BP 21: Neurobiophysics and Sensory Transduction

Time: Wednesday 14:00–17:00 Location: H43

Invited Talk BP 21.1 Wed 14:00 H43

Deconstructing hearing: mechanisms and molecules — Björn Nadrowski, Thomas Effertz, and •Martin Göpfert — Abt. Zelluläre Neurobiologie, Universität Göttingen, MPI Experimentelle Medizin, Hermann-Rein-Str. 3, 37075 Göttingen

Our ability to hear relies on dedicated mechano-electrical transduction (MET) channels in our inner ear that convert stimulus forces into electrical signals. Molecularly, these channels have not been identified yet. Work on vertebrate hair cells has provided insights into the physical workings of these channels, including their permeation characteristics and their direct gating by stimulus force. Work on Drosophila, in turn, has put forward channel proteins that are required for hearing, yet whether and, if so, how these channels contribute to the MET channel function remains unclear. Recent studies have shown that the gating of MET channels modulates the macroscopic performance of the fly*s auditory system, setting the stage for a combined physical and genetic dissection of MET channel function in the Drosophila ear. This ongoing dissection will be the topic of this presentation: Firstly, physical models will be presented that allow to quantitatively characterize MET channel function; these models suggest that at least two types of MET channels coexist in the Drosophila ear. And secondly, mutant analyses will be presented that identify genes that are needed for MET channel function. Some of these genes seem required for the proper MET channel localization or may form MET channels themselves.

BP 21.2 Wed 14:30 H43

Coupling a sensory hair-cell bundle to cyber clones enhances nonlinear amplification — •Kai Dierkes[1], Jérémie Barral[2], Benjamin Lindner[1], Frank Jülicher[1], and Pascal Martin[2] — [1]MPIPKS, Dresden, Germany — [2]Institut Curie, Paris, France

The mammalian cochlea's performance is marked by its exquisite sensitivity to weak amplitude stimuli, its sharp frequency selectivity and its wide dynamic range. It owes these abilities to a nonlinear process that actively boosts vibrations of the basilar membrane. Active hair bundle motility has been suggested to contribute to this cochlear amplifier. Indeed, hair bundles can actively oscillate and act as tuned nonlinear amplifiers. Their responsiveness, however, is limited by intrinsic fluctuations. Hair bundles typically are elastically coupled by overlying gelatinous membranes. In a recent theoretical work we have shown that elastic coupling of small groups of hair bundles could greatly enhance hair-bundle mediated amplification by means of a noise reduction effect (Dierkes et al., PNAS, 2008). Here we report on an experimental study for which we have interfaced dynamic force clamp performed on a hair bundle from the bullfrog's sacculus with real time stochastic simulations of a biophysical description of stochastic hair bundle dynamics. By means of this setup we could couple a hair bundle to two virtual neighbours, called cyber clones. We show that elastic coupling leads to synchronization and an increased coherence of spontaneous oscillations. Also, the sensitivity to weak driving is enhanced. Our results thus demonstrate the hair bundle's ability to team-up with other hair bundles to overcome the limitations of intrinsic noise.

BP 21.3 Wed 14:45 H43

Independent components of neural activity in the auditory midbrain — •Dominika Lyzwa[1], Dmitri Bibitchkov[2], Hubert H. Lim[3], and J. Michael Herrmann[1,4] — [1]Dept. Nonlinear Dynamics, MPI for Dynamics and Self-Organization, 37073 Göttingen, Germany — [2]Dept. Membrane Biophysics, MPI for Biophysical Chemistry, 37077 Göttingen — [3]Dept. Otolaryngology, Medical University, 30625 Hannover, Germany — [4]IPAB, School of Informatics, University of Edinburgh, Edinburgh EH8 9AB, U. K.

We study mechanisms of sound encoding in the inferior colliculus (IC) which recently has become a new target for auditory implants. The analysis is based on neural recordings where double-tetrodes were used in the IC in cats for acoustic stimulation at various frequencies and volumes. The multi-dimensional data is projected to independent components that are obtained by Independent Component Analysis (ICA) using the Molgedey-Schuster algorithm (MS), FastICA and JADE. The single-trial components are then classified with respect to the stimulus properties. The classification proves best for low frequencies and volumes (1-2 kHz, 10-20 dB) and depends on the localisation in the inferior colliculus, where the stimulus is applied. The results of the data analysis are used to justify a numerical model of the encoding mechanism.

