



Theoretical models of synaptic short term plasticity

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Short term plasticity is a highly abundant form of rapid, activity-dependent modulation of synaptic efficacy. A shared set of mechanisms can cause both depression and enhancement of the postsynaptic response at different synapses, with important consequences for information processing. Mathematical models have been extensively used to study the mechanisms and roles of short term plasticity. This review provides an overview of existing models and their biological basis, and of their main properties. Special attention will be given to slow processes such as calcium channel inactivation and the effect of activation of presynaptic autoreceptors.

Keywords: short term plasticity, synaptic transmission, mathematical model, synaptic depression, synaptic facilitation

INTRODUCTION

Chemical synapses are highly specialized structures that enable neurons to exchange signals, or to send signals to non-neural cells such as muscle fibers. Even though there is a staggering diversity of synapse morphologies and types in the brain, the fundamental process of synaptic transmission is always the same. A presynaptic membrane potential depolarization, typically caused by the arrival of an action potential, triggers the release of neurotransmitter, which then binds to receptors that, in turn, generate a response in the postsynaptic neuron.

A key quantity in neural circuits is the synaptic efficacy or strength, which varies over time. Cellular processes such as long-term potentiation and depression contribute to the patterning of the nervous system during development, and are thought to constitute the basis of learning and memory (Morris, 2003). Slow and long-lasting homeostatic processes adjust synaptic strength to maintain circuit activity within functional regimes (Turrigiano and Nelson, 2004). In addition, a whole range of activity-dependent processes exist that modulate synaptic efficacy continuously on very short time scales ranging from milliseconds to minutes (for reviews, see Zucker and Regehr, 2002; Fioravante and Regehr, 2011). Unlike long-term and homeostatic plasticity, short term plasticity, the topic of this review, has a direct influence on the computation performed by neural circuits as these dynamics take place on the time scale of stimulus-driven activity, neural computations and behavior.

Broadly, short term plasticity can be classified as synaptic depression and facilitation. Depression refers to the progressive reduction of the postsynaptic response during repetitive presynaptic activity, while facilitation is an increase synaptic efficacy. Each of these may be caused by a range of different mechanisms with different time constants, and the two forms are not mutually exclusive. For instance, a particularly well-studied example of a strongly depressing synapse is the calyx of Held, a giant synaptic terminal in the mammalian auditory brainstem (Schneeggenburger and Forsythe, 2006). A closer

look at the underlying mechanisms, however, reveals that the response is also modulated by facilitation, which is however, partially masked by depression. In fact, most synapses express some combination of these two mechanisms, but with considerable variability between different neuron types (Wang et al., 2006).

The purpose of this review is to summarize models of short term plasticity, to discuss their biological background and plausibility, and to provide a guide for selecting an appropriate model and level of detail. The focus here is on the mechanistic aspects of these models, for a review of functional implications see Abbott and Regehr (2004). The review begins with a reminder of the main processes involved in synaptic transmission. Next, the vesicle depletion model and its variants will be introduced as a canonical model for short term plasticity. Finally, several additions to this class of models will be discussed that were required to explain more recent experimental findings.

PRINCIPLES OF SYNAPTIC TRANSMISSION

Almost all factors contributing to short term plasticity are located in the presynaptic terminal. To identify the relevant variables required in models, we begin with a brief review of the main events following the arrival of a presynaptic action potential at a synapse, as illustrated in Figure 1. The site where synaptic transmission of neural activity is initiated is called the active zone (AZ), a presynaptic morphological specialization where vesicles containing neurotransmitter and proteins required for the release process are clustered. The AZ is opposed by the postsynaptic density (PSD), an area that contains a large number of different proteins implicated in synapse maintenance and plasticity. In addition to a whole variety of structural and signaling complexes, the PSD contains the bulk of the neurotransmitter receptors mediating the postsynaptic response.

