Methods in Neuronal Modeling

From Ions to Networks

Second edition

edited by

Christof Koch
and Idan Segev

Methods In Neuronal Modeling From Ions To Networks

Ranjit Kumar Upadhyay,Satteluri R. K. Iyengar

Methods In Neuronal Modeling From Ions To Networks:

   Methods in Neuronal Modeling Christof Koch,Idan Segev,1998 Kinetic Models of Synaptic Transmission Alain Destexhe Zachary F Mainen Terrence J Sejnowski Cable Theory for Dendritic Neurons Wilfrid Rall Hagai Agmon Snir Compartmental Models of Complex Neurons Idan Segev Robert E Burke Multiple Channels and Calcium Dynamics Walter M Yamada Christof Koch Paul R Adams Modeling Active Dendritic Processes in Pyramidal Neurons Zachary F Mainen Terrence J Sejnowski Calcium Dynamics in Large Neuronal Models Erik De Schutter Paul Smolen Analysis of Neural Excitability and Oscillations John Rinzel Bard Ermentrout Design and Fabrication of Analog VLSI Neurons Rodney Douglas Misha Mahowald Principles of Spike Train Analysis Fabrizio Gabbiani Christof Koch Modeling Small Networks Larry Abbott Eve Marder Spatial and Temporal Processing in Central Auditory Networks Shihab Shamma Simulating Large Networks of Neurons Alexander D Protopapas Michael Vanier James M Bower   Methods in Neuronal Modeling Christof Koch,Idan Segev,1991

   Methods in Neuronal Modeling, second edition Christof Koch,Idan Segev,2003-01-01 Much research focuses on the question of how information is processed in nervous systems from the level of individual ionic channels to large scale neuronal networks and from simple animals such as sea slugs and flies to cats and primates New interdisciplinary methodologies combine a bottom up experimental methodology with the more top down driven computational and modeling approach This book serves as a handbook of computational methods and techniques for modeling the functional properties of single and groups of nerve cells The contributors highlight several key trends 1 the tightening link between analytical numerical models and the associated experimental data 2 the broadening of modeling methods at both the subcellular level and the level of large neuronal networks that incorporate real biophysical properties of neurons as well as the statistical properties of spike trains and 3 the organization of the data gained by physical emulation of the nervous system components through the use of very large scale circuit integration VLSI technology The field of neuroscience has grown dramatically since the first edition of this book was published nine years ago Half of the chapters of the second edition are completely new the remaining ones have all been thoroughly revised Many chapters provide an opportunity for interactive tutorials and simulation programs They can be accessed via Christof Koch s Website Contributors Larry F Abbott Paul R Adams Hagai Agmon Snir James M Bower Robert E Burke Erik de Schutter Alain Destexhe Rodney Douglas Bard Ermentrout Fabrizio Gabbiani David Hansel Michael Hines Christof Koch Misha Mahowald Zachary F Mainen Eve Marder Michael V Mascagni Alexander D Protopapas Wilfrid Rall John Rinzel Idan Segev Terrence J Sejnowski Shihab Shamma Arthur S Sherman Paul Smolen Haim Sompolinsky Michael Vanier Walter M Yamada   Tutorials in Mathematical Biosciences I Alla Borisyuk,G. Bard Ermentrout,Avner Friedman,David H. Terman,2005-01-28 This volume introduces some basic theories on computational neuroscience Chapter 1 is a brief introduction to neurons tailored to the subsequent chapters Chapter 2 is a self contained introduction to dynamical systems and bifurcation theory oriented towards neuronal dynamics The theory is illustrated with a

