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Induced effects of backgrounds and foregrounds in three-dimensional configurations: the role of T-junctions

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Abstract. In three-dimensional configurations, and two-dimensional pictures of such configurations, simultaneous contrast induction from proximate backgrounds affects perceived brightness, color, and internal contrast to a greater extent than induction from coplanar or occluding surrounds or from more distant backgrounds. In the projected image the presence of occluding flanks or retinally adjacent distant backgrounds is indicated by T-junctions. However, the presence of T-junctions inhibits induced contrast irrespective of the three-dimensional percept. The configurations in this paper refute the notions that perceived coplanarity or perceptual belonging necessarily enhance induced contrast.

1 Induced brightness in three-dimensional configurations

A grey region appears brighter when viewed on a darker enclosing surround and darker when viewed on a brighter surround (Chevreul 1839). When the surround is variegated in brightness, the perceived brightness of the test region can depend on a multitude of factors. For example, in figure 1 (top row) the grey regions in the centers of the two configurations were made of identical materials and are of identical luminance (a purely physical measure), yet the grey region in the picture on the right appears considerably lighter than the grey region in the picture on the left. The top row of figure 1 consists of a photograph of two figurally identical three-dimensional configurations, each consisting of an H shape in the foreground with the grey square being the horizontal bar between the two vertical bars, and a larger square flap at an angle behind the H. If the perceived difference in the brightness of the two grey patches is due to induced contrast, then on the right the brightness induced by the dark background is of greater magnitude than the darkness induced by the light vertical bars. Similarly, the inducing effect of the light background prevails in the configuration on the left. In both pictures, each grey region has equal perimeter flanked by dark and light, and the visible areas of the background flaps are smaller than the visible areas of the vertical flanks. In spite of this, induced contrast from the flaps dominates that from the vertical flanks. The bottom row of figure 1 also consists of a photograph of two figurally identical three-dimensional configurations, each consisting of an L shape in the foreground, a grey square embedded in the crook of the L, and a larger square flap at an angle behind the L. In the bottom row, as in the top, induced contrast from the background flaps dominates that from the flanking L. The phenomenal effect is the same whether the three-dimensional configurations are viewed monocularly or binocularly.

Some Gestalt psychologists have claimed that induced contrast is greater from surrounds if the test region is seen as belonging to them (Benary 1924; Kanizsa 1979). We have not been able to find an operational definition of perceptual belonging in the literature, but the grey test regions in these configurations are part of the H or L, ie belong with the vertical or horizontal bars rather than with the background flap. Domination of the induced effect by the background thus refutes the notion that induced contrast is enhanced by belonging. Since the test regions are seen as parts of coplanar Hs or Ls, these configurations also provide a counter-example to Gilchrist's

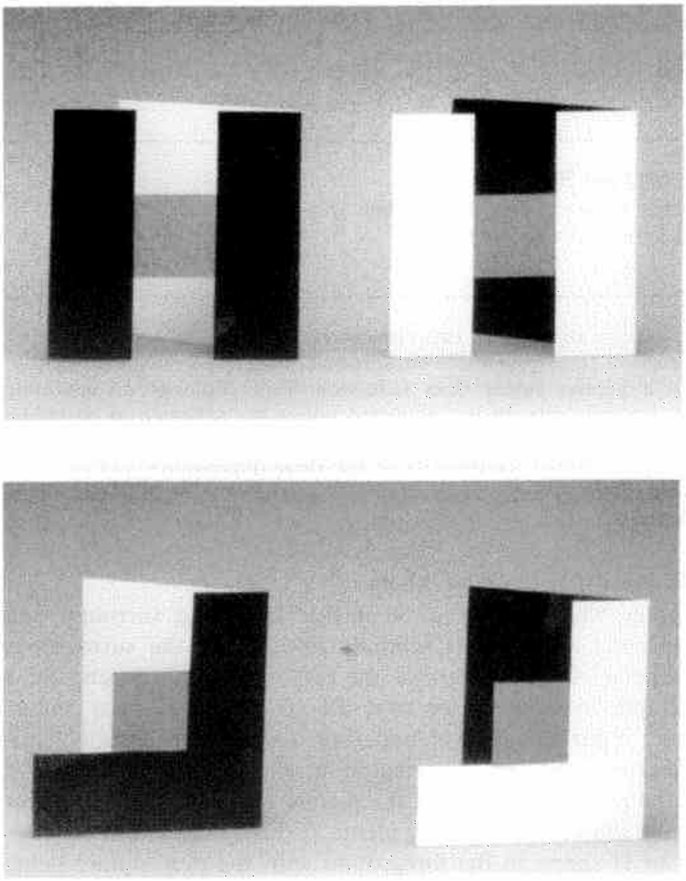

Figure 1. (Top and bottom row) Photographs of pairs of figurally identical three-dimensional configurations. In each row, the two grey regions are of equal luminance, so any perceived difference in brightness is due to a combination of induced lightness from dark surrounds and induced darkness from light surrounds. The relative brightness of the two grey regions can be used to infer the strength of the induced effect from the background versus the effect from the flanking surrounds.

(1977, 1980) coplanar-ratio hypothesis: "Perceived lightness of the target is governed by the luminance relationships between the target and whatever regions are seen as coplanar. The luminance relationship between the target and non-coplanar regions (despite retinal adjacency) is substantially irrelevant to the lightness of the target" (also see Hochberg and Beck 1954; Gogel and Mershon 1969).

