This is a preprint of

8291-36 paper in SPIE/IS&T Electronic Imaging Meeting, San Jose, January, 2012

Paintings, photographs, and computer graphics are calculated appearances

John J. McCann
McCann Imaging, Belmont, MA 02478 USA

Paintings, photographs, and computer graphics are calculated appearances

John McCann
McCann Imaging, 161 Claflin St., Belmont, MA 02474, USA

ABSTRACT

Painters reproduce the appearances they see, or visualize. The entire human visual system is the first part of that process, providing extensive spatial processing. Painters have used spatial techniques since the Renaissance to render HDR scenes. Silver halide photography responds to the light falling on single film pixels. Film can only mimic the retinal response of the cones at the start of the visual process. Film cannot mimic the spatial processing in humans. Digital image processing can. This talk studies three dramatic visual illusions and uses the spatial mechanisms found in human vision to interpret their appearances.

Keywords: HDR vision, illusions, spatial image processing, Retinex.

1. INTRODUCTION

The challenge of a reproduction is to capture the information contained in the physics of light (original 3-D color space) and to render it in a different size and shape of media (reproduction color space). The reproduction problem is very similar to moving everything in your house to a new one. The reproduction house has different dimensions for the length (amount of red), width (amount of green) and height (amount of blue). On a clear day, shadows cast by the sun are 32 times darker than direct sunlight. The 32:1 range of reflectances in a 32:1 range of illumination creates a 1024:1 range of light. Real-life scene reproduction is analogous to moving a castle into a cottage. Reproductions move everything in the old house into the new house, keeping all contents in corresponding rooms, even though the dimensions of the entire house, and each room, are different. Good reproductions are never exact physical copies of the original, because that is not possible. Good reproductions capture the appearance and relationships of objects in the scene.[1]

The papers in this section of the conference, organized by Huib deRidder, studied the interaction of science and art in rendering scenes. There are many examples of works by artists that design their pieces with human visual mechanisms in mind. By the skillful anticipation of the "way humans see things" the artists can make unusual and striking displays.

The definition of the word *paradox* is a seemingly absurd, or self-contradictory statement or proposition, that when investigated or explained may prove to be well founded or true. Visual illusions are striking examples of apparent paradoxes. The greater the departure from the expected appearance, or behavior, the better the illusion.

The usual pattern in research is to dissect the complex *whole* into separate *components* with well known mechanisms that can be assembled into the ensemble of all the properties. This paper will analyze three popular and dramatic illusions to see if understanding the components can make sense of the illusion. In other words, can we understand the magic of the illusion by identifying the tools of the magicians?

The three illusions are found as movies on YouTube. They are:

- "Impossible Balls Illusion!"
  <http://www.youtube.com/watch?NR=1&feature=endscreen&v=vmkaVoLoFEU>
  Balls roll up hill defying gravity.
- "Shady Optical Illusion 8"
  <http://www.youtube.com/watch?v=3713TagQDio&feature=relmfu>
  Papers change appearance when moved on the surface of a cube.
- "Impossible Shade Illusion!"
  <http://www.youtube.com/watch?v=z9Sen1HTu5o>
  Papers change appearance when moved to be in the shadow of a tower.

Figure 1 shows images from three YouTube movies demonstrating visual illusions.

Figure 1 shows images from three YouTube movies demonstrating visual illusions. (left) "Impossible Balls Illusion!"; (middle) "Shady Optical Illusion 8"; (right) "Impossible Shade Illusion!"

The scientific analysis of these illusions along with descriptions of the characteristics of chiaroscuro painting provide the explanation of the seemingly absurd propositions found in these visual paradoxes.

2. POINT OF VIEW OF "IMPOSSIBLE BALLS ILLUSION!"

Brusspup uses fixed points of view for movie cameras to create geometrical illusions. For the first half of the movie we watch wooden balls roll uphill and collect at the top. We see balls roll from the bottom of the ramps on both sides. In the second half of the movie, we see the camera move from the top front to lower back of the ramp. Figure 2 (top) shows the starting point of view in which the ramps appear to travel up to the middle.