model of Parkinson s disease Chapter 3 reviews the theory of coupled neural oscillators observed throughout the nervous systems at all levels it describes how oscillations arise what pattern they take and how they depend on excitory or inhibitory synaptic connections Chapter 4 specializes to one particular neuronal system namely the auditory system It includes a self contained introduction from the anatomy and physiology of the inner ear to the neuronal network that connects the hair cells to the cortex and describes various models of subsystems   **Neural Control Engineering** Steven J. Schiff,2022-11-01 How powerful new methods in nonlinear control engineering can be applied to neuroscience from fundamental model formulation to advanced medical applications Over the past sixty years powerful methods of model based control engineering have been responsible for such dramatic advances in engineering systems as autolanding aircraft autonomous vehicles and even weather forecasting Over those same decades our models of the nervous system have evolved from single cell membranes to neuronal networks to large scale models of the human brain Yet until recently control theory was completely inapplicable to the types of nonlinear models being developed in neuroscience The revolution in nonlinear control engineering in the late 1990s has made the intersection of control theory and neuroscience possible In Neural Control Engineering Steven Schiff seeks to bridge the two fields examining the application of new methods in nonlinear control engineering to neuroscience After presenting extensive material on formulating computational neuroscience models in a control environment including some fundamentals of the algorithms helpful in crossing the divide from intuition to effective application Schiff examines a range of applications including brain machine interfaces and neural stimulation He reports on research that he and his colleagues have undertaken showing that nonlinear control theory methods can be applied to models of single cells small neuronal networks and large scale networks in disease states of Parkinson s disease and epilepsy With Neural Control Engineering the reader acquires a working knowledge of the fundamentals of control theory and computational neuroscience sufficient not only to understand the literature in this trandisciplinary area but also to begin working to advance the field The book will serve as an essential guide for scientists in either biology or engineering and for physicians who wish to gain expertise in these areas   **Principles of Computational Modelling in Neuroscience** David Sterratt,Bruce Graham,Andrew Gillies,Gaute Einevoll,David Willshaw,2023-10-05 Taking a step by step approach to modelling neurons and neural circuitry this textbook teaches students how to use computational techniques to understand the nervous system at all levels using case studies throughout to illustrate fundamental principles Starting with a simple model of a neuron the authors gradually introduce neuronal morphology synapses ion channels and intracellular signalling This fully updated new edition contains additional examples and case studies on specific modelling techniques suggestions on different ways to use this book and new chapters covering plasticity modelling extracellular influences on brain circuits modelling experimental measurement processes and choosing appropriate model structures and their parameters The online resources offer exercises and simulation code that recreate many of the book s figures allowing students to practice as they learn Requiring

an elementary background in neuroscience and high school mathematics this is an ideal resource for a course on computational neuroscience   Complex Networks & Their Applications XIII Hocine Cherifi,Murat Donduran,Luis M. Rocha,Chantal Cherifi,Onur Varol,2025-04-02 This book highlights cutting edge research in network science offering scientists researchers students and practitioners a unique update on the latest advances in theory and a multitude of applications It presents the peer reviewed proceedings of the XIII International Conference on Complex Networks and their Applications COMPLEX NETWORKS 2024 The carefully selected papers cover a wide range of theoretical topics such as network embedding and network geometry community structure network dynamics diffusion epidemics and spreading processes machine learning and graph neural networks as well as all the main network applications including social and political networks networks in finance and economics biological networks and technological networks   Neuro-informatics and Neural Modelling F. Moss,S. Gielen,2001-06-26 How do sensory neurons transmit information about environmental stimuli to the central nervous system How do networks of neurons in the CNS decode that information thus leading to perception and consciousness These questions are among the oldest in neuroscience Quite recently new approaches to exploration of these questions have arisen often from interdisciplinary approaches combining traditional computational neuroscience with dynamical systems theory including nonlinear dynamics and stochastic processes In this volume in two sections a selection of contributions about these topics from a collection of well known authors is presented One section focuses on computational aspects from single neurons to networks with a major emphasis on the latter The second section highlights some insights that have recently developed out of the nonlinear systems approach   *An Introduction to Mathematical Modeling in Physiology, Cell Biology, and Immunology* James Sneyd,2002 In many respects biology is the new frontier for applied mathematicians This book demonstrates the important role mathematics plays in the study of some biological problems It introduces mathematicians to the biological sciences and provides enough mathematics for bioscientists to appreciate the utility of the modelling approach The book presents a number of diverse topics such as neurophysiology cell biology immunology and human genetics It examines how research is done what mathematics is used what the outstanding questions are and how to enter the field Also given is a brief historical survey of each topic putting current research into perspective The book is suitable for mathematicians and biologists interested in mathematical methods in biology   Computational Neuroscience Erik De Schutter,2000-11-22 Designed primarily as an introduction to realistic modeling methods Computational Neuroscience Realistic Modeling for Experimentalists focuses on methodological approaches selecting appropriate methods and identifying potential pitfalls The author addresses varying levels of complexity from molecular interactions within single neurons to the processing of information by neural networks He avoids theoretical mathematics and provides just enough of the basic math used by experimentalists What makes this resource unique is the inclusion of downloadable resources that furnish interactive modeling examples It contains tutorials and demos movies and

