

The Role of Low-Spatial Frequency Components in "High Vision" Experiments

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Abstract

Recent discussions about mechanisms for modeling human lightness have centered on whether these mechanisms are the result of "Early Vision", implying that lightness is calculated before depth is undertaken, or "Mid Vision", implying the simultaneous solutions of both depth and lightness, or "High Vision" mechanisms that imply depth information is used to estimate lightness.

This paper begins by reviewing a series of lightness experiments used as evidence for "High Vision". In particular, it analyzes the influence of both Simultaneous Contrast and low-spatial frequency components on apparent lightness.

Further, this paper investigates a variety of "Diamond Wall" lightness experiments. It argues that further study of the "Diamonds" experiments demonstrates an "Early-Vision" explanation, without reliance on illumination, transparency, apparent depth or junctions.

Grays ordinarily look darker on light backgrounds. Two rows of diamonds looked the same on different backgrounds, when the diamond tips crossed into the other background. The addition of different gray tips, consistent with illumination changes, released the rest of the diamonds to no longer match. Grays on light backgrounds reverted to looking darker. Additional experiments show that the introduction of any edge along the light-dark background boundary releases the diamonds to look different in different surrounds.

These experiments are arguments for "Early-Vision" lightness mechanisms because simultaneous contrast and low-spatial frequency sampling can account for lightness without the need for high-level mental processes.

Introduction

Over the past years a number of lightness experiments have raised questions about the mechanism for lightness, the appearance of objects from white and black. The simple hypothesis, that lightness, similar to photographic film density is the count of photons, is wrong.[1] A particular quantum catch can appear white, or gray or black. A variety of different hypotheses have been suggested to account for the fact that a constant quanta catch at the retina can appear different colors. Stockham suggested low-spatial frequency filtering.[2] Gilchrist,[3] Adelson[4] and Logvinenko[5] all suggested mechanisms in which depth altered the appearance of lightness. Land and McCann[6] suggested a simple iterative computational method based on the idea that lightness was a spatial calculation dependent on much, if not all the data in the image. The present paper reviews the evidence from a variety of experiments to help categorize each experiment into one of the three categories illustrated in Figure 1.

Further, this paper distinguishes between sensation vs. perception[7] trying to identify whether memory and past experiences are used to calculate lightness. Lightness sensations are the appearances between light and dark. Perceptions are sensations that have been modified by past experience.

Experimental Evidence for High Vision

Experiments reported by Adelson and reprinted by Fairchild[8] argues that lightness is controlled by the perception of a horizontal shadow in Figure 1. A, B, and C are controls. A shows that identical grays on white appear equal. The addition of tips in B does not change the appearance. Surprisingly, the addition of white and black surrounds in C to the rows of diamond also has virtually no effect. The addition of tips and surrounds in D makes the gray on white darker than the gray on black. The tips were

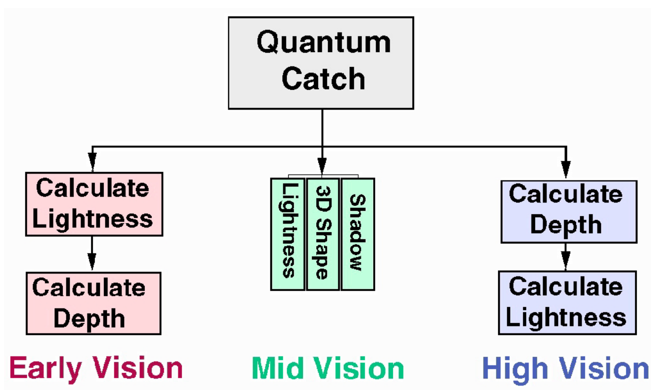

Figure 1. A diagram of alternative theories of Lightness mechanisms. Early Vision suggests that Lightness sensation comes before Depth perception. High Vision suggests Depth comes before Lightness. Mid Vision suggests that Lightness, shape and shadow are all calculated in parallel.

