Encyclopedia of Computational Neuroscience

Dieter Jaeger • Ranu Jung
Editors

Encyclopedia of Computational Neuroscience

With 1109 Figures and 71 Tables

Springer Reference

Editors

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Booknotes

This edition comprises 4 Volumes:

- Volume 1: Overview
A–C
- Volume 2: D–L
- Volume 3: M–P
- Volume 4: Q–W

Preface

Computational Neuroscience has emerged in the last three decades as an interdisciplinary research area combining approaches from mathematics, physics, engineering, computer science, and neurobiology. Combining theoretical and computational approaches with experimental data has proven to illuminate neural function from molecular to system levels. A testimony to this success comes from the emergence of several international conferences in this field of study, such as the Organization of Computational Neuroscience (<http://www.cnsorg.org/>) and Cosyne (<http://www.cosyne.org>) annual meetings. Specialized funding sources for this area of research have also made a huge impact, and the field owes much to the organizers of the NIH/NSF Collaborative Research in Computational Neuroscience program and the German Bernstein Network. Importantly, new initiatives in data sharing as well as model sharing based on modern markup language syntax and semantics will make it possible in the near future to present an accessible collaborative interface between investigators as the field matures. These efforts are in part promoted by the field of Neuroinformatics and the International Neuroinformatics Coordinating Facility (<http://incf.org/>).

We hope that the new Springer Encyclopedia of Computational Neuroscience will bring this young field closer to the eye of the general scientific community and provide a valuable resource in explaining the many angles of this highly active enterprise. The Encyclopedia highlights achievements and approaches to describe basic neural function and major brain systems as well as biomedical applications in more than 570 articles organized into 49 sections of research. At-depth articles provide comprehensive coverage of important topics in these disciplines, whereas short articles summarize individual concepts and key terms. The interplay between computational and theoretical approaches and experimental data is highlighted at all levels, from molecular to cognitive. Available shared database resources are also covered. While overall alphabetically sorted, an introduction of each section is presented in articles denoted with “Overview,” which also provide organized links to section articles.

The level of description in the Encyclopedia is aimed to make the material accessible to graduate students in the many disciplines that contribute to computational neuroscience while also providing a valuable reference to advanced researchers. Cited website links allow access to a more detailed level of information when needed. For those with institutional access to the

online SpringerReference enterprise, a hot-linked version of this encyclopedia is available under <http://www.springerreference.com/>.

The Editors in Chief are pleased to present this encyclopedia and are looking forward to readers' comments that will be taken to further improve and complete future updates of this work.

Dieter Jaeger
Ranu Jung

Research Interests

James Bednar uses computational modeling to understand how visual cortex circuitry develops and functions. The goal is to find a small set of developmental and other mechanisms that are sufficient to account for the wide range of functional properties that have been observed in populations of neurons in adult animals and humans.

Ulrik Beierholm's research focuses on developing machine-learning-inspired models (e.g., based on Bayesian statistics or reinforcement learning) to understand human choices in perception, cognition, and learning and on testing them through psychophysics and fMRI.

Dr. Ulrik Beierholm studied physics at the **University of Copenhagen** before deciding on a research career in Neuroscience. From 2001 to 2007, he was a Ph.D. student at the California Institute of Technology (**Caltech**) in the Computation and Neural Systems program, being awarded a Fulbright fellowship. After his studies, he completed further postdoctoral training at the **Gatsby Computational Neuroscience Unit** (at UCL) in London, where he worked with Professor Peter Dayan on modeling learning and decision making while on a Marie Curie Reintegration grant.

Sliman J. Bensmaia is an assistant professor in the Department of Organismal Biology and Anatomy at the University of Chicago, Illinois, USA, where he is also a member of the Committees on Neurobiology and on Computational Neuroscience. He received a B.A. in cognitive science from the University of Virginia in 1995 and a Ph.D. in cognitive psychology from the University of North Carolina at Chapel Hill, USA, in 2003 under the tutelage of Mark Hollins. He then joined the laboratory of Kenneth Johnson at the Johns Hopkins University Krieger Mind/Brain Institute, Baltimore, Maryland, USA, initially as a postdoctoral fellow and then as an associate research scientist. The main objectives of Bensmaia's research are to discover the neural basis of somatosensory perception using psychophysics, neurophysiology, and computational modeling. He also seeks to apply insights from basic science to develop approaches to convey sensory feedback in upper-limb neuroprostheses.

