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Region- and edge-based configurational effects in texture segmentation

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Abstract

We have found a new configurational effect in texture segmentation. In addition to collinear facilitation at the edge, this effect results from contextual modulation within the texture-region, i.e. from texels not abutting the segmented edge. The largest facilitation was found when two conditions were fulfilled: (i) elements along the edge were parallel to the edge and collinear, (ii) elements in the texture-region were also collinear but non-parallel to the edge. We show that this facilitation occurs when there are groups of different orientation from the edge in the texture-region. We suggest two possible underlying mechanisms: either a region-based process that links collinear iso-oriented elements and locates the edge when the orientation changes, or else second-order filters tuned to orientation differences rather than orientation per se.

Keywords: Texture segmentation; Lateral interactions; Grouping by collinearity; Energy models

1. Introduction

One of the first processing steps on the path to perception is the segregation of objects from the background. This operation has often been studied using texture images where, in the absence of mean luminance differences, a given texture-region can be segmented on the basis of discontinuities of some basic dimension such as orientation, spatial-frequency or motion.

The most popular accounts of texture segmentation are edge-based segregation models (see Landy & Graham, 2004; for a review). Briefly, these models predict that texture segmentation results from a non-linear transformation of the output of local spatial filters, followed by a 2nd-order spatial filtering to enhance activity at the texture-defined contours, where the local filter response changes. According to these models, edge-based segregation is thought to result from both enhanced signal processing at the texture-edge and local inhibitory activity in the texture-region, where filter response is weak (Malik & Perona, 1990; Sagi, 1991, p. 406).

However, the hypothesis of inhibition is difficult to conciliate with the phenomenological evidence that local properties of texture-region can be still salient after segmentation. Indeed, when observing a pair of zebras, say, we perceive a pair of zebra coats, not just the boundary between their bodies, and this can only result from texture-region information, with no feature gradient (Ben Shahar, 2006). Roelfsema, Lamme, Spekreijse, & Bosch (2002) attempt to accommodate phenomenology with visual processing. They propose that during texture segregation, locations where the properties of texture-elements change abruptly are assigned to boundaries, whereas image regions that are relatively homogeneous are not inhibited, but perceived as texture-regions by grouping elements together.

Moreover, psychophysical data strongly suggest that the properties of texture-regions are perceived by mechanisms different from those responsible for extracting texture edges (Ariely, 2001; Parkes, Lund, Angelucci, Solomon, & Morgan, 2001). Lee (1995) and Roelfsema et al. (2002) suggested that edge- and region-based mechanisms operate at different levels of processing.

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However, there are data suggesting that not only are textures perceived, but they produce contextual effects in segmentation. A well known contextual effect is a facilitation when texels are collinear and parallel to the edge (Caputo & Casco, 1999; Casco, Campana, Grieco, & Fuggetta, 2004; Casco, Grieco, Campana, Corvino, & Caputo, 2005; Nothdurft, 1992; Olson & Attneave, 1970; Wolfson & Landy, 1995). The underlying physiological mechanism (see Lamme, 2004; for a review) is based on the familiar phenomenon of enhancement of neuronal firing rate resulting from contextual influences from outside the receptive field. These contextual influences affect several visual tasks in addition to texture segmentation. For example, they reduce contrast threshold for a single target bar (Polat & Sagi, 1993, 1994) and enhance detection of contours embedded in background noise (Field, Hayes, & Hess, 1993; Hess & Dakin, 1997; Li & Gilbert, 2002).

An account for contextual effects from the region in edge segmentation is proposed by region-based models. According to these models, the visual system treats neighbouring texture-regions as belonging to the same texture if they are similar enough. In this way, individual elements are grouped by spreading neural activity emanating from highly stimulated detectors, and the edge is detected when linking operations interrupt because the output of local filters changes (Caelli, 1985). Interestingly, since linking between collinear elements is preferred, edge segmentation by such a mechanism results from spreading of activity in the direction non-parallel to the edge and cannot be assimilated to the mechanism accounting for the facilitation produced by collinear elements parallel to the texture-edge.

