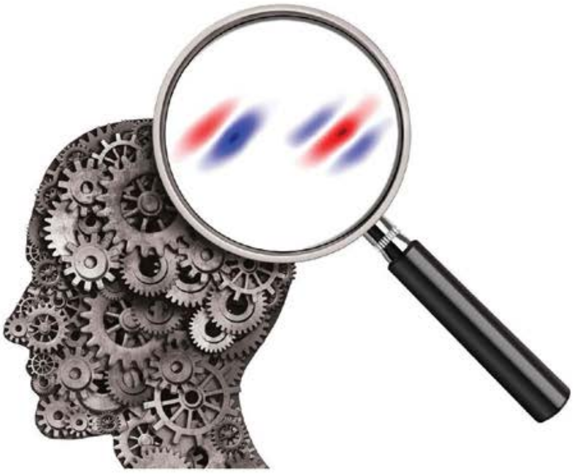

ARC Centre of Excellence for Integrative Brain Function

FENS Federation of European Neurosciences Societies

RECEPTIVE FIELDS: ANALYSIS, MODELS AND APPLICATIONS

FENS Brain Function CoE 2018 Satellite Meeting

Friday, 6 July 2018

The Australian Research Council Centre of Excellence for Integrative Brain Function is hosting a satellite meeting as part of the 11th FENS Forum on Neuroscience in Berlin, Germany.

Eight world-leading researchers, from Australia, France, Germany, United Kingdom and USA, will discuss modern perspectives about formation and analysis of visual receptive fields, bringing together insights and discoveries from around the globe.

The venue is in a prime location on the world famous Friedrichstrasse, close to Berlin's most famous sights including the Brandenburg Gate, Reichstag and Friedrichstagt Palace. The hotel is conveniently located with direct access to the S-Bahn Friedrichstrasse, which also directly provides access to the 'City Cube Berlin' where the FENS forum will commence the following day.

Schedule	
9:00	Welcome
9:15	Speaker
10:00	Speaker
10:45	MORNING TEA
11:00	Speaker
11:45	Speaker
12:30	LUNCH
13:30	Speaker
14:15	Speaker
15:00	AFTERNOON TEA
15:15	Speaker
16:00	Speaker
16:45	Closing remarks
17:00	FINISH

Venue: NH Collection Berlin Mitte Friedrichstrasse
Friedrichstrasse 96
10117 Berlin
(+49) 30 206 2660

Contact: Tenille Ryan
tryan@aco.org.au

Summary

The receptive field is a fundamental concept in our understanding of how visual stimuli are processed in the brain. For example, in visual cortex it describes the region of visual space to which a neuron responds, but also, through the RF structure, the selectivity for certain visual features. Modern analysis techniques have allowed us to reduce the reliance on human intuition about which stimulus features are relevant to activate given RFs, thus allowing objective assessment of RF characteristics. These techniques have had a particularly significant impact on understanding nonlinear processing in the cortex. Aligned with these advances, we have seen major progress in understanding the neural circuits involved in creating the observed RF characteristics. Experimental approaches have been greatly supported by the development of computational frameworks based on the idea that the visual system is predictive, efficient and adaptive.

This satellite meeting will highlight recent advances in several linked fields, including new computational approaches to capture the non-linear feature selectivity of neurons in higher centres of the visual hierarchy, analysis of the actual neural pathways in the brain that lead to observed RFs and the relationship of RF structure to theories of efficient and predictive coding.

Hosted by Professor's Michael Ibbotson and Ulf Eysel.

An initiative of the Australian Research Council Centre of Excellence for Integrative Brain Function.

Supported by the National Vision Research Institute of Australia and the SFB874 (www.rub.de/sfb874) of the German Research Foundation.