Kim T. Blackwell is a Professor in the Department of Molecular Neuroscience at George Mason University. Her research interests are to understand biophysical and biochemical mechanisms underlying memory storage. Her

approach interlaces experiments and model development on the network level, cellular level, and subcellular level in order to identify the mechanisms whereby particular spatiotemporal patterns of inputs produce changes in synaptic plasticity and intrinsic excitability in the hippocampus and striatum. She has developed the software tools Chemosis and NeuroRD for large-scale dynamical modeling of signaling pathways in neurons underlying memory storage.

Ingo Bojak has worked in computational neuroscience for the last decade, with over 30 publications in that field. He is an expert in neural population models (NPMs) and was the first to use them to simulate an entire human cortex on a parallel compute cluster with MPI-C. This has progressed to anatomically realistic neural mass meshes, which allow the inclusion of experimentally determined brain connectivity. Another main focus of his research has been modeling general anaesthetic agents. Bojak has also worked on the effect of axonal diameter distributions on brain dynamics, the influence of alpha rhythm phase on fMRI BOLD, long-range synchrony in cortical networks, and orientation sensitivity in the visual cortex. He is an editor with the journals *Neurocomputing* and *EPJ Nonlinear Biomedical Physics* and has served on the Board of Directors and Program Committee of the OCNS and as Node Representative of the INCF for the UK and the Netherlands. He has recently joined the EPSRC Peer Review College.

Alla Borisyuk is an Associate Professor of Mathematics and an associate faculty member in the Neuroscience Program at the University of Utah. Her research focuses on the mathematical analysis of neuronal models, particularly on the shaping of neural dynamics by low-level processes such as single-cell properties, network architecture, and plasticity of connections. She is working on both theoretical and collaborative (directly related to experiments) types of projects including applications in the auditory system, odor coding in the olfactory system, emergence of oscillations in noisy networks, and others.

Steven Bressler is a cognitive neuroscientist at the Center for Complex Systems and Brain Sciences at FAU who studies the dynamics of neural information processing during goal-directed behaviors. He has been awarded grants from the National Science Foundation and the National Institute of Mental Health to study the dynamics of large-scale cortical circuits in vision. His research is providing important insights into the interactions of neuronal assemblies from different brain regions that underlie visual perception, attention, and working memory.

Robert Butera is a Professor jointly appointed in the School of Electrical and Computer Engineering at Georgia Tech, the Wallace H. Coulter Dept. of Biomedical Engineering at Georgia Tech and Emory University, Atlanta, GA, USA. His research interests include peripheral nerve modulation of sensation and autonomic/organ function, real-time computing methods for

electrophysiology experiments, and general mechanisms of rhythm central pattern generation.

Carmen Canavier's major research interest is the nonlinear dynamics of oscillatory neurons and oscillatory networks of neurons. She uses phase resetting theory to study synchronization between oscillators and nonlinear dynamical theory to understand how individual neurons, and midbrain dopamine neurons in particular, produce different firing patterns under different conditions.

Yoonsuck Choe is a professor and director of the Brain Networks Laboratory in the Department of Computer Science and Engineering at Texas A&M University. His research interests are broadly in computational neuroscience, computational neuroanatomy, neuroinformatics, and neuroevolution. His work ranges from visual cortical modeling (<http://computationalmaps.org>) to sensorimotor learning, temporal aspects of brain function (delay, memory, and prediction), whole-brain physical sectioning imaging (Knife-Edge Scanning Microscopy), and web-based brain atlas frameworks (<http://kesm.org>).

Diego Contreras' main focus of research is on how the nervous system encodes information. In particular, he is studying (i) the possible role of oscillatory activity in the gamma band (20–80 Hz) for encoding visual stimuli in corticothalamic networks and (ii) the role of corticothalamic feedback. Responses to visual stimuli are recorded from the cortex and thalamus with combined intracellular and optical recordings using voltage-sensitive dyes and calcium indicators.

Dr. Contreras also studies the mechanisms by which neural networks engage in the abnormal, paroxysmic activity that characterizes epilepsy.

Sharon Crook holds a joint appointment between the School of Mathematical and Statistical Sciences and the School of Life Sciences at Arizona State University. Using mathematical models and computer simulations, her research focuses on the dynamics of neurons and neuronal networks and the mechanisms underlying plasticity in neural physiology, morphology, and behavior due to trauma or learning. Dr. Crook also contributes to the development of NeuroML, an international effort to create a common standard for describing computational models for neuroscience research.

Gennady S. Cymbalyuk is an associate professor in the Neuroscience Institute and the Physics and Astronomy Department of Georgia State University, Atlanta, GA, USA. He is interested in the mechanisms governing the dynamics of single neurons and oscillatory neuronal networks. His research is focused on the dynamics of central pattern generators, neuromodulation, control of bursting activity, and multistability of activity regimes. In his research, he combines methods developed in dynamical systems theory with electrophysiological techniques.