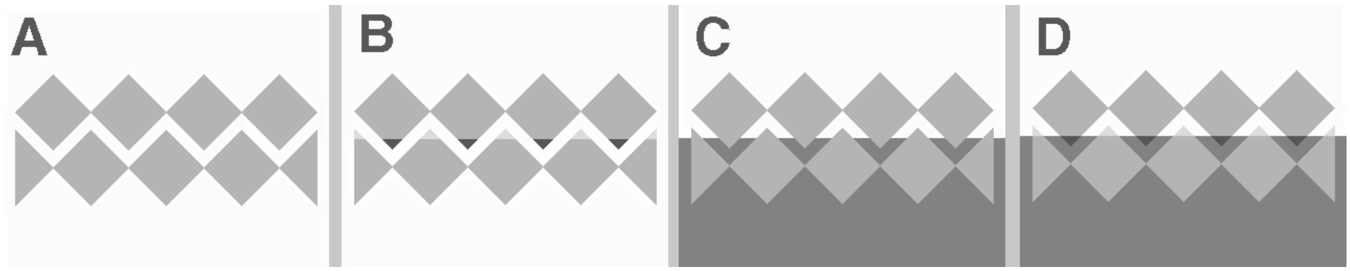

Figure 2. These four displays support "High Vision". A is a control using identical gray diamonds. B adds a dark tips to the top diamonds and light tips to the bottom diamonds. This control shows that the tips do not change the appearance of the grays. C places a dark surround around the bottom row, while leaving a light surround around the top row. Surprisingly, the change of the grays is small. D is the combination of the tips from B and the surround from C. Here the rows of gray diamond surrounded by white look darker than those surrounded by black. The "High Vision" hypothesis is that human visual system interprets the grays on white as grays in sunlight and the grays on black as shadow. The dark tips on the upper diamonds and the light tips on the bottom ones provide consistent evidence of the sun shade hypothesis. By "High Vision" theory humans adjusts the lightness of the lower diamonds to be lighter because they appear to be in a shadow.

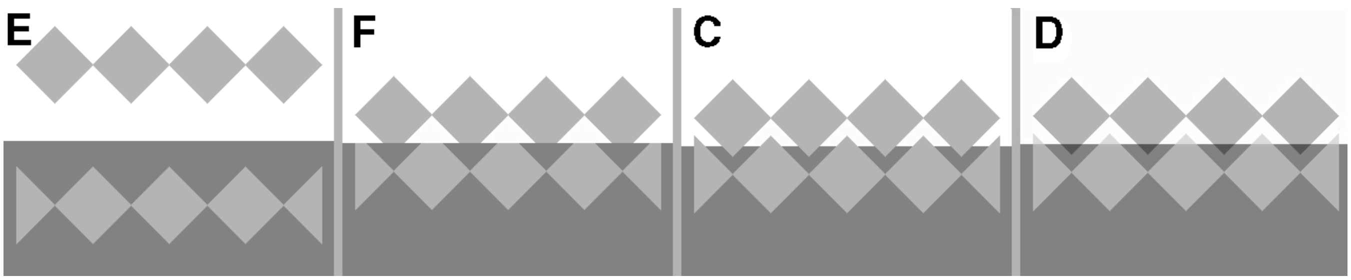

Figure 3. These four displays support Simultaneous Contrast. E is the familiar grays-on-white and grays-on-black. Grays-on-white looks darker. In F the diamond are moved to the white-black edge, with tips removed. The grays-on-white still look darker. C and D are the same as Figure 2. D behaves just like E and F exhibiting the familiar Simultaneous Contrast effect. C is the anomalous result. Display C has shut off Simultaneous Contrast.

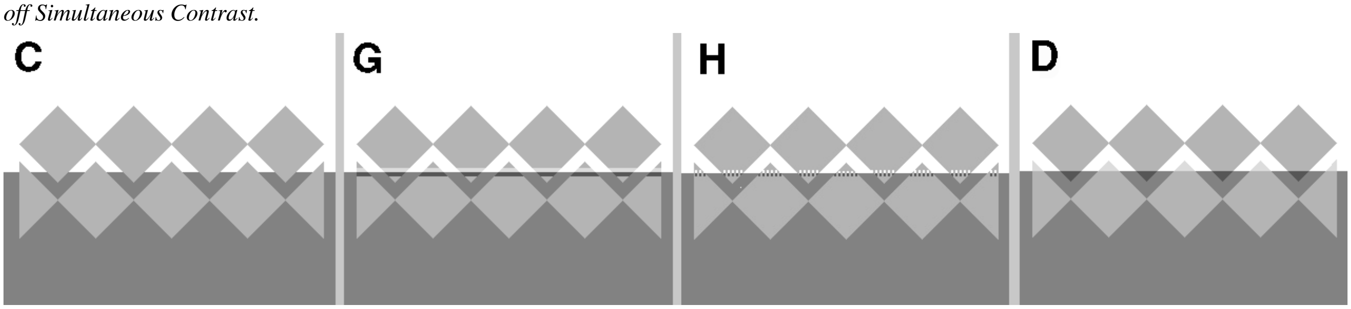

Figure 4. Four displays used to test the role of edges in displays C & D. G shows that the introduction of a light and dark line across the gray diamond along the white-black border restores simultaneous contrast. H shows that dots work as well. By this hypothesis the anomalous behavior of display C is controlled by the uniform gray diamonds. Any contour that breaks up the uniformity of the diamonds will restore simultaneous contrast.

intentionally chosen to create the perception of a high illumination horizontal stripe above a shadow. The tips of the gray diamond are light in the bright light and dark in the shadow. The appearance of the gray in the shadow is lighter. By this argument the "High Vision" perception of light and shadow is the controlling mechanism.