To function effectively in the real world, an observer must segregate different objects from each other and from the background. A number of visual cues, including brightness, color, texture, motion, shape, stereo-disparity, and occlusion facilitate this task. In a number of studies it has been shown that the perceived magnitude of almost every visual modality is influenced by the magnitude of that modality in the surround. In fact, Chevreul's (1839) law of simultaneous contrast of colors can be safely generalized: "In the case where the eye sees at the same time two contiguous fields, they will appear as dissimilar as possible in almost every modality". Obviously, a visual process that enhances perceived differences between contiguous fields will facilitate object segregation. In a three-dimensional world some segregations confer greater functional advantages than others. One that has received extensive consideration is segregation of figure from ground. We had two main aims in this study. First, to test whether there is a difference in induced contrast from surrounds that differ in perceived depth relationships, eg background, coplanar, or occluding, but which are equal in retinal adjacency to the test. Second, to identify among the cues that are used to perceive three-dimensional organization those that also influence induced contrast.

To eliminate lighting, shadowing, and viewpoint variations, and to enable precise control over the stimuli and measurements, we have chosen to work with CRT pictures of three-dimensional configurations, ie projections to the two-dimensional picture plane. Each retinal image of a three-dimensional configuration can be approximated by a two-dimensional projection, and retinal images on the two eyes are similar for objects at reasonably large distances from the observer. The use of pictures enabled us to concentrate on visual cues that are important in inferring three-dimensional organization from retinal images even when stereoscopic disparity is not available. By using a variety of orthographic projections (Foley et al 1990) we were able to identify visual cues which enhance or inhibit induced contrast independently of viewing angle and the presence or absence of other depth or perspective cues. Only a small number of the pictures examined can be presented here, but the conclusions reached in this paper held for every picture that was examined.

2 Induced effects of perceived backgrounds, coplanar surrounds, and occluders

Figure 2 shows the two-dimensional CRT display that was used to confirm the effects in the top row of figure 1. The phenomenal observations presented in this paper were confirmed by ten observers, including the three authors. All ten observers reported the grey region on the left as lighter than the grey region on the right. One observer suggested a legitimate perceptual alternative for the CRT picture, namely that the grey regions could be the visible portions of longer horizontal bars that were being occluded by the vertical parts of the H figure. The brightness illusion was in the same direction for this observer as for the others. Thus in this case the perceived background had a stronger inducing effect than occluders.

As additional evidence, we quantified the observations by the following method. A high-spatial-frequency background composed of alternating light and dark squares filled the screen. There were 400 squares deg^{-2} and the dark and light squares had luminances of 1.1 and 92.0 $\mathrm{cd\ m}^{-2}$. On one side of the midline, one of the pictures comprising figure 2 was presented. The light, grey, and dark regions were at 92.0,

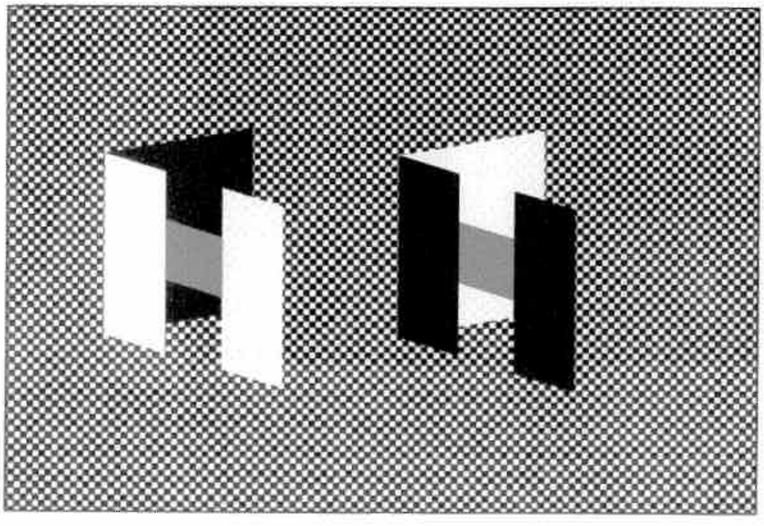

Figure 2. Two-dimensional CRT projections of the configuration in the top row of figure 1.

46.3, and 1.1 cd m^{-2}, respectively. Each side of the central grey region (the 'standard') subtended 1.0 deg visual angle. On the other side of the midline, and at the same distance as the standard grey region, a test region of the same size and shape was presented. The luminance of the test patch was adjusted to achieve a brightness match between the test and standard regions. The signed magnitude of the brightness illusion in figure 2 was represented by a single quantity—the perceived difference as a percentage of the standard:

$$\frac{L_\mathrm{L} - L_\mathrm{R}}{L_\mathrm{S}} \times 100\,, \tag{1}$$

where L_L, L_R, and L_S are the luminances in cd m^{-2} of, respectively, the test that matched the brightness of the standard in the left panel, of the match to the standard in the right panel, and of the standard itself which was identical in the two panels. This index was measured for every pair of comparisons presented in this paper for two of the authors, QZ and MS. For figure 2 the perceived difference was 29.00% for QZ and 22.63% for MS, consistent with the phenomenal reports.

The four pictures in figure 3 are presented in support of the notion that the vertical flanks and the background flap both induce brightness or darkness, and that the perceived brightness of the grey region reflects a mixture of the two effects. The top row is a copy of the two pictures in figure 2, except that the induced effects of the background flaps are equated by making them physically identical light-greys, so that the slightly brighter appearance of the test region in the right picture as compared to the test in the left picture is due wholly to induction from the vertical bars of the H shapes. For the measurements the light-grey surrounds were set at 69 cd m^{-2}. The perceived difference between the left and right grey regions was −11.96% for QZ and

