# BP 20: Neurobiophysics

Time: Wednesday 10:15–13:00 Location: ZEU 250

**Invited Talk** BP 20.1 Wed 10:15 ZEU 250

**Quantitative universality and non-local interactions in neural pattern formation** — •Matthias Kaschube — Lewis-Sigler Institute for Integrative Genomics and Physics Department, Princeton University, Princeton NJ, USA

The occurrence of universal quantitative laws in a strongly interacting multi-component system indicates that its behavior can be elucidated through the identification of general mathematical principles rather than by the detailed characterization of its individual components. In this talk I show that universal quantitative laws govern the spatial layout of orientation selective neurons in the visual cortex in three mammalian species separated in evolution by more than 65 million years. Most suggestive of a mathematical structure underlying this universality, the average number of pinwheel centers per orientation hyper-column in all three species is statistically indistinguishable from the constant $\pi$. Mathematical models of neural pattern formation can reproduce all observed laws if non-local interactions are dominant, indicating that non-local interactions are constitutive in visual cortical development. The spatial layout adheres to these laws even if visual cortical organization exhibits marked overall inhomogeneities and when neuronal response properties are experimentally altered. These results demonstrate that mathematical principles can shape the organization of the brain as powerfully as an organism's genetic make-up.

BP 20.2 Wed 10:45 ZEU 250

**Optically Clamping Neurons in vitro** — •Kai Bröking[1,3,5], Ahmed ElHady[1,2,4,5], Ragnar Fleischmann[1], Theo Geisel[1,3,4,5], Walter Stühmer[2,4,5], and Fred Wolf[1,3,4,5] — [1]Max-Planck-Inst. für Dynamik und Selbstorganisation, Göttingen, Germany — [2]Max-Planck-Inst. für experimentelle Medizin, Göttingen — [3]Fakultät für Physik, Georg-August-Universität Göttingen — [4]Bernstein Center for Computational Neuroscience, Göttingen — [5]Bernstein Focus for Neurotechnology, Göttingen

Transfecting neurons to express the light-gated ion channel Channelrhodopsin2 (ChR2) makes it possible to influence their activity non-invasively, by means of photostimulation [1]. We have implemented a feedback control system using optical stimulation at $\lambda \approx 480$ nm which can be used to regulate the firing rate of neural networks cultured on multielectrode arrays. Our system allows closed loop feedback on timescales comparable to those of synaptic response ($1-5$ ms). We present an experimental setup for adjusting the average firing rate of neurons by means of feedback controlled photostimulation, thus devising a way of optically clamping an ensemble of cells. [1] Boyden, E., et al., Nat Neurosci **8**, 1263-1268, doi:10.1038/nn1525

BP 20.3 Wed 11:00 ZEU 250

**A nonlinear oscillator underlies flight control in flies** — •Jan Bartussek[1], Kadir Mutlu[1], Martin Zapotocky[2], and Steven N. Fry[3] — [1]Institut für Neuroinformatik, Uni/ETH Zürich, Schweiz — [2]Akademie der Wissenschaften der Tschechischen Republik, Prag, Tschechien — [3]FB Bionik, Hochschule Rhein-Waal, Deutschland

Flies serve as model organisms for research on neuromotor control since decades. Despite huge efforts, it is still unclear how such complex and robust behavior emerges from a relatively small number of motorneurons. Especially, theoretical control principles that relate to the known neuromotor feedback circuits remain largely elusive. In our approach we consider the stretch activated thorax-power muscle system as a nonlinear oscillator (NLO) and the steering muscles as an external forcing, whose magnitude depends on the perceived mechanosensory feedback. We developed an experimental setup, in which a piezoelectric actuator oscillated a tethered fly's body to stimulate its mechanoreceptors. A laser Doppler vibrometer was used to measure the stimulation amplitude and phase relative to the wingbeat, while simultaneously recording the induced response of the fly. We determined regions of synchronization within the amplitude-frequency parameter space, the so-called Arnold tongues. As expected for NLOs, synchronization occurred at various ratios n/m of wingbeat frequency n and stimulation frequency m. Moreover, we show that flies display adaptive entrainment consisting of phase and frequency locking. The results emphasize the importance of the inherent nonlinearity of the musculoskeletal dynamics for understanding flight control in flies.