Experimental Evidence for Simultaneous Contrast

A second set of similar experiments can be used to make the case for the familiar "Early Vision" simultaneous contrast mechanism[9]. Figure 2 shows darker grays in white surrounds in E, F and D. The unusual result is C. Here the absence of tips, or the presence of continuous gray diamonds have shut off the simultaneous contrast mechanism. How can we sort out the two opposing explanations. They center on C. Is it a control showing that surround does not matter, or is it a curious anomaly?

Early vs. High Vision

There are three convincing arguments for simultaneous contrast or "Early Vision" as the controlling mechanism. First, any edge, continuous in G or intermittent in H, restores simultaneous contrast[9] (Figure 4). Second, the rows of diamond are made up of a simple repeating pattern. The

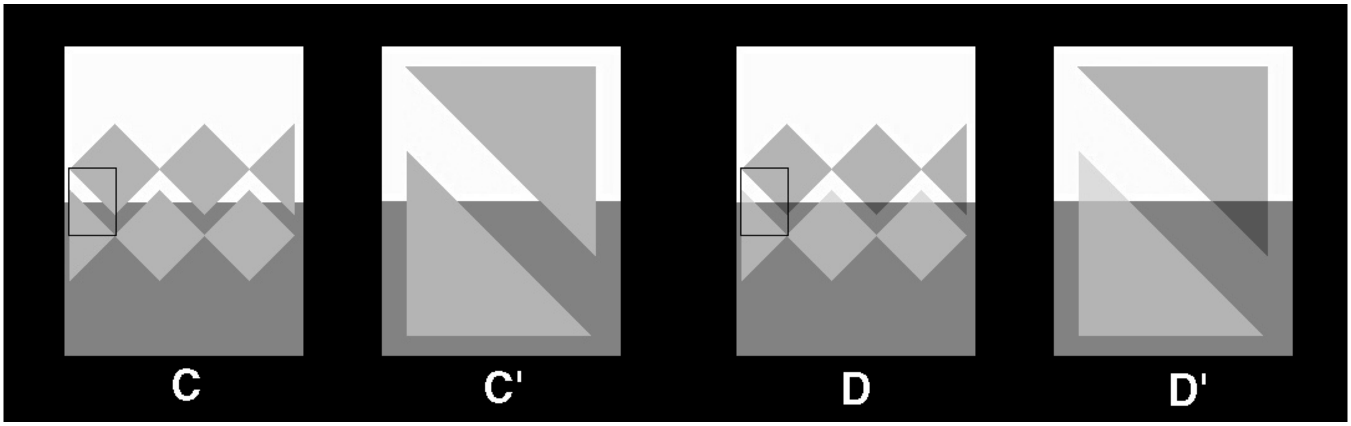

Figure 5. The same lightness are seen in displays C and a simplified one-quarter diamond pattern C'. The same is true for D and D' with tips. There is no difference in lightness between the complex displays with implied illumination and the simple ones without any implied illumination.