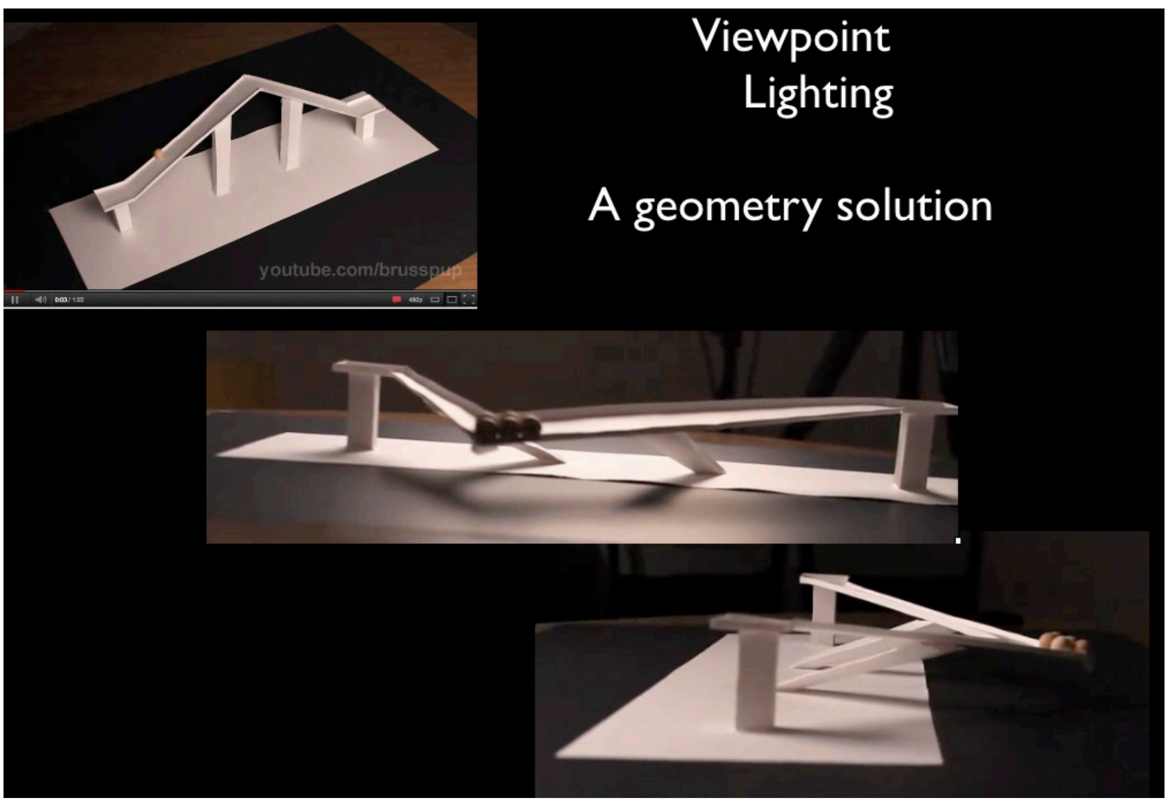

Figure 2 (top) shows the point of view from top, front position of the camera. (middle) shows the lower, back point of view; (bottom) shows the lower side point of view. In the top view the balls appear to roll up hill, while the back and side views show that ramp is actually down hill.

Using a movie camera mounted on a tripod is critical to the success of this illusion. It will appear much less convincing in real life. The image on the plane of the camera sensor is consistent with two uphill ramps, even though the ramps are actually downhill. When we look at such 3D objects with binocular vision, the disparities of the left and right eye viewpoints make it easy to discriminate between uphill and down hill ramps. As well, monocular vision motion parallax, caused by very small head movements, can provide very accurate depth assessments. Video cameras have fixed viewpoints that help in making ambiguous geometric images.

The second half of this movie clearly demonstrates the illusion works best from the original point of view. Other views reveal that the perceived uphill ramps are actually downhill. Brusspup's collection of movies show a variety of point of view phenomena.

3. MAXIMA, EDGES AND GRADIENTS

The other two illusions demonstrate changes in appearance of objects simply by moving them around on the top of a table. That simply never happens in real life. Ordinarily when one takes a piece of paper and slides it across a table it does not appear to change as much as observed in these movies. Why do we observe such large changes in appearance in these "illusions". What are the tools these video magicians used to make their images so dramatic? How do these scenes differ from everyday scenes that generate everyday appearances? The explanation of these illusions comes from our understanding of how vision responds to paintings, photographs and computer graphics.

3.1 Computer Graphics

Computer graphics begins with an idea that is represented by a 3D shape. The shape is given a surface that is then modified by its illumination that varies in spectra, position and intensity. It is a well-defined system designed to fit the color space of the display media. That means that we can see clearly the details in the shadows. In addition, we can see the details in the bright areas and scene highlights. Figure 3 shows a frame of Toy Story with a ImageJ3D plot of intensity vs. (x,y) position in the image.