Susan Denham's program has two main aims: (a) the development of a theoretical view of sensory perception and perceptual organization (Winkler et al. 2009, 2012; Mill et al. 2012) and (b) the consideration of the potential of novel findings from this account for more detailed neurocomputational modeling (e.g., Lanyon and Denham 2010) and the development of artificial systems (e.g., Sheik et al. 2012).

Current research themes include studies aimed at (a) understanding the dynamics and influences on perceptual switching (Bendixen et al. 2010), (b) methods for analyzing individual differences in multistability (Denham et al. 2012), (c) developing computational models which explain perceptual flexibility (Mill et al. 2013), and (d) applying this work to the development of novel solutions to problems of tracking speech in noise, especially in the elderly (in collaboration with I Winkler, Hungary). Underlying all this is the aim to identify principles of biological computation, which can be used in the development of novel brain-inspired technology for deployment in real-world environments.

Alain Destexhe is Research Director at the CNRS in the research campus of Gif sur Yvette near Paris. He leads a team of computational neuroscientists, in which his colleagues and he study the nature of brain states and their impact on neuronal computations. This work operates at the interface between experimental and theoretical neuroscience, often combining them. He is also director of the European Institute for Theoretical Neuroscience (www.eitn.org), recently created in the center of Paris. He has published more than 100 peer-reviewed journal articles and is author of numerous chapters and edited books and two monographs.

Alexander Dimitrov's main research interests involve the study of neural information processing, neural coding, and information representation in biological systems. In particular, he is interested in understanding information-processing functions of neural ensemble activity and the biological mechanisms through which these functions are implemented. Quantitative tools applied to achieve these research goals come mostly from branches of applied probability (information theory, signal processing theory, multivariate statistics, and stochastic differential equations), dynamical systems theory, and group theory.

Fabrizio Gabbiani is a Professor in the Department of Neuroscience at Baylor College of Medicine. His research interest is in the computation of sensory processing and sensorimotor transformations in the central nervous system.

Marc-Oliver Gewaltig is codirector of the Neurorobotics subproject in the recently approved EU FET Flagship "Human Brain Project" and leads the Neurorobotics Section of the Blue-Brain Project at the EPFL in Lausanne. In his research, Marc-Oliver Gewaltig investigates the computational properties of the neocortical column in closed action-perception loops. He also has a strong interest in computer science for large-scale neural simulations

and is coauthor of the neural simulation tool NEST (www.nest-initiative.org). Before joining the EPFL in 2011, Marc-Oliver Gewaltig worked for the Honda Research Institute Europe in Offenbach, Germany, where he served as Principal Scientist (2003–2011) and Project Leader (1998–2002). In 1999, Marc-Oliver Gewaltig received his Ph.D. in Physics for his work on activity propagation in cortical networks.

Padraig Gleeson is a postdoc in the lab of Angus Silver at University College London (<http://www.ucl.ac.uk/silverlab>). His initial work toward developing more anatomically detailed models of the cerebellar cortex in this lab led to the development of the application neuroConstruct (<http://www.neuroconstruct.org>), which has been widely used for creating other detailed 3D network models. This application's ability to generate code for multiple neuronal simulators got him involved in the development of the NeuroML language for model specification in computational neuroscience (<http://www.neuroml.org/>), which has had a major update over the past 2 years for the version 2.0 of the language. He has recently been leading the development of the Open Source Brain repository (<http://www.opensourcebrain.org>) for collaborative model development, which will be the subject of his presentation.

Joshua Goldberg works on preclinical models of Parkinson's disease and other movement disorders. His work focuses on the physiological mechanisms underlying neurodegeneration and the pathophysiological adaptations that occur both in global brain dynamics and in the autonomous activity of neurons affected by these disorders.

Sonja Grün's research goal is to gain an understanding of the relevant spatiotemporal scale(s) at which the cortex effectively interacts and to contribute to the uncovering of its function. Her work involves the simultaneous observation of large portions of the network on the single neuron and population levels (in collaboration with experimentalists), the development of statistical tools for the analysis of multichannel data from awake-behaving animals, the analysis of experiments to extract and condense the relevant characteristics of the system, the interpretation of the system dynamics by construction of theoretical (biophysical and functional) models, and the development of software and workflows for reproducible analysis.

