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. One basic process in feature integration that is needed to e.g. form the shape of objects is contour integration. Models studying this process usually focus on orientation alignment as the defining feature of a contour, however, experimental work has shown that also other features such as spatial frequency (SF) strongly shape contour integration. In our framework we include SFs as a second cue to gain deeper insight into mechanisms of contour integration, by hypothesizing that similar SFs will be integrated more strongly than dissimilar ones.

We constructed a structurally simplistic cortical model with population dynamics described by simplified Wilson-Cowan equations. The model was presented with stimuli consisting of an ensemble of oriented Gabor patches with different orientations and spatial frequencies, into which contours of aligned and/or SF-homogeneous patches are embedded. Feature integration is performed by recurrent interactions between populations with receptive fields (RFs) tuned to the orientation and SF of localized stimulus patches. Interactions comprise excitatory and inhibitory couplings, with inhibition providing normalization and being independent on orientation preference. Excitatory connections realize an association field [1] specifying the linking strength for elements with different properties: In particular, we implement strong links between collinear and co-circularly aligned RFs, and we assume that interaction strength exponentially increases with decreasing SF difference (i.e., "what fires together wires together").

By quantitatively reproducing the results of multiple psychophysical studies [2] we are able to provide a unifying account of contour integration in a variety of different stimulation paradigms. Our model suggests a novel mechanism involved in feature integration, namely spatial-frequency dependent interactions, which accounts for previously unexplained findings (see Figure 1), thus going beyond contour integration on orientation information only, and helping to create a more comprehensive understanding of computation in the visual system.

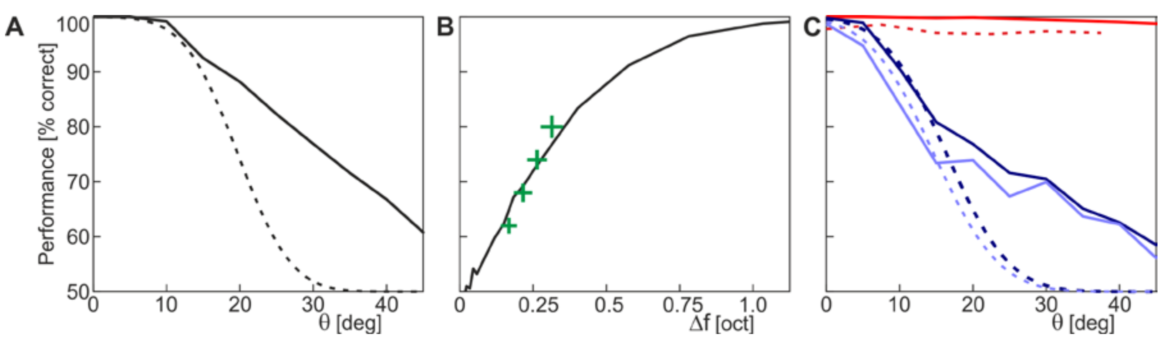

Figure 1. Comparison of model (solid lines) and experimental psychometric curves (dashed lines) for contour detection in a 2-AFC design. Since the model is not subject to noise, we expect its performance to be equal or higher than for human observers. **A:** Contour defined by orientation alignment only (same SF for all Gabors): performance decreases with increasing tilt angle deviating from perfect alignment. **B:** Contour defined by SF shift between contour and background elements (random orientations for all Gabors): performance increases with increasing SF shift (green crosses: experiment). **C:** Contour defined by orientation alignment, with SFs of contour and background subject to different levels of random jitter (2 octaves and 3 octaves width, light and dark blue, respectively): detection threshold decreases with increasing jitter. For jitter on the contour elements only (red), the target remains visible even for large tilt angles (prediction of model confirmed by new experiments, unpublished data).

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References

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