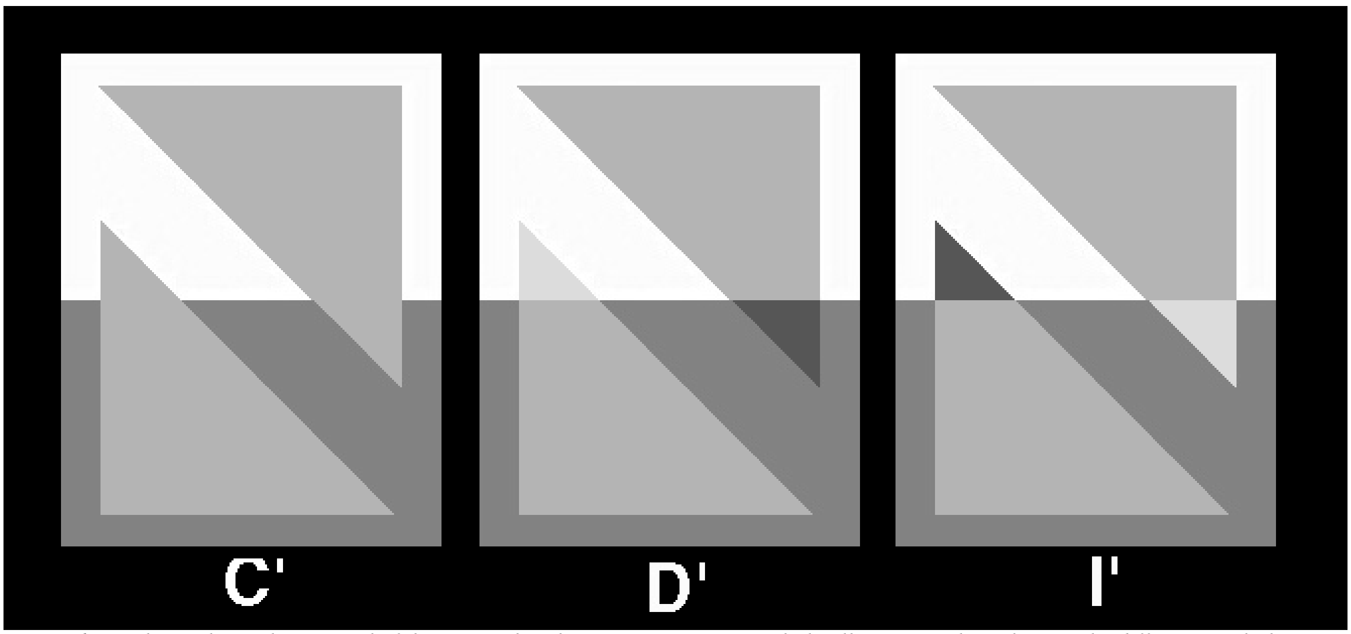

Figure 6. Display I' shows the reversal of the tips so that they are inconsistent with the illumination hypothesis. The difference in lightness is slightly smaller than that found in D', however it is larger that found in C'. These inconsistent tips also restores simultaneous contrast.

lightnesses of these simple patterns are the same as those in the complex patterns with the shadow argument (Figure 5). Third, the tips used in D to make a shadow-consistent image restores simultaneous contrast. The same is true if we reverse the tips and make a shadow-inconsistent image (Figure 6). Simultaneous contrast is all we need to understand this diamond experiment.

White's Effect

White's Effect[10] is the inverse simultaneous contrast effect is shown in Figure 7. The author suggests that humans perceive that the gray areas are behind stripes and adjusts perception to appear the same as if the stripes were removed. The reverse of contrast. A recent paper[11] has first excluded scattered light as the mechanism. It further showed that multi-resolution sampling can account for the lightnesses on the right being higher than those on the left (Figure 8). Full- resolution models, that can successfully predict lightness in simultaneous contrast cannot predict White's effect. Nevertheless almost any multi-resolution model can account for these results by sampling the output from each resolution independent of the others (Figure 9). Figure 10 plots the model response to Whites effect. The grays on the left are darker than those on the right.

Logvinenko's Edges

Figure 11 shows still another "Diamond Wall" experiment.[5] The author observes that the difference in lightness between gray diamonds (light surround vs. dark surround) in Figure 11a is greater than the difference in 11b. He measures the difference in lightness as 1.0 Munsell units. The

