Calculating Color Appearances in Complex and Simple Images

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Abstract
Grays look different in white and black surrounds. An explanation, using small-excitatory receptive fields and large-inhibitory surrounds, suggests that white surrounds cause greater inhibition. By this hypothesis, inhibition is controlled by the average response to the surround.

This paper reports experiments using segmented black and white surrounds. The square gray-center pixel subtends 1.25° with 8 surrounding pixels (4 adjacent- 4 diagonal). There are 256 combinations of white-black pixels in 8 locations. Removing stereoisomers leaves 56 unique spatial surround tests.

Matches showed marked dependence on the surround’s spatial pattern. Adjacent pixels have much more influence than diagonal pixels. The appearance of grays with segmented surrounds having constant average luminance depends on the spatial pattern. Observed matches from segmented surround targets are much more complex than predictions from center-surround opponent processes that calculate concentric averages.

Introduction
In real scenes and in complex Mondrians the appearance of two identical colored papers in different locations is remarkably constant. Changing the position, and hence the surround, does not usually alter appearance. In simple displays, grays vary in lightness with surround. The spatial arrangement of the surround can make appearance more similar to (assimilation), or different (contrast) from the surround. A model that converts real image radiances to calculated sensations exhibits contrast, but not assimilation (McCann, 1999). In order to expand the model to also exhibit assimilation, it is necessary to process the image in parallel, keeping separate the outputs of different spatial frequency channels. (McCann, 2001a). This paper studies the visual effects of segmented surrounds to understand the transition from contrast to assimilation. Shevell and colleagues have measured the effect of checkerboard backgrounds on color chromatic displays (Shevell and Wei, 1998; Barnes, Wei and Shevell, 1999; Shevell, 2000).

In describing lightness effects “contrast” refers to the fact that a white surround makes a gray center appear darker than a black surround. Following Barlow’s (1953) and Kuffler’s (1953) discovery of spatial opponent ganglion cells, it is generally believed that the white surround stimulates inhibition of the center, making that gray look darker. The black surround does not generate inhibition and that gray appears lighter. It is important to recall that these displays are usually much larger than the receptive fields of ganglion cells.

Assimilation is the name of the mechanism with the opposite effect (Gilchrist, 1994). Grays with adjacent white no longer look darker than the same gray with adjacent black. Examples are Benary’s Cross, White’s Effect, Checkerboard and Dungeon Illusions. These effects have been used to suggest a top-down analysis of the scene, implying mechanisms based on the recognition of illumination, objects or junctions.
Recent experiments demonstrate that contrast is much more complex than predicted on the basis of inhibition by average luminance in the surround. Displays with a square gray central element and 8 square surround elements demonstrate significant sensitivity to the placement of white and black surround elements. Equal-average surrounds do not give equal gray appearances.

Other experiments show that periodic assimilation effects are sensitive to average luminance over very-large-receptive fields (McCann, 2000a, b). All of the above assimilation effects have gray center lightnesses that correlate with large-receptive-field averages. One cannot assume that these experiments are evidence for unconscious inference.

Contrast is the result of complex spatial interactions, while assimilation can be understood as large receptive field averages.

**Segmented Surrounds**

This paper reports experiments using segmented black and white surrounds. Figure 1 illustrates a 1346 test target. The square gray center element subtends 1.25° with 8 surrounding elements (4 adjacent- 4 diagonal). There are 256 combinations of white and black elements in 8 locations. A single black segment at position the top center (target 1) is assumed to be the same as all the other single adjacent black squares (targets 3 [east side], 5 [bottom], and 7 [west side]). Target 1 was tested and the stereoisomers, targets 2,3 and 4 were not. Removing all the stereoisomers leaves 56 unique spatial surround tests.

![Segmented Test Target](image)

Figure 1 shows a “1346” segmented test target (left) and a diagram of the nomenclature (right). The center [c] and the background were both constant and fixed at 17% maximum luminance. The surround was segmented into 8 elements, numbered clockwise starting at the top center. Independently, the luminance of each surround segment could be set to 100% or 3%. This display has 3% luminance in the 1,3,4,6 segments, hence its name.

