Gabor limits and hyper-selectivity in the tuning of V1 neurons

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In this talk, we will explore two forms of selectivity in sensory neurons. The first form is the linear or "basic selectivity". It is a traditional form of selectivity that is revealed by the classical receptive field. This receptive field traditionally describes the response of a neuron as a function of position. This receptive field will also typically describe the stimulus that optimally stimulates the neuron. The second type of selectivity we describe as "hyper-selectivity" and it is either implicitly or explicitly a component of several models including sparse coding, gain control, some cascaded linear non-linear (LNL) models. Hyper-selectivity is unrelated to the stimulus that maximizes the response. Rather, it is the relative drop-off in response around that optimal stimulus that determines the hyper-selectivity (i.e., there is a curve in the iso-response surfaces). Models with hyper-selectivity allow what appear to be paradoxical results. For example, it is possible for a neuron to be very narrowly tuned (hyper selective) to a broadband stimulus - or broadly tuned to a narrow-band stimulus (linear selectivity). We note that the Gabor/Heisenberg tradeoffs apply to selectivity with linear neurons. However, non-linear neurons with exo-curvature (gain-control-like) non-linearities can easily break this limitation and we show this with both model data published data from V1 neurons. We also argue that results with over-complete sparse coding typically focuses on the linear selectivity but we argue that the hyper-selectivity changes in important and systematic ways as the network becomes more overcomplete. We show through simulations that the receptive fields of neurons when measured with spots or gratings will mis-estimate the optimal stimulus for the neuron. For 4x overcomplete codes, we find that the difference between the optimal stimulus and the receptive field is surprisingly large (typically different by 40 degrees in image state-space). Finally, we argue that although gain control models, some linear non-linear models and sparse coding have much in common, we believe that our approach to hyper-selectivity provides a deeper understanding of why these non-linearities are present in the early visual system.