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Spatiotemporal Stereopsis

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Perhaps one of James Gibson's most important insights was that certain changes over time at the edges of a moving object can serve as invariant information for the boundaries of that object (Gibson, Kaplan, Reynolds, & Wheeler, 1969). Recent work suggests that the class of changes that can define the boundaries of a moving object extend well beyond the original suggestion of accretion and deletion. Changes in color, shape, and location of texture can also be used to perceptually define the boundaries of a moving object (Shipley & Kellman, 1993). Furthermore, both the spatial and temporal density of these changes appears to play important but independent roles in the perceptual process, which we refer to as spatiotemporal boundary formation (SBF). However, relatively little is know about how SBF interacts with other perceptual processes. There has been some work on perception of depth in accretion/deletion displays that suggests the perception of depth may be effected by the motion of texture elements relative to boundaries (Yonas, Croton, & Thompson, 1987). Furthermore, Lee (1970) has suggested that the visual system can utilize the disparity between contours defined by accretion/deletion to perceptually localize an object in depth (Lee refers to this information as "kinetic disparity"). Here, we explore Lee's suggestion by studying how spatial variations in changes over time affect stereopsis based on the disparity of spatiotemporally defined boundaries.

Method

Subjects. 8 undergraduates served as subjects in each experimental condition.

Apparatus. A mirror stereoscope was used to view displays presented on two Macintosh High Resolution color monitors. The monitors were 20.3 cm high by 26.7 cm wide with a resolution of 28 dots per cm. Viewing distance was 90 cm.

Displays. The stereo-displays consisted of two fields of stationary discrete circular elements (3 arc min) distributed randomly over a 4.8 by 4.8 arc deg area. The position and color of the elements in the left and right field were identical except as noted below. The number of elements varied across displays from 50 to 400. In the first experiment (which employed unidirectional (UNI) element transformations, see Figure 1) all of the elements were white on a black background. In the second experiment (bidirectional (BI) transformations, Figure 1) half of the elements were black and half white, all were randomly distributed on a black background.

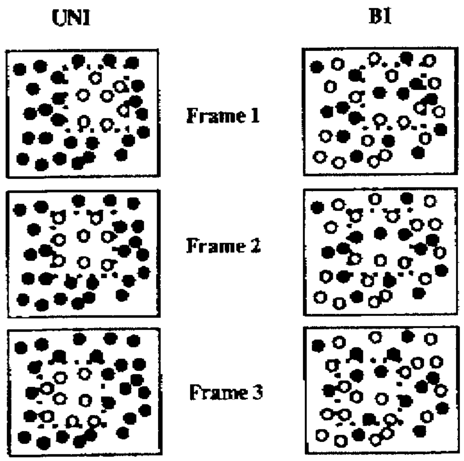

Figure 1. Three frame sequences illustrating unidirectional (UNI) and bidirectional (BI) transformations with a square region. For the purposes of illustrative clarity, the colors of the elements and background in this figure, are the reverse of the colors used in the experimental displays. So, the open and filled circles correspond to black (invisible) and white (visible) elements, respectively.

In each display one of ten mathematically defined regions (e.g. triangle, circle, several unfamiliar shapes) (~1.8 arc deg) moved along a circular path transforming the elements in an all-or-none fashion. As a region edge (either a leading or trailing edge) encountered an element, the element's color was changed (from white to black or vice versa). In the UNI displays all of the elements inside the region were invisible (black on black background; illustrated with open circles in Figure 1). In the BI displays half of the elements inside the region were white (transformed from black; illustrated with filled circles in Figure 1) and half black (transformed from white). Since the region moved in a circular path, all edges functioned as a leading edge at some point, and as a trailing edge at some other point.

The stereoscopic disparity of a region was varied by changing the horizontal offset of the region's path in the two images. Crossed, uncrossed, and no disparity displays (i.e. the region is in front, behind, and on the field of elements, respectively) were created using an offset of -8 (10.8 arc min), +8, and 0 pixels, respectively. In displays with an offset, some elements would change at different times in the two images. So the only difference between the left and right images was in the color of the few elements located in the area defined by the offset between the two regions. In UNI displays, spatial luminance differences, due to the absences of visible elements inside the moving region, could be used to determine binocular disparity. In BI displays, no such spatial information (not even the spatial differences in texture motion found in Lee's display) is available to define the boundaries of the moving regions. There is, however, spatiotemporal information in the pattern of element changes over time that occur at the edges of the moving regions. If the visual system can use the binocular disparity between spatiotemporally defined edges, then depth should be seen in these displays.

Procedure. Subjects were given two tasks, a 10-alternative forced-choice (10-AFC) where they had to identify the shape of the moving region, and a 3-AFC where they had to identify the depth of the moving region relative to the field of elements ("In Front", "On", or "Behind" the elements).

Using ten regions, four element densities, and three disparity levels yielded 120 trials. The 120 trials were presented in random order. After every tenth trial, subjects were asked to make a simple stereoscopic depth judgment to make sure they were still fusing the left and right images.

Results and discussion

Subjects correctly identified the shape of the moving region on 86% of the trials in the UNI case and 54% in the BI case. Shape identification accuracy increased with increasing spatial density of element changes ($F(3,42)=117.9$, $p<.001$) (see Figure 2).

Subjects could use the disparity of edges defined over time to perceive the depth of a moving object; they were significantly above chance in judging depth for all three disparities in both the UNI and BI cases (for the *set of three comparisons*, $t(31) > 4.05, p < .001$). Overall depth accuracy was 69% and 57% for the UNI and

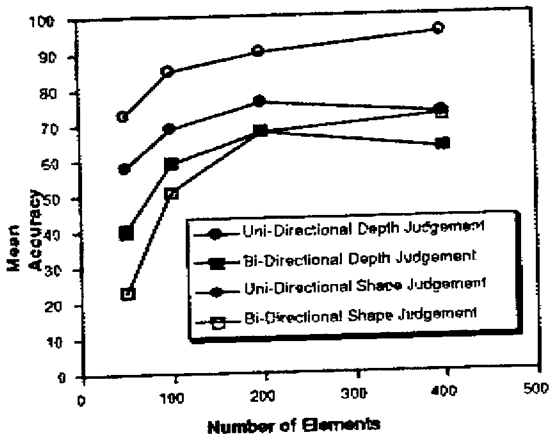

Figure 2. Shape and depth accuracy for UNI and BI displays as a function of the number of texture elements in each display.

BI conditions respectively. Depth accuracy increased with increases in element density (*for the set*, $F(3,42) > 6.4, p < .001$) for both the UNI and BI cases (see Figure 2).

When one surface occludes another, the surface that is being accreted and deleted is always behind, and the unchanging surface is in front (Gibson et al. 1969; Yonas et al. 1987). In the UNI case, the interior of the moving region does not change, but the field of elements is being accreted and deleted. This would, in everyday life, mean that the moving region is in front of the field of elements. It is interesting to note, then, that subjects were significantly above chance in judging depth in the "Behind" and On" conditions (63% and 64% respectively) where the occlusion related information conflicts with disparity. However, depth accuracy was higher in the "In Front" condition (80%) than in the other two.

Subjects can accurately identify the depth of a figure even when its boundaries are defined by purely spatiotemporal information. That subjects are using boundary information is consistent with the relatively high correlation between shape and depth accuracy ($r = .93$). Clearly, the results of a SBF process can be used for binocular matching. It remains be seen whether or not the reverse holds: can local changes in disparity be used to define the boundaries of a moving object?

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