6th Bernstein Sparks Workshop: Multi-modal closed-loop stimulation and virtual realities

Tutzing 2015

Introduction

During recent years, virtual reality (VR) techniques have become well established in neuroscience. Greatly extending its strong focus on human psychophysics, VR has been successfully applied by various labs to a wide range of animal models, including insects, rodents and non-human primates. However, VRs in use typically provide only visual stimulation. Only few labs have embarked to design VRs that provide stimuli adequate for audition, olfaction or the somato-sensory system. Attempts to combine VR techniques across sensory modalities are extremely rare.

The stimulus repertoire of VRs is thus highly reduced compared to “real” reality. This is a particularly severe constraint as many neurophysiological and neuroanatomical studies have demonstrated a strong interaction and interconnectedness of different sensory modalities. There is evidence for mutual influences among our senses during sensory processing in the mammalian neocortex and even in pre-cortical brain areas. These findings highlight the need to extend VR techniques to multi-modality and to provide more realistic experimental setups for probing sensory processing, including the perceptually correct synchronization and weighting of the modalities. The workshop will bring together internationally renowned labs that use state-of-the-art VR systems and will concentrate their expertise towards the development of perceptually plausible, multi-modal VRs optimized for key model organisms in neuroscience. The workshop includes invited talks as well as informal discussions to elucidate the strengths and open challenges of the different approaches.

Abstracts

Aslı Ayaz – A virtual tactile environment to study somatosensory processing in mouse cortex during exploratory locomotion

Recent studies have shown that navigationally relevant signals (e.g. locomotion and expectation) modulate responses of neurons in the primary visual cortex (Saleem et al., Keller et. al.). In their natural habitat, rodents navigate their environment utilizing their whisker system extensively. To investigate somatosensory processing during navigation we developed a naturalistic setting by creating a virtual tactile environment, in which mice can run in the dark along a "wall", on which varying textures are presented. Mice are head restrained on a linear treadmill and textures are presented on rotating cylinders in reach of the whiskers. This experimental setting allows us to manipulate the speed of the texture independent from the speed of the animal on the treadmill, permitting closed loop (animal and texture speed are coupled) as well as open loop (decoupled) conditions. While mice are running and whisking along the "wall" we perform 2-photon calcium imaging of large population of neurons, expressing the genetically encoded calcium indicator (Yellow Cameleon-Nano140, or RCamp1.07) across lamina in primary somatosensory cortex (S1). We compare responses under various conditions arising from a free walk along this virtual wall, in the dark.

Stephan Ewert, Giso Grimm, Torben Wendt, Steven van de Par, and Volker Hohmann – Virtual acoustic environments for psychophysics and audiology

Humans deal with complex acoustic scenes including reverberation and multiple (moving) sound sources in everyday life. Particularly with increasing age and/or hearing loss, auditory perception including communication and localization can be affected in such complex scenarios. One possibility to assess the effect of the spatial sound field on perception in a controlled and systematic way is the use of virtual acoustic environments. Application in the field on psychophysics and audiology pose perceptual as well as physical constraints on the sound reproduction based on the perception by the listener and, e.g., the use of multi-microphone arrays in hearing aids. Here the toolbox for acoustic scene creation and rendering (TASCAR) is presented offering real-time generation of dynamic content which can be interactively controlled. The underlying time-domain simulation method utilizes a hybrid approach with direct rendering of early reflections (image sources) combined with simulated or recorded late reverb offering excellent real-time capabilities. For the simulated late reverb, a fast and perceptually plausible method is presented which can be used in headphone and speaker array reproduction. The acoustics requirements from a psychophysical and audiological perspective as well as the limitations of the applied rendering methods are discussed.

James G Heys – Using Virtual Reality to Enable Cellular Resolution 2-Photon [Ca^{2+}] Imaging of Medial Entorhinal Cortex Grid Cells

The goal of understanding brain function at the cellular and systems level has been limited by our ability to observe the behaviorally correlated activity of many neurons and selectively manipulate these neurons to test how they might be functionally connected in the brain. However, recently developed methods using optical imaging in neurons in awake-behaving animals provides promise towards this goal. The medial entorhinal cortex, which is important for spatial memory, contains a functional class of neurons, termed grid cells, which fire selectivity when the animal visits a triangular array of regularly spaced locations. Using a novel optical approach combined with navigation using virtual reality, we show that grid cells are functionally micro-organized in medial entorhinal cortex. I will discuss how we have used virtual reality to enable the study of grid cells using linear tracks and how these methods can be further developed to study grid cells in richer virtual environments.

Patrick Kaifosh, Nathan B Danielson, Jeffrey D Zaremba, John C Bowler, Matthew Lovett-Barron, and Attila Losonczy – Imaging hippocampal activity during virtual context-based behaviors

By combining of stimuli spanning multiple sensory modalities, we create virtual contexts for head-restrained mice. Consisting of tactile cues along a one-dimensional treadmill-track, as well as olfactory, auditory, and visual stimuli, these virtual contexts allow us to apply in vivo 2-photon imaging in the hippocampus of head-restrained mice to study the neural circuitry involved in contextual behaviors. The presentation will consist of an overview of our methods and the reporting of results from our most recent studies, in which we examine representation of location and context in the hippocampus and dentate gyrus.

Steven M LaValle – What Can VR Applied to Various Organisms Teach Us About Engineering?