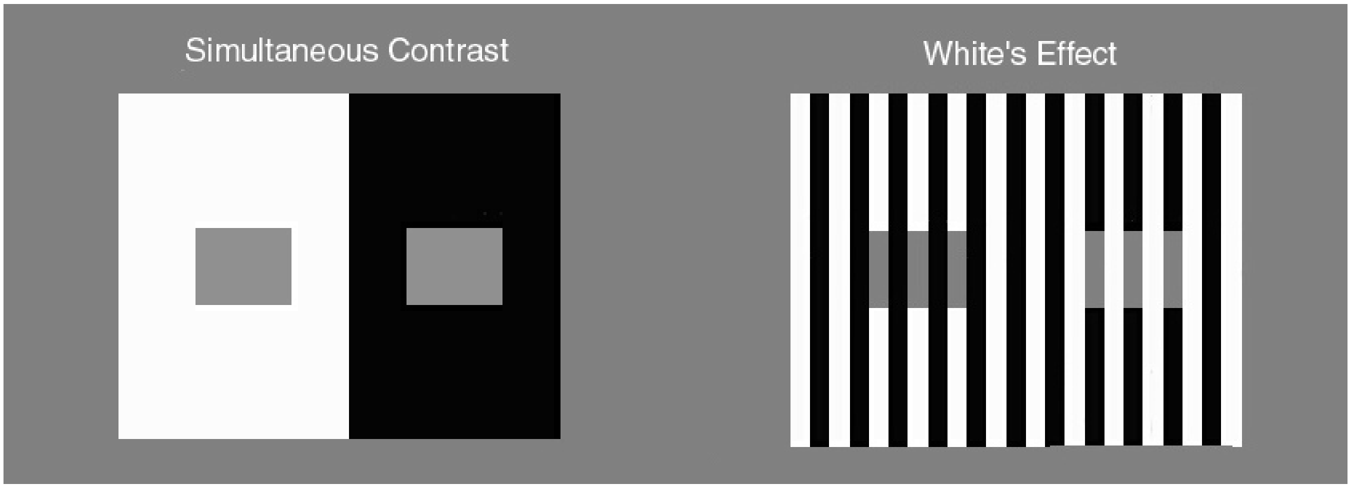

Figure 7. The comparison of Simultaneous Contrast with White's effect. The gray on right in White's effect is lighter than the left. In White's effect there is more white adjacent to the gray than black.

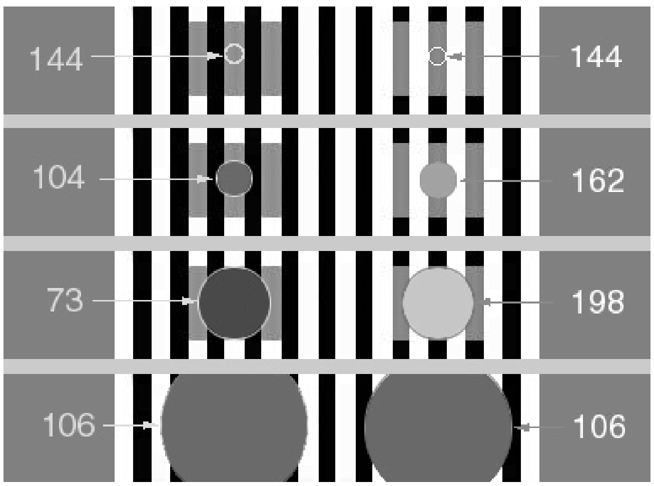

Figure 8. Sampling values of hypothetical large receptor pools. Single receptors up to pools the width of the gray stipes give equal responses (144). As right pool get larger the black stipes on the right lower the pool response to as low as 73, while the white stripes raise the pool on the right ti a high as 198. As the pool gets larger, the pool response returns to equal values.

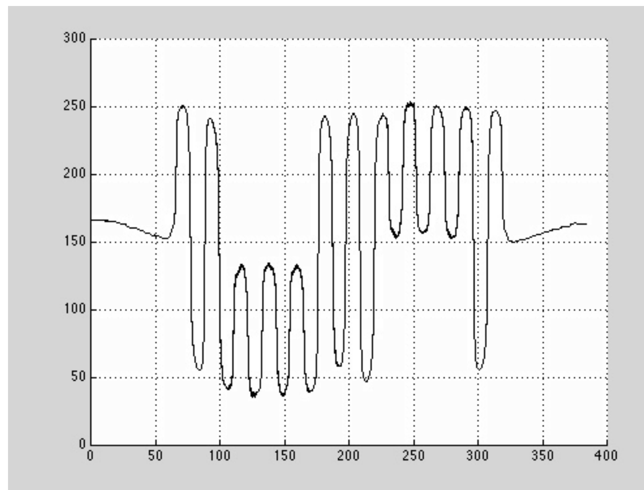

Figure 10. The results of a calculation done with the process shown on the right of figure 9.

