BP 14: Neuronal and Sensory Systems

Time: Wednesday 14:00–17:15 Location: HÜL 186

Invited Talk BP 14.1 Wed 14:00 HÜL 186

Nerve signals as density pulses, conduction events, and the role of anesthetics — •Thomas Heimburg — Niels Bohr Institute, University of Copenhagen, Denmark

It has long been known that nerve pulses are accompanied by a reversible heat exchange. After a first phase of heat release the heat is practically completely reabsorbed into the nerve membrane. This indicates that the fundamental physical processes underlying nerve action are predominantly of reversible nature. The famous Hodgkin-Huxley model, however, relies on dissipative processes, i.e., on electrical ion currents flowing through resistors (ion channel proteins). Here we show that under physiological conditions there is the possibility of electromechanical soliton generation. This notion is supported by the fact that during nerve pulses various mechanical changes are experimentally observed. The necessary requirement for solitons is a melting transition in the biomenbranes slightly below physiological temperature leading to a nonlinear compressibility. This transition is in fact present in biomembranes. Interestingly, exactly in these transitions one finds quantized ion currents through membranes that are indistinguishable from those reported for ion channel proteins. Anesthetics influence these processes because the induce melting point depression. Thus, they render the pulse excitation more difficult. Again, this is in agreement with data on real nerves. Further, anesthetics are able to "block" the conduction events through membranes.

BP 14.2 Wed 14:30 HÜL 186

Living optical elements in the vertebrate retina — Moritz Kreysing[1], Kristian Franze[1], Boris Joffe[2], Thomas Cremer[2], Leo Peichl[3], Andreas Reichenbach[4], and •Jochen Guck[1] — [1]Cavendish Laboratory, University of Cambridge, GB — [2]Institute of Human Genetics, LMU Munich, Germany — [3]MPI for Brain Research, Frankfurt, Germany — [4]Institute for Brain Research, University of Leipzig, Germany

While cells are mostly transparent they are phase objects that differ in shape and refractive index. Any image that is projected through layers of cells will normally be distorted. Strangely, the retina of the vertebrate eye is inverted and light must pass through several tissue layers before reaching the light-sensitive photoreceptor cells (PRC). Here we report how nature has optimized this apparently unfavourable situation. We investigated the optical properties of retinal tissue, individual Müller glial cells and PRC nuclei. We found that Müller cells act as optical fibers and guide light, which would otherwise be scattered, from the retinal surface to the PRCs. Their parallel arrangement in the retina is reminiscent of fiber-optic plates used for low-distortion image transfer. There is also a specific adaptation of the rod PRC nuclei for improved light transmission through the outer nuclear layer (ONL) of nocturnal animals. These nuclei have an inverted chromatin structure that turns them into micro-lenses channeling the light through the ONL. These findings ascribe a new function to glial cells, demonstrate the first nuclear adaptation for an optical function, and shed new light on the inverted retina as an optical system.

BP 14.3 Wed 14:45 HÜL 186

Eye dominance induces pinwheel crystallization in models of visual cortical development — •Lars Reichl[1], Siegrid Loewel[2], and Fred Wolf[1] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Goettingen — [2]Institute of General Zoology and Animal Physiology, University Jena

The formation of orientation preference maps during the development of the visual cortex is sensitive to visual experience and impulse activity. In models for the activity dependent development of these maps orientation pinwheels initially form in large numbers but subsequently decay during continued refinement of the spatial pattern of cortical selectivities. One attractive hypothesis for the developmental stabilization of orientation pinwheels states that the geometric relationships between different maps, such as the tendency of iso-orientation domains to intersect ocular dominance borders at right angles can prevent extensive orientation map rearrangement and pinwheel decay. We present a analytically tractable model for the coupled development of orientation and ocular dominance maps in the visual cortex. Stationary solutions of this model and their dynamical stability are examined by weakly nonlinear analysis. We find three different basic solutions, pinwheel free orientation stripes, and rhombic and hexagonal pinwheel crystals locked to a hexagonal pattern of ipsilateral eye domains. Using amplitude equations for these patterns, we calculate the complete stability diagram of the model. In addition, we study the kinetics of pinwheel annihilation or preservation using direct numerical simulations of the model.