The 3x3-segment test target and the same size white-surround matching display were both on a 18.75° x 11.25° gray background (Figure 2). With 8-white-surround elements, grays matched 17.5% maximum luminance [17.9%± 2.5% MAM/17.3%±0.4% JMC]; with 8-black-surround, 68.2 % maximum luminance [67.9% ± 6.52% MAM/ 68.5± 6.52% JMC]. The results are analyzed using log luminance axes with 100% scaled to 1.0. The matching value on this scale for the white surround is 0.23, and for the black surround is 0.85.
Figure 2 diagrams the segmented surround experiment. In a dimly lit room, observers viewed an 18.75° by 11.25° background. On the left observers saw a variable 3.75° test surround and a constant 1.25° test center. On the right observers saw a constant 3.75° maximum luminance surround and an observer-controlled, variable intensity, 1.25°- matching center. The experimenter controlled the pattern of the segmented surround on the left. The observer varied the intensity of the right matching gray center in a constant maximum luminance surround. With all 100% surround elements the observer average was 17.5%; with all 3% surround elements the observer average 68.2% maximum luminance.

The result from all 56 targets, for 8 trials each target, for two observers is shown in Figure 3. The vertical axis is the average log matching luminance (LML). The horizontal axis identifies the segmented surround. The data have been sorted so that the number of black elements increases from left to right. The matches showed little correlation with the number of black segments, or the spatial average. If the number of black elements, or a surround average, were controlling contrast, then we might expect a series of flat steps with vertical risers at the change in number of black segments. Instead we found a marked dependence on the surround’s spatial pattern. Target 2 (LML=0.24) with one diagonal black segment is the same as target 0 (LML=0.23) with an all white surround. However, target 1 with one adjacent black segment is lighter (LML=0.32). Among the 6 targets with two black sectors, the average log matching luminances vary from 0.22 to 0.53. Among the 12 targets with three black sectors, the average log matching luminances vary from 0.26 to 0.56. Among the 14 targets with four black sectors, the average log matching luminances vary from 0.26 to 0.67. Among the 12 targets with five black sectors, the average log matching luminances vary from 0.29 to 0.74. Among the 6 targets with six black sectors, the average log matching luminances vary from 0.31 to 0.75. In the 2 targets with two black sectors, the average log matching luminances vary from 0.22 to 0.53. Target 2345678 (LML=0.83) with one diagonal white segment is the same as the all black target 12345678 (LML=0.85). However, target 2345678 with one adjacent white segment is darker (LML=0.59). Instead of flat steps correlating with number of black sectors, we find that there is a very wide range of matches for each set of constant number of black sectors.
Figure 3 shows matching data for all 56 surround arrays. The vertical axis plots the relative log luminance of observer’s matches. The icon for the all white surround is placed at 0.23, and the icon for the black surround match is placed at 0.85 on the axis to illustrate the range of possible matches. The horizontal axis identifies the segmented surround. The data have been sorted so that the number of black elements increases from left to right. In each group the data is ordered by average log matching luminance.

Figure 4 is a plot of Segment Pattern vs. Log Matching Luminance for all 14 patterns with 4 white and 4 black elements in the surround. They are sorted from left to right in order of increasing average log matching luminance. The two lowest LML values have 0 adjacent blacks. The next two patterns have one adjacent black. The next 7 LML values have two adjacent blacks. The remaining five LML values increase with the number of adjacent blacks, but with more variability than previous patterns. The adjacent segment has more influence than the diagonal on matching luminance. The data from the 14 test targets with 4 white and 4 black elements are more consistent with the number of gray-black edges / gray-white edges than with the average luminance of the surround.
Figure 4 shows matching data for all the 4-white/4-black surround targets. All 14 targets have the same number of surround elements. The vertical axis plots the relative log luminance of observer’s matches. The icon for the all white surround is placed at 0.23, and the icon for the black surround match is placed at 0.85 on the axis to illustrate the range of possible matches. The horizontal axis identifies the segmented surround (illustrations above the bars). Matches vary from 0.26 to 0.67 LML depending on the placement of the white and black surround elements.