I am not a neuroscientist and do not know the answer to this question; however, I will share my experiences while developing the Oculus Rift from 2012-2014. I developed perceptually tuned head tracking methods based on IMUs and computer vision. I also led a team of perceptual psychologists to provide principled approaches to VR system calibration and the design of comfortable user experiences. The current generation of VR technology is much higher quality and fidelity than were possible before. Questions about comfort, presence, health, safety, and simulator sickness are becoming increasingly important as VR is poised for widespread, mass consumer use. I will highlight many of the challenges we encountered, while hoping that workshop participants have insightful perspective based on the neuroscience behind VR and how this knowledge could help us to engineer better VR systems for humans.

Tobias Meilinger and Stephan de la Rosa – Human navigation in virtual large scale spaces
The Social and Spatial Cognition group at the Max Planck Institute for Biological Cybernetics employs interactive virtual environments to examine cognitive processes underlying navigation and social interaction. Our research on navigation showed that humans physically walking through complex multi-corridor/-street spaces memorize these spaces within multiple, local reference frames. In case humans also had access to maps as, for example, in their city of residency, they rely on a map-based reference frames for survey estimates, but on local reference frames for route planning. By having participants learn the same layout by manipulating the learning conditions we showed that separation into multiple reference frames is not driven by active walking or successive visibility of the elements, for example, when walking down multiple streets, but rather by having no common visible reference present during learning. We conclude that humans compartmentalize their surrounding within memory and visual access seems to be the crucial factor of separation.

Ville Pulkki – Acoustic VR: Methods and evaluation of synthesised or reproduced spatial sound
In amplitude panning methods a virtual source is created to desired direction by using a set of real loudspeakers (or HRTFs in headphone reproduction), and by applying the sound with different gain factors to a subset of them. The panning techniques and evaluation methods are reviewed in the talk. A more complex problem is how to record and reproduce a complete 3D sound field. While linear methods with arrays of microphones can not overcome constraints posed by vast range of the wavelenghts of sound, non-linear time-frequency-domain techniques provide better authenticity as they take the advantage of relatively low spatial accuracy of human hearing system. The techniques are overviewed, and the methods to evaluate the systems are discussed.

Inês MA Ribeiro, Michael Drews, Armin Bahl, Alexander Borst, and Barry Dickson – How *Drosophila* males track females during courtship
In *Drosophila* visual behavior, an important yet unresolved question is how fly-sized visual objects are processed by the optic lobe and central brain. During courtship, males rely on visual cues to track the female, making courtship an ideal behavior to search for visual projection neurons (VPN) relaying fly-specific visual cues. We blocked neurotransmitter release in several VPNs and tested males in single male-female pair courtship assays. We found that *fru*-LC10 neurons are required for female tracking during courtship, independently of courtship arousal. There are about 100 *fru* neurons with arborisations in the lobula neuropile in the fly optic lobe. To understand what visual information *fru*-LC10 might convey, tethered males walking on a treadmill ball were placed in a virtual reality environment of purely visual stimuli. Males with *fru*-LC10-silenced neurons displayed a normal optomotor response and fixated a long bar in closed loop comparably to controls, but failed to track fly-size visual objects. To characterize tuning properties of *fru*-LC10 neurons, we presented the same visual stimuli while recording intracellular calcium and found calcium responses specific to fly-sized visual objects. Our results suggest that the *fru*-LC10 visual projection neurons extract and relay fly-specific visual features to the central brain.

Christoph Schmidt-Hieber and Michael Häusser – Probing neuronal activity in the mouse hippocampus during virtual navigation

Recording and manipulating neuronal activity at cellular and subcellular resolution *in vivo* is a fundamental goal in systems neuroscience. In particular, understanding neural computations at this scale in behaving animals is technically challenging due to accessibility and stability issues. The use of virtual-reality (VR) systems with head-fixed rodents represents an attractive solution to these problems, as they enable the use of state-of-the-art optical and electrophysiological techniques in behaving animals with high mechanical stability in the micrometre range. Moreover, VR offers the unique opportunity to introduce precise and reproducible manipulations of the sensory environment. We have developed a virtual-reality system to perform combined optical and electrophysiological recordings from mouse hippocampal neurons. Head-restrained mice navigate on an air-supported spherical treadmill (Hölscher et al., J Exp Biol, 2005). A quarter-sphere mirror placed underneath the animal reflects the projected warped image onto a spherical dome screen. Importantly, the screen covers nearly the entire unobstructed vertical and horizontal field of view of the mouse, and conveniently allows ready access for the electrophysiological and optical recording assembly. We have used this approach to identify synaptic mechanisms of spatial firing in medial entorhinal cortex (Schmidt-Hieber & Häusser, Nat Neurosci, 2013), and are currently performing patch-clamp recordings and 2-photon imaging from hippocampal neurons to probe the cellular and circuit mechanisms of pattern separation and completion.

Michael Vorländer – Virtual Acoustic Environments for normal and hearing-impaired listeners

Auralization techniques are used in engineering, architecture, sound design, and similar applications. The components of this technique are acoustic simulation and signal processing tools and the data interfaces in between, which are all well established. Nevertheless, characterization of sound sources and interfaces to spatial audio technology are still subject to research. Whether the virtual environment is considered sufficiently accurate or not, depends on many perceptual factors, and on the pre-conditioning and the required degree of immersion of the user in the virtual environment. In this presentation the processing steps for creation of Virtual Acoustic Environments are briefly presented and the achievable degree of realism discussed in examples. Approaches to utilize auralization techniques and virtual auditory displays specifically for psychoacoustic tests are discussed considering normal hearing and listeners with hearing aids and CI.

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