BP 3: Neuronal Systems

Time: Monday 14:00–17:15 Location: C 243

Invited Talk BP 3.1 Mon 14:00 C 243

How to Take a Quick Look—Rapid Neural Coding of Visual Information in the Retina — •Tim Gollisch — Max Planck Institute of Neurobiology, München-Martinsried

The neural processing and computation that underlies our visual perception begins in the retina, a neural network at the back of the eyeball. Here, all visual information available to the central brain is encoded into patterns of electrical pulses ("spikes"). Elucidating the nature of this neural code forms a central goal in visual neuroscience. A particular challenge for natural visual processing arises from frequent eye movements ("saccades"), which bring a new image onto the retina and initiate a short episode of visual processing. In this talk, I will discuss recent findings that specific retinal neurons encode the structure of a suddenly appearing image in the relative timing of their spikes. The characteristics of this neural code and its underlying circuitry are studied with a combination of experimental recordings of retinal spikes under visual stimulation and mathematical modeling. These retinal signals may serve as a channel for rapid and robust information transmission from the eye to the brain.

BP 3.2 Mon 14:30 C 243

Reorganization of neural circuitry during growth of cat visual cortex — •Wolfgang Keil[1,2,3], Fred Wolf[2,3], Siegrid Löwel[4], and Matthias Kaschube[1] — [1]Princeton University, Princeton, NJ USA — [2]MPIDS, Göttingen, Germany — [3]BCCN, Göttingen, Germany — [4]Friedrich-Schiller-University, Jena, Germany

In cat visual cortex, the period of postnatal cortical growth largely overlaps with the period of enhanced plasticity, but little is known about the interrelation between these two phenomena. We analyzed the two-dimensional spatial organization of ocular dominance (OD) columns during postnatal cortical growth. Despite a size increase of 50% of area 17 between postnatal week 3 and 10, the mean spacing between adjacent OD columns increased only slightly. Consequently, the number of hypercolumns increased considerably during this expansion period. Furthermore, this process was paralleled by a strong tendency of columns to change appearance from stripe-like to disordered patterns. Theoretically, this process resembles a behavior known as the zigzag instability in dynamical systems. This is a generic behavior in expanding self-organizing systems dominated by Mexican-hat like interactions and is therefore predicted by a large class of models for activity dependent visual cortical development. We analyzed the effect of cortical expansion on columnar layouts in an Elastic Net model and compared it to the degree of reorganization observed experimentally. We find that the observed reorganization indeed exhibits signatures of this type of instability. Thus, these models indicate that the observed mode of columnar reorganization results from cortical expansion.

BP 3.3 Mon 14:45 C 243

Fasciculation dynamics of sensory neurons — •Debasish Chaudhuri[1], Peter Borowski[2], Pradeep K. Mohanty[3], and Martin Zapotocky[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany — [2]University of British Colombia, Vancouver, BC, Canada — [3]Saha Institute of Nuclear Physics, Kolkata - 700064, India

Sensory neurons are typically spread out in the periphery, but their axons connect to precisely determined locations in the brain. In addition to graded guidance cues, axon-axon interactions can strongly influence this connectivity. To understand these effects in the intrinsically dynamic neural connectivity of, e.g., the mammalian olfactory system, we model the axons as a set of interacting directed random walkers with turnover. The growing axons form fascicles. In the steady state we obtain scaling, and the exact functional form of the fascicle size distribution. The auto-correlation time of the number of axons in a fascicle shows a crossover from a short time-scale which is the inverse of axonal death rates to a long time scale as the fascicle size grows. A set of effective rate equations in terms of dynamical variables characterizing fascicles (rather than individual axons) explains the time-scales qualitatively.

15 min. break

BP 3.4 Mon 15:15 C 243

Broadband coding with dynamic synapses — •Benjamin Lindner[1], John Lewis[2], and Andre Longtin[3] — [1]Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany — [2]Department of Biology, University of Ottawa, Ottawa, Canada — [3]Department of Physics, University of Ottawa, Ottawa, Canada

Short-term synaptic plasticity (STP) is commonly thought to provide a basis for low-pass or high-pass filtering of information transmission across the synapse depending on whether depression or facilitation, respectively, is dominant. To evaluate this assumption, we consider a general case of information transmission from a population of independent synaptic inputs to a model neuron. We show using standard information theoretic approaches that the changes in synaptic response amplitude produced by STP interact with associated membrane fluctuations, such that information transmission is frequency-independent (no high-pass or low-pass filtering), regardless of whether synaptic depression or facilitation dominates. Interestingly, the baseline firing rate of the post-synaptic neuron is a critical factor in determining whether or not this frequency-independence is reflected in the output spike train: high-firing rates maintain broadband transmission, whereas low-firing rates recover the expected filtering. This suggests that neurons in a rate-coding regime will not be influenced by STP.