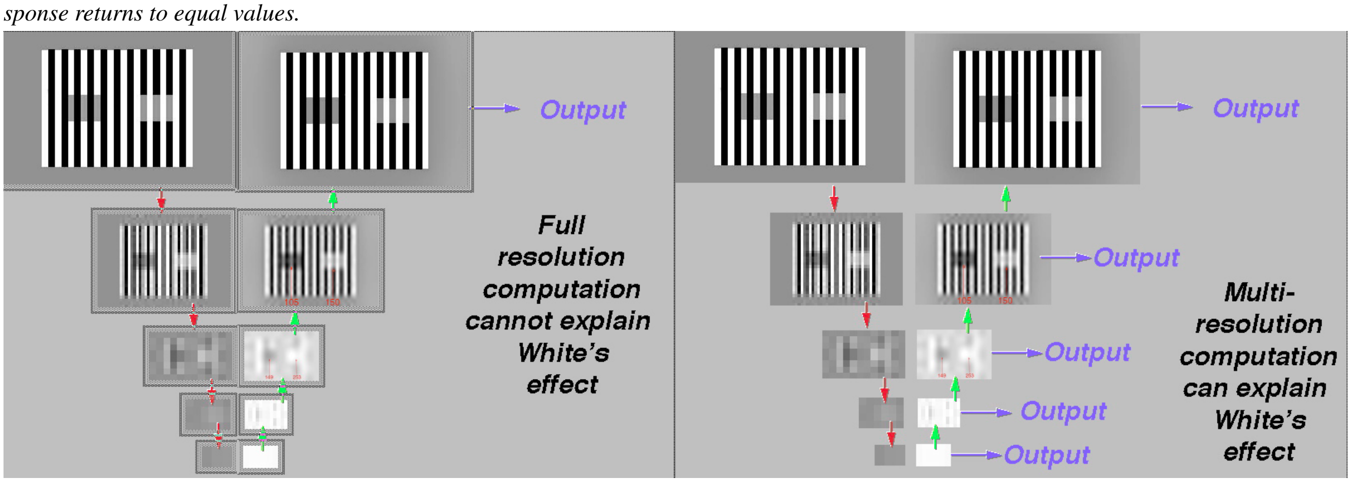

Figure 9. The left side shows that multi-resolution computations do not explain Whites effect. The right side shows that models that include directly calculations from low-resolution stages can explain Whites effect.

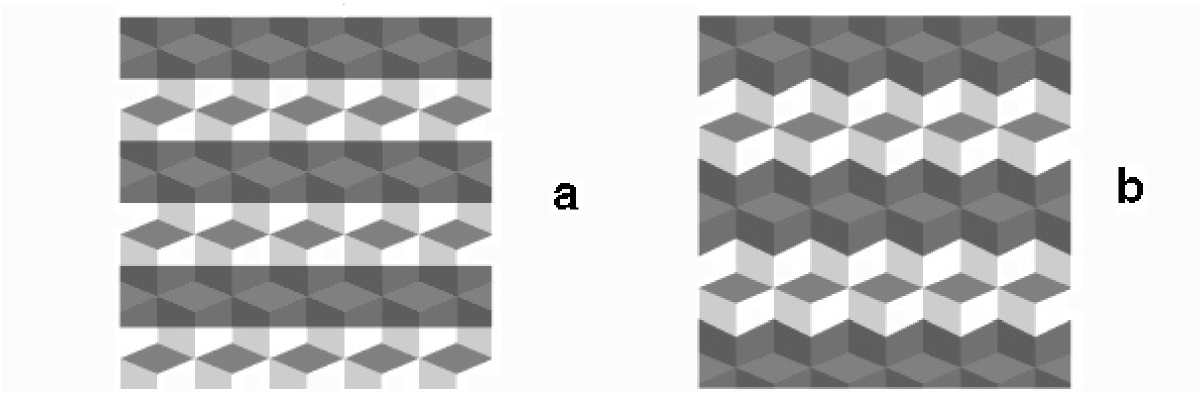

Figure 11. Logvinenko displays illustrating the difference in lightness with straight light dark edges and angular borders. Here again the argument is that the straight edges are associated with an illumination edge and the angular edge is not. By this hypothesis lightnesses associate d with illumination edges are different.

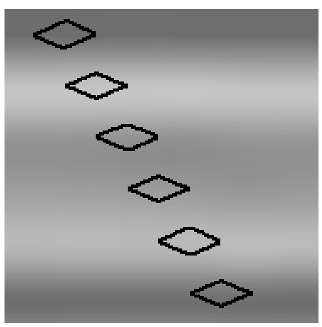

Figure 12. The average radiance in Figure 11b at the 32 x32 average level. The corresponding average for Fig 11a is uniform. The black outlines show the locations of the gray diamonds at full resolution.

author asserts that the lightnesses are different because the long light-dark straight edges (11a) can be interpreted as a an illumination edge while the sawtooth light-dark edges (11b) cannot.

We wanted to see if this pair of displays could be explained by either low-frequency sampling (White's effect), or simultaneous contrast (Adelson's diamonds).

