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Selective biasing of stereo correspondence in an ambiguous stereogram

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Abstract

In spite of numerous studies in stereoscopic perception, it is still not clear how the visual system matches features between the two eyes. One reason is that these previous studies used stimuli that presented little perceptual ambiguity, so the correspondence problem had only one solution. We present here a novel stimulus that presents a more complex correspondence problem. This stimulus is inspired by "wallpaper" stimuli and was specifically designed to put into conflict two possible constraints underlying stereo correspondence matching. These constraints are the nearest neighbour matching rule—that biases surfaces towards the horopter—and the nearest disparity rule—that biases surfaces to be smooth. By varying the contrast of adjacent image features in this stimulus, we were able to reveal and quantify a preference for nearest disparity matching. The magnitude of this preference is dependent upon the magnitude of possible disparities in the scene and is consistent with the idea that the visual system seeks to minimise local differences in disparity. We discuss these results with regard to the use of prior constraints in models of stereo matching.

Keywords: Stereopsis; Correspondence problem; Prior constraints; Wallpaper illusion

1. Introduction

The perception of depth from binocular disparity depends upon the correct matching of corresponding features between the left and right eyes' images. In complex scenes the visual system may be confronted with multiple candidate features for matching and must reduce the number of possible correspondences in order to attain a stable, unified representation of the scene. The resolution of this correspondence problem for stereo vision has been a topic of near constant interest for researchers in the 40 years since Julesz' popularisation of the random dot stereogram (Julesz, 1964). Many computational models of the correspondence matching process have been proposed (e.g. Jones & Malik, 1992; Marr & Poggio, 1976, 1979; Pollard, Mayhew, & Frisby, 1985; Prazdny, 1985; Prince & Eagle, 2000; Qian & Zhu, 1997; Read, 2002a, 2002b; Sato & Yano, 2000; Tsai & Victor, 2003). To resolve the correspondence problem, such models must limit possible matches with a series of constraints or rules. Models often differ in the constraints they use and the extent to which these are employed in an explicit (e.g. Marr & Poggio, 1976, 1979; Pollard et al., 1985) or implicit (e.g. Prince & Eagle, 2000; Qian & Zhu, 1997; Read, 2002a, 2002b) manner. Constraints on matching include feature similarity, matching to the nearest neighbour or nearest disparity, and considering only epipolar matches (for an extensive review of proposed matching rules, see Howard & Rogers, 2002).

In this paper, we concentrate on the visual system's adherence to the solutions provided by nearest neighbour, nearest disparity and contrast similarity matching rules. *Nearest neighbour* matches (Arditi, Kaufman, &

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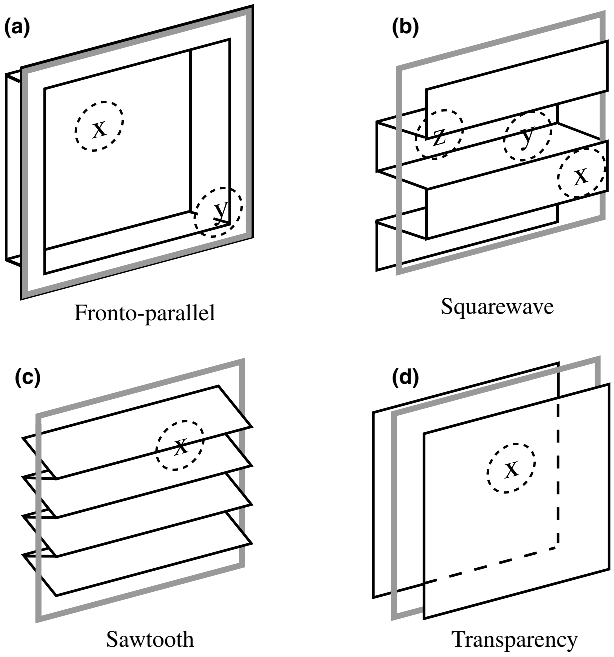
Movshon, 1981) minimise the absolute disparity of image features. That is, they select the correspondence solution that places the image feature closest to the horopter. In contrast, the *nearest disparity* rule (Marr & Poggio, 1976, 1979; McKee & Mitchison, 1988; Mitchison & McKee, 1987a, 1987b) minimises the relative disparity of image features, giving the correspondence solution that minimises the difference in disparity between nearby points. As such, the nearest disparity rule has been thought of as a 'smoothness' constraint and is often referred to as a continuity or cohesiveness constraint. The contrast similarity rule is one of a series of constraints—including also, orientation similarity—concerned with feature similarities. Under this constraint, matches are made between features of maximally similar contrast (Smallman & McKee, 1995).