Christian Hauptmann works in the field of computational neuroscience, neuromodulation, and neurotechnology. He received his physics degree from Darmstadt Technical University, Germany, in 1997 and worked in the field of epilepsy research at the University of Cologne, where he received his Ph.D. in 2000. After a postdoc at McGill University, Montréal, Canada (Humboldt fellowship), with Michael Mackey he started in 2002 to work at the Juelich Research Center, Germany, in the team of Peter A. Tass. Christian Hauptmann contributed to the development of novel stimulation techniques and developed medical devices needed to test innovative therapeutic concepts. In 2008, he received his habilitation in the field of medical physics from the

University Hospital of Cologne, Germany. He has published more than 40 peer-reviewed articles.

His research interests are the modeling of the effects of neuromodulation and the development of devices for invasive and noninvasive neuromodulation.

William Holmes is a Professor in the Department of Biological Sciences at Ohio University. His research interests include understanding how computation and synaptic modification take place in individual neurons of the hippocampus. To do this, he develops mathematical and computational models at three levels of organization: the neuron, the synapse, and biochemical reactions within dendritic spines to understand how these levels interact to affect signaling mechanisms involved with long-term potentiation (LTP).

Dieter Jaeger is a Professor in the Department of Biology at Emory University. His research interest is in studying synaptic integration in and function of basal ganglia and cerebellar structures and their feedback to the cerebral cortex. His approaches combine cellular and system-level electrophysiology with detailed compartmental neuronal modeling.

Devin Jindrich is an Assistant Professor at the California State University, San Marcos. His research goals are to understand the dynamic interactions among the nervous system, the musculoskeletal system, behavioral task demands, and the environment that result in movement. Current research projects focus on the neuromechanics of unsteady locomotion, the motor control of upper-extremity function to prevent injuries associated with human–computer interfaces, and developing strategies to restore motor function after injury.

Ranu Jung holds the Wallace H. Coulter Eminent Scholars Chair in Biomedical Engineering at Florida International University, Miami, FL where she is Professor and Chair of the Department of Biomedical Engineering. Her research interests are in neural engineering and computational neuroscience. She is actively engaged in understanding the neural control of end organs and in the development of neurotechnology that is inspired by biology, is adaptive, and could be used to promote plasticity in the nervous system to overcome neurological disability or trauma. Of special interest to her are biomimetic and biohybrid living-hardware systems interfaced at the peripheral nerve or spinal cord levels to restore function after amputation or spinal cord injury.

Jeanette Hellgren Kotaleski's main focus of research has been to use mathematical modeling to understand the neural mechanisms underlying information processing, rhythm generation, and learning in motor systems. Of specific interest are the basal ganglia, a structure in the brain that is important for the selection and initiation of motor (and cognitive) actions. The levels of investigation using computational models range from simulations of large-scale neural networks using both biophysically detailed but also

more abstract system-level models down to kinetic models of subcellular processes (e.g., dopamine-induced cascades). The latter approach is important for understanding mechanisms involved in, e.g., synaptic plasticity and learning.

Michel Lemay obtained his Ph.D. in biomedical engineering from Case Western Reserve University in 1994 with a specialization in functional neuromuscular stimulation. He is currently professor of Bioengineering at Temple University, where he studies the effects of providing exogenous neurotrophins on locomotor recovery and the spinal circuitry in a large animal model of spinal cord injury.

Christiane Linster is a Professor in the Department of Neurobiology and Behavior at Cornell University. Her research interests focus on neuromodulation and plasticity in sensory processing using the olfactory system as a model system. Her approaches combine system-level electrophysiology, behavioral pharmacology, and compartmental neuronal modeling.

Nigel Lovell received the B.E. (Hons) and Ph.D. degrees from the University of New South Wales (UNSW), Sydney, Australia. He is currently at the Graduate School of Biomedical Engineering, UNSW, where he holds a position of Scientia Professor. He has authored 180+ journal papers and been awarded over \$76 million in R&D and infrastructure funding. His research work has covered areas of expertise ranging from cardiac modeling, telehealth technologies, biological signal processing, and visual prosthesis design. He has commercialized a range of telehealth technologies for managing chronic diseases and falls in the older population. He is also one of the key researchers leading an R&D program to develop in Australia a retinal neuroprosthesis or “bionic eye.”

William Lytton is a Professor in Physiology, Pharmacology, and Neurology at SUNY Downstate and works as a clinical neurologist at Kings County Hospital, seeing patients with a variety of brain ailments. His research is in Computational Neuroscience, with a focus on the application of multiscale modeling to various disorders of the brain including Alzheimer’s, stroke, Parkinson’s, epilepsy, and schizophrenia. He is the author of a Springer textbook in the field.