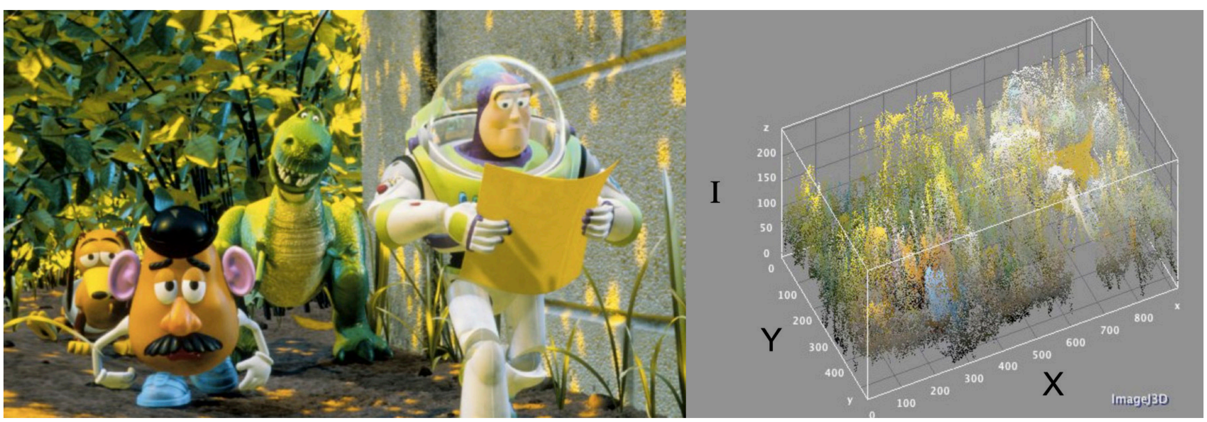

Figure 3 (left) shows a frame from Toy Story©; (right) shows an ImageJ3D plot of the image. The base of the 3D plot is position in the image x, y with intensity I plotting the third axis. The hue of each pixel is rendered as the pixel color for each plotted point.

The plot of the scene shows a complex mixture of edges and gradients. These animation frames are much more complex than hand-drawn traditional cartoons. The human visual system synthesizes our sense of shapes and motions from these edges and gradients.

Photography makes images from objects in variable illumination. The range of illumination determines the range of light falling on the camera sensor. The High Dynamic Range (HDR) of the world can be reduced by spatial modification to fit on the Low-Dynamic-range of the print or display. Ansel Adams described techniques for spatial processing in silver halide photography. In digital imaging spatial algorithms can compress scene range while maintaining the appearance of the scene.[1: Section A] These techniques render scenes the way that artists have done in chiaroscuro painting for centuries.

3.2 Black and White Mondrian - Edges and Gradients

The common feature among paintings, photographs and computer graphics is the use of gradients and edges. Edges generate large changes in appearance from small changes in luminance. Gradients with the same change in luminance are almost invisible. While objects are recognized by the shape of their edges, gradients connect the rest of the image. Understanding the appearances in images depends on identifying edges and gradients and their different roles in vision.

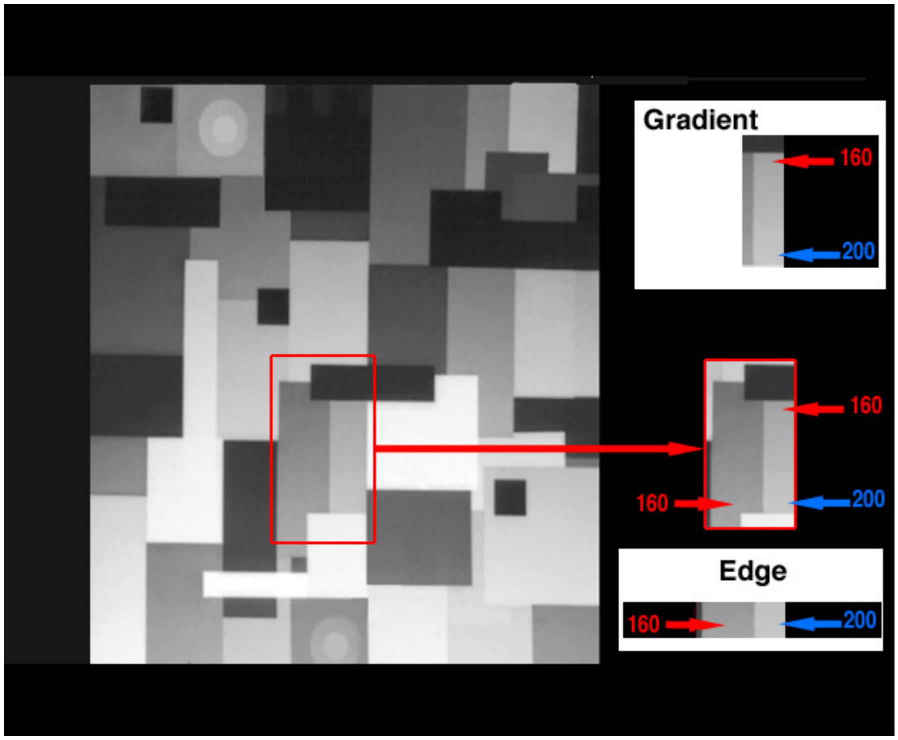

Figure 4 (left) Land's Black and White Mondrian with an area of interest in the lower middle (red outline). (right) Segments illustrating "Gradients" and "Edges" generate changes in appearance from changes in luminance (160 and 200).

