Estimating Population Receptive Fields in Space and Time

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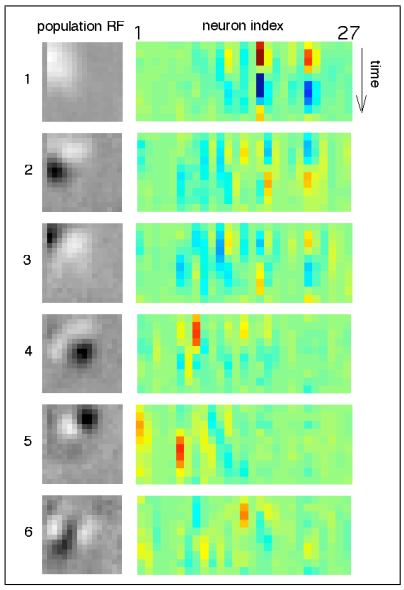

Right from the first synapse in the retina, visual information gets distributed across several parallel channels with different temporal filtering properties. Yet, commonly used system identification tools for characterizing neural responses, such as the spike-triggered average, only allow one to investigate the individual neural responses independently of each other. Conversely, many population coding models of neurons and correlations between neurons concentrate on the encoding of a single-variate stimulus.

We seek to identify the features of the visual stimulus that are encoded in the temporal response of an ensemble of neurons, and the corresponding spike-patterns that indicate the presence of these features.

We present a novel data analysis tool for the identification of such temporal population codes based on canonical correlation analysis (Hotelling, 1936). The "*population receptive fields*" (PRFs) are defined to be those dimensions of the stimulus-space that are maximally correlated with the temporal response of the entire neural population, irrespective of whether the stimulus features are encoded by the responses of single neurons or by patterns of spikes across neurons or time. These dimensions are identified by canonical correlation analysis, a convex optimization technique which essentially solves an eigenvalue problem and is not prone to local minima.

Each receptive field can be represented by the weighted sum of a small number of functions that are separable in space-time. Therefore, non-separable receptive fields can be estimated more efficiently than with spike-triggered techniques, which makes our method advantageous even for the estimation of single-cell receptive fields.

The method is demonstrated by applying it to data from multi-electrode recordings from rabbit retinal ganglion cells in a whole mount preparation (Zeck et al, 2005). The figure displays the first 6 PRFs of a population of 27 cells from one such experiment. The recovered stimulus-features look qualitatively different to the receptive fields of single retinal ganglion cells. In addition, we show how the model can be extendended to capture nonlinear stimulus-response relationships and to test different coding-mechanisms by the use of kernel-canonical correlation analysis. In conclusion, we suggest to characterize responses of ensembles of neurons in terms of PRFs, rather than discussing stimulus-neuron and neuron-neuron dependencies separately.

References

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Zeck GM, Xiao Q, Masland RH (2005) The spatial filtering properties of local edge detectors and brisk-sustained retinal ganglion cells. Eur J Neurosci 22:2016-2026.