Americo Migliaccio is a vestibular researcher with a broad range of skills, including basic (animal) science, clinical studies, and biomedical engineering. He is currently a Senior Research Fellow and Group Leader at Neuroscience Research Australia, where he has been head of the Balance and Vision Laboratory since 2008. He is a Conjoint Associate Professor at the University of New South Wales and an Adjunct Associate Professor at Johns Hopkins University (USA).

The focus of his laboratory is on vestibular treatment and rehabilitation that *increases/restores* vestibular function. His three main objectives include

(1) investigation of the physiological basis for the development of a human vestibular prosthesis for the ~5 % of vestibular patients that have lost complete (bilateral) vestibular end-organ function, (2) determining the crucial pathways needed for vestibular adaptation and compensation after peripheral vestibular end-organ injury using animal models, in particular the *alpha9 knockout* mouse and the *tilted* mouse, and (3) investigation of techniques that maximize vestibular plasticity to increase vestibular responses in patients that have lost partial vestibular function, i.e., the majority of vestibular patients. This work has led to the development of a portable vestibular rehabilitation device presently undergoing clinical trials.

John Milton's research interest is in the interplay between sensory uncertainty and time delays in shaping the dynamic behaviors of neural feedback control mechanisms. Current interests include balance control, the development of expertise, and epilepsy.

Kendall F. Morris is a Professor in the Department of Molecular Pharmacology and Physiology at the Morsani College of Medicine of the University of South Florida, Tampa, FL. His research interests include the study of brainstem neural networks that control breathing and cardiovascular function. His approaches combine in vivo multineuron recording and analysis with neural network computer simulations.

Farzan Nadim is a Professor of Neurobiology in the Federated Department of Biology of the New Jersey Institute of Technology and Rutgers University–Newark. He has a joint appointment in the Department of Mathematical Sciences at NJIT. His area of expertise is Central Pattern Generation. His research combines electrophysiology with mathematical and computer modeling to understand the role of synaptic and neuronal dynamics in producing network oscillations in the central nervous system.

Theoden I. Netoff is an Associate Professor in the Department of Biomedical Engineering at the University of Minnesota. His research interest is in epilepsy. In particular, he is interested in how changes in connectivity between neurons result in pathological network behavior, such as seizures.

Klaus Obermayer received his Ph.D. in 1992 from the Department of Physics, Technical University of Munich, Germany. From 1992 to 1993, he was a postdoctoral fellow at the Rockefeller University, New York, and the Salk Institute for Biological Studies, La Jolla, USA. From 1994 to 1995, he was member of the Technische Fakultät, University of Bielefeld, Germany. He became associate professor in 1995 and full professor in 2001 at the Department of Electrical Engineering and Computer Science of the Berlin University of Technology, Germany. He is head of the Neural Information Processing Group and member of the steering committee of the Bernstein Center for Computational Neuroscience Berlin. He was member of the governing board of the International Neural Network Society from 2004 to 2012 and was Vice President of the Organisation for Computational

Neuroscience from 2008 to 2011. From 1999 to 2003, he was one of the directors of the European Advanced Course of Computational Neuroscience. His current areas of research are computational neuroscience, artificial neural networks and machine learning, and the analysis of neural data. He coauthored more than 250 scientific publications.

Karim G. Oweiss received his B.S. (1993) and M.S. (1996) degrees with honors in Electrical Engineering from the University of Alexandria, Egypt, and his Ph.D. degree (2002) in Electrical Engineering and Computer Science from the University of Michigan, Ann Arbor. He completed a postdoctoral training in Biomedical Engineering at the University of Michigan, Ann Arbor, in 2002. In 2003, he joined the department of Electrical and Computer Engineering and the Neuroscience Program at Michigan State University, where he is currently an Associate Professor and Director of the Neural Systems Engineering Laboratory. His research interests span the areas of statistical signal processing and information theory, neural integration and coordination in sensorimotor systems, computational neuroscience, and brain-machine interfaces.

Dr. Oweiss is a senior member of the IEEE and a member of the Society for Neuroscience. He served as a member of the board of directors of the IEEE Signal Processing Society on Brain Machine Interfaces and continues to serve on the technical committees of the IEEE Biomedical Circuits and Systems, the IEEE Life Sciences, and the IEEE Engineering in Medicine and Biology societies. He was awarded the Excellence in Neural Engineering award from the National Science Foundation in 2001. His lab is currently supported through the Neural Interfaces Program (NIP) and the Repair and Plasticity Program (RPP) at the National Institute of Neurological Disorders and Stroke as well as DARPA's Reliable Central-Nervous-System Interfaces (RCI) program. He is the editor and coauthor of the book *Statistical Signal Processing for Neuroscience and Neurotechnology* published by Academic Press in 2010.