BP 3.5 Mon 15:30 C 243

Gating charge effects as an intrinsic mechanism for channel noise reduction — Gerhard Schmid, Igor Goychuk, and •Peter Hänggi — Institut für Physik, Universität Augsburg, D-86135 Augsburg

Within generalizations of the archetypical Hodgkin-Huxley modelling we investigate the influence of intrinsic properties of ion channel gating on the spiking activity of neuronal membrane patches. Channel noise which stems from the randomness of ion channel gating causes spontaneous spiking and synchronization effects as Stochastic Resonance or Coherence Resonance. The random switching of voltage-gated ion channels between open and closed configurational channel states is connected with gating charge movement within the cell membrane. The latter results in a drastically reduced spontaneous spiking activity [1]. Consequently, this demonstrates a prominent intrinsic mechanism for channel noise reduction. Within the effect of Stochastic Resonance the effective reduction of intrinsic noise level manifests itself.

[1] G. Schmid, I. Goychuk, P. Hänggi, Phys. Biol. **3** (2006) 248

BP 3.6 Mon 15:45 C 243

Neuronal Avalanches in Networks with Short-Term Synaptic Plasticity — •Anna Levina[1,2,3], J. Michael Herrmann[1,4], and Theo Geisel[1,3,4] — [1]BCCN Göttingen — [2]GK "Identification in Mathematical Models" — [3]MPI for Dynamics and Self-Organization — [4]Göttingen University, Dept. of Physics, Bunsenstr. 10, Göttingen

Critical avalanches of neural activity have been identified analytically in globally coupled networks of spiking neurons and were observed subsequently in neurophysiological recordings in cortical slices. While in previous models a fine-tuning of the connectivity parameters was required, we recently showed that the biologically well-established activity-dependent dynamics of the synaptic efficacies provides a possible mechanism for the self-organized criticalization of the neuronal dynamics.

The present work is based on a realistic model of short-term plasticity that includes both facilitation and depression of the synaptic efficacies. In a simplified model that uses depression only, the critical regime is reached by a second-order phase transition, where the critical phase is characterized by a stable balance of neural activity and synaptic depression. We show here that the incorporation of synaptic facilitation entails a first-order transition from the sub-critical regime into the extended critical parameter range. The results are obtained by a stochastic mean-field analysis and are related to numerical experiments by finite-size scaling of the critical distribution. Furthermore, we discuss effects of non-trivial connectivity structure, and neural properties such as leakage and long-term potentiation of the synaptic strengths.

BP 3.7 Mon 16:00 C 243

Exact mean, variance, and autocorrelation function of neural subthreshold voltage — •Lars Wolff and Benjamin Lindner — Max-Planck-Institut für Physik komplexer Systeme

Neurons are subject to a vast number of synaptic inputs from many other cells. These inputs consist of spikes changing the conductivity of the target cell, i.e. they enter the neural dynamics as multiplicative shot noise. Up to now, only for simplified models like current-based (additive-noise) point neurons or models with Gaussian white noise input, exact solutions are available. We will present a method to calculate the exact time-dependent moments and the autocorrelation function for the voltage of a point neuron with conductance-based Poissonian shot noise and a passive membrane. The exact solutions show novel features (for instance, maxima of the moments vs time) and are in excellent agreement with numerical simulations. The theoretical analysis of subthreshold membrane fluctuations may contribute to a better comprehension of neural noise in general. It may also help devising schemes for the extraction of synaptic parameters or network parameters from voltage recordings.

BP 3.8 Mon 16:15 C 243

Chaotic dynamics in the balanced state — •Michael Kreissl[1], Siegrid Löwel[2], and Fred Wolf[1] — [1]Max Planck Institute for Dynamics and Self-Organization, BCCN in Göttingen, Germany, — [2]Friedrich Schiller University in Jena, Germany

We study the dynamics of sparse, neural networks in the balanced state. In our networks N Theta-neurons (phase representation of the Quadratic Integrate&Fire model) [Gutkin1998] are pulse-coupled to other neurons with the probability K/N. Using closed expressions for the time evolution of the individual neurons, we perform numerically exact, event based simulations of the network dynamics. Furthermore, we derive the Jacobian of the mapping between spikes analytically, which is used to calculate the long term Lyapunov spectrum through the evolution of a tangential orthonormal system.