The Black and White Mondrian experiment (Figure 4) identifies two areas in a complex display that appear near white and near black when they both have the same luminance.[2] The experiment used a smooth gradient of illumination with maximum light on the bottom of the display; minimum light falling on the top. A dark paper on the bottom had the same luminance as a white paper at the top. The key to understanding the experiment is illustrated in the area outlined in red. At the bottom we see an *Edge* (change from 160 to 200) with a large change in appearance. We also see a *Gradient* from the 200 to 160 that is difficult to see. Edges cause large changes in appearance while gradients are hard to see. Imaging uses these properties to control appearances.

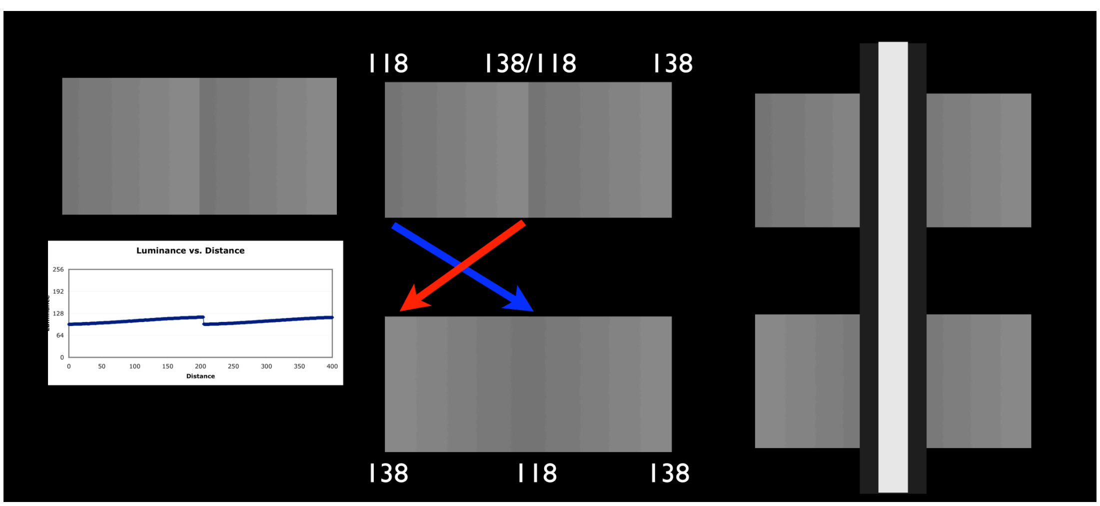

Figure 5 (left) shows the appearance of two identical gradient squares. The left square appears light, and the right appears darker; (lower left) plots the luminance vs. distance across the two squares. (middle top) shows digits for the ends of the gradient; (middle lower) shows the left square rotated 180°; (right) shows the effect of additional edges covering the edges of the squares. The luminance of the center of the square is inconsequential for appearance. The edges control lightness. The squares are the same when the edges match; they are different when the edges are different. Edwin Land called this demonstration "Two Squares and a Happening" in 1971.

A key principle in understanding images is the juxtaposition of edges and gradients. Figure 5 shows two identical gradients. Sometimes they look the same; other times different. When the lighter end of the gradient is adjacent to the darker end of an identical gradient they appear different. The identity of the centers of the areas does not matter; they look different. Rotating one square 180° places both darker ends together the squares form the appearance of a uniform rectangle. Introducing addition of more edges between the gradients makes the gradients look the same.[2]

Pawan Sinha's experiment [3] with two gradients and two identical squares demonstrates the interactions of gradients and edges. Identical squares look different when placed on a gradient (Figure 6, left). The darker square is surrounded by the brighter part of the gradient. The lighter square is surrounded by the darker part of the gradient. When Sinha added the outer gradient, it made the inner gradient look more uniform. The change in appearance of the inner gradient did not change the appearance of the squares. The square-gradient edges controlled appearance. This experiment makes the case that it is the spatial content of the inner gradient, and not its perception that affects the appearance of the squares.

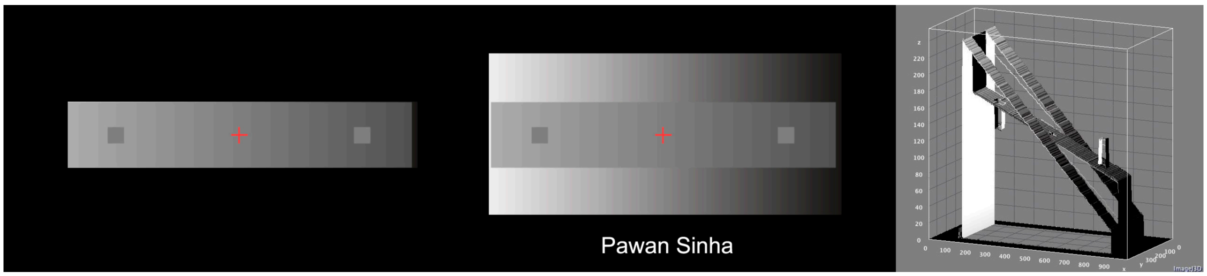

Figure 6 (left) Central gradient with two identical squares. (middle) Pawan Sinha's outer gradient makes the inner gradient look more uniform. How can the same gray appearance surround generate much lighter appearance for the right square? (right) ImageJ3D plot of Sinha's double gradient. This plot demonstrates that the edge ratio for the left square to surround (128/160) is darker than the right edge ratio (128/95).