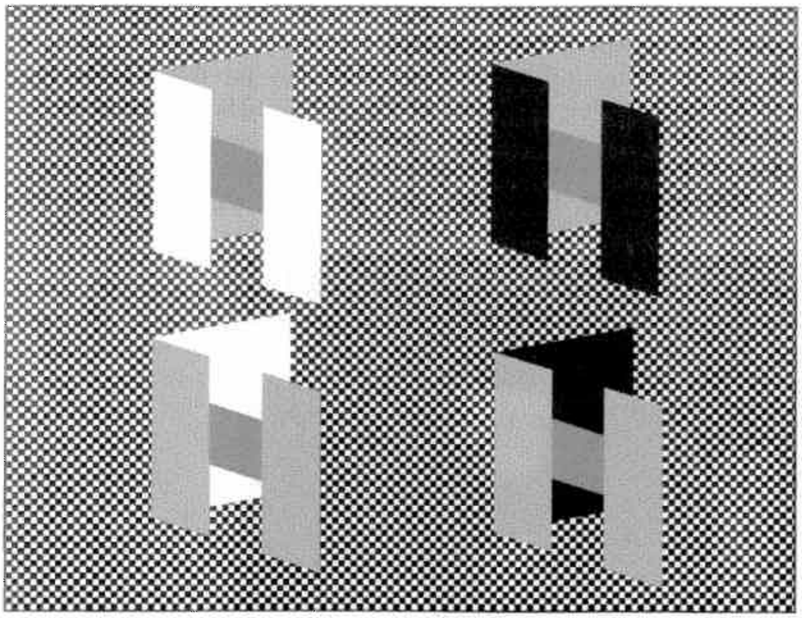

Figure 3. (Top row) A copy of the two pictures in figure 2, except that the induced effects of the background flaps are equated by making them physically identical light-greys, so that any difference in the brightness of the test regions is due wholly to induction from the vertical bars. (Bottom row) A copy of the two pictures in figure 2, except that the induced effects of the vertical bars are equated by making them physically identical light-greys, so that any difference in the brightness of the test regions is due wholly to induction from the background flaps.

−5.99% for MS (the negative sign indicates that the grey region in the picture on the left was matched by a lower luminance than in the picture on the right). The bottom row of figure 3 is another copy of figure 2, except that the induced effects of the vertical bars of the H shapes are equated by making them light-greys that are physically identical to the flaps in the top row, so that the considerably brighter appearance of the test region on the right as compared to the region on the left is due entirely to induction from the background flaps. The perceived difference between the left and right grey regions was −28.63% for QZ and −12.16% for MS. The larger perceived difference between the tests in the bottom row, as compared to the top row, indicates that the induced effects of the perceived backgrounds are stronger than those of the coplanar/occluding vertical flanks, and will dominate when the induced effects are opposite in direction as is the case in figure 2. Parenthetically, if the equating greys used in figure 3 are darker instead of lighter than the test, the conclusions reached are the same as above.

Without presenting additional demonstrations, we would like to note that in pictures similar to figure 2 we also examined perceived color and contrast (of textured fields). In configurations where a test region is encompassed by a surround, an achromatic test appears tinged with the hue that is complementary to that of its equiluminant colored surround (Krauskopf et al 1986), and the internal contrast of a textured region appears higher or lower when viewed on lower and higher contrast surrounds respectively (Chubb et al 1989). In the surrounds in figure 2 we replaced light and dark with pairs of equiluminant complementary colors (reddish and greenish, or yellowish and violet). In each case the test region was perceived as tinged with the hue complementary to the hue of the background flap. In another set of pictures we replaced the light and dark regions of the pictures in figure 2 with textured fields of high and low contrast around an identical mean luminance level, and the grey test regions with medium contrast fields of similar texture and mean luminance. The test region in the picture with the high-contrast background flap appeared of lower contrast than the test region with the high-contrast vertical bars. Consequently, color induction and contrast induction are influenced by the same perceptual factors as brightness induction.

3 Induced effects of perceived proximate and distant backgrounds

In many cases an object is viewed against multiple backgrounds at different distances. Figure 4 contains two figurally similar pictures, each of which is perceived by most observers as consisting of two planar surfaces angled with respect to one another, with the narrower plane (containing the central grey test region) in front of the larger plane. The test region in the picture on the right appears brighter than the test region in the picture on the left, even though they are of identical luminance. The perceived difference between the left and right grey regions was −46.53% for QZ and −20.45% for MS. Unlike figure 2, in both these pictures the induced effects from the flanking surrounds in the narrower plane dominate the induced effects from the backgrounds. This occurs despite the background having a greater visible area and at least an equal length of shared perimeter with the test. For some observers the brightness difference between the tests was smaller in figure 4 than in figure 2. The effects are more noticeable if the figures are viewed from a distance.

Figure 4 has been reproduced twice in figure 5, with the two backgrounds equated to light-greys in the top row, and the flanking surrounds equated to the same light-grey in the bottom row. In the top row the perceived difference between the left and right grey regions was −30.48% for QZ and −14.16% for MS. In the bottom row the corresponding numbers were −1.98% and −8.08%. In both rows the test regions in the picture on the left appear darker than the test regions in the picture on the right, indicating that brightness is induced both from backgrounds and from flanks. However, the difference in perceived brightness is larger for the test regions in the top row than for the test regions in the bottom row, indicating that the magnitude of induction is greater from the flanks than from the backgrounds.

In viewing the pictures in figure 4 some observers interpreted the narrow occluding planar surfaces as continuous regions overlaid with the grey test regions. For these observers, an analysis of the percepts in terms of foregrounds and backgrounds would

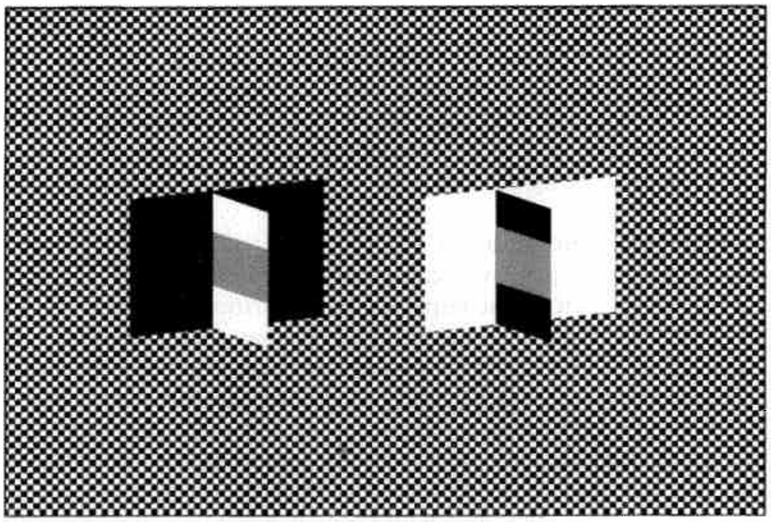

Figure 4. Two pictures of a three-dimensional configuration. The two grey regions are of equal luminance, so any perceived difference in brightness is due to a combination of induced lightness from dark surrounds and induced darkness from light surrounds. The relative brightness of the two grey regions can be used to infer the strength of the induced effect from the background versus the effect from the flanking surrounds on the top and bottom.