The vertical spacing between corresponding gray diamonds is smaller in Fig 11a than 11b. If we compare the averages both figures we find they are similar for 2x2, 4x4, 8x8, 16x16. However, they are marked different for 32x32. Fig 12 shows the 32x32 averaged down and bicubically interpolated back up. The corresponding image for figure 11a is uniform.

We can make the average data more uniform by adjusting the vertical distances to match Figure 11a. Figure 13 shows such targets. The lightness differences between 13a with straight edges are still larger than 13b. Although this made the two displays much more like each outer in the very low spatial frequencies, it did not remove all the differences. Again we took the digital data input for Figure 13 and averaged it to model lower-spatial frequency

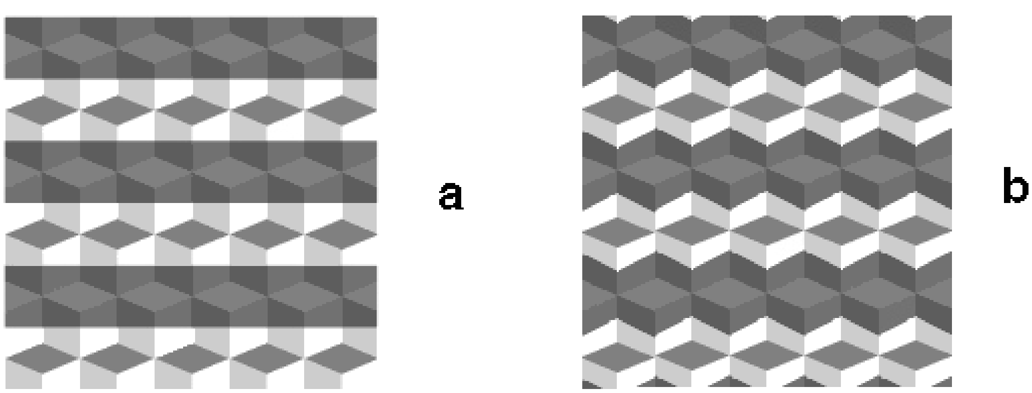

Figure 13. Revised versions of Logvinenko displays with uniform average radiance in the 12 by 8 resolution. The lightnesses of the diamonds surrounded white and black is still larger in Figure 13 a.

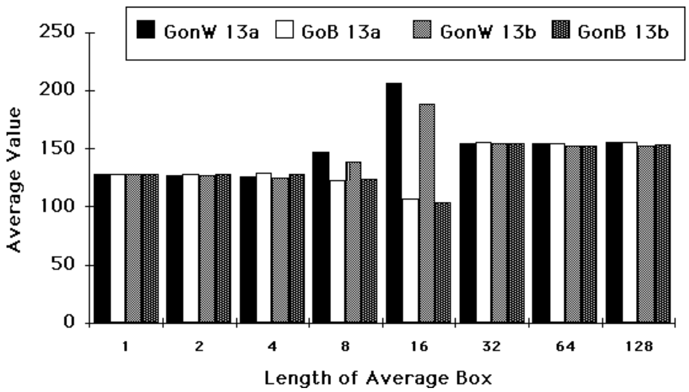

Figure 14 shows the histogram of average low-spatial frequency input. The horizontal axis plots the length of each side of the averaging box. The value 2 means that a 2 by 2 area of 4 pixels were averaged. After averaging a full size image was reconstructed using bicubic expansion. The vertical axis plots the average digital value of 120 pixel samples from the middle of the gray diamonds in Fig 13. Data is shown for gray diamonds surrounded by white areas in Figure 13a [GonW 13a], gray diamonds surrounded by black areas in Figure 13a [GonB 13a], gray diamonds surrounded by white areas in Figure 13b [GonW 13b], gray diamonds surrounded by black areas in Figure 13b [GonB13b}. Averages with box length 8 and 16 show grays that have unequal average values. The difference in lightness between [(GonW 13a-GonB 13a) - (GonW 13 - GonB 13b)] is 9 for length 8 and 15 for length 16. This shows that low-spatial frequency can account for the fact that the difference in lightness in Figure 13a is larger than Figure 13b. these results are consistent with White's effect.

Figure 15 shows that the elements that make up figure 13 do not exhibit Lovinenko's effect. The difference in the diamond's lightness is the same in both figures.

responses. We wrote a program that calculated the average values in a box with lengths 2, 4, 8, 16, 32, 64, and 128. We used bicubic expansion to regenerate images the size of the original. We averaged the values for 120 pixels corresponding to the center gray diamond surrounded by whites [GonW] and 120 pixels from the gray diamond on black [GonB]. These values show the average input values for low-spatial frequency input information.