images and the simulation scripts necessary to run the full simulation described in the chapter examples Each chapter covers the theoretical foundation parameters needed appropriate software descriptions evaluation of the model future directions expected examples in text boxes linked to the downloadable resources and references The first book to bring you cutting edge developments in neuronal modeling It provides an introduction to realistic modeling methods at levels of complexity varying from molecular interactions to neural networks The book and downloadable resources combine to make Computational Neuroscience Realistic Modeling for Experimentalists the complete package for understanding modeling techniques   *An Introductory Course in Computational Neuroscience* Paul Miller,2018-10-02 A textbook for students with limited background in mathematics and computer coding emphasizing computer tutorials that guide readers in producing models of neural behavior This introductory text teaches students to understand simulate and analyze the complex behaviors of individual neurons and brain circuits It is built around computer tutorials that guide students in producing models of neural behavior with the associated Matlab code freely available online From these models students learn how individual neurons function and how when connected neurons cooperate in a circuit The book demonstrates through simulated models how oscillations multistability post stimulus rebounds and chaos can arise within either single neurons or circuits and it explores their roles in the brain The book first presents essential background in neuroscience physics mathematics and Matlab with explanations illustrated by many example problems Subsequent chapters cover the neuron and spike production single spike trains and the underlying cognitive processes conductance based models the simulation of synaptic connections firing rate models of large scale circuit operation dynamical systems and their components synaptic plasticity and techniques for analysis of neuron population datasets including principal components analysis hidden Markov modeling and Bayesian decoding Accessible to undergraduates in life sciences with limited background in mathematics and computer coding the book can be used in a flipped or inverted teaching approach with class time devoted to hands on work on the computer tutorials It can also be a resource for graduate students in the life sciences who wish to gain computing skills and a deeper knowledge of neural function and neural circuits   **Neural Masses and Fields: Modelling the Dynamics of Brain Activity** Karl Friston,2015-05-25 Biophysical modelling of brain activity has a long and illustrious history and has recently profited from technological advances that furnish neuroimaging data at an unprecedented spatiotemporal resolution Neuronal modelling is a very active area of research with applications ranging from the characterization of neurobiological and cognitive processes to constructing artificial brains in silico and building brain machine interface and neuroprosthetic devices Biophysical modelling has always benefited from interdisciplinary interactions between different and seemingly distant fields ranging from mathematics and engineering to linguistics and psychology This Research Topic aims to promote such interactions by promoting papers that contribute to a deeper understanding of neural activity as measured by fMRI or electrophysiology In general mean field models of neural activity can be divided into two classes neural mass and neural field

models The main difference between these classes is that field models prescribe how a quantity characterizing neural activity such as average depolarization of a neural population evolves over both space and time as opposed to mass models which characterize activity over time only by assuming that all neurons in a population are located at approximately the same point This Research Topic focuses on both classes of models and considers several aspects and their relative merits that span from synapses to the whole brain comparisons of their predictions with EEG and MEG spectra of spontaneous brain activity evoked responses seizures and fitting data to infer brain states and map physiological parameters **Spatial Dynamics and Pattern Formation in Biological Populations** Ranjit Kumar Upadhyay,Satteluri R. K. Iyengar,2021-02-24 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 **Encyclopedia of Nonlinear Science** Alwyn Scott,2006-05-17 In 438 alphabetically arranged essays this work provides a useful overview of the core mathematical background for nonlinear science as well as its applications to key problems in ecology and biological systems chemical reaction diffusion problems geophysics economics electrical and mechanical oscillations in engineering systems lasers and nonlinear optics fluid mechanics and turbulence and condensed matter physics among others **Neural Fields** Stephen Coombes,Peter beim Graben,Roland Potthast,James Wright,2014-06-17 Neural field theory has a long standing tradition in the mathematical and computational neurosciences Beginning almost 50 years ago with seminal work by Griffiths and culminating in the 1970ties with the models of Wilson and Cowan Nunez and Amari this important research area experienced a renaissance during the 1990ties by the groups of Ermentrout Robinson Bressloff Wright and Haken Since then much progress has been made in both the development of mathematical and numerical techniques and in physiological refinement und understanding In contrast to large scale neural network models described by huge connectivity matrices that are computationally expensive in numerical simulations neural field models described by connectivity kernels allow for analytical treatment by means of methods from functional analysis Thus a number of rigorous results on the existence of bump and wave solutions or on inverse kernel construction problems are nowadays available Moreover neural fields provide an important interface for the coupling of neural activity to experimentally observable data such as the electroencephalogram EEG or functional magnetic resonance imaging fMRI And finally neural fields over rather abstract feature spaces also called dynamic fields found successful applications in the cognitive sciences and in robotics Up to now research results in neural field theory have been disseminated across a number of distinct journals from mathematics computational neuroscience biophysics cognitive science and others There is no comprehensive collection of results or reviews available yet With our proposed book Neural Field Theory we aim at filling this gap in the market We received consent from some of the leading scientists in the field who are willing to write contributions for the book among them are two of the founding fathers of neural field theory Shun ichi Amari and Jack Cowan *Unsupervised Learning* Geoffrey Hinton,Terrence J. Sejnowski,1999-05-24 Since its founding in 1989 by Terrence Sejnowski Neural Computation has become the leading journal in the field Foundations of Neural Computation collects by topic the most significant papers that have appeared in the journal over the past nine years This volume of Foundations of Neural Computation on unsupervised learning algorithms focuses on neural network learning algorithms that do not require an explicit teacher The goal of unsupervised learning is to extract an efficient internal representation of the statistical structure implicit in the inputs These algorithms provide insights into the development of the cerebral cortex and implicit learning in humans They are also of interest to engineers working in areas such as computer vision and speech recognition who seek efficient representations of raw input data *Using The Biological Literature* Diane Schmidt,Elisabeth B. Davis,2001-12-06 Provides an in depth review of current