Neurotransmitter release from vesicles located at the AZ is initiated by an elevation of the intracellular calcium concentration $[Ca^{2+}]_i$ due to opening of voltage gated calcium channels

Theoretical Models Of Synaptic Short Term Plasticity

**Dirk Feldmeyer, John F. Wesseling, P.
Jesper Sjöström**



Theoretical Models Of Synaptic Short Term Plasticity:

Synaptic Plasticity - Neurobiology, Neuroanatomy, and Clinical Neuroscience Ioannis Mavroudis, 2025-09-03 Synaptic Plasticity Neurobiology Neuroanatomy and Clinical Neuroscience explores the brain's remarkable capacity to adapt through changes in synaptic strength and connectivity This volume brings together leading experts to examine the mechanisms that underlie learning memory development and recovery from injury Spanning molecular biology structural neuroanatomy and clinical practice the book offers an integrated perspective on how synaptic changes shape behavior and influence neurological and psychiatric conditions Topics include long term potentiation synaptic remodeling neurotransmitter systems network level plasticity and emerging therapies targeting synaptic function Designed for neuroscientists clinicians and advanced students the book is divided into three parts 1 Mechanisms of Synaptic Plasticity and Dysfunction 2 Therapeutic Modulation of Plasticity 3 Synaptic Plasticity in Specific Systems and Conditions Whether you are conducting research treating patients or teaching the next generation of scientists this book offers a comprehensive yet accessible resource on one of neuroscience's most dynamic fields The book will help you understand how the brain changes explore the foundations of neuroplasticity and apply this knowledge to clinical care

Neural Information Processing with Dynamical

Synapses Si Wu, Michael K Y Wong, Misha Tsodyks, 2015-01-08 *Form Versus Function: Theory and Models for Neuronal Substrates* Mihai Alexandru Petrovici, 2016-07-19 This thesis addresses one of the most fundamental challenges for modern science how can the brain as a network of neurons process information how can it create and store internal models of our world and how can it infer conclusions from ambiguous data The author addresses these questions with the rigorous language of mathematics and theoretical physics an approach that requires a high degree of abstraction to transfer results of wet lab biology to formal models The thesis starts with an in depth description of the state of the art in theoretical neuroscience which it subsequently uses as a basis to develop several new and original ideas Throughout the text the author connects the form and function of neuronal networks This is done in order to achieve functional performance of biological brains by transferring their form to synthetic electronics substrates an approach referred to as neuromorphic computing The obvious aspect that this transfer can never be perfect but necessarily leads to performance differences is substantiated and explored in detail The author also introduces a novel interpretation of the firing activity of neurons He proposes a probabilistic interpretation of this activity and shows by means of formal derivations that stochastic neurons can sample from internally stored probability distributions This is corroborated by the author's recent findings which confirm that biological features like the high conductance state of networks enable this mechanism The author goes on to show that neural sampling can be implemented on synthetic neuromorphic circuits paving the way for future applications in machine learning and cognitive computing for example as energy efficient implementations of deep learning networks The thesis offers an essential resource for newcomers to the field and an inspiration for scientists working in theoretical neuroscience and the future of

computing **Emergent neural computation from the interaction of different forms of plasticity** Cristina Savin, Matthieu Gilson, Friedemann Zenke, 2016-03-22 From the propagation of neural activity through synapses to the integration of signals in the dendritic arbor and the processes determining action potential generation virtually all aspects of neural processing are plastic This plasticity underlies the remarkable versatility and robustness of cortical circuits it enables the brain to learn regularities in its sensory inputs to remember the past and to recover function after injury While much of the research into learning and memory has focused on forms of Hebbian plasticity at excitatory synapses LTD LTP STDP several other plasticity mechanisms have been characterized experimentally including the plasticity of inhibitory circuits Kullmann 2012 synaptic scaling Turrigiano 2011 and intrinsic plasticity Zhang and Linden 2003 However our current understanding of the computational roles of these plasticity mechanisms remains rudimentary at best While traditionally they are assumed to serve a homeostatic purpose counterbalancing the destabilizing effects of Hebbian learning recent work suggests that they can have a profound impact on circuit function Savin 2010 Vogels 2011 Keck 2012 Hence theoretical investigation into the functional implications of these mechanisms may shed new light on the computational principles at work in neural circuits This Research Topic of Frontiers in Computational Neuroscience aims to bring together recent advances in theoretical modeling of different plasticity mechanisms and of their contributions to circuit function Topics of interest include the computational roles of plasticity of inhibitory circuitry metaplasticity synaptic scaling intrinsic plasticity plasticity within the dendritic arbor and in particular studies on the interplay between homeostatic and Hebbian plasticity and their joint contribution to network function [An Introductory Course in Computational Neuroscience](#) Paul Miller, 2018-10-09 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

