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Flank transparency: transparent filters seen in dynamic two-color displays

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Abstract. Flank transparency is the perception of a colored transparent filter evoked by apparent-motion displays containing as few as two colors. Displays of flank transparency contain a random array of line segments placed on a uniform background. Small flanks are added to the line segments if the segments fall in the interior of a moving virtual shape, such as a virtual disk. This leads to the perception of a colored transparent disk with well-defined boundaries moving over the array of lines. Current qualitative and quantitative models of luminance and color conditions for perceptual transparency do not account for flank transparency as they require displays containing at least three different colors.

1 Introduction

Perceptual transparency refers to the impression of seeing objects in different depths one through another in the same direction of view (Koffka 1935). The visual system thus attributes the information at one point of the image to several distinct causes in the environment. The occurrence of physical transparency is neither necessary nor sufficient to trigger this image decomposition, which is commonly called scission or laminar segmentation (Mausfeld 1998), and this fact makes evident the need for a psychological model of the perceptual processes involved.

Various such models have been proposed which deal with different stimulus aspects required in order to evoke the perception of transparency, such as qualitative and quantitative conditions for luminance (Metelli 1970; Beck et al 1984; Gerbino 1994), color (Da Pos 1989; D'Zmura et al 1997; Faul 1997), and figural characteristics (Metelli 1974; Kanizsa 1979; Anderson 1997). Four lines of research dealing with perceptual transparency are briefly outlined below, with a focus on the type of stimulus material that is used.

Metelli (1970) studied the generative equations of color fusion using an episcotister over a bipartite background to produce his widely cited episcotister model for transparency in achromatic displays. This setup results in displays consisting of four different areas (figure 1), which are often used in transparency research. Kanizsa (1979, page 155) indeed thought that "in order to have the impression of transparency we need, first of all, four areas in the visual field".

With recent efforts to understand color transparency (Chen and D'Zmura 1998; D'Zmura et al 2000) came the use of more complex stimuli with a higher number of areas, similar to those used in related research on color constancy. The models derived from this line of research also require a minimum of four distinct colors in the display.

Investigations of the role of X and T junctions in transparency displays made by Watanabe and Cavanagh (1993) and Anderson (1997) demonstrate qualitative conditions for scission and transparency to occur. These analyses require images containing at least three differently colored areas. Fuchs transparency (Fuchs 1923; Masin 1998) does not rely on X or T junctions, but also requires the presence of three different areas in the stimulus.

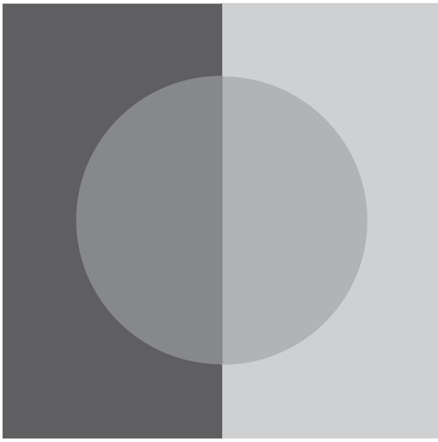

Figure 1. Conventional transparency display with four areas.

Color-from-motion displays created by Cicerone and Hoffman (1991, 1992; Cicerone et al 1995) and Shipley and Kellman (1993, 1994) also evoke perceptual transparency in displays with three distinct colors. Here, apparent motion triggers neon color spreading and the impression of a moving transparent disk. Indeed, most static or dynamic color-spreading displays were found to give rise to perceptual transparency (see eg Nakayama et al 1990; Bressan et al 1997), albeit sometimes faintly so. Ekroll and Faul (submitted) modelled transparency in neon-color-spreading displays with an adaptation of Faul's (1997) extended episcotister model, which requires at least three different colors.

2 Flank transparency

Given below is a way to generate flank transparency from only two colors while still inducing the vivid impression of a moving transparent disk. The display results from combining dynamic color spreading (see eg Cicerone et al 1995) with a static edge-induced color-spreading effect devised by Pinna (Pinna 1987; Pinna et al 2001; see also Broerse et al 1999).