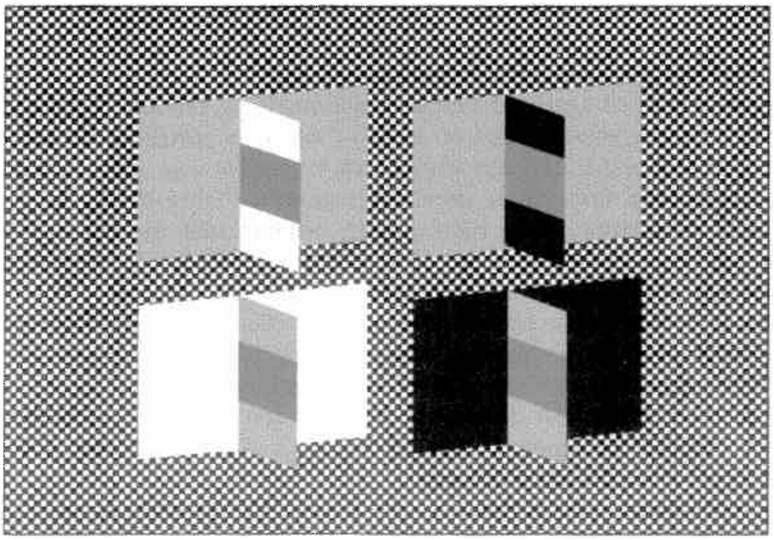

Figure 5. (Top row) A copy of the two pictures in figure 4 except that the induced effects of the backgrounds are equated by making them physically identical light-greys, so that any difference in the brightness of the test regions is due wholly to induction from the vertical flanks. (Bottom row) A copy of the two pictures in figure 4, except that the induced effects of the vertical flanks are equated by making them physically identical light-greys, so that any difference in the brightness of the test regions is due wholly to induction from the backgrounds.

lead to the conclusion that backgrounds that are perceived as closer in depth have a greater induced effect than more distant backgrounds, despite similar retinal adjacency. However, some observers interpreted the test region as coplanar with the flanks along the narrower plane, and for them induction from the coplanar flanks was greater than from the background, ie opposite to the effects for figure 2. Clearly, a common explanation for the brightness illusions in figures 2 and 4 requires a more elemental analysis, which is the purpose of the next section.

4 Analysis of White's illusion in terms of three-dimensional interpretations

White (1979) presented a remarkably simple brightness illusion that has resisted explanation both by simple additive models of induced effects (see the discussion section for an extended treatment of these models) and by higher level perceptual notions (Spehar et al 1995). White's original figure consisted of rectangular grey regions that replaced portions of the dark and light bars of a square-wave grating. The shorter sides of the tests abutted the bars they replaced, and the longer sides abutted bars of the opposite brightness. Paradoxically, the tests that replaced portions of the dark bars appeared lighter than the tests that replaced portions of the light bars. In figure 6 we have extracted the essential portions of White's pattern. Figure 6 consists of two pictures, each with a central test region enclosed by light and dark surrounds in a similar fashion as the tests in White's pattern. The test region on the right appears brighter than the test on the left, despite the fact that they are of identical luminance, that they share equal perimeters with light and dark surrounds, and that the light surround in the picture on the right subtends a larger area than the dark surround, whereas the dark surround subtends a larger area in the picture on the left. The perceived difference between the left and right grey regions was −28.14% for QZ and −16.29% for MS. These numbers are comparable to the standard White's illusion (Spehar and Zaidi 1997), and confirm that figure 6 represents an instance of White's illusion.

A number of investigators have suggested that perceptual inferences regarding depth and transparency may be important clues to understanding White's illusion (Spehar et al 1992; Taya et al 1995). Although it takes a different approach, this study was inspired by the possibility of testing hypotheses concerning specific perceptual inferences.

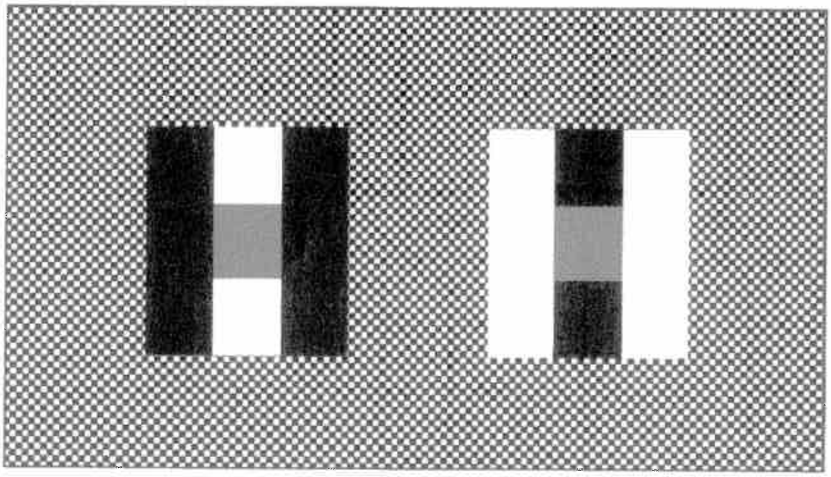

Figure 6. An extraction of the essential portions of White's (1979) pattern (see Zaidi 1990). The two grey regions are of equal luminance, so any perceived difference in brightness is due to a combination of induced lightness from dark surrounds and induced darkness from light surrounds.