An alternative approach conciliates the contextual effects with edge-based models of texture segmentation. Wolfson & Landy (1999), for example, suggest that reduced detection of a target element oriented differently from the surrounding region, when the background surrounding the region is iso-oriented with the target (Caputo, 1996), could depend on inhibitory connections between orientation and spatial-frequency selective linear-filters. This explanation is, however, local and does not account for facilitatory contextual effects resulting from grouping in the texture-region.

Thus, contextual influences from elements parallel to the edge are well compatible with edge-based models (as shown by Wolfson & Landy, 1995) and can modulate—either facilitating or inhibiting—edge-based segregation. On the other hand, contextual influences from the texture-region are instead taken in account by a region-based mechanism, predicting that a texture-edge is detected not explicitly but rather implicitly when the "growing" of two different texture-regions causes their interaction. In this case, facilitation should occur when collinear elements are non-parallel to the texture-edge.

Our experiments were designed to investigate the interaction between region- and edge-based mechanisms. We predicted that, if texture-edge segmentation depended on region-based analysis, then contextual influences from the texture-region should affect the saliency of the edge. To test this hypothesis we checked how the texture overall-orientation affected the discrimination of the edge.

In order to distinguish between the effect of collinearity at the edge and region-based effects, we arranged the edge to segment a larger texture-region from a narrow one. Consequently, when elements in the narrow region were parallel to the edge they were also collinear, whereas collinear elements in the larger texture were either parallel or orthogonal to the edge.

Results show a new facilitatory configurational effect resulting from grouping by collinearity in the texture-region, and independent of collinear facilitation at the edge.

2. Methods

2.1. Stimuli

Stimuli were generated by using a VSG 2/3 Cambridge Research System graphic card with 12-bit luminance resolution and displayed on a gamma-corrected Sony Triniton monitor with a resolution of 1024×768 pixels refreshed at 100 Hz. Observers viewed the stimuli in a dark room at 57 cm viewing distance.

In all experiments, we used textures composed of 8×8 (9.2×9.2 deg of visual angle) matrices of cosine-phase [even] Gabor-elements with circular support or envelope. Each Gabor-patch was defined as a sinusoidal-modulated carrier with a wavelength [λ] of .31 deg (spatial-frequency of 3.2 cycles/deg) multiplied by a Gaussian envelope with standard deviation [σ] of .19 deg. Centre-to-centre elements distance was equal to 3.66 λ. Mean luminance of a Gabor-element was equal to the background luminance (49 cd/m^2).

By selecting two orientations of the Gabor-elements amongst four possible orientations (0, 45, 90 and 135 deg) we obtained, for each pattern, two texture sub-regions separated by a *texture-edge* (Fig. 1). The texture-edge was located either between the two extreme stripes of elements (the up/down rows or the left/right columns) or between the two central stripes. In the first case, we will refer to the area with the larger number of iso-oriented elements as the 'larger' texture-region.

Segmented textures were differentiated on the basis of two distinct configurational properties (Fig. 1):

- *collinearity at the edge:* the texture-elements (texels) in one of the two stripes abutting the edge, were either iso-oriented and collinear to each other, (in this case parallel to the edge), or iso-oriented and non-collinear (in this case non-parallel to the edge).

- *congruency in the larger texture-region:* the texels in the larger texture-region were always iso-oriented and collinear to each other (except in Experiment 4) but their orientation was either congruent (parallel to the edge) or non-congruent (non-parallel to the edge).

2.2. Subjects

Subjects were aged 20–35 years, all volunteers with normal or corrected-to-normal visual acuity. All the participants, except the authors, were ignorant of the purposes of the experiments. Each of the twelve subjects executed two experiments in random order: six participated in Experiments 1 and 2 and six in Experiments 3 and 4. Two new naïve subjects and the authors participated in Experiment 5.

2.3. Task

Subjects performed a binary classification task and were asked to discriminate, by pressing one of two alternative keys, the orientation of the texture-edge (horizontal vs vertical).