Speaker and Institution	Title of presentation
Tatyana Sharpee The Salk Institute of Biological Sciences, USA	Cortical computations in the secondary visual area V2
Michael Ibbotson National Vision Research Institute (NVRI), Australia	Non-linear receptive fields in visual cortex: structure and adaptive characteristics
Yves Frégnac Centre National de la Recherche Scientific (CNRS), France	Horizontal connectivity in V1: Prediction of coherence in contour and motion integration
Jose-Manuel Alonso State University of New York (SUNY), USA	The neural circuits underlying cortical receptive fields
TR Vidyasagar University of Melbourne, Australia	Influence of subcortical processing on receptive fields and architecture of primary visual cortex
Dirk Jancke Ruhr University, Germany	Past, presence, future: All-in V1
Elizabeth Zavitz Monash University, Australia	Naturalistic stimulus structure reveals nonlinear spatial integration in primate V1 and V2
Simon R Schultz Imperial College, UK	Place cells, receptive field estimation, and readout of memory

Abstracts

Cortical computations in the secondary visual area V2

Tatyana Sharpee
The Salk Institute for Biological Studies, USA

In this talk I will describe our recent findings of several organizing principles of feature selectivity of neurons in secondary visual area V2. This area have long been enigmatic in terms of how this area represents visual stimuli. We developed a new statistical method to characterize responses of V2 neurons in terms of inputs it receives from V1, the primary visual cortical area. Responses of individual V1 neurons can be largely described by specifying the position, orientation, and size of an optimal edge or a bar for that neuron. Analyzing responses of individual V2 neurons, we described their responses using sets of excitatory and suppressive edges that caused increases or decreases in the response rate, respectively. We found that both excitatory and suppressive edges occurred in pairs at slightly displaced positions, and that excitatory/suppressive pairs were locally orthogonal. This orthogonality increased the selectivity of V2 responses to natural stimuli. The resultant four-feature motif was assembled in various way depending on V2 neuron to give rise to the relevant multi-edge pattern for that neuron. However, responses of V2 neurons could be simplified further by noting the final pattern of relevant edge combinations was repeated across space in approximately uniform manner or biphasic manner. Such pooling of response characteristics across could explain the selectivity of V2 neurons to texture patches or edges defined by changes in texture. These principles of V2 feature selectivity echo our findings in area V4 (where V2 neurons project) concerning the presence of local and global position invariance.

Non-linear receptive fields in visual cortex: structure and adaptive characteristics

Michael R Ibbotson
National Research Vision Research Institute, Australia

The receptive fields (RFs) of visual neurons characterize their selectivity for image features. In primary visual cortex, we have a good understanding of the response characteristics of cells with linear summation properties (simple cells) but we have only taken the first steps in understanding the full repertoire of the response characteristics and feature selectivity of cells with nonlinear RFs (complex cells). To date, studies have used natural scenes or binary white noise to characterize complex cell RFs. I will describe experiments we have developed that use white Gaussian noise stimuli to provide an unbiased stimulus with which to assess RF structures in cat primary visual cortex. We compare the RFs using two analysis techniques: non-parametric spike triggered analysis and the parametric generalized quadratic model. In doing so, we uncover a rich variety of RF properties. Many complex cells are best described by the combination of linear and quadratic terms. In some cells, the RFs are composed of independent linear and quadratic filters. In other cells the linear terms result from a deviation of the feature contrast nonlinearity away from an even-symmetric quadratic function. Both variations from the classical complex cell RF result in violations of the polarity invariance normally associated with complex cells. The results show that phase sensitivity is inherently coded within many complex cell RFs, perhaps offering advantages for high level image processing through nonlinear mechanisms.

Horizontal connectivity in V1: Prediction of coherence in contour and motion integration

Yves Frégnac
CNRS-UNIC - Unit de Neuroscience, Information et Complexité, Gif-sur- Yvette, France

Contextual long-range interactions in visual processing are thought to depend on cortico-cortical feedback and attentional processes. In contrast, the contribution of mechanisms intrinsic to V1, such as recurrent amplification and lateral propagation, remains largely unknown.