print and electronic tools for research in numerous disciplines of biology including dictionaries and encyclopedias method guides handbooks on line directories and periodicals Directs readers to an associated Web page that maintains the URLs and annotations of all major Inernet resources discussed in th **The Computing Dendrite** Hermann Cuntz,Michiel W.H. Remme,Benjamin Torben-Nielsen,2013-11-23 Neuronal dendritic trees are complex structures that endow the cell with powerful computing capabilities and allow for high neural interconnectivity Studying the function of dendritic structures has a long tradition in theoretical neuroscience starting with the pioneering work by Wilfrid Rall in the 1950s Recent advances in experimental techniques allow us to study dendrites with a new perspective and in greater detail The goal of this volume is to provide a r sum of the state of the art in experimental computational and mathematical investigations into the functions of dendrites in a variety of neural systems The book first looks at morphological properties of dendrites and summarizes the approaches to measure dendrite morphology quantitatively and to actually generate synthetic dendrite morphologies in computer models This morphological characterization ranges from the study of fractal principles to describe dendrite topologies to the consequences of optimization principles for dendrite shape Individual approaches are collected to study the aspects of dendrite shape that relate directly to underlying circuit constraints and computation The second main theme focuses on how dendrites contribute to the computations that neurons perform What role do dendritic morphology and the distributions of synapses and membrane properties over the dendritic tree have in determining the output of a neuron in response to its input A wide range of studies is brought together with topics ranging from general to system specific phenomena some having a strong experimental component and others being fully theoretical The studies come from many different neural systems and animal species ranging from invertebrates to mammals With this broad focus an overview is given of the diversity of mechanisms that dendrites can employ to shape neural computations **Computational Neuroscience** Jianfeng Feng,2003-10-20 How does the brain work After a century of research we still lack a coherent view of how neurons process signals and control our activities But as the field of computational neuroscience continues to evolve we find that it provides a theoretical foundation and a set of technological approaches that can significantly enhance our understanding *Visual Population Codes* Nikolaus Kriegeskorte,Gabriel Kreiman,2012 How visual content is represented in neuronal population codes and how to analyze such codes with multivariate techniques Vision is a massively parallel computational process in which the retinal image is transformed over a sequence of stages so as to emphasize behaviorally relevant information such as object category and identity and deemphasize other information such as viewpoint and lighting The processes behind vision operate by concurrent computation and message passing among neurons within a visual area and between different areas The theoretical concept of population code encapsulates the idea that visual content is represented at each stage by the pattern of activity across the local population of neurons Understanding visual population codes ultimately requires multichannel measurement and multivariate analysis of activity patterns Over the past decade the

multivariate approach has gained significant momentum in vision research Functional imaging and cell recording measure brain activity in fundamentally different ways but they now use similar theoretical concepts and mathematical tools in their modeling and analyses With a focus on the ventral processing stream thought to underlie object recognition this book presents recent advances in our understanding of visual population codes novel multivariate pattern information analysis techniques and the beginnings of a unified perspective for cell recording and functional imaging It serves as an introduction overview and reference for scientists and students across disciplines who are interested in human and primate vision and more generally in understanding how the brain represents and processes information

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