BP 20.4 Wed 11:15 ZEU 250

**Spatio-temporal encoding of sound in the inferior colliculus** — •Dominika Lyzwa[1], Hubert H. Lim[2], and J. Michael Herrmann[3] — [1]Dept. Nonlinear Dynamics, MPI for Dynamics and Self-Organization, Göttingen, Germany — [2]Dept. Otolaryngology, Hanover Medical University, Germany — [3]IPAB, School of Informatics, University of Edinburgh, U.K.

The inferior colliculus (IC) is an important stage in the auditory pathway. We study the spatio-temporal encoding taking place in the laminated central inferior colliculus. We analyze multi-unit activity (MUA) recorded from the IC in cats during acoustic stimulation with pure tones and in guinea pigs during stimulation with vocalizations of these animals as an example of natural stimulation.

Using linear discriminant analysis we obtain that for pure tone stimuli the classification into different stimulus categories is best for time intervals of the recording that contain the onset activity. The latency of the classification is found to be 5-10 ms, increasing from low to high stimulus tones. The information about the stimulus frequency is mostly contained in the first principal component of the response and at early latencies. In the recordings from the vocalization stimulation the dynamic correlations of the response properties from neuron populations along the tonotopic axis and in particular within an isofrequency lamina are investigated. The results from pure tone and natural stimulation are combined to give a phenomenological model of spatio-temporal encoding in the ICC.

**15 min. break**

BP 20.5 Wed 11:45 ZEU 250

**Up-Down state stimulation of a cortical model for slow waves in sleep** — Arne Weigenand, Thomas Martinetz, and •Jens Christian Claussen — Neuro- und Bioinformatik, Univ. zu Lübeck

Neural systems exhibit complex dynamics on several time scales that can be significantly longer that that of single neuron spikes. The cortical slow oscillation is such an example where awake-like bursts (Up-states) are interrupted by Down states: low activity and absence of bursts. Up-Down state transitions are the dominant dynamical phenomenon manifesting mammalian slow wave sleep, and occur as macroscopic oscillations over the whole cortex. To model their minimal constituting dynamical mechanism still remains a challenge. An important means of model testing is to investigate perturbations of the model which correspond to an electrical stimulation in the experiment. A paradigmatic recent experiment [1] investigated the on- and off switching of bursting activity in ferret brain slices. We use a conductance-based model [2] following the approach of [3] to reproduce the spike-burst dynamics and the triggering of up states as observed in [1]. We also investigate the phase diagram of the qualitatively different network states depending on the coupling strength and network noise intensity [4]. While designed for the cortical up- down switching, it could be seen as a generic model of a driven fast-slow dynamical system.

[1] Y. Shu, A. Hasenstaub, and D. A. McCormick, Nature 423, 288 (2003). [2] A. Weigenand et al, Proc. Biosignal 2010 [3] A. Compte, M.V. Sanchez-Vives, D.A. McCormick, and X. Wang, J. Neurophysiol. 89, 2707 (2003). [4] A. Weigenand et al., in preparation

BP 20.6 Wed 12:00 ZEU 250

**How stochastic adaptation currents shape interspike interval statistics - theory vs experiment** — •Tilo Schwalger[1], Karin Fisch[2], Jan Benda[2], and Benjamin Lindner[1] — [1]MPI Physik komplexer Systeme, Dresden, Germany — [2]Biozentrum der LMU, Department Biologie II, Planegg-Martinsried, Germany

