Modeling Luminance Contrast Orientation Illusions

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Abstract

Luminance contrast orientation illusions are illusions of tilt whose presence or absence depends on the luminance values of some elements of their configurations. A simple model is presented which can account for a number of illusions of this type. Its basic feature is that the neural distributions corresponding to illusory tilt are similar to neural distributions induced by actually tilted stimuli.

Keywords: orientation illusions; luminance contrast; neural models

Orientation illusions

Illusions of orientation or tilt arise when perceptual judgments of angles of elongated stimuli differ from the geometrically correct angles. There are several classes of such illusions. One class, often labeled as ‘tilt illusion’, involves circular or ring-shaped target extents filled with oriented patterns, such as sinusoidal gratings, surrounded by inductor patterns with different orientation, subtending an oblique angle with respect to the target. In such circumstances the judged orientation of targets is rotated in the opposite direction from the orientation of inductors, an effect usually ascribed to inhibition between oriented channels in the visual system. Another class of orientation illusions arises in Zöllner configurations, in which the targets are long lines and the inductors are sets of short lines crossing the targets at various oblique angles. The effect on the judged orientation of the targets is similar as in the tilt illusion. Here I will discuss a third class, which will be called luminance contrast orientation illusions. Such illusions arise in configurations that usually do not involve oblique angles and in which the presence and direction of illusory effects depends on the luminances of their constituent elements.

The oldest illusion in this class was discovered by Münsterberg (1897). It was studied by a number of researchers in the following years (Benussi & Liel, 1904; Fraser, 1908; Heymans, 1897; Hyde, 1929; Lehmann, 1904), but then it seems to have been forgotten, only to be rediscovered in an improved version by Gregory & Heard (1979), under the name ‘Café wall’ illusion. The illusory configuration consists of a shifted chessboard pattern with gray parallel lines between rows of checks, which do not look horizontal but tilted. However, if the lines are darker or lighter than the checks, there is no tilt illusion and the lines are seen veridically as horizontal and parallel. This effect shows that the presence of the illusion does not depend only on the geometry of the illusion-inducing configuration but also on the luminance contrast between its elements. In recent years a number of other researchers have presented various configurations involving geometrically parallel orientations that don’t look parallel (Kitaoka, Pinna, & Brelstaff, 2004; Kitaoka, 1998, 2007; Parlangeli & Roncato, 2008, 2010; Roncato & Casco, 2009). There is also a related class of configurations involving elements arranged on concentric circles that don’t look circular but are perceived as having other shapes, such as spiral-like (Fraser, 1908; Pinna & Gregory, 2002).

Model of orientation illusions

A neural model of the Münsterberg - Café wall illusion was presented by Morgan & Moulden (1986; see also Earle & Maskell, 1993; Kitaoka et al., 2004; Fermüller & Malm, 2004; Takeuchi, 2005). In the model the illusion-inducing configuration is filtered by a sheet of units modeled after cells with retinal concentric-antagonistic receptive fields and cortical line-detectors. They have shown that in the output of such convolutions ‘both peaks and troughs along the mortar are oriented along lines that are slightly tilted with respect to the horizontal. The result is a Fraser twisted cord, which underlies the Münsterberg effect.’ (Morgan & Moulden, 1986, p. 1793). Here I will present a related model which can account for a number of luminance contrast illusions in addition to the Münsterberg - Café wall illusion. It is shown that patterns of simulated neural distributions corresponding to stimulus configurations inducing illusory tilt are similar to patterns induced by actually tilted stimuli.

The model has two levels, both constituted by grids or sheets of 32×32=1024 units. Level 1 is the input level, composed of pixels with various luminances. The role of this level is to specify stimulus patterns which are then processed by Level 2 units. This level is the output level, composed by simple simulated neurons, whose reactions to the stimuli form various patterns of distributions of stimulated neural activity. Several types of receptive fields of level 2 units were implemented. One set used were the so-called edge detectors, whose receptive fields have odd symmetry and horizontal orientation. Two types with opposite polarity were used, depicted in Figure 1a and 1b. Orange dots mark the excitatory portion, blue dots mark the inhibitory portion, and their size corresponds to the sensitivity of the neuron at that position of the receptive field; the red dot marks the receptive field center. The receptive field profiles were modeled by Gaussians, and the simulations were done in Mathematica. Units with these receptive fields were used in the simulations of the model presented here in Figure 1c-f.

