The roles of polarity and symmetry in the perceptual grouping of contour fragments

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Received 7 December 1998; revised 27 June 1999; accepted 1 September 1999

Abstract—We describe two experiments that investigate the roles of polarity and symmetry in the perceptual grouping of contour fragments. Observers viewed, for one second on each presentation, arrays of oriented, spatial-frequency band-pass, elements, in which a subset of the elements was aligned along a twisting curve. In each of five conditions we measured observers’ ability to detect aligned combinations of even- and odd-symmetric elements, of the same and different polarities, against a background of ‘noise’ elements. As with previous experiments we found that the ‘path’ could be reliably detected, even when the elements of the path were oriented at angles of up to ±60 deg relative to each other. Detection of the path was still possible when the polarity of path elements alternated. However, the probability of detection of the path was raised significantly when the path elements were all of the same polarity. Perceptual grouping of even-symmetric elements was no different to perceptual grouping of odd-symmetric elements. The results provide evidence, that in achieving integration of contour fragments, the visual system uses a process that is to some degree phase selective. We use the results to describe how the visual system may resolve natural contours when they occur against backgrounds that vary over a wide range of intensities. The data presented here have been published in conference-abstract form (Hayes et al., 1993; Field et al., 1997).

Keywords: Gestalt ‘law’ of good continuation; phase; visual coding; natural-image contours.

1. INTRODUCTION

Much physiological and psychophysical research endorses the idea that neurones in the early visual pathway employ highly localised receptive fields to code the retinal image. The evidence suggests that the retinal image is decomposed at the primary visual cortex by cells selective to local properties of the image such as orientation, spatial frequency, and direction of motion. Local coding of the retinal
image by these cells may offer the advantage of the removal of redundancy (see e.g. Field, 1994), but for the purpose of recognition the visual system must unite image-structure related information carried by a small set of active units; this is sometimes referred to as the ‘binding problem’.

One important direction of local unification is along the length of a line or edge, and a number of studies have investigated how the visual system binds the elements of a fragmented contour to result in the perception of unified whole. In earlier work (Field et al., 1993) we established that the visual system groups locally oriented, fragmented, elements of contours by combining the components according to a set of preferences we describe as an ‘association field’. As with the ‘relatability’ notion of Kelman and Shipley (1991), aggregation of locally oriented fragments into visible contours occurs when the fragments align closely to the tangent of smooth curves. Several studies have shown that the grouping of fragments into detectable contours also depends on disparity (Hess and Field, 1995; Hess et al., 1997), hue (McIlhagga and Mullen, 1996), eccentricity (Hess and Dakin, 1997), number of elements (Moulden, 1994), and closure (Kővacs and Julesz, 1993; it should be noted that recent evidence suggests that sensitivity to closure may be explained by smoothness constraints on contour integration, see Pettet et al., 1998).

In our earlier work (Field et al., 1993) we investigated the element-alignment rules for the detection of contours where contours were constructed from small separate elements that were set against a background of similar ‘noise’ elements. Using a two-alternative, forced-choice procedure, observers were required to detect which of two images contained the set of aligned elements or ‘path’. Each image consisted of an array of 256, oriented, band-pass ‘Gabor-patch’ elements (circular, Gaussian-windowed sinusoids), where one image contained a path that consisted of a subset of 12 elements that were aligned along a twisting curve. Observers were capable of detecting a path when the elements of the path differed in their inter-element orientation by up to 60 deg. Orienting the elements side-to-side, as opposed to end-to-end, decreased substantially the ability of observers to detect the path, as did the introduction of small displacements — either as small lateral displacements or as random orientation jitter — of elements off the axis of the path (see also Beck et al., 1989; Hayes, 1997; Hess et al., 1997). One of the five experiments that were reported in our 1993 study explored the role of the phase of the sinusoid of the Gabor-patch in perceptual grouping of contour fragments. We set the windowed sinusoids of the path elements and of the background elements to random phase, instead of fixed cosine phase (i.e. even symmetry), but the ability of observers to detect the path was unchanged.

This earlier experiment is open to criticism along two lines. First, the elements of the path were relatively narrow-band and thus each element contained several bright and dark bars so, although grouping of the elements may be phase sensitive (e.g. bright-bar to bright-bar and dark-bar to dark-bar), the use of narrow-band stimuli may have precluded measurement of phase selectivity. Second, the phases of the sinusoids of the elements were set to random values. This procedure results in an