A Neural Model of Illusory Contours and Shapes: A Multi-scale Investigation

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The strength of illusory contour and shape perception, as in the case of the Kanzisa Square and Ehrenstein cross displays, crucially depends the alignment, thickness, contrast, and number of inducers (Lesher & Mingolla, 1993; Francis & Grossberg, 1996). Neurons in primate visual area V2 have been demonstrated to selectively respond to gaps, only when they are perceived as illusory contours, yet the underlying neural mechanisms remains controversial (Peterhans & von der Heydt, 1984). V2 neurons that respond to illusory contours must be sensitive to inducer alignment and integrate information over large visuotopic distances, despite having a limited receptive field size. This suggests the visual system performs long-range grouping across various spatial scales. We present a dynamical neural model of primate V2 and V4 with convex-shaped receptive field units that elicit activity to the interior of figures at the appropriate size, but not to their exterior. The model exhibits maximal sensitivity when the number of inducers and their alignment yields the most robust illusory contour and shape percept. Our neural model contains two layers within V4: units with convex-shaped receptive fields that are selective to figures at a single size (*single-scale V4 cells*) and units that perform a multi-scale integration on the single-scale units (*multi-scale V4 cells*). The multi-scale V4 cells in the model perform a nonlinear integration of their subunits that vary in retinotopic location and receptive field size, and feed back to units that are selective to figures of a single size. Sensitivity to illusory contour and shape alignment and configuration can be explained in the model via feedback from the multi-scale units, which integrate the convex-shaped single-scale V4 unit activity across different retinal eccentricities and receptive field sizes. Local convexity is ambiguous with respect to figure-ground assignment because contours may constitute convex parts of the figure or concave parts of the background or vice versa. Determining whether a local region within a visual scene belongs to the interior or exterior of a shape requires analysis across multiple spatial scales. By simultaneously grouping across spatial scale and extent, multi-scale V4 cells in the model can resolve figure-ground assignment in displays with ambiguous local convexity (e.g. C-shape, cross, annuli). Our results are consistent with a combined feedforward and feedback mechanism in cortex to yield illusory contour selectivity (Pan et al., 2012, von der Heydt, 2013). The model predicts that shape contours that are perceived as illusory represent the least important geometric aspects that contribute to the perception of the non-illusory version of the shape.

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