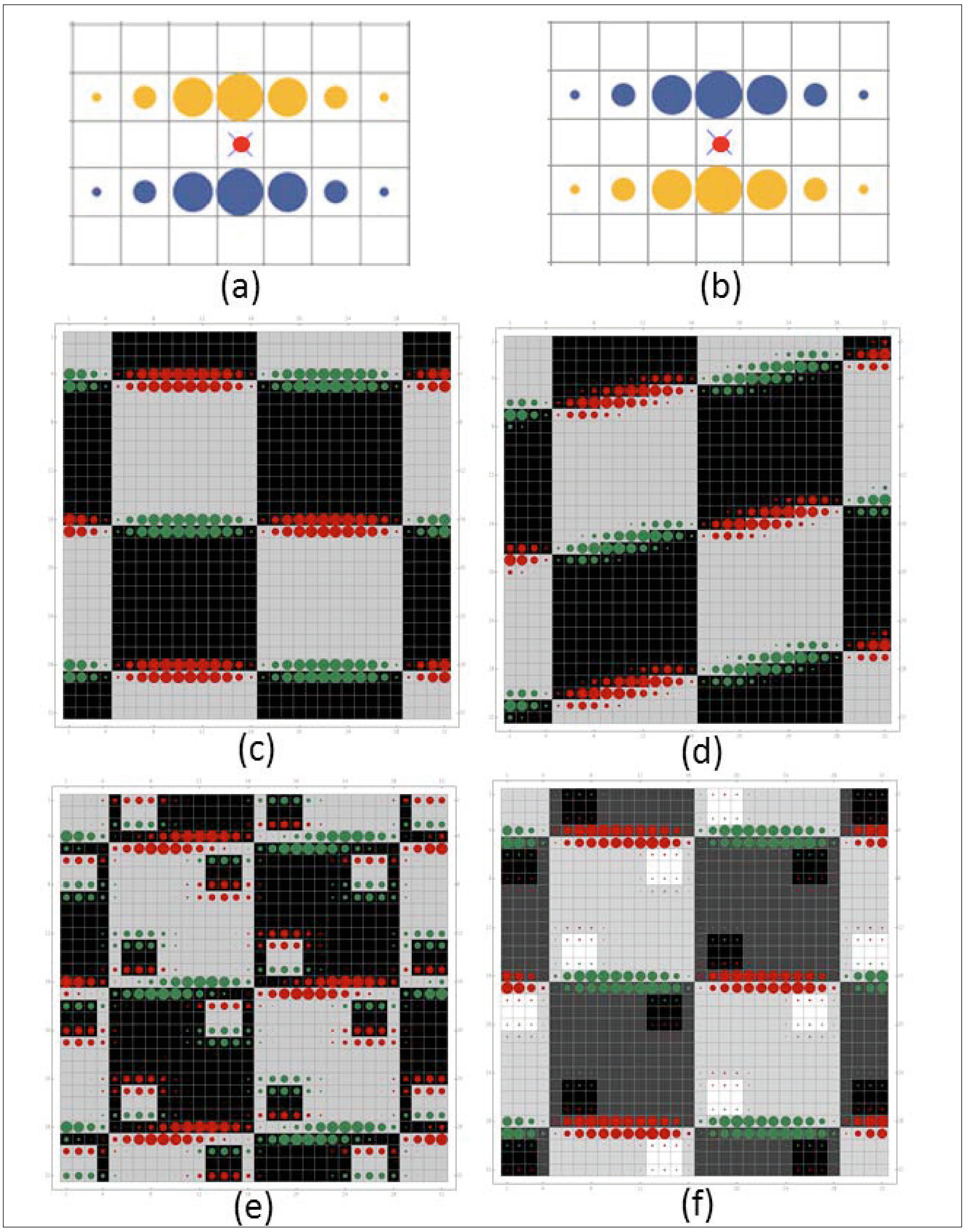

Figure 1. (a-b) Receptive fields of horizontal edge detectors. (a) Top-excitatory bottom-inhibitory. (b) Top-inhibitory bottom-excitatory. (c-f) Input configurations with superimposed reaction patterns. (c) Standard chessboard, parallel rows pattern. (d) Tilted chessboard, shifted rows pattern. The graphical expression of the tilt is limited by the resolution of the model. (e) Illusion inducing chessboard with small squares, shifted rows pattern. (f) Non-illusion inducing chessboard with small squares, parallel rows pattern.

Simulations of orientation illusions

This model was used to simulate a number of luminance contrast orientation illusions and their variations, but here the simulations of only one set of related configurations will be presented. Figure 1c depicts an input configuration in the form of a standard chessboard, superimposed upon which is the pattern of the output distribution of Level 2 units. The reaction of Figure 1a units is coded in green, and the reaction of Figure 1b units is coded in red; the sizes of the red and green dots code the intensity of the output. Note the parallel rows of signals of alternate polarity along the horizontal edges of the input pattern. For comparison, Figure 1d presents a tilted chessboard as the input configuration, also with the superimposed output of Level 2 units. Note that in this case the output pattern consists of spatially shifted rows of signals of alternating polarity.

Figure 1e is a portion of the Enhanced checkered illusion (Kitaoka, 2007). The chessboard pattern has horizontal edges, but they look tilted; this is due to the presence of small inductor squares located near the corners of the fields of the chessboard; black squares are present inside the light fields of the chessboard and white squares are present inside the dark fields. Note that the output pattern of the simulated distribution of neural activity along the horizontal edges involves shifted rows of signals, similar to the output in Figure 1d. The difference from the parallel rows pattern of the distribution for the regular chessboard (Figure 1c) is due to the presence of the inductor squares, which cause ‘gaps’ in the distributions along the horizontal edges, generating the shifted rows pattern. The crucial point to note is that impressions of tilt in different figures are associated with similar underlying patterns of neural distributions (shifted rows of signals), presumably explaining why they look similar.