3.3 Role of Maxima

Maxima play a special role in human vision. The study of small spots of light show small changes of appearance with large changes in luminance. Figure 7 shows a chiaroscuro painting, segments of the painting and ImageJ3D plots of the segments.

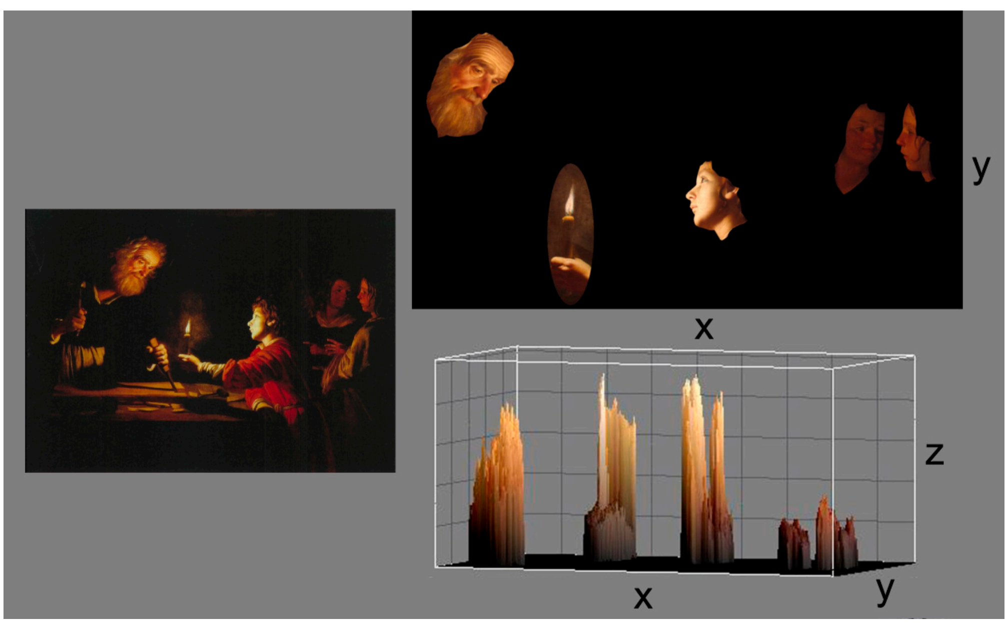

Figure 7 (left) shows van Honthorst's painting, "The Childhood of Christ, 1620"; (top right) five painting segments of the candle and faces; (bottom right) shows the ImageJ3D plots of the image segments.

The most intense area of the painting is the candle flame. The face of Christ has nearly as bright. Joseph is slightly darker, and the other boys are still darker. The rendition of the change of illumination from the candle uses small changes in reflectances of the paint on the canvas.

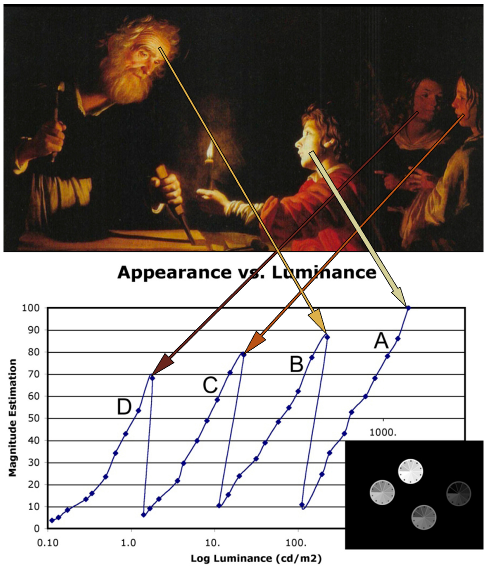

Figure 8 (top) compares "The Childhood of Christ" with (bottom) psychological magnitude estimates of four identical transparencies viewed in four different levels of illumination. The circular transparencies have 10 pie shaped sectors that have a range of 20 to 1. The top sector (A) has no neutral density behind it, while the left (B) has 1.0 ND; the bottom (C) has 2.0; and the right (D) has 3.0 ND. The dynamic range of the entire target is 4.3 log units. The illustration of the black opaque surround with A, B, C, and D does not reproduce the range or the appearance of the display.