Astrid Prinz is an Associate Professor in the Department of Biology at Emory University. Her lab combines experimental and computational approaches to study rhythmic pattern generation and neuronal homeostasis in pattern-generating neuronal circuits.

Sylvie Renaud is a Professor at ENSEIRB-MATMECA at the University of Bordeaux. Her research interest is in analog and mixed neuromorphic and bioprocessing VLSI; in hybrid systems interfacing electronics and biological excitable tissues; in smart ASICs for biological signal conditioning, event detection, and tissue stimulation; in active VLSI implants for neurodegenerative diseases and diabetes; and in closed-loop living-artificial systems.

Jorge Riera's scientific interest is to develop methods for the integration of neuroimaging multimodalities based on modeling mesoscopic phenomena in the cerebral cortex. To that end, he focuses attention on the following issues: signal integration by neurons and astrocytes, microcircuitries and networks of

cells in the cortex, dynamics of neuronal masses and brain connectivity graphs, biophysics of neurovascular/metabolic coupling, and spatiotemporal inverse problems in neuroimaging.

Patrick Roberts is an affiliate Associate Professor in the Department of Biomedical Engineering at Oregon Health & Science University and an adjunct Associate Professor in the Systems Science Program at Portland State University. His research interest is to develop appropriate mathematical methods, both analytical and computational, to study the dynamics of neural activity patterns and to help understand the relationship between these dynamics and behavior. He applies these theoretical tools to understand neural processing and learning in sensory systems and to model the efficacy of drug actions on symptoms of neurological and psychiatric diseases.

Jonathan Rubin is a Professor of Mathematics at the University of Pittsburgh. His interests focus on the dynamic mechanisms yielding bursting and other complex activities seen in neurons and neuronal networks, in the generation of rhythms (e.g., in central pattern generators) and oscillations, and in understanding and treating parkinsonism. Beyond these central themes, he has diverse interests, mostly relating to dynamics in neural models but also including synaptic plasticity and parameter estimation.

Ilya A. Rybak received his M.S. in Electrical Engineering from Odessa Polytechnic University (Odessa, Ukraine) in 1975 and his Ph.D. in Biophysics from St. Petersburg State University (St. Petersburg, Russia) in 1988. He began his scientific career in 1977 at A.B. Kogan Research Institute for Neurocybernetics at the Rostov State University. After moving to the USA in 1991, he worked in the DuPont company as Visiting Scientist. In 1993–1994, he was Visiting Professor at Le Havre University, France. Dr. Rybak joined Drexel University in 1999 as Research Professor at the School of Biomedical Engineering. Since 2006, he has been Professor at the Department of Neurobiology and Anatomy at Drexel University College of Medicine. Dr. Rybak published more than 300 papers on the mathematical and computer modeling of various biological neural networks in different areas of the brain; neural oscillations; and the neural control of locomotion and breathing, visual perception, and recognition.

Emilio Salinas grew up in Mexico City. He obtained a B.Sc. degree in Physics there at the Universidad Nacional Autónoma de México (UNAM). At that time, he became interested in mathematical models of single neurons and decided to pursue a doctoral degree. He obtained his Ph.D. from Brandeis University in 1996 under the supervision of Larry Abbott. During this time, he worked on various projects related to how populations of neurons encode sensory and motor information. He then returned to Mexico to join the laboratory of Ranulfo Romo, where he worked on the analysis and modeling of neurophysiological data from awake, behaving monkeys. In 1999, he went to the laboratory of Terry Sejnowski at the Salk Institute in San Diego, California, for another postdoctoral stay. There, he studied the effects of

correlated synaptic inputs on the responses of single model neurons. Emilio Salinas is currently an Associate Professor in the Department of Neurobiology and Anatomy at Wake Forest School of Medicine in Winston-Salem, North Carolina. His current research interests include constructing model neural circuits that are able to switch tasks in a context-dependent way, understanding the optimality of cortical sensory representations, and exploring the neural mechanisms that determine how choices are made.

Fidel Santamaria was born in a small town in Mexico called Mexico City; at that time, it probably only had a few million people. There, he went to college at the Universidad Nacional Autonoma de Mexico (UNAM) to study Physics. His first research experience was in a short-lived space program (PUIDE) in which he got involved in studying rocket propulsion. It was fun at the time; however, he had been always interested in robotics, artificial intelligence, and brain function. He then moved to the lab of Prof. Ismael Espinosa, director of the Cybernetics Lab, who got his Ph.D. from Gerstein at Penn. He studied and built artificial neural networks, experienced firsthand extracellular electrophysiology, and decided that he wanted to learn more.