BP 21.4 Wed 15:00 H43

Local exponents of nonlinear compression in periodically driven noisy oscillators — •Benjamin Lindner, Kai Dierkes, and Frank Jülicher — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

Nonlinear compression of periodic signals is a key feature of the active amplifier in inner ear organs of all vertebrates. Different exponents $\alpha_0 \in [-0.88, -0.5]$ of the sensitivity vs forcing amplitude $|\chi| \sim f^{\alpha_0}$ have been observed. Here we calculate analytically the local exponent for a generic oscillator, the normal form of a Hopf bifurcation driven by noise and a periodic signal. For weak noise and sufficient distance from the bifurcation on the unstable side, the exponent may be close to -1 for moderate forcing amplitudes beyond linear response. Such strong compression is also found in a model of hair bundle motility. Ref.: Lindner, Dierkes, Jülicher Phys. Rev. Lett. (in print, 2010)

BP 21.5 Wed 15:15 H43

When less is more: Spike Sequence Processing in Neurons with Adaptive Synapses — •Hinrich Kielblock[1] and Marc Timme[1,2] — [1]Network Dynamics Group, Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Bernstein Center for Computational Neuroscience Göttingen, Germany

The input-output relation of a neuron centrally underlies the computational capabilities of neural circuits. The response of a neuron to incoming spike signals strongly depends on the relative timing of the presynaptic spikes. For example, if the input's timing is highly regular, an increase in excitatory input can lead to a decrease of the neurons firing rate. This counterintuitive phenomenon occurs in various neural systems but its underlying mechanism is still unclear.

Here we investigate single neuron systems where a neuron receives precisely timed spiking input via one depressive synapse. Our analysis reveals that and how non-monotonic input-output relations are created by a spike timing-dependent transmission efficiency.

15 min. break

BP 21.6 Wed 15:45 H43

Effect of noisy adaptation on the interspike interval statistics of neurons — •Tilo Schwalger[1], Karin Fisch[2], Jan Benda[2], and Benjamin Lindner[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]Biozentrum der LMU, Department Biologie II, Planegg-Martinsried

Adaptation and noise are key features of almost any neuron and have a profound impact on signal processing by neurons. This neural processing depends on the specific biophysical implementation of spike generation and spiking variability. In particular, different noise sources might result in markedly different statistics of neural spike trains. However, for many neurons, especially for sensory neurons, the major source of noise is hard to identify. Here, we study analytically a perfect integrate-and-fire neuron with adaptation and either white noise driving or noise resulting from fluctuations in the slow adaptation mechanism. The latter "adaptation noise" could, for instance, arise from channel noise associated to the slow adaption current. Surprisingly, we find a large difference in the statistics of interspike intervals (ISI): A stochastic adaptation current can be mapped to an effective colored noise driving giving rise to long-range positive ISI correlations and a pronounced peak of the ISI density. In contrast, when variability stems from white noise one observes anticorrelations and a less pronounced peak. These results suggest that insight into the major source of noise in certain neurons might be gained from the ISI statistics.

BP 21.7 Wed 16:00 H43

Controlling effective connectivity between cortical areas via collective dynamics transitions — •Demian Battaglia[1,3], Annette Witt[1,2,3], Theo Geisel[1,3], and Fred Wolf[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen — [2]German Primate Center, Göttingen — [3]Bernstein Center for Computational Neuroscience, Göttingen

Anatomic connections between cortical areas constrain the spatio-temporal complexity of brain rhythmic activity. However, structural connectivity does not coincide with effective connectivity, related to the more elusive question: Which areas cause the activity of which others? Effective connectivity is directed and task-dependent. Its fast changes are incompatible with the slow variation of anatomical connections in a mature brain.

We propose here a theory of controllable rewiring of effective connectivity based on dynamical transitions in the collective organization of neural activity. We consider small network motifs of interacting cortical areas, modeled first as mean-field rate units and then as large populations of spiking neurons. Even when the underlying structural networks are fully symmetric, we obtain chaotic dynamical configurations which spontaneously break the permutation symmetry between areas. Different dynamical configurations are shown to correspond to different causality flows when probed by tools like Granger Causality, Mutual Information or the better performing Transfer Entropy. Fully symmetric structural networks can thus give rise to multiple selectable effective connectivities with reduced symmetry.

