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**TRANSPARENCY**

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Transparency began to be studied quite early in the 19th century, and it yielded a number of puzzles and apparent paradoxes (see Helmholtz-Hering controversy).

But what is transparency? As Metelli mentions [1], one can consider two meanings of the word "transparent". One is the physical one, i.e. the fact that light passes through a thing or medium. The other one is characterized as "perceptual", i.e. the fact that one not only sees the surfaces behind a certain medium, but also one is aware of this medium. In other words, in a certain scene, one perceives two different layers (in the simplest example). It turns out that the physical and the perceptual aspects of transparency are distinct, which is to say that it is neither necessary nor sufficient to superpose a transparent layer over an opaque one in order to obtain a scene in which one perceives transparency. Illustrative examples can be given from the two dimensional world [1] which is simpler to consider than the Euclidean space.

The fact that the above condition is not sufficient is proved by creating a scene in which a transparent layer exactly covers a homogeneous opaque layer. This scene does not create the sensation of transparency. The condition is not necessary because one can create scenes out of opaque pieces that exhibit transparency (the Metzger mosaics).

Then what is going on in the process of perceiving transparency? A first point to establish is the level at which the human vision system decides that a scene exhibits transparency. Marr [2] suggests that transparency as well as many other perceptions (fluorescence, disparity, texture, etc.) are computational problems in low level vision. Low level vision is faced with intensity arrays and its duty is to encode symbolically the useful information contained therein. What information has to be extracted in order to assert transparency of a certain scene? For simplicity my work was done on achromatic Mondrians (flat areas divided into subregions of uniform mat shades of gray). Intuitively one deals with two types of constraints: the figural constraints and the color constraints.

Metelli [1] suggests that there are three main figural constraints: figural unity of the transparent layer, continuity of the boundary line, and adequate

stratification. He gives examples illustrating all these cases, but his approach to the problem is not systematic and does not show any way to mechanize the process.

However one of his examples is rather interesting and offers some insight into the problem. Consider figure 1 and figure 2.

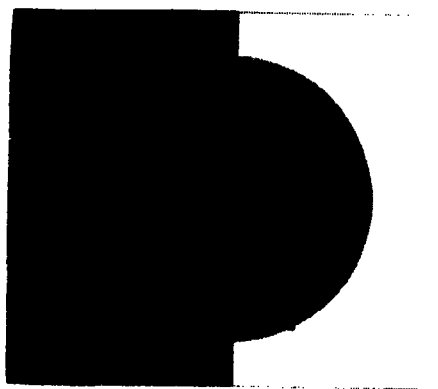


FIGURE 1

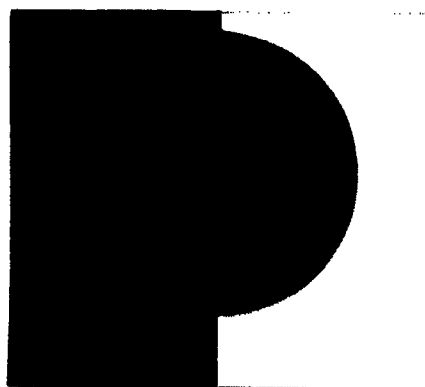


FIGURE 2

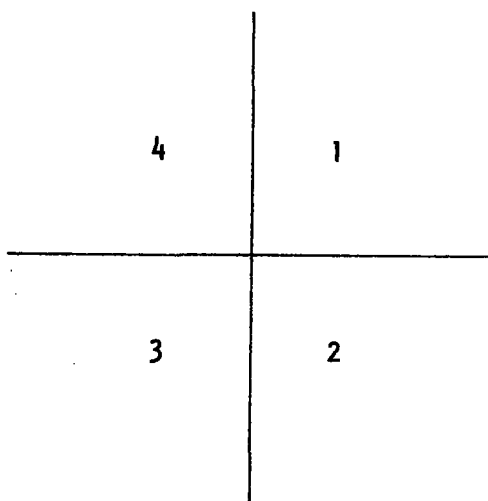


FIGURE 3

At first sight one perceives transparency only in figure 1. But if one thinks of a figure obtained from a disk by sliding one of its halves against the other, then figure 2 exhibits transparency as well. The moral is that, in establishing which figure is which, the vision system likes, if it has a choice, to follow a smooth line (whose derivative is continuous) provided that some conditions discussed below are satisfied). But if it receives a high-level message then it discards its algorithm and uses whatever choice was indicated.