Figure 14 show the histogram of these averages. The data shows the average values of input data for different low-spatial frequency images. Sampling using boxes of length 1, 2, and 4 show equal average values of 128. When the box has sides 8 and 16 the average process incorporates the higher, white surround values and the lower, black surround values in the average. When the overage length reaches 32, 64 and 128 the data incorporates several rows of data and averages approach 155 with slightly different averages of the entire images.

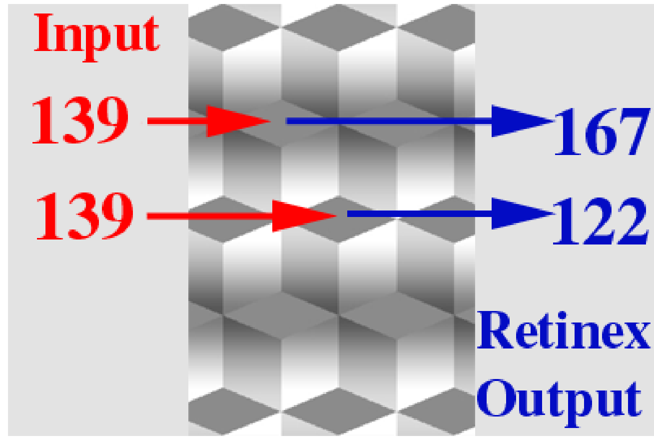

Figure 16 The input and Retinex output for Logvinenko's Figure 4. Despite constant input (139), a Ratio-Product-Reset-Average model can calculate lightness outputs consistent with observer values.

The data for length 8 and 16 show that the difference in lightness for 13a is slightly lighter that that for 13b. Nevertheless, this small difference is enough to account for the small difference is lightness reported by Logvinenko.

Other experiments, shown in Figure 15, show that the Logvinenko effect is different from simultaneous contrast found in Adelson's experiments. Here we reduced 13a and 13b to their simplest components. We see here that they do not exhibit simultaneous contrast. The grays look the same.

A recent paper reviews the lightness models response to complex images that are planar and appear planar.[9] The argument was that flat displays present a problem that must be addressed by a lightness model. This paper showed that Ratio-Product-Reset-Average model can calculate the observed lightness in simultaneous contrast, black and white Mondrians, color Mondrians, and a variety of real life images. Included in this series was the successful prediction of another Logvinenko "Diamond Wall" (Figure 16). Clearly the Ratio-Product- Reset-Average model predicts the observations in Figure 16.

Conclusions

This paper has reviewed a wide variety of visual display all dealing with the "High Vision" and "Early Vision" theories. Adelson's "diamond rows" can have either a light and shadow perception, or a simultaneous contrast sensation explanation. The experiments here argue for the later for three reasons. First, any edge added to the anomalous target C restores simultaneous contrast. Second, the long rows of diamonds are not necessary. The same lightness effects are found in simple, one quarter diamond displays.

Third, simultaneous contrast is restore when the tips in Display D are reversed. The tips now inconsistent with a shadow perform the same "releasing" function as consistent ones. Simultaneous contrast mechanisms can account for "Diamond Row" experiments.

White's Effect is an example of a simple visual display that cannot be explained by simultaneous contrast. Here we review the case that multi-resolution sampling can explain these results. "High Vision" mechanism need not be required to find an explanation of these results.

Logvinenko's straight and saw tooth "illumination edge" has been studied in context of multi-resolution sampling and simultaneous contrast. Here we found the original displays were very different in low-spatial frequency components. We made an improved display that still exhibited Logvinenko's effect. We showed that this improved image did not remove all the differences in low-spatial frequency input. We showed that sampling can the cause of the effect. In addition we showed that the larger lightness shifts from another Logvinenko display can be explained by a Retinex model calculation. This argues that not all "Diamond Wall" effects are caused by the same visual mechanisms.

All of these experiment share the same categorization. Either because of simultaneous contrast, or multi-resolution sampling they can be explained by "Early Vision" mechanisms. The corollary of that statement is that they cannot be used as evidence of the existence of "High Vision" mechanisms.

Acknowledgments

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Biography

John McCann received his B.A. degree in Biology from Harvard University in 1964. He managed the Vision Research Laboratory at Polaroid from 1961 to 1996. His work concentrated on research in human color vision, large format instant photography and the reproduction of fine art. He is a Fellow of the IS&T. He is a past President of IS&T. He is currently consulting and continuing his research on color vision.