Our simulations show that the Lyapunov spectrum in general contains a considerable fraction of positive Lyapunov exponents, indicating chaotic behavior of the network dynamics. The dimension of the attractor is in general large (approx. N/3). The mean Lyapunov exponent is found to be negative, expressing the networks dynamics to be dissipative. In a random matrix approximation, we find an analytic expression of the mean Lyapunov exponent, which is verified by the numerical simulations. We conclude that the balanced state in networks of neurons with active spike generation exhibits conventional and most-probably extensive chaos. This distinguishes such models from binary networks, exhibiting hyperchaos [Vreeswijk1996], and Leaky Integrate&Fire networks, exhibiting stable chaos [Zillmer2006, Jahnke2007].

BP 3.9 Mon 16:30 C 243

Statistical framework incorporating temporal and mutual correlations in a neural network ensemble. — •Tatjana Tchumatchenko[1,2], Theo Geisel[1,2], Stefan Treue[3], and Fred Wolf[1,2] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen — [2]Bernstein Center for Computational Neuroscience (BCCN), Göttingen — [3]Kognitive Neurowissenschaften, Deutsches Primaten Zentrum, Göttingen

We present a new class of parametric models for multiple impulse sequences correlated in time and between channels, which we call Gaussian Pseudo Potential Models (GPPMs). In our approach, correlated impulse sequences are defined by threshold crossings of temporally continuous random functions, called the Pseudo Potentials (PPs). Assuming Gaussian statistics of PPs, a correlated spike train ensemble is uniquely specified by the Matrix of cross- and auto-covariance functions of the PPs. Many spike train statistics, as e.g. firing rates, auto and cross conditional firing rates, can then be expressed in closed form [1]. In an ensemble of spike trains from a pair of neurons, we analyse the mapping between PP correlations and spike correlations. We show, that that for weak coupling strength the cross conditional rate is connected to the PP cross correlation function by a linear differential equation. The applicability of these differential equations is numerically confirmed for a simple set of model PP correlation functions. These and other exact results suggest that GPPMs provide a analytically very tractable parametric model of multiple correlated neuronal impulse sequences. [1] B. Naundorf et al. Nature, 440:1060–1063, 2006

BP 3.10 Mon 16:45 C 243

Optimal active network topologies for information transmission — •murilo da silva baptista — Max-Planck-Institut fuer Physik Komplexer Systeme, Noethnitzerstr. 38, D-01187 Dresden

The relation between neural circuits and behavior is a fundamental matter in neuroscience. In this talk, I will present a theoretical approach that has the potential to unravel such a relationship in terms of network topology, information, and synchronization, in active networks, networks formed by elements that are dynamical systems (such as neurons, chaotic or periodic oscillators). As a direct application of the proposed approaches, I will show how one can construct optimal neural networks that not only transmit large amounts of information from one element to another in the network, but also are robust under alterations in the coupling configuration.

This theoretical approach is general and do not depend on the particular dynamic of the elements forming the network, since the network topology can be determined by finding a Laplacian matrix (the matrix that describes the connections and the coupling strengths among the elements) whose eigenvalues satisfy some special conditions.

Since information might not always be easy to be measured or quantified in experiments, I will also better clarify the non-trivial relation between information and synchronization, a phenomenom which is often not only possible to observe but also relatively easy to characterize.

I will illustrate the theoretical approaches mainly using neural networks of electrically connected chaotic Hindmarsh-Rose neurons.

BP 3.11 Mon 17:00 C 243

Mechanical properties of coupled hair bundles — •Kai Dierkes, Frank Jülicher, and Benjamin Lindner — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

In all vertebrates the hair bundle is the mechano-electrical transducer in both the auditory and the vestibular system. In contrast to being purely passive resonators hair bundles from the sacculus of the bullfrog have been shown to possess the ability to amplify weak periodic stimuli by means of an active process. Spontaneous and evoked oscillations of single hair bundles in lower vertebrates have been studied in order to probe the underlying mechanism. Recently Nadrowski at al. (PNAS 2004) have proposed a model for active hair bundle motility that very well captures the experimental findings. In vivo hair bundles in the sacculus of the bullfrog are attached to an overlying structure that effectively mediates a coupling between them: the otolithic membrane. The same holds true for the hair bundles of outer hair cells in the mammalian cochlea whose tips are connected to the overlying tectorial membrane. We report on results that suggest that collective effects in arrays of coupled hair bundles could indeed play a significant role for signal detection in inner ear organs.