But let's go back and see how the default choice is made. Let us suppose that all the lines in the scene are found, and one wants to know which figure is which. One method is to travel along the contour lines. When a contour line closes, one can assert that it is a figure (object). In the process one encounters joints, and therefore has to make decisions about which direction to follow. It turns out that the crucial points are the x-joints (points where four regions meet), i.e. a point around which the lightness function [4] has four discontinuities. This also suggests that from the information obtained by the cortex [3] the step changes in intensity are important (at least at this stage). If the figure-finding algorithm encounters a T-joint (point where three regions meet), then it does not take the smooth path (with the continuous derivative). If, on the contrary, it is an X-joint, then one is faced with a possible candidate for transparency, i.e. it might be the smooth path, and one can find a figure which is perceived in a different layer than the background. This seems to be the point where all the counterexamples of Metelli's criteria succeed.

Now once an X-joint is found, one has to check the color constraints. They also seem to help in describing a once-found transparent-scene (i.e., more transparent, more translucent, different degrees of transparency). Consider in figure 3 a typical X-joint -- regions 2 and 3 belonging to the transparent layer. Denote by  $r_i$  the reflectance of the region  $i$ , by  $I$  the illuminance, by  $t$  and  $r$  respectively the (double) transmittance and the reflectance of the transparent layer and by  $i_i$  the intensity of region  $i$  (supposedly they are homogeneous). Then

$$\begin{aligned}
 i_1 &= tr_1 \\
 i_2 &= l(tr_1 + r) \\
 i_3 &= l(tr_2 + r) \\
 i_4 &= tr_4
 \end{aligned}$$

where  $t + r < 1$ , and  $r_i < 1$

Suppose for concreteness that  $r_1 > r_2$ . This implies that  $i_1 > i_4$  and  $i_2 > i_3$ . Some algebraic manipulation shows that if the X-joint is to yield a candidate for transparency then one of the following must be satisfied:

$$i_1 > i_2 > i_3 > i_4 \quad (1)$$

$$i_1 > i_2 > i_4 > i_3 \quad (2)$$

$$i_1 > i_4 > i_2 > i_3 \quad (3)$$

$$i_2 > i_3 > i_1 > i_4 \quad (4)$$

If none of the above conditions are satisfied, then the color test fails. If  $r=0$  (perfect transparency -- no translucency), then

$$i_1 i_3 = i_2 i_4$$

It is interesting to notice that given an X-joint and the four intensities associated with it, one cannot tell where the transparent layer is. This can be seen easily from the above inequalities. One cannot even say (in the general case) to which layer the brightest or the darkest area belongs. (In the special case,  $r=0$ , the brightest belongs to the opaque layer whereas the darkest region belongs to the transparent layer). This also says that one has to keep information in hand to establish where the transparent layer is (the sense in which one traverses the contour).

It turns out that the conditions (1)-(4) are necessary color conditions (constraints). One can study the effect of varying the shades of gray in an X-joint

in order to get refined descriptions for the scene. Some of the scenes look more transparent, others more translucent. It turns out that effects are produced by small differences in intensity between different regions. A scene looks more transparent if the difference in intensity between the covered regions and the opaque layer are respectively very small (in figure 3 the difference between regions 1 and 2 and also 3 and 4). Similarly, a scene looks more translucent if the difference in intensities between regions 2 and 3 is small. How small? It is hard to quantify because humans seem to have different thresholds in this matter (some of my subjects did not recognize as "translucent" scenes that some others did).

A more interesting problem seems to be that of recognizing scenes that exhibit different degrees of transparency (i.e., the transparent layer is not homogeneous). This is another label that one can attach to a scene found to be transparent and I believe that this one is the default label (it is attached when the other two tests fail).

This was suggested to me by the following experiment: consider a "more translucent X joint". region 1 is white, region 4 is black, and the other two are similar shades of gray. If region 3 is replaced by a darker gray, then the image changed considerably and region 2 looks like a darker transparent layer. I repeated the experiment using other arrangements of shades of gray with the same result. More accurate measurements and experiments are required in order to clarify the ranges for different naming.

BIBLIOGRAPHY

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