In fact, the pictures in figure 6 are possible projections (frontal views) of both the three-dimensional compositions pictured in figures 2 and 4, ie figures 2 and 4 show two possible three-dimensional interpretations of figure 6.

In understanding the common factor underlying the illusions in the different perceptual interpretations of White's pattern we found it useful to analyze these pictures in terms of the line labels employed in recovering three-dimensional configurations from line drawings by Huffman (1971), Clowes (1971), Waltz (1975), Sugihara (1984, 1987), and particularly Kanade (1980). Any two-dimensional picture can be the projection of infinitely many different three-dimensional configurations, so in concordance with all of our observers we make the simplifying assumption that the pictures in this paper represent orthographic projections of configurations composed solely of planar surfaces, ie whose orientation is constant.

We will use Kanade's terminology. An *edge* is a straight boundary of a plane surface. A *vertex* is a point where edges of the surface(s) meet. A *line* is an orthographic projection of an edge to the picture plane. A *junction* is a point in the picture where lines meet, ie the projection of a vertex or the point where an edge is interrupted by an occluding surface. Junctions are classified according to the number of lines meeting at a point and their geometrical configurations in the picture, eg as L, arrow, fork, T, X, Psi, XK or asterisk. A *region* is an area in the picture enclosed by lines and corresponds to the visible part of a surface. In Kanade's dictionary there are three possible classifications of an edge according to its three-dimensional properties: '+' a convex edge along which two surface meet; '−' a concave edge along which two surfaces meet, '>' or '<' an edge along which the surface to the right of the arrow direction occludes the surface to the left. For planar surfaces, we have found it convenient to introduce a fourth class of edge: 'o' an edge along which two coplanar surfaces abut precisely.

Figures 7a–7e are line drawings of the projection shown in figure 6. To assign labels to the lines is equivalent to giving three-dimensional meanings to these drawings. A set of assignments of line labels to a drawing is called an *interpretation*. Since figures 2 and 4 provide two possible interpretations of this projection, they will be used as guides to label the line drawings. Figure 7a represents an interpretation of the

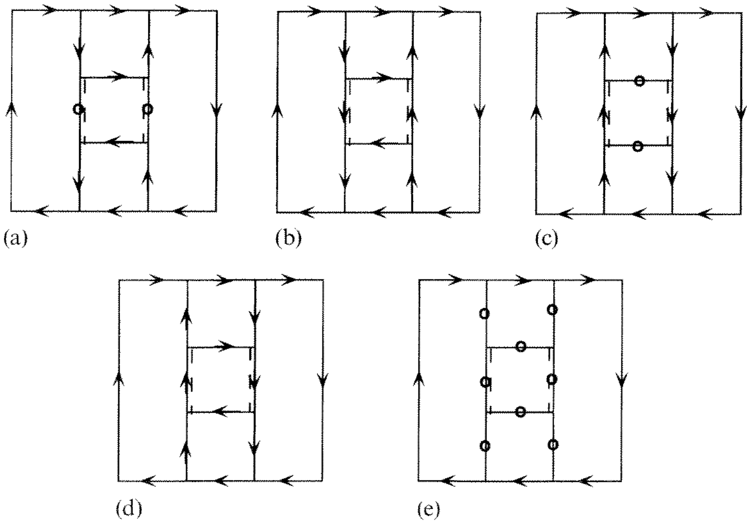

Figure 7 (a–e). Line drawings of the projection shown in figure 5, with assignments of line labels that give three-dimensional meanings to these drawings, corresponding to the three-dimensional configurations perceived in figures 2, 4, and 6.

projection that is consistent with figure 2 seen as an H shape in front of a flap, where all parts of the H are seen as coplanar. Figure 7b is an interpretation consistent with figure 2, if the H shape seen in front of the flap is seen as two vertical strips occluding a horizontal strip. Figure 7c interprets the projection as consistent with figure 4 seen as a coplanar narrow plane in front of the broader plane. The interpretation in figure 7d is consistent with figure 4 if the test region is seen as occluding a portion of the continuous narrow plane. The interpretation in figure 7e is consistent with seeing all parts of figure 6 as coplanar. (Figure 8 is an accordion pattern made out of the pictures in figure 6. Whereas figure 6 could be a frontal view of a three-dimensional configuration, in figure 8 each panel appears coplanar. The brightness illusion present in figure 8 is similar to the one in figure 6.)

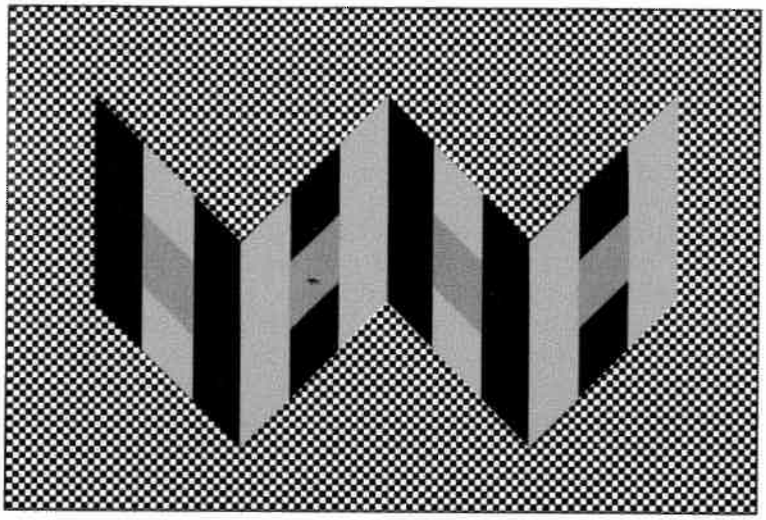

Figure 8. An accordion pattern made out of the pictures in figure 6, that shows the brightness illusion even when the percept of each picture is made explicitly coplanar by figural cues.