Computational Modelling of the Brain Michele Giugliano,Mario Negrello,Daniele Linaro,2022-04-26 This volume offers an up to date overview of essential concepts and modern approaches to computational modelling including the use of experimental techniques related to or directly inspired by them The book introduces at increasing levels of complexity and with the non specialist in mind state of the art topics ranging from single cell and molecular descriptions to circuits and networks Four major themes are covered including subcellular modelling of ion channels and signalling pathways at the molecular level single cell modelling at different levels of spatial complexity network modelling from local microcircuits to large scale simulations of entire brain areas and practical examples Each chapter presents a systematic overview of a specific topic and provides the reader with the fundamental tools needed to understand the computational modelling of neural dynamics This book is aimed at experimenters and graduate students with little or no prior knowledge of modelling who are interested in learning about computational models from the single molecule to the inter areal communication of brain structures The book will appeal to computational neuroscientists engineers physicists and mathematicians interested in contributing to the field of neuroscience Chapters 6 10 and 11 are available open access under a Creative Commons Attribution 4 0 International License via link [springer.com](https://www.springer.com)

Methods for Synaptic Interrogation Dirk Feldmeyer,John F. Wesseling,P. Jesper Sjöström,2020-07-14 This eBook is a collection of articles from a Frontiers Research Topic Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series they are collections of at least ten articles all centered on a particular subject With their unique mix of varied contributions from Original Research to Review Articles Frontiers Research Topics unify the most influential researchers the latest key findings and historical advances in a hot research area Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office frontiersin.org/about/contact

Computational Neuroscience ,2014-02-18 Progress in Molecular Biology and Translational Science provides a forum for discussion of new discoveries approaches and ideas in molecular biology It contains contributions from leaders in their fields and abundant references This volume brings together different aspects of and approaches to molecular and multi scale modeling with applications to a diverse range of neurological diseases Mathematical and computational modeling offers a powerful approach for examining the interaction between molecular pathways and ionic channels in producing neuron electrical activity It is well accepted that non linear interactions among diverse ionic channels can produce unexpected neuron behavior and hinder a deep understanding of how ion channel mutations bring about abnormal behavior and disease Interactions with the diverse signaling pathways activated by G protein coupled receptors or calcium influx adds an additional level of complexity Modeling is an approach to integrate myriad data sources into a cohesive and quantitative model in order to evaluate hypotheses about neuron function In

particular a validated model developed using in vitro data allows simulations of the response to in vivo like spatio temporal patterns of synaptic input Incorporating molecular signaling pathways into an electrical model allows a greater range of models to be developed ones that can predict the response to pharmaceuticals many of which target neuromodulator pathways Contributions from leading authorities Informs and updates on all the latest developments in the field Thalamic Function - Beyond a Simple Relay Vincenzo Crunelli,William Martin Connelly,W. Martin Usrey,2016-05-20 The thalamus is often described as a relay Typified by sensory pathways this concept leads to thalamic nuclei being viewed as areas that passively streams information from a single source to the cortex without affecting the nature of that information However diverse intrathalamic connections the varying synaptic and membrane properties of thalamic neurons and the large number of inputs from non sensory sources make the idea that the thalamus is just a passive relay unlikely Furthermore a large number of thalamic nuclei are not primarily driven by sensory signals nor do they exclusively target the cortex meaning the thalamus must do more than simply pass sensory signals to the cortex Finally there is a wealth of research demonstrating that the thalamus does indeed function in ways that are not captured by the concept of a simple relay So why given all of this is the primary paradigm for describing the thalamus a relay This Research Topic covers original research reviews and hypotheses on thalamic function that explore the concept that the thalamus performs computational tasks other than simply passively relaying information Hippocampal Microcircuits Vassilis Cutsuridis,Bruce P. Graham,Stuart Cobb,Imre Vida,2019-02-04 This is the 2nd edition of a very well received and popular book that reflects the current state of the art of the ongoing research avenues concerning the hippocampus and processing units bridging the gap between single cell activity network activity and global brain function It aims to provide a methodology to anyone interested in developing microcircuit level models of the hippocampus The book is divided into two thematic areas I Experimental background and II Computational analysis In part I leading experimental neuroscientists discuss the morphological physiological and molecular characteristics as well as the connectivity and synaptic properties of the various cell types found in the hippocampus Behaviour related ensemble activity patterns of morphologically identified neurons in anesthetized and freely moving animals provide insights on the function of the hippocampal areas In part II computational neuroscientists present models of the hippocampal microcircuits at various levels of detail e g single cell level network level etc Synaptomics and connectomics models of hippocampal structures are initially discussed Then network models of memory rhythm generation and spatial navigation are presented followed by abstract and biophysical models of synaptic plasticity Network models of hippocampal implicated disorders epilepsy and schizophrenia are then detailed and how their network topologies connectivities and activities change in these diseases Finally two chapters are dedicated to describing simulator environments of single neurons and networks currently used by computational neuroscientists in developing their models and modelling tools to parametrically constrain them This engaging volume is invaluable to experimental and computational neuroscientists