Since he wanted to do biophysical modeling and experiments to understand how neurons and networks work, he applied to the Ph.D. program in Computation & Neural Systems at Caltech. There, he joined the lab of Prof. James M. Bower. His thesis was a combination of network modeling and electrophysiological recordings to understand how the cerebellar cortex processes sensory information.

By the end of his Ph.D., he became more interested in understanding the inner workings of neurons instead of looking at large numbers of cells. He wrote a letter to Prof. George J. Augustine at Duke University, asking him if he would be interested in having a person like Fidel Santamaria in his lab. Luckily, he was. Fidel Santamaria studied how the structure of a neuron affects the diffusion of soluble molecules. For that, he used ultrafast confocal microscopy and Monte Carlo simulations of molecular diffusion.

Lars Schwabe aims at understanding cortical information processing in terms of the underlying principles, the neuronal dynamics, and as to whether the two can be separated at all. The focus of his research has been on the dynamic properties of strongly recurrent networks in the visual cortex, their emergent dynamical properties, and how those are affected by inter-areal feedback from extra-striate cortical areas. The physiology of so-called contextual effects in the visual system continue to serve as the main phenomenon to be explained. He is also interested in testing if theories and models that have been developed for the visual system generalize. For example, can we shed some light into (currently) conceptually more fuzzy fields such as, for example, ‘the neuroscience of the self’ using theories from neural coding, learning and inference? Method-wise, he is applying mathematical modeling and simulations, but he also engaged in standardization efforts for describing neuronal models using strictly declarative approaches. Continuing that work,

he is currently applying core computer science concepts such as process algebras and model checking to simulated neuronal systems.

Frances Skinner is a Senior Scientist in the Division of Fundamental Neurobiology at the Toronto Western Research Institute, University Health Network, and a Professor at the University of Toronto.

Her research interests are in determining the mechanisms underlying the dynamic output of neurons and neuronal networks. Her approach involves the use, development, and analysis of mathematical models that have intimate links with experimental data and analysis. The present focus is on oscillatory activities in the hippocampus and inhibitory cells.

Volker Steuber is a Reader (Associate Professor) in Biocomputation and Head of the Biocomputation Research Group in the Science and Technology Research Institute at the University of Hertfordshire. His research involves the development of multiscale models of neurons and neuronal networks and the application of machine-learning techniques to analyze biological data. One of his main research interests is synaptic plasticity and information processing in the cerebellum.

Peter Tass develops stimulation techniques with computational methods. He studied medicine (M.D., Universities of Ulm and Heidelberg, Germany), physics (Ph.D., University of Stuttgart, Germany), and mathematics (diploma, University of Stuttgart, Germany) and made a Habilitation in physiology (RWTH Aachen University, Germany). He is the director of the Institute of Neuroscience and Medicine—Neuromodulation at Juelich Research Center, Juelich, Germany, and full professor in neuromodulation and head of the research division for neuromodulation at Cologne University, Germany. Furthermore, Peter Tass is consulting professor at the Department of Neurosurgery, Stanford University, Stanford, CA, USA.

Matthew Tresch is Associate Professor in Biomedical Engineering, Physical Medicine and Rehabilitation, and Physiology at Northwestern University. He is interested in the interaction between the neural control of movement and peripheral limb mechanics using rodent models and drawing on techniques from neurophysiology, behavioral analyses, and biomechanics.

Sharmila Venugopal is a Research Faculty in the Department of Integrative Biology and Physiology at UCLA and a part-time Teaching Faculty in the College of Engineering at California State University, Long Beach. She has a bachelor's degree in Electrical Engineering, a master's degree in Computer Engineering, and a Ph.D. in Neuroscience. Her research interests include the computational modeling of neurological disease dynamics, the experimental investigation of progressive changes in neural excitability in neurodegenerative disease models, and the development of software and hardware signal- and image-processing tools for neuroscience applications.

Wei Wang is an assistant professor in the Department of Physical Medicine and Rehabilitation, Department of Bioengineering, and Clinical and Translational Science Institute at the University of Pittsburgh. Dr. Wang's primary research interests include motor system neurophysiology, brain-computer interfaces, and neurorehabilitation.