The central squares in figures 7a–7e represent the test region. To facilitate visual analysis, in each line drawing, the edges of the test across which induced contrast was weakest are indicated by an extra dashed line. An inspection reveals that, in all the drawings, the test regions are joined to the rest of the picture exclusively through T-shaped junctions, one at each of the corners of the test. For each T-junction we differentiate between the edges meeting at the shaft of the T and the edges meeting at each branch of the top. The line labels show that, for each drawing, all the T-junctions are of the same kind in terms of the types of edges that meet there, but that they differ from figure to figure. Despite the differences in type of T-junction, in all five drawings the edge of the test that is adjacent to the top of each T is dashed, ie it represents the edge that was resistant to induced contrast. We have found that this result holds not only for the cases demonstrated here, ie where the top of the T indicated that the test region was occluding, occluded by, or coplanar with the surrounding region, but also where the top of the T was labeled as a convex or concave edge. In other words, in every situation tested the presence of a T-junction inhibits induced contrast across the edge projected on to its top.

Junctions have been found to be useful in recovering shape from images, especially from raw range data. For example, in Sugihara's (1987) knowledge-guided system for range data analysis, a junction dictionary is used for the extraction and organization of edges and vertices, by consulting it to predict positions, orientations, and physical types of missing edges. These predictions guide the system as to where to search and what kinds of edges to search for, as well as how to label the extracted edges into an interpretation. An analysis of brightness illusions in terms of junctions affecting transparency and depth interpretations has previously been found useful by Adelson (1993) and Pessoa and Ross (1996). In particular, Pessoa and Ross (1996) followed up a suggestion of Spehar et al (1992) and looked at the role of T-junctions, but reached quite different conclusions emphasizing the importance of inferred coplanarity in White's illusion.

5 Analysis of Benary's cross illusion in terms of three-dimensional interpretations

In this section we show that an analysis in terms of line labels and junctions reveals a similarity between White's illusion and Benary's (1924) cross, which is another brightness illusion that has resisted explanation. Benary's original figure consisted of a thick dark cross on a light background, and two identical grey test triangles. One test was embedded in an arm of the cross such that it shared perimeters with the background and the insides of the cross. The other test was placed outside the cross, but fit into a crook of the cross, so that the two tests shared equal perimeters with the background and the insides of the cross. The test that appeared embedded within the cross appeared lighter than the test that appeared outside the cross, leading Benary to postulate that belonging enhances induced contrast. Figure 9 extracts the essential portions of the Benary cross illusion. The two central grey squares of identical luminance are enclosed by a larger and a smaller L-shaped region, each of which bounds two sides of the test, ie each test region is enclosed by light and dark surrounds in a similar fashion as the tests in Benary's cross. Even though the picture on the right contains the larger dark L, the test region on the right appears darker than the one on the left. The perceived difference between the left and right grey regions was 18.05% for QZ and 18.36% for MS. Hence figure 9 represents an instance of Benary's illusion.

When the configuration in figure 9 is analyzed in terms of line labels, each test square is shown to share two L-shaped junctions, one with each of the surrounding L-shaped regions, and two T-junctions with the edge shared with the larger L-shaped region projecting to the top of the T, and the edge shared with the smaller L region

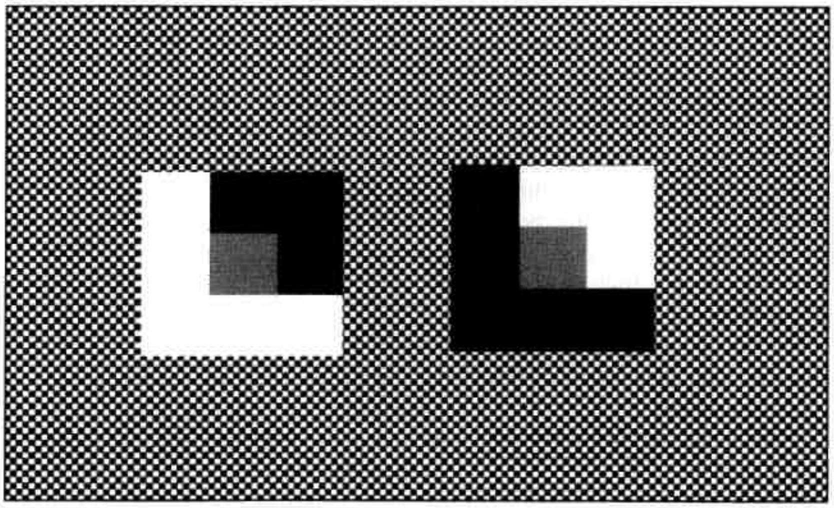

Figure 9. An extraction of the essential portions of Benary's (1924) cross. The two grey regions are of equal luminance, so any perceived difference in brightness is due to a combination of induced lightness from dark surrounds and induced darkness from light surrounds.

projecting to the shaft. Benary's illusion is thus explainable in the same manner as White's, ie induced contrast from the larger L regions is inhibited by the top edges of the two T-junctions, so that induced contrast from the smaller L regions dominates the perceived brightness of the test region.