Trial-to-trial variability and irregular spiking is an ubiquitous phenomenon throughout the nervous system. In many cases, the origin of this neural noise is not known and difficult to access experimentally. Here, we explore the possibility to distinguish between two kinds of intrinsic noise solely from the interspike interval (ISI) statistics of a neuron. To this end, we consider an integrate-and-fire model with spike-frequency adaptation in which fluctuations (channel noise) are either associated with fast ionic currents or with slow adaptation currents. We show by means of analytical techniques that the shape of the ISI histograms and the ISI correlations are markedly different in both cases: for a deterministic adaptation current, ISIs are distributed according to an inverse Gaussian density and the ISI correlations are negative. In contrast, for stochastic adaptation currents, the ISI density is more peaked than an inverse Gaussian density and the serial correlations are positive. We applied these measures to intracellular recordings of locust auditory receptor cells in vivo. By varying the stimulus intensity, we observed intriguingly similar statistics corresponding to both cases of the model. The results suggest that stochasticity of slow adaptation currents may contribute to neural variability in sensory neurons. Ref.: Schwalger T, Fisch K, Benda J, Lindner B, PLoS Comp Biol 2010

BP 20.7 Wed 12:15 ZEU 250

**Interspike Interval Statistics of Neurons Driven by Stochastic Oscillations: Theory vs. Experiment** — •Christoph Bauermeister[1], Tilo Schwalger[1], Alexander Neiman[2], and Benjamin Lindner[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA

Stochastic oscillations are a ubiquitous phenomenon in neural systems. We study the role of these oscillations in an analytically tractable model, the stochastic perfect integrate-and-fire neuron with narrow-band (harmonic) noise. The latter represents stochastic oscillations. We obtain approximations for the firing statistics including interspike interval density, serial correlations and power spectrum of the spike train. We apply our formulas to experimental data of electro-sensory receptors in the paddlefish and show how to infer intrinsic parameters of this system from its firing statistics.

BP 20.8 Wed 12:30 ZEU 250

**Sensitive dependence on single spike perturbations in the dynamics of cortical circuits** — Michael Monteforte[1,2,3] and •Fred Wolf[1,2,3] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Bernstein Center for Computational Neuroscience, Göttingen, Germany — [3]Georg-August-University, Göttingen, Germany

London et al. [1] recently showed that triggering a single additional spike in a cerebral cortical neuron can cause an exponentially growing cascade of extra spikes in the network that largely decorrelate the network's microstate. The network mechanism involved in this extreme sensitivity of cortical networks is currently not well understood. Here, we show in a minimal model of cortical circuit dynamics that exponential state separation after single spike and even single synapse perturbations can occur although the dynamics is stable to infinitesimal perturbations and rate responses are extremely weak. We present a conciliatory picture of exponentially separating flux-tubes around unique stable trajectories constituting the networks' state spaces. [1] M. London, A. Roth, L. Beeren, M. Häusser and P. E. Latham, Nature 466, 123 (2010);

BP 20.9 Wed 12:45 ZEU 250

**Plasticity in a Spiking Neural Network Model** — •Cornelia Petrovic and Rudolf Friedrich — Westfälische Wilhelms-Universität Münster, Institut für Theoretische Physik

We study the influence of spike-timing-dependent plasticity (STDP) in a spiking neuronal network which consists of pulse-coupled phase oscillators introduced by Haken as the lighthouse model [1]. It is a single neuron model that falls between spiking neuron models and firing rate descriptions and thus combines "best of both worlds". In the limit of slow synaptic interactions it can be reduced to the classic Wilson-Cowan and Amari type firing rate models [2,3,4]. For fast synaptic dynamics, it shows some of the complex properties of spiking neural networks.

[1] H. Haken, Brain Dynamics, Springer-Verlag, New York, Berlin, 2002.
[2] H.R. Wilson and J.D. Cowan, Biophys. J., 12 (1972), pp. 1-24.
[3] S. Amari, IEEE Trans. Systems Man Cybernet., 2 (1972), pp. 643-657.
[4] C.C. Chow and S. Coombes, SIAM J.Appl. Dyn. Syst., 5 (4) (2006), pp. 552-574.