electrical engineers physicists mathematicians and others interested in developing microcircuit models of the hippocampus Graduate level students and trainees in all of these fields can find this book a significant source of information **Neural Computation in Embodied Closed-Loop Systems for the Generation of Complex Behavior: From Biology to Technology** Poramate Manoonpong, Christian Tetzlaff, 2018-10-11 How can neural and morphological computations be effectively combined and realized in embodied closed loop systems e g robots such that they can become more like living creatures in their level of performance Understanding this will lead to new technologies and a variety of applications To tackle this research question here we bring together experts from different fields including Biology Computational Neuroscience Robotics and Artificial Intelligence to share their recent findings and ideas and to update our research community This eBook collects 17 cutting edge research articles covering neural and morphological computations as well as the transfer of results to real world applications like prosthesis and orthosis control and neuromorphic hardware implementation

The Plastic Brain Rommy von Bernhardi, Jaime Eugén, Kenneth J Muller, 2017-10-26 A comprehensive overview of the many factors that can influence brain plasticity throughout the lifespan Addresses perinatal plasticity functional state plasticity injury induced plasticity and stressor induced plasticity Because it looks at so many aspects of the field this volume will serve as a great resource for students as well as researchers interested in expanding their knowledge The volume comes out as an integrated view based in the expertise of Ibero American neuroscientists working in the field

The Role of Synaptic Tagging and Capture for Memory Dynamics in Spiking Neural Networks Jannik Luboeinski, 2021-09-02 Memory serves to process and store information about experiences such that this information can be used in future situations The transfer from transient storage into long term memory which retains information for hours days and even years is called consolidation In brains information is primarily stored via alteration of synapses so called synaptic plasticity While these changes are at first in a transient early phase they can be transferred to a late phase meaning that they become stabilized over the course of several hours This stabilization has been explained by so called synaptic tagging and capture STC mechanisms To store and recall memory representations emergent dynamics arise from the synaptic structure of recurrent networks of neurons This happens through so called cell assemblies which feature particularly strong synapses It has been proposed that the stabilization of such cell assemblies by STC corresponds to so called synaptic consolidation which is observed in humans and other animals in the first hours after acquiring a new memory The exact connection between the physiological mechanisms of STC and memory consolidation remains however unclear It is equally unknown which influence STC mechanisms exert on further cognitive functions that guide behavior On timescales of minutes to hours that means the timescales of STC such functions include memory improvement modification of memories interference and enhancement of similar memories and transient priming of certain memories Thus diverse memory dynamics may be linked to STC which can be investigated by employing theoretical methods based on experimental data from the neuronal and the

behavioral level In this thesis we present a theoretical model of STC based memory consolidation in recurrent networks of spiking neurons which are particularly suited to reproduce biologically realistic dynamics Furthermore we combine the STC mechanisms with calcium dynamics which have been found to guide the major processes of early phase synaptic plasticity in vivo In three included research articles as well as additional sections we develop this model and investigate how it can account for a variety of behavioral effects We find that the model enables the robust implementation of the cognitive memory functions mentioned above The main steps to this are 1 demonstrating the formation consolidation and improvement of memories represented by cell assemblies 2 showing that neuromodulator dependent STC can retroactively control whether information is stored in a temporal or rate based neural code and 3 examining interaction of multiple cell assemblies with transient and attractor dynamics in different organizational paradigms In summary we demonstrate several ways by which STC controls the late phase synaptic structure of cell assemblies Linking these structures to functional dynamics we show that our STC based model implements functionality that can be related to long term memory Thereby we provide a basis for the mechanistic explanation of various neuropsychological effects

Keywords synaptic plasticity synaptic tagging and capture spiking recurrent neural networks memory consolidation long term memory

[Axon Neurobiology: Fine-Scale Dynamics of Microstructure and Function](#) Haruyuki Kamiya, Dominique Debanne, 2020-12-09 This eBook is a collection of articles from a Frontiers Research Topic Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series they are collections of at least ten articles all centered on a particular subject With their unique mix of varied contributions from Original Research to Review Articles Frontiers Research Topics unify the most influential researchers the latest key findings and historical advances in a hot research area Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office frontiersin.org/about/contact