In figures 10 and 11 we have provided pictures of two possible three-dimensional interpretations of figure 9. In figure 10 the test region is seen as coplanar with and belonging with the smaller L region, and in figure 11 as coplanar with and belonging with the larger L region. In figure 10 the perceived difference between the left and right grey regions were 24.02% for QZ and 12.16% for MS. In figure 11 the corresponding numbers were 16.01% and 6.10%. In both cases induced contrast is inhibited from the surround that is adjacent to the top of the T-junction with the test region. In particular,

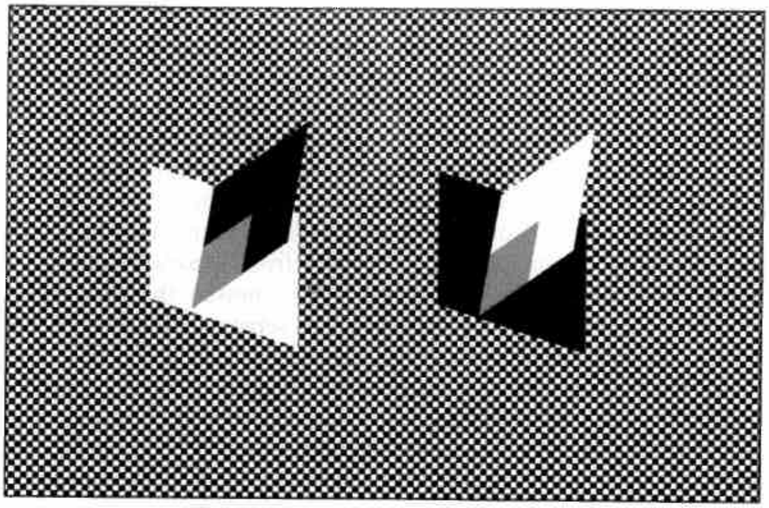

Figure 10. The grey regions are seen as coplanar with and 'belonging' with the smaller L region. The two grey regions are of equal luminance, so any perceived difference in brightness is due to a combination of induced lightness from dark surrounds and induced darkness from light surrounds.

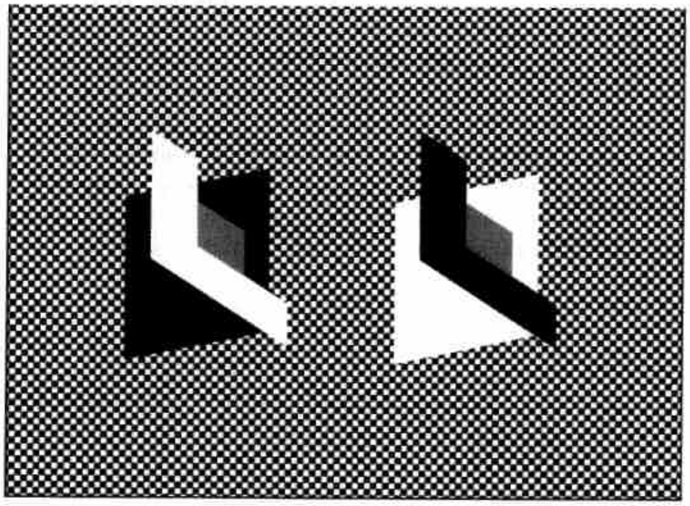

Figure 11. This depiction of the Benary cross illusion refutes explanations that are based on 'belonging' or coplanarity (eg Benary 1924), because the L-shaped region has less induced effect despite appearing coplanar and 'belonging' with the test region.

figures 11 and 1 (bottom row) refute explanations of the Benary cross illusion that are based on belonging or coplanarity (eg Benary 1924), because the larger L region has less induced effect despite appearing coplanar and belonging with the test region.

In the figure following the original illusion Benary showed that the illusion can be abolished by manipulating the figural configuration to make the test in the crook of the cross appear to belong to it. However, this manipulation also had the effect of removing the T-junctions. In fact, all of the brightness illusions presented by Benary (1924) can be explained by the T-junction analysis.

6 Discussion

We have cursorily suggested that the magnitude of brightness induction in the pictures in this paper cannot be explained without taking perceptual interpretations into account. This assertion needs to be justified, because even from a nonfigural variegated surround, brightness induction depends in a complex manner on the relative luminance of the test and individual regions of the surround, eg the same surround consisting of equal numbers of light and dark squares distributed randomly makes a test at higher than its average luminance appear darker than on a spatially uniform surround at the average luminance, and makes a test at lower than the average luminance appear lighter than on the spatially uniform average luminance surround (Zaidi et al 1995).

When the surround of a test region contains spatial variations in brightness, the total induced effect is some combination of induced effects from separate regions of the surround. Zaidi et al (1992) and Zaidi and Zipser (1993) showed that brightness induction can be modeled as a summation of the effects of separate elements of the surround, where the effect of each element falls off as a negative exponential function of distance from the test. They used a method of producing spatial variations purely by temporal modulation of the luminance of individual pixels of a display, thus equating the DC luminance of all points in the stimulus and separating the effects of induction from those of DC adaptation. To simulate spatially complex surrounds they used basis functions consisting of concentrically and radially varying spatial sinusoids, and as evidence for additivity of independent induced effects from individual elements of the surround showed that the induced effect of superimposed sinusoids was equal to the sum of the effects from individual components. Spatial additivity of effects is independent of a possible nonlinear decrease in weighting of effects as a function of distance from the test. Because brightness induction satisfied the superposition test, the spatial weighting function was estimated from the Fourier transform of the function relating magnitude of induction to the spatial frequency of sinusoidal surrounds. Spehar et al (1996) extended this work to the case where the surround consisted of random binary noise texture which contained spatial variations with no discernible figural interpretation, and where individual elements were at different DC luminance levels. They found that the weighted spatial summation model provided excellent fits to their data, when augmented with contrast-gain controls on lateral connections and spatially local luminance-adaptation mechanisms.

For each of figures 2, 4, 6, and 9 in this paper, the prediction of the relative brightness of the test regions by the model was opposite to the perceived effects, thus indicating that figural cues have to be factored into any adequate explanation. It is possible that incorporating perceptual cues that influence induced contrast, eg T-junctions, will eventually lead to mechanistic models that can explain brightness perception in natural settings.