BP 21.8 Wed 16:15 H43

Soft Brains, Signal Amplification through Noise, and Taking the Brain by its Horns — Allen Ehrlicher, Timo Betz, Daniel Koch, Thomas Fuhs, Melanie Knorr, Kristian Franze, Steve Pawlizak, and •Josef A. Käs — Division of Soft Matter Physics, Institute of Experimental Physics I, University of Leipzig

For the brain's viscoelastic properties single cell measurements reveal the softness of neurons and Glial cells, which consequentially rules out the notion of Glial cells as structural support. In contrary the mechanosensitive neurons follow in their growth and development the even softer Glial cells by inverse durotaxis. The motion of growth cones, the leading motile structures of growing neurons, results from a competition of stochastic processes responsible for forward and backward movement. Noise tuning of the growth cone's stochastic fluctuations increases neuronal sensitivity to chemotaxis. The forces underlying the spatial interplay of random actin polymerization driving the forward motion and molecular motor-based retrograde flow responsible for stochastic retraction are measured either by applying conservation laws (continuity equation and force balance) to the cytoskeletal dynamics of GFP-actin transfected growth cones or by directly detecting these forces with AFM. By a simple mechanical lever arm effect weak optical gradient forces acting on the spike-like filopodia, the exploring "horns" of growth cones, are sufficient to control the direction of growth cones' stochastic forward motion.

BP 21.9 Wed 16:30 H43

Chromatin rearrangements transform mammalian photoreceptor nuclei into micro-lenses — •Moritz Kreysing[1], Lars Boyde[1], Kevin Chalut[1], Irina Solovei[2], Boris Joffe[2], Leo Peichel[3], Thomas Cremer[2], and Jochen Guck[1] — [1]Cavendish Laboratory, University of Cambridge, UK — [2]Institute for Human Genetics, LMU Munich, Germany — [3]MPI for Brain Research, Frankfurt, Germany

The vertebrate retina is inverted with respect to its optical function. This means light needs to propagate through hundreds of microns of living neuronal tissue before it can be detected by the photoreceptor cells.

In this work we focus on the optical properties of the photoreceptor nuclei that are stored in multiple layers directly before the light sensitive segments. Based on micro-interferometry we show that a unique inversion of their spatial chromatin distribution in mammals with a nocturnal lifestyle transforms these nuclei into micro-lenses. Analytical models and finite difference time domain simulations suggest that the arrangement of these nuclei in columns greatly improves transmission characteristics by a reduction of scattering and an effective channeling of light through the outer nuclear layer.

These results change our understanding of the mammalian retina as an optical system. Furthermore, our findings indicate that the standard model of a nucleus with the heterochromatin located near the nuclear envelope is not the only solution to gene expression and regulation.

BP 21.10 Wed 16:45 H43

Analytical multi-particle scattering model for the simulation of light propagation through biological tissue — •Lars Boyde — Biological and Soft Systems, University of Cambridge, UK

The scattering of light from an assembly of arbitrarily arranged, dielectric particles has a multitude of applications in the fields of physics, biology, and medicine. Specific examples include aerosol scattering, remote sensing, radiative transfer, and the propagation of light through biological tissue, such as the retina of the eye.

The author developed and implemented an analytical model that can be used to compute the electromagnetic near- and far-field intensities for the incidence of a plane wave or Gaussian laser beam on an ensemble of dielectrically coated particles. The underlying theoretical basis of the model is the solution of Maxwell's equations using Mie theory and the so-called vector translation theorems which facilitate the transformation of the fields between the coordinate systems of the individual particles.

The model has been applied to simulate the propagation of light through the outer nuclear layer of the retina in the mammalian eye – one of the crucial stages of light transmission in the process of vision. Using the established properties of the photoreceptor cell (PRC) nuclei embedded in this layer, the simulations conclusively show that the PRC nuclei of *nocturnal* animals act as strongly focusing micro-lenses. Unlike their *diurnal* counterparts, the chromatin-inverted, nocturnal PRC nuclei effectively channel light onto the light-sensitive outer segments of the rods and cones, leading to enhanced night vision.