I will review evidence demonstrating that spatio-temporal inferences and predictive “filling-in” responses are detectable in the primary visual cortex (V1) of higher mammals, even in the anesthetized state. Intracellular and VSD studies show that the read-out of synaptic activity evoked by apparent motion sequences of oriented elements originating from the “silent” surround of cortical receptive fields (RF) reveals a built-in bias in V1 structuro-functional organization.

Two distinct neural diffusion mechanisms may operate along orthogonal dimensions of V1 receptive fields: facilitation and prediction propagating along the orientation preference RF axis; anticipation along the RF width axis. The speed tuning of collinear-biased iso-orientation integration (100-250°/sec in cat) fits the spatial anisotropy and propagation speed of long distance horizontal connectivity (0.1-0.3 m/s), supporting the concept of a "dynamic perceptual association field”. The second effect operates at lower speed (10-30°/sec (cat and monkey)) and the build-up of anticipatory activity facilitates directional integration of a moving object along predictable trajectories. It most likely implies a cascade of shorter-range horizontal interactions and intra-V1 reverberation.
At a more conceptual level, these data suggest that horizontal connectivity participates to the propagation of a self-generated collective belief, resulting in the multiplexing of "dynamic prediction" (filling-in) or "anticipatory" processes travelling at various speeds through the V1 network.

The neural circuits underlying cortical receptive fields

Jose-Manuel Alonso
SUNY Optometry, USA

Visual processing in the brain is mediated by two major thalamocortical pathways that signal local light increments (ON) and decrements (OFF) in the visual scene. In carnivores and primates, ON and OFF channels segregate in the retina and thalamus but combine in visual cortex. Our work demonstrates that this ON-OFF cortical mixing is not complete; it is partial and unbalanced. OFF thalamic afferents make stronger connections and occupy more territory in primary visual cortex than ON afferents, OFF-dominated cortical receptive-fields largely outnumber ON-dominated cortical receptive-fields, and cortical responses to dark stimuli are stronger, faster, more linearly related to luminance contrast and have better spatial and temporal resolution than responses to light stimuli, making the cortex OFF-dominated. In addition, our work demonstrates that ON and OFF afferents segregate in primary visual cortex, forming ON and OFF cortical domains that run orthogonal to ocular dominance columns and making the visual cortical maps OFF-centric. In these OFF-centric cortical maps, ON retinotopy frequently rotates around OFF retinotopy causing a rotation in the cortical representation of orientation preference. We propose that this surprising OFF-dominated/OFF-centric organization of visual cortical topography is a consequence of a size distortion for lights that originates already at the photoreceptor and that has important implications in the construction of cortical receptive fields, cortical maps, visual function and visual disease.

Influence of subcortical processing on receptive fields and architecture of primary visual cortex

TR Vidyasagar
Department of Optometry & Vision Sciences, University of Melbourne, Australia

It is now widely recognized that orientation selectivity is not a prerogative of cortical areas, but it is also observed in retinal or thalamic neurons of a number of mammalian species, including cats, monkeys, ferrets, tree shrews and mice. Though usually much broader than the selectivity seen in the cortex, such broad tuning encountered subcortically is in fact a necessary condition if a feature is already coded peripherally, as in the classical case of trichromatic vision. To retain spatial resolution, the feature can be coded only in a limited number of broadly tuned channels. Orientation biases seen in the responses of retinal and lateral geniculate (LGN) neurons also exhibit only a few preferred orientations, the most common being the radial orientation. Elaboration of a range of preferred orientations in the primary visual cortex (V1) from these limited number of co-ordinates can also create the gradual change of preferred orientations as seen in the pattern of orientation domains. Such a process is probably common to other features represented in V1, such as hue preferences, binocular interactions and ON/OFF dominances. Consistent with this framework, our recent experiments show (1) thalamic signals in the input layers of the macaque V1 are dominated by preference for the radial orientation, (2) there is a significant correlation between the preferred orientation of thalamic afferents and the postsynaptic V1 cells in orientation columns of the cat and (3) computational modeling of V1 selectivity, applying both values of spatial convergence along the long axis of the V1 RF from recent published data and known orientation bias values, shows that subcortical biases may be more determinative of V1 orientation selectivity than spatial convergence.