The display is similar to those from Cicerone and Hoffman or Shipley and Kellman in the sense that it is animated and has a virtual disk moving over a static background. The background is a uniformly colored field containing line segments randomly spread across it, with all line segments having the same color as each other, but a different color from the uniformly colored field. In each frame the virtual disk is horizontally translated a slight amount, and little flanks of the same color as the lines are added collinear to them in the interior of the disk. The result is a slight thickening of those line segments that are inside the disk (figure 2). While each frame alone produces at best a faint impression of illusory contours and color spreading, the animated display evokes the clear perception of a transparent disk with well-defined boundaries moving over an array of line segments. The effect is strongest if the observer views the disk parafoveally.

An effective display has a white background, and comprises a visual angle of about 15 deg. It contains black lines of width about 0.2 deg and length 4.5 deg with black flanks one or two pixels in size. The virtual disk of size 2.5 deg moves roughly at a speed of 3 deg s^{-1}.[(1)] In the case of black lines and flanks on a white background, the perceived color of the disk is a light gray. Four observers matched the luminance of a solid achromatic disk to the luminance of the virtual disk in four trials each. CIE 1931 (Wyszecki and Stiles 1982) coordinates of the solid disk were $x = 0.28$, $y = 0.30$, luminance $= 133$ cd m^{-2}, averaged across trials and subjects. The standard

[(1)] A version of this display can be found at http://aris.ss.uci.edu/cogsci/personnel/hoffman/Applets/Outline/Outline.html

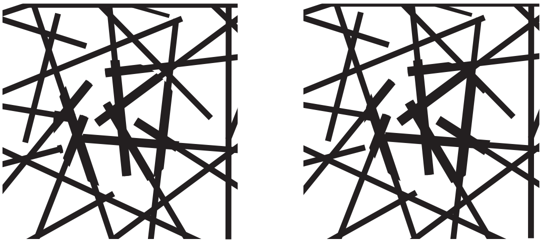

Figure 2. Two frames from a flank-transparency display. The two frames can be stereo fused to give some impression of the flank-transparency effect.

error of the luminance adjustment was 9.98 cd m^{-2}. The CIE coordinates of the lines and the background were $x = 0.28$, $y = 0.30$, luminance $\leqslant 0.2$ cd m^{-2} and $x = 0.28$, $y = 0.30$, luminance $= 156$ cd m^{-2}, respectively. All lights were measured with a Spectracolorimeter (Photo Research, PR-650).

Small gaps between lines and flanks can be added without destroying the effect. Making the color of the line flanks different from that of the line segments creates another type of stimulus that contains three distinct colors and therefore resembles more closely traditional neon-color-spreading displays, and particularly those used by Cicerone and Hoffman and by Shipley and Kellman. Casual observation indicates that in this case the perceived color of the disk is a variant of the color of the flanks.

Flank transparency differs from standard two-color displays of subjective surfaces such as Kanizsa's (1979) triangle or Parks' (1980) disk in that subjective surfaces are seen as opaque, not as transparent. Flank transparency differs from kinetic occlusion, where again the subjective surfaces are seen as opaque (Kaplan 1969). Flank transparency also differs from transparent versions of Kaplan's display in which two fields of identically colored dots drift past each other. In these displays no colored filter is seen whereas in flank transparency a colored filter is seen.

It is evident that the perception of transparency is determined by the interaction of multiple different cues, such as form, luminance, and color. However, the way these cues are integrated is not clear. We demonstrate that, with the introduction of apparent motion as a powerful shape cue, luminance conditions are effectively bypassed that in traditional perceptual transparency displays are required to hold.

Regardless of the relative influence of one particular cue class, two main questions addressed by models of color and luminance can be asked for any kind of perceptual transparency display. First, under which color and luminance circumstances does the visual system decompose the image into two separate layers such that transparency is perceived? Second, how does the visual system assign properties to the perceived transparent layer, ie color and degree of translucency? As we have pointed out, we are not aware of a current model that can be applied to our display in order to answer these questions.

3 Conclusion

Flank transparency shows that only two different colors are necessary in a display in order to create the impression of a transparent filter. This poses a problem for current qualitative and quantitative models of perceptual transparency and neon color spreading (see eg Bressan et al 1997 for a review); in their current form these models apply only to richer stimulus classes, and in particular require the presence of at least three differently colored areas. It seems necessary to include motion as an important cue for triggering or enhancing the perception of illusory contours, color spreading, and transparency in order to achieve a more complete understanding of the mechanisms underlying these phenomena.

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