The Handbook of Brain Theory and Neural Networks Michael A. Arbib, 2003 This second edition presents the enormous progress made in recent years in the many subfields related to the two great questions how does the brain work and How can we build intelligent machines This second edition greatly increases the coverage of models of fundamental neurobiology cognitive neuroscience and neural network approaches to language

Midwest Neuronal Stochastic Variability: Influences on Spiking Dynamics and Network Activity Mark D. McDonnell, Joshua H. Goldwyn, Benjamin Lindner, 2016-07-18 Stochastic fluctuations are intrinsic to and unavoidable at every stage of neural dynamics For example ion channels undergo random conformational changes neurotransmitter release at synapses is discrete and probabilistic and neural networks are embedded in spontaneous background activity The mathematical and computational tool sets contributing to our understanding of stochastic neural dynamics have expanded rapidly in recent years New theories have emerged detailing the dynamics and computational power of the balanced state in recurrent networks At the cellular level novel stochastic extensions to the classical Hodgkin Huxley model have enlarged our understanding of neuronal dynamics and action

potential initiation Analytical methods have been developed that allow for the calculation of the firing statistics of simplified phenomenological integrate and fire models taking into account adaptation currents or temporal correlations of the noise This Research Topic is focused on identified physiological internal noise sources and mechanisms By internal we mean variability that is generated by intrinsic biophysical processes This includes noise at a range of scales from ion channels to synapses to neurons to networks The contributions in this Research Topic introduce innovative mathematical analysis and or computational methods that relate to empirical measures of neural activity and illuminate the functional role of intrinsic noise in the brain

Neural and Brain Modeling Ronald MacGregor, 2012-12-02 Neural and Brain Modeling reviews models used to study neural interactions The book also discusses 54 computer programs that simulate the dynamics of neurons and neuronal networks to illustrate between unit and systemic levels of nervous system functions The models of neural and brain operations are composed of three sections models of generic mechanisms models of specific neuronal systems and models of generic operations networks and systems The text discusses the computational problems related to galvanizing a neuronal population through an activity in the multifiber input system The investigator can use a computer technique to simulate multiple interacting neuronal populations For example he can investigate the case of a single local region that contains two populations of neurons namely a parent population of excitatory cells and a second set of inhibitory neurons Computer simulation models predict the various dynamic activity occurring in the complicated structure and physiology of neuronal systems Computer models can be used in top down brain mind research where the systemic global and emergent properties of nervous systems are generated The book is recommended for behavioral scientists psychiatrists psychologists computer programmers students and professors in human behavior

Introduction to Neuroscience , Artificial Neural Networks - ICANN 2009 Cesare Alippi, Marios M. Polycarpou, Christos Panayiotou, Georgios Ellinas, 2009-09-16 This volume is part of the two volume proceedings of the 19th International Conference on Artificial Neural Networks ICANN 2009 which was held in Cyprus during September 14-17 2009 The ICANN conference is an annual meeting sponsored by the European Neural Network Society ENNS in cooperation with the International Neural Network Society INNS and the Japanese Neural Network Society JNNS ICANN 2009 was technically sponsored by the IEEE Computational Intelligence Society This series of conferences has been held annually since 1991 in various European countries and covers the field of neurocomputing learning systems and related areas Artificial neural networks provide an information processing structure inspired by biological nervous systems They consist of a large number of highly interconnected processing elements with the capability of learning by example The field of artificial neural networks has evolved significantly in the last two decades with active participation from diverse fields such as engineering computer science mathematics artificial intelligence system theory biology operations research and neuroscience Artificial neural networks have been widely applied for pattern recognition control optimization image processing classification signal processing etc

The Hippocampus Book Richard

Morris, David G. Amaral, Tim Bliss, Karen Duff, John O'Keefe, 2024-11 Known to be important for memory the hippocampus has long been a prime focus for neuroscience research This second edition of The Hippocampus Book is written by experts in a wide range of disciplines with new chapters summarizing how disorders of hippocampal function contribute to neurological and psychiatric conditions The editors draw on their experience in hippocampal anatomy physiology cognitive neuroscience and disease pathobiology to weave together an authoritative book which will interest those working in numerous neuroscientific disciplines

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