Integration of orientation and spatial frequency in a model of visual cortex

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In the visual system complex scenes have to be integrated from simple local features into global and meaningful percepts. Contour integration, a basic process useful for figure-ground segregation and object recognition, is already well understood in terms of orientation alignment. However, there are other features playing a role in this process. Spatial frequency for example has a strong influence on contour visibility.

To gain deeper insights into the process of contour integration, we quantified the effect of spatial frequency (SF) on contour visibility as a second cue and investigated if the observed psychophysical effects can be explained by a simple neural mechanism: We hypothesized that interactions are strong between neurons with similar preferred SFs, and that the effective range of the interactions scales with SF.

Specifically, we constructed a structurally simplistic cortical model integrating contour integration stimuli consisting of oriented Gabor patches with different orientations and SFs, into which contours of aligned and/or SF-homogeneous patches were embedded. Feature integration in the model is performed by recurrent interactions between populations with receptive fields (RFs) selectively tuned to orientation and spatial frequency of localized stimulus patches. Excitatory connections realize a long-ranging association field with strong links between collinear and co-circularly aligned RFs. Inhibitory interactions provide medium-range normalization and are independent of orientation preference. Interaction strength exponentially decreases with increasing SF difference, and also the range of interaction depends on SF.

We were able to quantitatively reproduce the results of psychophysical studies examining the effect of SF on contour integration [1, 2]. For three different experimental paradigms, we show a comparison of model (solid lines) and human psychometric curves (dashed lines) for contour detection in Fig. 1. Thus, we can explain multiple SF-depending effects on contour integration by a simple unifying principle: The more similar the preferred SFs of two neuronal populations, the stronger they are connected. Different magnitudes of effects depending on 'low' or 'high' SFs can be explained by a variable length scaling of the interactions. This mechanisms that we suggest accounts for previously unexplained findings, helping to create a more comprehensive understanding of computation in the visual system.

Acknowledgements

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References

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Figures

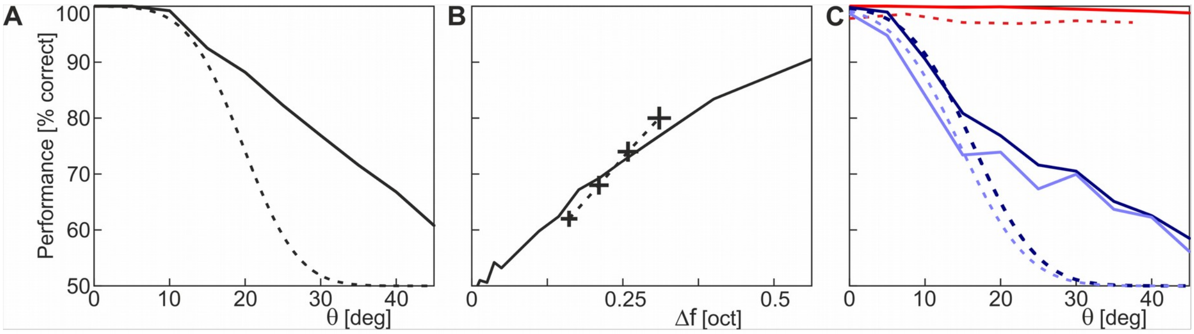

Figure **1**: A: Contour defined by alignment only. B: Contour defined by SF shift only (between contour and background). C: Contour defined by alignment, plus SF jitter on all Gabor patches (light and dark blue). For jitter on contour elements only (red), the target remains visible even for large tilt angles.