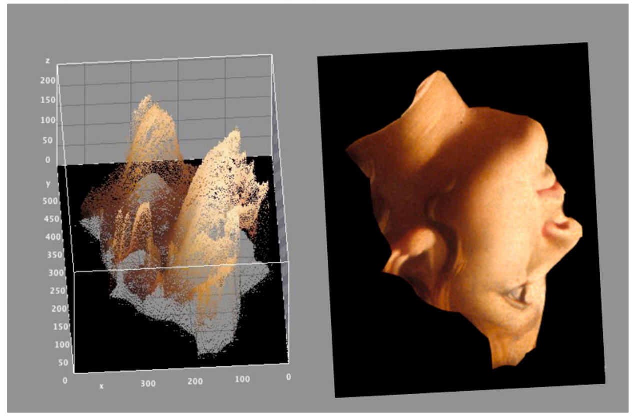

Figure 9 (left) ImageJ3D plot of Christ's face (right) photograph of Christ's face. The images are inverted to be able to see the gradient of reflectance across the face. Observe the large changes in appearance with abrupt changes in luminance. As well, the small changes in appearance with gradients. The gradients are used to portray the shape of the face.

Figure 8 compares psychophysical measurements of appearance with a painting's rendition. Each decrement in illumination generates a small change in appearance.[1:Chapter 12] In the vicinity of these local maxima we see rapid changes in appearance with small changes in luminance. We see this in the painting and in the psychophysical experiment. The graph plots observer's magnitude estimates of each sector on a scale of white (100) to black (1). The maxima in top circle (A) has the appearance white (100). The darkest pie sector in A is 1/20 the luminance and observers estimate it to be 10. Even though the lightest sector in B is the about same luminance as the darkest sector in A it appears a dim white (88). Areas in the vicinity of the local maxima change appearance rapidly, while local maxima change slowly with changes in luminance.

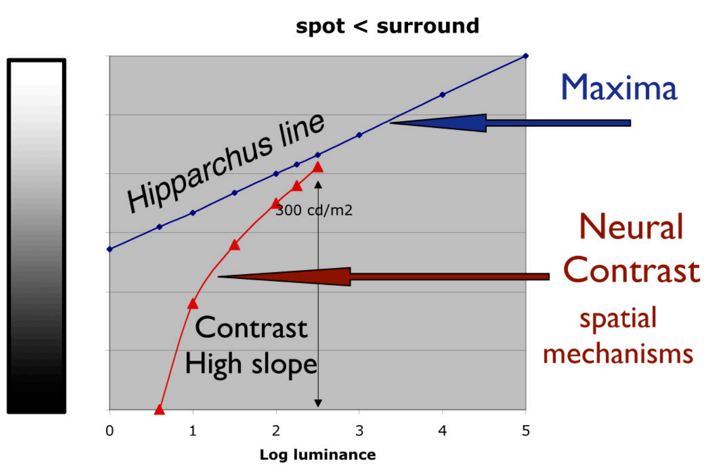

Figure 10 illustrates the two rates of change of appearance with changes in luminance. Maxima change slowly with luminance. Areas darker than maxima change quickly with luminance.

Reviewing the documentation of the painting, the "Childhood of Christ" we can summarize our observations in three statements. For a fixed change in luminance

1. Edges generate large changes in appearance.
2. Overall changes in illumination cause small changes in appearance.
3. Gradients cause small changes in appearance.

These are very useful in understanding the appearance of illusions. All three rules address the spatial information in scenes. Edges are measured as the ratio of two image segments. The value of either segment is not important.

4. ROLE OF MAXIMA IN "SHADY OPTICAL ILLUSION 8"

The first thing to notice in the "Shady Optical Illusion 8" is that it is not a cube, but a photograph of a cube. In fact, it is a movie of a photograph of a cube.The movable tiles are a pieces of another photograph, that are easy to move around on a table. The right side of the of photograph shows the two movable pieces that look identical. They have appearance between the bright yellow tile in shade and the dark brown tile in bright light.

The top of the cube has all high-reflectance areas surrounded by white grout lines. The white next to the central brown tile is the local maximum. That central brown tile is much darker than the adjacent maximum. It is illustrated on the plot on the right side of Figure 11. The white on the top (W) is the maximum of all values in the photograph. The appearance of the central brown tile is determined by the change in luminance of the tile from the maximum along the solid white line for that locality of the image. The distance along the white line places its lightness on the vertical axis.

