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A functional model of recurrent V1 long-range interactions

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Motivation Physiological studies reveal that tangential long-range connections in primary visual cortex i) extend far beyond the 'classical receptive field', ii) are highly selective, connecting primarily cells with similar orientation preference, iii) have a modulating, rather than a generating effect on cell activities. While the precise functional role of these connections still remains unclear, it has been hypothezised that long-range connections may represent a low-level neural implementation of the Gestalt principle of good continuation.

Methods A functional model of long-range connections in V1 is proposed, where long-range connections have the computational role of enhancing activities in coherent structures. The model consists of a feedforward path which generates the input to a recurrent long-range interaction. In the geniculo-cortical feedforward path, initial luminance distribution is processed by isotropic LGN-cells, orientation-selective simple and complex cells. Complex cell responses constitute the input to the long-range stage, where activities are processed by a bipole filter. In order to model the dendritic long-range connections in V1 layer 2/3, the bipole filter is narrowly tuned to orientation and about twice the size of the complex cell RFs. In the recurrent cycle, long-range responses are fed back and modulate complex cell responses at the same spatial location. Modulated responses are self-normalized and input to the long-range stage, thus closing the recurrent cycle.

Results The model is applied to noisy synthezised as well as natural 2D stimuli. Self-normalization guarantees saturation after a few recurrent cycles. Compared to the feedforward responses of the complex cells, the recurrent long-range interaction enhances activities in coaligned spatial arrangements, while non-coaligned noisy activities are suppressed. For a quantitative analysis we examined the temporal evolution of orientation significance during recurrent interaction. It shows that significance is increased at edges but remains almost constant in homogeneous regions.

Conclusion We developed a functional model of intracortical recurrent long-range interactions in V1. Qualitatively, simulations show an enhancement of responses to coherent structures. This further supports the view of long-range interactions as low-level Gestalt detectors. Quantitatively, the model demonstrates for orientation significance, how recurrent interaction can diminish uncertainty of measurement compared to a simple feedforward scheme.