Given the present state of knowledge about visual neurophysiology, it is not possible to even speculate about possible physiological mechanisms for extracting T-junctions and inhibiting induced contrast. On the other hand, explanations based on functional considerations have a tendency to appear attractive initially, but to prove embarrassingly mistaken as accumulating knowledge invalidates the premises. However, we feel that we should address whether it could be functionally advantageous for the visual system to grant T-junctions a strong inhibiting effect on induced contrast. A comprehensive analysis about functional utility must take into account the costs and benefits of adopting or not adopting a particular strategy, and weigh them by the probabilities of occurrence of various classes of situations (Von Neumann and Morgenstern 1944; Luce and Raiffa 1957). Neither an empirical analysis of costs/benefits nor of probabilities is possible at present. However, in a world composed of three-dimensional objects, the possibility of two coplanar surfaces abutting precisely is very small, so that in cases like figures 2 and 4, the top edges of the T-junctions are likely to signify occluding and more distant surrounds respectively. In both these cases, it would be advantageous to increase contrast from proximate backgrounds to facilitate figure – ground segregation. In fact, given the high utility of this segregation, especially for objects at a distance at which there are no other cues to the three-dimensional configuration, it may be useful for the visual system to function as if T-junctions always separate foreground from background. The cost of illusory brightness differences in perceptually coplanar displays like figures 6 and 9 is probably much smaller than the benefits of a simple strategy that enhances figure – ground segregation.

In summary, the pictures in this paper demonstrate that T-junctions have an inhibitory effect on laterally induced contrast, irrespective of any three-dimensional interpretation. To the extent that T-junctions explain White's and Benary's illusions, they do so without requiring that the observer use them to infer coplanarity, belonging, or any other perceptual organization.

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References

Adelson E H, 1993 "Perceptual organization and the judgment of brightness" *Science* **262** 2042 – 2044

Benary W, 1924 "Beobachtungen zu einem Experiment über Helligkeitskontrast" *Psychologische Forschung* **5** 131 – 142

Chevreul M E, 1839 *De la loi du contraste simultané des couleurs* (Paris: Pitois-Levreault)

Chubb C, Sperling G, Solomon J A, 1989 "Texture interactions determine perceived contrast" *Proceedings of the National Academy of Sciences of the United States of America* **86** 9631 – 9635

Clowes M B, 1971 "On seeing things" *Artificial Intelligence* **2** 79 – 116

Foley J D, Dam A van, Feiner S K, Hughes J F, 1990 *Computer Graphics, Principles and Practice* 2nd edition (Reading, MA: Addison-Wesley)

Gilchrist A L, 1977 "Perceived lightness depends on perceived spatial arrangement" *Science* **195** 185 – 187

Gilchrist A L, 1980 "When does perceived lightness depend on perceived spatial arrangement?" *Perception & Psychophysics* **28** 527 – 538

Gogel W C, Mershon D H, 1969 "Depth adjacency and simultaneous contrast" *Perception & Psychophysics* **5** 13 – 17

Hochberg J, Beck J, 1954 "Apparent spatial arrangement and perceived brightness" *Journal of Experimental Psychology* **47** 263 – 266

Huffman D A, 1971 "Impossible objects as nonsense sentences", in *Machine Intelligence 6* Eds B Mettzer, D Michie (Edinburgh: Edinburgh University Press) pp 295 – 323

Kanade T, 1980 "A theory of origami world" *Artificial Intelligence* **13** 279 – 311

Kanizsa G, 1979 *Organization in Vision* (New York: Praeger)

Krauskopf J, Zaidi Q, Mandler M B, 1986 "Mechanisms of simultaneous color induction" *Journal of the Optical Society of America A* **3** 1752 – 1757

Luce R D, Raiffa H, 1957 *Games and Decisions* (New York: Wiley)

Pessoa L, Ross W D, 1996 "A contrast/filling in model of 3-D lightness perception: Benary cross, White's effect and coplanarity" *Investigative Ophthalmology and Visual Science, Supplement* **37** 1066

Spehar B, DeBonet J S, Zaidi Q, 1996 "Brightness induction from uniform and complex surrounds: a general model" *Vision Research* **36** 1893 – 1906

Spehar B, Gilchrist A L, Arend L A, 1992 "White's illusion: the role of intensity and figural relationships" *Perception* **21** Supplement 2, 81

Spehar B, Gilchrist A L, Arend L A, 1995 "The critical role of relative luminance relations in White's effect and grating induction" *Vision Research* **35** 2603 – 2614

Spehar B, Zaidi Q, 1997 "New configurational effects on perceived contrast and brightness: Second-order White's effects" *Perception* **26** 409 – 417

Sugihara K, 1984 "An algebraic approach to shape-from-image problems" *Artificial Intelligence* **23** 59 – 95

Sugihara K, 1987 "Use of vertex-type knowledge for range data analysis", in *Three-dimensional Machine Vision* Ed. T Kanade (Boston: Kluwer) pp 267 – 298

Taya R, Ehrenstein W H, Cavonius R C, 1995 "Varying the strength of the Munker – White effect by stereoscopic viewing" *Perception* **24** 685 – 694

Von Neumann J, Morgenstern O, 1944 *Theory of Games and Economic Behavior* (Princeton, NJ: Princeton University Press)

Waltz D, 1975 "Understanding line drawings of scenes with shadows", in *The Psychology of Computer Vision* Ed. P H Winston (New York: McGraw-Hill) pp 19 – 91

White M, 1979 "A new effect of pattern on perceived lightness" *Perception* **8** 413 – 416

Zaidi Q, 1990 "Apparent brightness in complex displays: A reply to Moulden and Kingdom" *Vision Research* **30** 1253 – 1255

Zaidi Q, DeBonet J, Spehar B, 1995 "Perceived grey-levels in complex configurations" *Proceedings of The Society for Imaging Science and Technology/The Society for Information Displays Third Color Imaging Conference, Scottsdale, AZ* pp 14 – 17

Zaidi Q, Yoshimi B, Flanigan N, Canova A, 1992 "Lateral interactions within color mechanisms in simultaneous induced contrast" *Vision Research* **32** 1695 – 1707

Zaidi Q, Zipser N, 1993 "Induced contrast from radial patterns" *Vision Research* **33** 1281 – 1286