SYNP 1: Symposium Neurophysics (SYNP): Physical Approaches to Deciphering Neuronal Information Processing

Time: Tuesday 9:30–12:15 Location: H 0105

Invited Talk SYNP 1.1 Tue 9:30 H 0105

Connectomics: The dense reconstruction of neuronal circuits — •Moritz Helmstädter — Department of Connectomics, Max Planck Institute for Brain Research, Max-von-Laue-Str. 4, 60438 Frankfurt am Main, Germany

The mapping of neuronal connectivity is one of the main challenges in neuroscience. Only with the knowledge of wiring diagrams is it possible to understand the computational capacities of neuronal networks, both in the sensory periphery, and especially in the mammalian cerebral cortex. Our methods for dense circuit mapping are based on 3-dimensional electron microscopy (EM) imaging of brain tissue, which allows imaging at nanometer-scale resolution across substantial volumes (typically hundreds of micrometers per spatial dimension) using Serial Block-Face Scanning Electron Microscopy (SBEM). The most time-consuming aspect of circuit mapping, however, is image analysis; analysis time far exceeds the time needed to acquire the data. Therefore, we developed methods to make circuit reconstruction feasible by increasing analysis speed and accuracy, using a combination of crowd sourcing and machine learning. We have applied these methods to circuits in the mouse retina, mapping the complete connectivity graph between almost a thousand neurons, and we are currently improving these methods for the application to much larger neuronal circuits in the cerebral cortex. Using these methods, we want to measure the similarity between neuronal networks in the cortex of different individuals and different species in search for the algorithms of sensory perception, search for engrams of sensory experience in the cerebral cortex, and ultimately understand the alterations in neuronal network structure in psychiatric disease.

References: Helmstaedter M, Briggman KL, Turaga S, Jain V, Seung HS, Denk W (2013) Connectomic reconstruction of the inner plexiform layer in the mouse retina. Nature 500:168-174. Helmstaedter M (2013) Cellular-resolution connectomics: challenges of dense neural circuit reconstruction. Nat Methods 10:501-7. Denk W, Briggman KL, Helmstaedter M (2012) Structural Neurobiology: Missing link to a mechanistic understanding of neural computation. Nat. Rev. Neuroscience 13:351-358. Briggman KL, Helmstaedter M, Denk W (2011) Wiring specificity in the direction-selectivity circuit of the retina. Nature 471:183-188. Helmstaedter M, Briggman KL, Denk W (2011) High-accuracy neurite reconstruction for high-throughput neuroanatomy. Nat Neurosci 14:1081-1088.

Invited Talk SYNP 1.2 Tue 10:00 H 0105

Whole-brain imaging and analysis of network activity in behaving zebrafish — •Misha Ahrens — Janelia Research Campus, Howard Hughes Medical Institute, USA

The nervous system endows animals the ability to generate complex behavior. A central challenge in neuroscience is to understand how large recurrent networks of neurons, spanning from the sensory to the motor periphery, implement computations required for driving behavior in response to environmental cues. We developed techniques for measuring neural activity at the cellular level in almost the entire brain of a small vertebrate, the larval zebrafish, as it behaves in virtual reality. Three-dimensional light-sheet imaging paired with large-scale analyses can generate whole-brain maps of neuronal populations involved in sensory processing and the generation of motor output, and allow for analyses of the temporal interactions between members of these populations. We used these techniques to gain insight into the generation of spontaneous behavior as well as learned adaptation in sensory to motor pathways. In many cases, the analyses identified small neural populations restricted to known or unknown nuclei. These nuclei often consisted of only a few hundred cells out of a total of 100,000 brain cells, generating hope that such techniques can be used to eventually dissect whole-brain function into understandable subunits.

Invited Talk SYNP 1.3 Tue 10:30 H 0105

Circuit neurophysics: Theory and biophysics of information-flow through large-scale neuronal systems — •Fred Wolf — Theoretical Neurophysics, Max Planck Institute for Dynamics and Self-Organization — Bernstein Center for Computational Neuroscience, Am Fassberg 17, 37077 Goettingen, Germany.

Understanding information flow and processing in the brain requires quantitative concepts and theoretical approaches tailored to the complex dynamics of biological neuronal systems. In the cerebral cortex, information is represented and processed by the activity of large populations of nerve cells operating in densely connected neuronal circuits. Nerve cells encode changes in their continuously varying input in discrete action potentials. The dynamical mechanism of action potential generation thus represents a fundamental bottleneck for the flow of information through neuronal populations and circuits. We have developed concepts and approaches for dissecting the dynamics of neuronal circuit information flow based on stochastic dynamics, statistical physics and ergodic theory. Recent findings by us and others indicate (1) that the bandwidth of information encoding by neuronal populations in the cerebral cortex is much higher than previously assumed and (2) that the subcellular biophysics of action potential generation is optimized to achieve a high bandwidth of information flow through large scale circuits. After a review of concepts and findings, I will discuss open theoretical and experimental problems in the nano-physiology of action potential generation.

15 min break

Invited Talk SYNP 1.4 Tue 11:15 H 0105

Cognitive devices based on ion currents in oxide thin films — •Stuart Parkin — Max Planck Institute for Microstructure Physics, Halle (Saale), Germany

Conventional silicon based electronic computing devices use about one million times more energy to carry out a computing operation than does a mammalian brain. The devices, interconnections, and information processing paradigms in the latter are profoundly different from those used in today*s computers. Approaches to the development of extremely energy efficient computing will likely rely on devices that operate on entirely different principles, that are mutable, and which likely possess innately three dimensional structures and architectures. We discuss one possible approach that relies on the control of the conductivity of oxide thin films via tiny but reversible ionic currents of oxygen ions that are induced by very large electric fields at the interface with ionic liquids [1]. Removal of sub atomic percent concentrations of oxygen from structures that have open channels for the ready migration of oxygen gives rise to giant structural distortions and metallization of what were initially insulating layers. This may allow a path to innately mutable, cognitive switches. [1] Jeong, J. et al. Suppression of Metal-Insulator Transition in VO2 by Electric Field-Induced Oxygen Vacancy Formation. Science 339, 1402-1405, (2013).

Invited Talk SYNP 1.5 Tue 11:45 H 0105

Distributed neuro-physical interfaces: technology and "exciting" biophysics — •Shy Shoham — Dept. Biomedical Eng., Technion - I.I.T., Haifa, Israel

In addition to the widely-used ability to selectively target specific cell types, Optogenetics and other emerging strategies for remote stimulation also offer a path towards spatio-temporally-controlled targeting. For example, projected patterns of light can be used to selectively and flexibly control and image activity patterns distributed across entire populations of neurons.

The talk will present an overview of our recent work on distributed neuronal interfacing with large populations of neurons using optical and acoustic wavefront shaping approaches. Our results demonstrate that patterned computer-generated holographic stimulation can achieve millisecond temporal precision and cellular resolution in two-dimensions (retinas) and three dimensions (bioengineered brain-like "optonets") and are shown as a promising path towards simultaneously controlling populations of retinal ganglion cells in a next generation retinal prosthesis. I will conclude by discussing the emerging model-based Neural Intramembrane Cavitation Excitation (NICE) framework for elucidating the physical basis of neuro-acoustic excitation and some "exciting" insights it provides into this emerging technology for noninvasive neuromodulation.