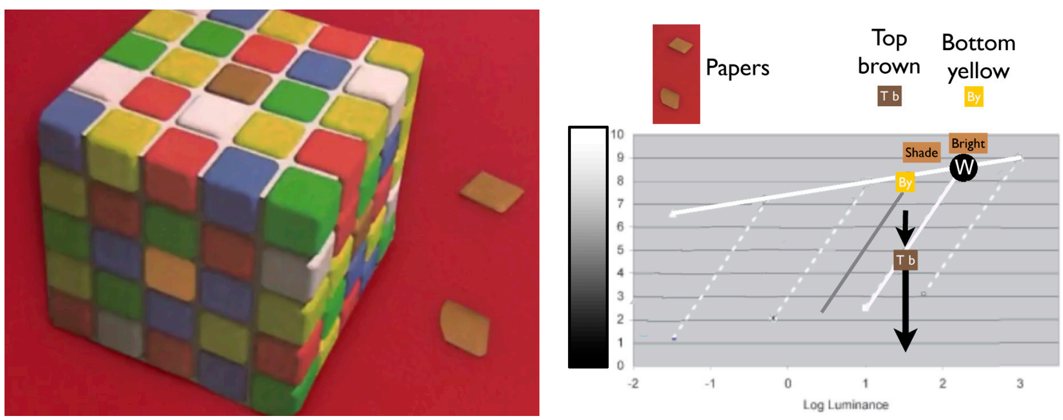

Figure 11 (left) A photograph of cube of colored tiles with papers that match center tiles on the bright top and shaded side. (right) Plot of the local influence on constant reflectance samples. The dark brown appearance is in the bright locality where the constant paper is one the lowest reflectances. In the shade however it has the highest luminance.

In the part of the photograph with the side of the cube in shade the central test square is the local maximum.[1: ch 21] The shadows make the white grout darker than all the tiles. Somehow the yellow tile is lighter than the white tile in the shade in the print. This implies that the rendition of the photograph of the cube darkens the shaded areas. Regardless, the yellow tile is the local maximum. That places it in the line for maxima. The appearance of the constant tile is lightest in the dark surround of the shadow; intermediate in the red surround and darkest in the presence of a lot of higher luminance areas.

The above analysis, namely that colors change appearance with changes in surround, is traceable back to da Vinci. The presentation of "Shady Optical Illusion 8", although dramatic, fits in well with our understanding of visual processes involving maxima and edges.

5. ROLE OF GRADIENTS AND EDGES IN "IMPOSSIBLE SHADE ILLUSION!"

The "Impossible Shade Illusion!"is a video adaptation of Ted Adelson's "Checkerboard Illusion". As with the cube of tiles the key element that makes the illusion work is the fact that the papers are not uniform papers. Rather they are photographic gradients. They appear uniform, but have variable edge luminances. As we saw in Figure 5, the position of gradients controls their influence on appearance.

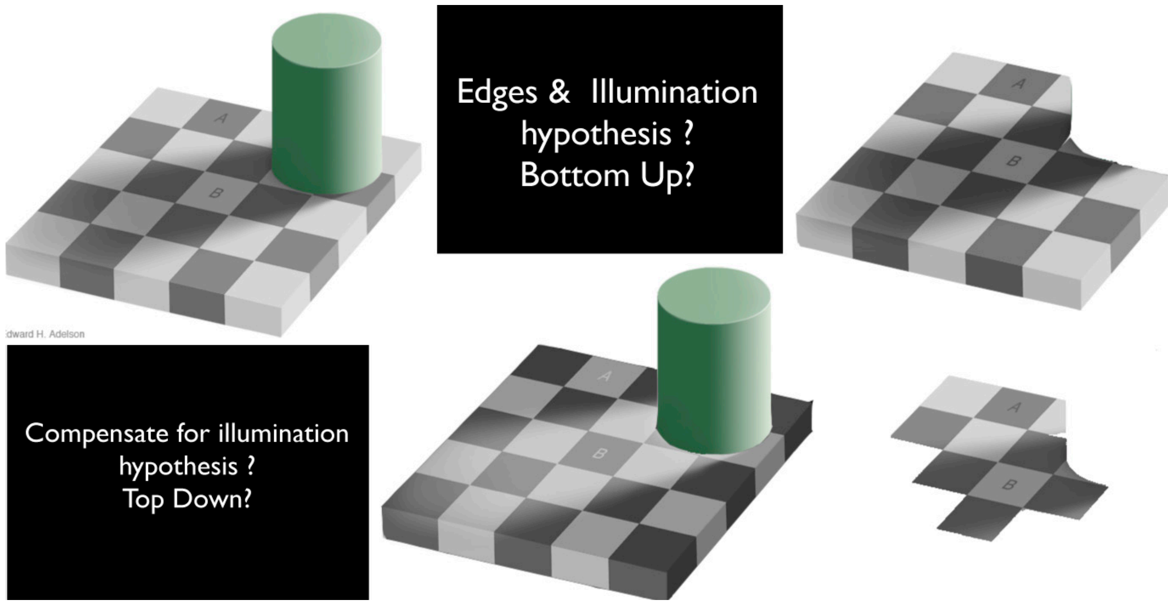

Figure 12 (left top) Ted Adelson's checkerboard made of edges and gradients. Areas A & B have equal digits. (middle-bottom) Negative image of the tower experiment in which the tower emits light. (right top) Tower is removed. (right bottom) More than half the checkerboard has been removed.

A number of sites on the web describe this illusion as evidence that humans recognize the illumination is lower behind the tower and compensate by altering perceptions. Thus, this hypothesis assumes the area B should look lighter because you can cognitively recognize the shadow, and that cognition feeds back to modify lower level sensory response. This top-down feedback has been hypothesized to modify sensation.