Past, presence, future: All-in V1

Dirk Jancke
Optical Imaging Group, Institut für Neuroinformatik, Ruhr University Bochum, Germany

Anticipation, expectation based on inference from past events, and plasticity, are fundamental strategies of neuronal systems to flexibly cope with rapid changes in the environment. The primary visual cortex (V1) as the first cortical processing step — comprising a significant portion of the brain — is, however, often considered only as a fixed "instantaneous decoder" that merely reconstructs and tracks current basic stimulus features. Dependent on spatial and temporal context there is, on the other hand, a large body of evidence for widespread intra-cortical interactions that dynamically change V1 output dependent on context and past events beyond simple normalization and spatiotemporal filtering. We use voltage-sensitive dye imaging to enable visualization of the widespread spatiotemporal dynamics across populations of neurons in cat V1. I will show how population activity patterns with correlates to perception evolve in the millisecond range across multiple square millimeters of cortical surface, representing multiplexed characteristics of input and incorporating signatures of "predictive encoding". Thus, I will put forward the idea that V1 produces multifold facets of visual input at staggered times, providing a rich spectrum of signals for flexible read-out and anticipatory perceptual decisions at downstream processing stages.

Naturalistic stimulus structure reveals nonlinear spatial integration in primate V1 and V2

Elizabeth Zavitz
Department of Physiology, Monash University, Australia

Boundaries in visual scenes are readily apparent when they are defined by properties such as luminance, contrast, or orientation. The physiology underlying boundary segmentation by simple first- (luminance, colour) and second-order (contrast, orientation, spatial frequency) segmentation is quite well understood. However, natural images and textures vary in a range of properties that are not well captured by these statistical summaries, but do influence and enable human boundary segmentation. A linear-nonlinear-linear model of human vision suggests that a compressive intermediate nonlinearity can account for much of this influence. Because of the compressive nonlinearity, the model predicts nonlinear spatial summation within the early visual cortex. Namely, it indicates that image density, like contrast, is an intensive property where sparser stimuli should elicit a stronger response in the visual system. To test this, we made recordings in primary and secondary visual cortex of the marmoset monkey to flashing, oriented stimuli with a range of energy densities, and found that sparser stimuli often do elicit a stronger response in V2 neurons, and occasionally in V1 as well. This provides convergent evidence that sublinear summation over space occurs in early visual cortex and affects how we process and perceive the natural world.

Place cells, receptive field estimation, and readout of memory

Simon R Schultz
Centre for Neurotechnology and Department of Bioengineering, Imperial College London, UK

The finding of cells which fire when an animal visits a particular location – the so-called “place cells” of the hippocampus – ignited something of a revolution in memory research. The “place field” can be viewed as a special case of receptive field, by analogy to sensory systems: mathematically speaking, it behaves much as would a retinal receptive field, restricted to sparse two-dimensional (x-y point) input. Generation of place field selectivity by a CA1 cell, however, requires that the animal have laid down a memory of the spatial environment, and to recall that memory from suitable cues. Place fields thus provide a “readout” of spatial memory. This can be quantified, in information theoretic terms, to provide a measure of the spatial information provided – with the simple Skaggs Information rate quantifying how informative the place field is about spatial position, in units of bits per spike. Place fields have, in the hippocampal literature, traditionally been computed via basic histogram techniques – we show that this leads to inaccurate place fields, and a substantial bias in the Skaggs information, for typical experimental conditions. By replacing this with a modern machine learning approach based on Gaussian processes, we are able to estimate place fields and their spatial information with greater accuracy and precision, with only a few minutes of data. We apply this approach to two photon calcium imaging data recorded from place cells in hippocampal subfield CA1 of head-fixed mice performing a spatial exploration task, in a flat real-world environment. In ongoing work, we are using the readout of spatial memory by hippocampal place cells to quantify memory deterioration in several mouse models of Alzheimer’s Disease, with the hope that this will provide a robust method for assessing therapeutic strategies.