For comparison, Figure 1f contains a version of the Enhanced checkered configuration in which the luminances of the inductor squares are switched and thus their luminance polarities with respect to the background are reversed, compared with Figure 1e. In this configuration the white inductor squares are located inside the light fields and the black inductor squares are located inside the dark fields, inducing reversed and much weaker luminance contrast, compared to Figure 1e. In such patterns there is no perception of illusory shift. Note that the output pattern consists of parallel rows of signals, very similar to the pattern in Figure 1c.

Discussion

The main point to note in these simulations is that the output pattern in the case of illusory tilt (Figure 1e) is similar to the output pattern in the case of real tilt (Figure 1d). This result suggests that the neural correlate of perception of tilt, whether veridical or illusory, is a certain signature pattern involving shifted rows of signals. On the other hand, a non-illusory configuration such as in Figure 1f, which is geometrically equivalent to the illusion-inducing configuration in Figure 1e, but with photometrically inverted inductor squares, induces an output pattern similar to the non-illusory chessboard configuration such as in Figure 1c.

This pattern of results was essentially reproduced using other types of receptive fields, such as concentric-antagonistic and line detectors (odd symmetrical receptive fields). Similar results were obtained with a number of other luminance contrast orientation illusions from papers mentioned above, including several variants of the Münsterberg-Café wall illusion, such as by McCourt (1982) and Kitaoka et al. (2004), as well as various illusions created by Akiyoshi Kitaoka, such as the striped cords illusion (Kitaoka, 1998), the illusion of Y-junctions (Kitaoka et al., 2001) and the shifted lines illusion (Kitaoka, 2007). The simulations share the feature that illusory percepts of tilt are associated with shifted rows patterns of signals, whereas geometrically equivalent but luminance reversed configurations, which do not evoke illusory tilt impressions, are not associated with such patterns.

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