Waiting Time Between a Chemical Reaction
17.6 Uniform Distribution
17.7 Gaussian from Poisson Distribution: Both Distributions Have the Same Mean and Variance ????
17.7.1 Properties of a Gaussian/Normal Distribution
17.7.2 Other Important Properties of a Normal Random Variable
17.7.3 Property 1: The Sum of Two Independent Normal Random Variables is Again a Normal Random Variable
17.7.4 Property 2: The Sum of More Than Two Mutually Independent Normal Random Variables is a Normal Random Variable
17.7.5 Property 3: Linear Transformation of a Normal Random Variable
17.8 Numerical Simulation of Random Variables from Distributions
17.8.1 Generation of Bernoulli's Random Variable
17.9 Generation of Exponential Random Variable from Exponential Distribution
17.10 Simulation of a Poisson Random Variable
Summary
Practice Zone
References
18 Stochastic Simulations
18.1 Introduction
18.2 Internal and External Noise
18.3 Some Basics
18.4 Chemical Master Equation
18.5 Stochastic Simulation Algorithm: Gillespie's Method
18.5.1 Software Codes
18.6 Example 1: Protein Production and Loss
18.6.1 Example 2: Stochastic Simulation of Schlögl Model: Bistability
18.6.2 Example 3: Triggering of Oscillations by Noise
18.7 Chemical Langevin Equation
18.8 Modeling the Stochastic Dynamics of MM and Hill's Equation of Gene Regulatory Networks
18.8.1 Stochastic Simulation of MM Kinetics: Quasi-Steady State Approximation
18.9 Example: Molecular or Internal Noise in Circadian Oscillations
Summary
Practice Zone
References
Index

To purchase this product, please visit:
https://www.wileyindia.com/a-mathematical-introduction-to-biology-understanding-biological-systems-with-computational-models.html

Scan to buy