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Douglas Weber's general research area is Neural Engineering including studies of functional electrical stimulation (FES), activity-based neuromotor rehabilitation, neural coding, and neural control of prosthetic devices. He has expertise in a range of advanced techniques for neurophysiology and biomechanics research including 3D motion analysis, electromyography, multichannel neural recording and stimulation, human magnetoencephalography (MEG), and human electrocorticography (ECoG). He has experience with a variety of animal models including rats, cats, and nonhuman primates as well as human subject testing in laboratory and clinical studies. Active projects in his lab include the development of motor and sensory neural interfaces for controlling and sensing prosthetic limbs.

Douglas Weber is currently splitting his time (until August 2015) between the University of Pittsburgh and the Defense Advanced Research Projects Agency (DARPA), where he is a program manager in the Biological Technology Office (BTO). At DARPA, he is responsible for managing several neurotechnology programs including RE-NET, HAPTIX, and ElectRx.

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Acknowledgements

The last decade of the twentieth century, the “Decade of the Brain,” saw Computational Neuroscience emerge as an essential complement to experimental neuroscience. The first decade of the “twenty-first century” has seen the additional emergence of the field of Neural Engineering dedicated to important practical implementations in Computational Neuroscience such as neuroprosthetics and clinical neurostimulation. It is thus an opportune time to bring forth a major dynamic living reference work on “Computational Neuroscience” to convey the diversity of information needed for conducting basic and applied computational neuroscience research and design and development of novel neurotechnologies.

This seminal *Encyclopedia of Computational Neuroscience* was initiated under the pseudonym of “Project Bhaskara.” Bhaskara I (c. 600–c. 680) was an ancient Indian mathematician. He was apparently the first to write the numbers in the Hindu-Arabic decimal system and use the symbol for zero (the language of computers). He used figures to present the positional or place-value decimal system (Coding) and linked mathematical theory with observational astronomy. He commented on an ancient treatise, the *Aryabhatiya*, and wrote a major eight chapter encyclopedia, the *Mahabhaskariya*. With this inspiration, Project Bhaskara has now culminated in a twenty-first-century collaborative effort bringing together diversity of knowledge in the pursuit and synthesis of computational neuroscience.

In 2010, Ann Avouris, Senior Editor, *Neuroscience* at Springer Inc., approached Ranu Jung, then President of the Organization for Computational Neuroscience, to consider editing a major reference work. She and Dieter Jaeger, then Vice-President of the organization, agreed to shepherd the project because of the willingness of the members of the Board to support the Editors-in-Chief in creation of this work. It was only then, with their enthusiastic support, that an international effort was launched.

The work could not have been compiled and completed without the extensive and thoughtful actions of many. Fifty-three section editors spent several months developing the topics to be covered under their sections. They invited authors from around the world to contribute to each of their sections, and as of today there are 545 entries. Many biologists, engineers, mathematicians, neuroscientists, and physicists have contributed entries. They have provided definitions, descriptions, and references. The section editors have provided overviews to intertwine the entries and provided section overviews

to the readers. It is through this collective engagement that this first edition is being launched.

An effort such as this rests on the discoveries, development of methodologies, and application of ideas by many. Investment to support the birth and implementation of these ideas is crucial and rests on the championship of peoples and institutions with foresight. In the USA, Kenneth Whang, from the National Science Foundation, and Dennis Glanzman and Yuan Liu, from the National Institutes of Health, in particular have provided unrelenting support for computational neuroscience from within the funding agencies. The early establishment of the “Bernstein Centers” in Germany and the International Neuroinformatics Coordinating Facility (INCF) with its Secretariat in Sweden also played a crucial role in globalizing the field. Consequent to the steadfast investments such as these, as of 2014 there are formal mechanisms to support global collaborations between USA and France, USA and Germany, USA and Israel, and the 17 INCF national nodes in countries in Europe, USA, and Asia in computational neuroscience.

The entire project would not have been possible without the momentous ongoing support of the Springer Editorial Staff based in the USA and the Federal Republic of Germany. Besides championing the effort, Ann Avouris shepherded the project through most of its three-year journey. Early on, Jutta Jaeger-Hamers, Daniela Graf, and Melanie Thanner helped shape the sections. Daniela and Melanie have tirelessly provided many an answer to questions from authors and editors and implemented suggestions and changes. Taking over for Ann in 2013, Simina Calin has taken the responsibility to bring the encyclopedia to the finish line and pave the groundwork for the next edition. It has been a pleasure working with the whole team and we look forward to continued engagement.

We (Dieter and Ranu) are not only sincerely thankful to all for their confidence in us, but also for affording us the opportunity to develop a stronger friendship as we have communicated and discussed the birth and growth of the encyclopedia over the 3 years. We look forward to the dynamic growth of the project and a second edition to follow.

Miami, Florida and Atlanta, Georgia
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