Figure 5 is the plot of number of gray-black edges vs. log matching luminance for all 56 targets. The graph shows good correlation in that the data are clustered around the solid-line plot of average log luminance values for 0, 1, 2, 3, 4 black segments. Nevertheless, the range of data around the average suggests that number of black segments is not a sufficient explanation of the data. A more complex spatial analysis is required.

It is important to note that although the data are reported in terms of number of gray-black segments, it is equally accurate to describe it as the number of gray-white edges. The essential result here is that the spatial pattern, and not the average of the spatial pattern, correlates with matching luminance. The mechanism controlling the appearance of the grays is not identified further by these experiments. Other experiments studying assimilation make that point very well.
Figure 5 shows the analysis of the number of black vs. white edges for all 56 displays. The vertical axis is log matching luminance. The horizontal axis is a count of the number of black edges adjacent to the central gray segment. As shown in Figure 4, the there is a degree of correlation between the log matching luminance and the number of adjacent edges for 4 white/4 black displays. Here we plot the data for all 56 displays. The solid line connects the matches for white (0) and black (4) along with the average matches for all displays having one black edge (1), two black edges (2), three black edges A(3). The number of adjacent blank squares is an first order predictor of matching luminace, but a more sophisticated spatial model is required to fully account for the data.

The analysis of data from all 56 test targets shows that adjacent elements have much more influence than diagonal elements, although adjacent elements alone cannot account for the matching data. The appearance of grays with segmented surrounds having constant average luminance show dependence on spatial pattern. Contrast effects with segmented surrounds are much more complex than predictions of models in which the radiance of a central area is compared with a spatial average of a concentric surround.

**Assimilation**
Although often associated with top-down cognitive interpretations, Benary’s Cross, White’s Effect, the Checkerboard and Dungeon Illusions can be explained by the spatial components of the stimulus. All four of these experiments demonstrate appearance shifts opposite to those found in simultaneous contrast. Here, grays with adjacent white no longer look darker than those surrounded by black. Unlike the above segmented contrast effects, these experiments show a correlation of appearance with spatial averages (McCann, 2001b).
Top-down cognitive mechanisms, as well as T-junction segmentation algorithms (Ross & Pessoa 2000), are not necessary to account for observed lightness shifts in assimilation experiments. Large receptive fields can account for the observations. There is ample evidence that large receptive field pools are present in the visual system. Hecht, Haig and Wald’s (1935) threshold sensitivity, Hubel and Wiesel’s (1968) cortical measurements, and Blakemore and Campbell’s (1969) adaptation experiments all demonstrate receptor pooling. The grays in the assimilation experiments correlate with sampled averages using very large pools.

**Contrast – Assimilation Antagonism**

In contrast, white edges make grays look darker; in assimilation, white edges make grays lighter. The antagonism is apparent when you compare the assimilation found in the checkerboard illusion and contrast found in the very similar 1357 and 2468 segment pair (Figure 6). The only difference is the outer ring of black and white segments. It is as if this ring shuts off contrast and lets assimilation be apparent. One important feature is the outer ring be a periodic addition to the 9 segment inner area. If the outer ring is replaced with equal areas of white and black in an aperiodic pattern, then contrast remains and assimilation is not apparent. (McCann, 2001c).

![Contrast + Outer Ring = Assimilation](image)

Figure 6 (left) shows contrast matches for adjacent white and black sides. Figure 6(middle) adds an outer ring. Figure 6 (right) shows assimilation matches, reversing the relative lightness of the central gray squares.

**Summary**

Contrast is a complex spatial mechanism that is evident with simple center-surround displays. It can be shut off, and reintroduced by the spatial pattern of outer-surround elements.

Assimilation in periodic displays is a simple mechanism found in the absence of contrast. It depends on the average value of very large-receptive fields.