BP 14.4 Wed 15:00 HÜL 186

Comparison of stochastic integrate-and-fire models — •Benjamin Lindner and Rafael D. Vilela — Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany

We study three different integrate-and-fire (IF) models, the perfect, leaky, and quadratic IF model driven by white Gaussian noise and present a systematic comparison of their spontaneous and driven firing statistics in terms of power spectra, susceptibilities, and coherence functions. We also look at the correlations induced in the spike trains of two neurons by a common stimulus. Our comparison is based on parameter choices for the different models that make their firing rate and the CV of their interspike intervals equal — a choice that is unique for the three models under investigation as we have recently demonstrated[1]. We find that power spectra are rather similar for all three models while the input-output and the correlation statistics depend on the specific voltage dependence of the model and on the firing regime (combination of rate and CV) considered. Refs: [1] R. D. Vilela and B. Lindner J. Theor. Biol. (in press, 2008).

BP 14.5 Wed 15:15 HÜL 186

From Integrator to Resonator: The effect of dendrites on neuronal excitability — •Christoph Kirst[1], Andreas Herz[2], and Martin Stemmler[2] — [1]Network Dynamics Group, MPI for Dynamics and Self-Organization and BCCN Göttingen, Germany — [2]LMU and BCCN München

Neurons fall into two excitability classes: Type I integrates over synaptic inputs, while type II exhibits a resonance to a particular synaptic frequency [1]. Neuronal excitability is a function not only of the underlying ion-channel kinetics but also of the neuron's spatial structure. For example, the addition of a dendritic tree can change a neuron from a resonator into an integrator [2]. Here we show that the opposite transition can also occur: the presence of dendrites changes a saddle node on limit cycle bifurcation into a Hopf bifurcation, leading to a resonance where there was none before.

In a Morris-Lecar neuron model we show how an increase in the dendritic leak – e.g. by increasing the dendritic membrane surface – induces a change from type I to type II excitability. We analyze the underlying bifurcation structure to reveal the mechanism and the universality of such a transition. Consequences for the dynamics of networks of such neurons are discussed.

[1] G. B. Ermentrout, Neural Comput. 8, 979 (1996); Izhikevich E.M.Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting. MIT Press (2007).

[2] J. A. Goldberg, C. A. Deister and C. J. Wilson, J. Neurophysiol. 97, 208 (2007).

BP 14.6 Wed 15:30 HÜL 186

Extensive Chaotic Dynamics of Spiking Neuron Networks in the Balanced State — Michael Kreissl[1], •Siegrid Löwel[2], and Fred Wolf[1] — [1]Max Planck Institute for Dynamics and Self-Organization and BCCN in Göttingen, Germany — [2]Friedrich Schiller University and BGCN in Jena, Germany

Based on the calculation of the spectrum of Lyapunov exponents we reveal extensive, spatiotemporal chaos in deterministic neural networks of canonical type I neurons in the balanced state. In the balanced state of cortical networks, neurons are driven by strongly fluctuating inputs that result from balanced recurrent inhibition and excitation. It is the prevailing explanation of asynchronous, irregular firing patterns often observed in vivo. While its robust emergence from the collective dynamics of spiking neuron networks has been shown in several theoretical studies, the precise nature of the network dynamics remains controversial. It depends strongly on the single neuron dynamics. Initially, using binary neurons, Vreeswijk and Sompolinsky found that nearby trajectories diverge faster than exponential. Contrary, using leaky integrate and fire neurons, Zillmer et. al and Jahnke et. al recently showed that nearby trajectories converge. In our study of sparse networks of theta neurons we find conventional chaos with a fat attractor and high entropy production. Because theta neurons exhibit the same type of bifurcation from resting to spiking as real cortical neurons, we expect that this extensive chaotic dynamics is characteristic of the balanced state in biophysically realistic network models.

15 min. break

BP 14.7 Wed 16:00 HÜL 186

First order phase transition to criticality by adaptive interactions — •Anna Levina[1,2], J. Michael Herrmann[1,2,3], and Theo Geisel[1,2] — [1]BCCN-Göttingen, Bunsenstr. 10, 37073 Göttingen — [2]MPI DS, Bunsenstr. 10, 37073 Göttingen — [3]University of Edinburgh, 10 Crichton Street, Edinburgh EH8 9AB, U.K.