Despite the suggestion of so many constraints in the literature, very little research has been conducted to examine the competition between matching rules. There is precious little empirical data showing which solution the visual system adheres to when confronted with multiple plausible matches (i.e. multiple matches that satisfy one or more matching constraint). Zhang, Edwards, and Schor (2001) recently investigated this issue. Using a periodic stimulus consisting of a one-dimensional luminance Gabor flanked, above and below, by two similar Gabors, they found that matching tends towards the solution that minimises the disparity between adjacent surfaces; that is, the solution that minimises relative disparity. This finding was particularly interesting since their stimulus put nearest neighbour and nearest disparity matching rules into conflict. Their experiments thus suggest that the process of correspondence matching is concerned more with finding solutions that satisfy the nearest disparity constraint than those that satisfy the nearest neighbour constraint.

One important characteristic of the study of Zhang et al. (2001) is that their stimuli consisted of three isolated objects rather than a single surface, so their result can be interpreted as a contextual effect. Furthermore, the stimuli used by Zhang et al. (2001) contain a potential confound between local changes in disparity and the total change in disparity across the scene. We here define this maximum change in disparity across the scene as the *global relative disparity*. This distinction between local and global relative disparity is clearer if one considers the relative disparities that arise, at a global and local level, with different stimuli. Consider the stimuli depicted in Fig. 1. Fig. 1a illustrates a single, fronto-parallel surface in depth, with two local areas—x and y—highlighted. At area x relative disparity is zero, since all points are at the same depth. However, at area y, relative disparity is determined by the difference in disparity between the stimulus and a zero disparity surround. Thus, although relative disparity is zero across much of the image, the relative disparity across the entire image—the *global relative disparity*—is determined by those few areas containing a difference in disparity between stimulus and surround. Figs. 1b–d illustrate increasingly complex stimuli, where the presence of local areas with zero relative disparity is increasingly scarce. In such stimuli the global relative disparity is determined by the largest change in disparity across the entire scene. For example, in the case of the squarewave illustrated in Fig. 1b, the global relative disparity is the peak-to-trough disparity of the waveform.



Fronto-parallel

Squarewave

Sawtooth

Transparency

Fig. 1. Distinction between locally and globally defined relative disparities. All four figures (a–d) have identical global relative disparity—defined as the largest change in disparity across the entire scene—but different local relative disparity structure. (a) Illustration of a fronto-parallel surface located behind a frame. Highlighted areas x and y show points where relative disparity is zero (x) and non-zero (y). Global relative disparity is determined by the disparity between the surface and the surround (y). (b) Illustration of a squarewave modulation in depth. The squarewave contains many areas where relative disparity is zero (x and y), though fewer than (a). Global relative disparity is determined by the peak-to-trough relative disparity of the waveform (z). (c) Illustration of a sawtooth modulation in depth, which contains no areas with a relative disparity of zero (e.g. area x). Global relative disparity is determined by the disparity at the sharp depth transitions. (d) Illustration of two overlapping transparent surfaces in depth. Local relative disparity is never zero since both surfaces are present within any local area (x). Global relative disparity is determined by the disparity between front and back surfaces.

Readers should note that a stimulus with a small global relative disparity may, locally, have a great deal of variation in disparity. Consider the transparent surfaces depicted in Fig. 1d. There are no local areas containing zero relative disparity in such a stimulus since, over a local area, both surfaces are visible. However, the global relative disparity—determined by the disparity between front and back surfaces—may be small if the separation