The concept of self-organized criticality (SOC) describes a variety of phenomena ranging from plate tectonics, the dynamics of granular media to neural avalanches. In all these cases the dynamics is marginally stable and event sizes obey a characteristic power-law distribution. It was previously shown that an extended critical interval can be obtained in a neural network by incorporation of depressive synapses. In the present study we scrutinize a more realistic dynamics for the synaptic interactions that can be considered as the state-of-the-art in computational modeling of synaptic interaction. Interestingly, the more complex model does not exclude an analytical treatment and it shows a type of stationary state consisting of critical and a subcritical phases. The phases are connected by first- or second-order phase transitions in a cusp bifurcation which is implied by the dynamical equations of the underlying biological model. We present exact analytical results supported by extensive numerical simulations. Although presented in the specific context of a neural model, the dynamical structure of our model is of more general interest. It is the first observation of a system that combines a complex classical bifurcation scenario with a robust critical phase. The system may account not only for SOC behavior, but also for various switching effects observed in the brain.

BP 14.8 Wed 16:15 HÜL 186

Self-organized criticality in a neural network — •Christian Meisel and Thilo Gross — Max-Planck Institut für Physik komplexer Systeme

We evolve a network of excitatory and inhibitory neurons according to two topology-changing rules of synaptic plasticity: spike-time dependent plasticity (STDP) and homeostatic synaptic plasticity (HSP). Both local rules lead to convergence to an average number of synapses per neuron at which the network is at a phase transition. At the evolved connectivity, avalanche sizes for the HSP rule and amplitudes of neuronal activity for the STDP rule are power law distributed. Critical exponents are comparable to those observed in real cortical networks for both power laws. When extrapolated for realistic synaptic strengths, for the STDP rule the evolved average number of synapses per neuron is in the order of the one found in the brain.

BP 14.9 Wed 16:30 HÜL 186

Magnetoreception mechanisms in birds - towards the discovery of the sixth sense — •Ilia Solov'yov and Walter Greiner — Frankfurt Institute for Advanced Studies, Goethe University, Frankfurt am Main, Germany

Many birds are able to orient themselves accurately when the sky is not visible (e.g. covered with clouds). This requires non-visual sources of information. Many studies have established that birds are sensitive to the Earth's magnetic field. European robins, pigeons and other bird species use the geomagnetic field as a compass, and are also sensitive to slight temporal and spatial variation in the magnetic field that is potentially useful for determining location.

We study a putative avian magnetoreception mechanism, which is based on the interaction of two iron minerals (magnetite and maghemite) experimentally observed in subcellular compartments within sensory dendrites of the upper beak of several bird species. The iron minerals in the beak form platelets of crystalline maghemite and clusters of magnetite nanoparticles. We develop a theoretical model [1] to quantitatively describe the interaction between the iron-mineral containing particles, and demonstrate that depending on the external magnetic field the external pull or push to the magnetite clusters may reach a value of 0.4 pN. This might be principally sufficient to excite specific mechanoreceptive membrane channels leading to different nerve signals and causing a certain orientational behavior of the bird.

[1] I. Solov'yov and W. Greiner, Biophys. J. 93, 1493 (2007)

BP 14.10 Wed 16:45 HÜL 186

Enhancement of signal detection by coupling of active hair bundles — •Kai Dierkes, Benjamin Lindner, and Frank Jülicher — 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. 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. *In vivo* hair bundles in the sacculus of the bullfrog are attached to an overlying structure that 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. Using a stochastic description of hair bundle dynamics we have studied the effect of an elastic coupling of hair bundles. We report that collective effects in systems of coupled hair bundles can e.g. enhance the amplification gain and the sharpness of frequency tuning as compared to the performance of a single hair bundle. Our results thus suggest that coupling of hair bundles could indeed play a significant role for signal detection in inner ear organs.

Reference: Dierkes et al., 2008, *PNAS* 105(48),18669-18674

BP 14.11 Wed 17:00 HÜL 186

Information Filtering by Synaptic Short-Term Plasticity — •Matthias Merkel and Benjamin Lindner — Max-Planck-Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany

Short-term plasticity (STP) changes the transmission properties of synapses on the scale of 100ms. It is commonly thought to act as a filter for information passing through the synapse. There are two competing effects: synaptic facilitation and depression. They either increase or decrease the postsynaptic amplitude of a presynaptic spike depending on the spike history. We study this filtering process for rate-modulated Poissonian input spike trains and a population of independent synapses. We derive expressions for information-theoretical measures like the spectral coherence in the limit case of pure facilitation and discuss by means of our analytical results conditions for a broadband transmission of information (frequency-independence of the coherence function) which previously has been found numerically [1].

[1] B. Lindner, D. Gangloff, A. Longtin, and J. E. Lewis "Broadband coding with dynamic synapses", (submitted, 2008)