We can test this top-down influence of the tower by the sequence of experiments in Figure 12. By making the checkerboard a negative image we can make the tower emit light instead of shading light. Regardless, the difference in appearance of A and B (middle bottom). Removing the tower as no effect (Figure 12, right top). Removing the majority of the squares has no effect (Figure 12, right bottom).

Figure 13 is an Image J3D plot of the gray squares in Figure 12 (top left). It shows that the areas A and B are uniform and have identical. The areas around B are all gradients. The edges of the gradients all contribute to making B appear lighter. Instead of one gradient as seen in Figure 5, we have many gradients building up the lighter sensation of B.

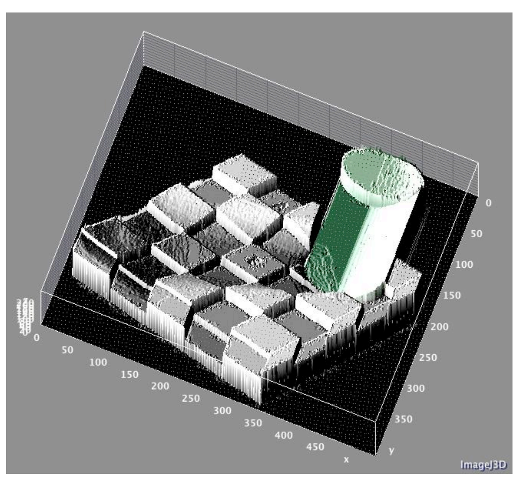

Figure 13 is an ImageJ3D plot of the checkerboard. Areas A and B are uniform, and the areas around B are gradients. The edges formed by the gradients with B make it appear lighter.

If you study the images in Photoshop®, you find that Brusspup's video is subtly different from Adelson's checkerboard. Adelson incorporated illumination into the digital image. His test areas A & B are uniform. Some of the other squares are gradients. Brusspup's moving paper is a gradient. Brusspup adds a nonuniform light source. Nevertheless, it is the edges formed by these gradients that generates the appearances.

6. RETINEX PHOTOGRAPHS OF ILLUSIONS

Bob Sobol led the software spatial processing development for a series of HP digital cameras.[6, 1:chapter 32] Its spatial processing used a combined RGB signal as the input to Retinex. It scaled that output to apply it to the RGB color space. If this commercial camera actually mimics vision then we can use the camera to render some scenes that illustrate the spatial processing in vision. The images in Figure 14 show photographs of important vision experiments taken with a HP 945 HP ("Digital Flash"full) of a computer screen. There is no object recognition in the firmware. Nevertheless, the camera takes identical digital inputs, and by using spatial comparisons, generates shifts in the output values in the same direction that human vision does.

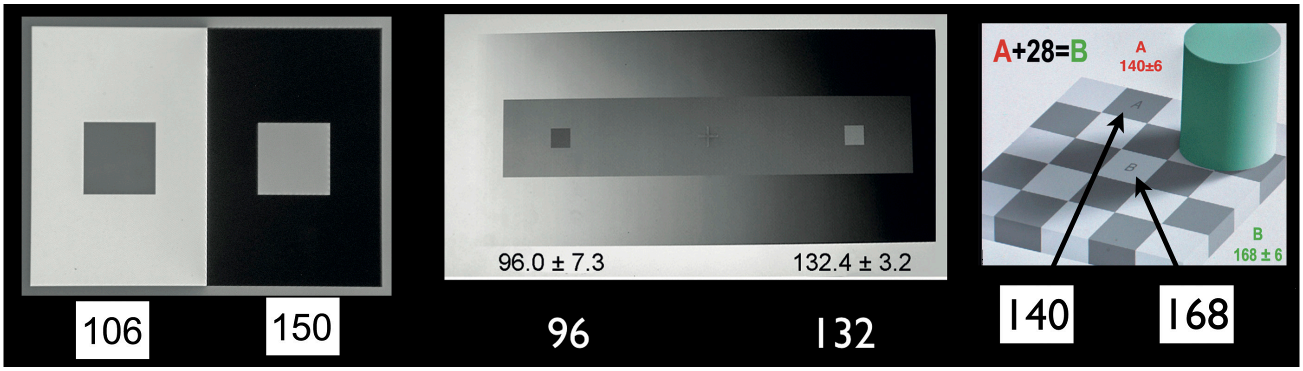

Figure 14. HP 945 photographs of a computer screen; (left) in simultaneous contrast the gray in black is lighter; (middle) in Pawan Sinha's double gradient the right square is lighter; (right) in Ted Adelson's Checkerboard illusion B is lighter.

While these photographs of illusions are interesting, and provide existence proofs of the things spatial processing can do, they are not the same as more controlled measurements and models of vision. The HP-945 is not a substitute for such models, but does provide an interesting benchmark for spatial processing. The fact that algorithms, designed to make better HDR renditions of the world, respond the same as humans to illusions goes well beyond coincidence. There are no cognitive frameworks in the camera's firmware. The low-level spatial processing of scene data is central to HDR image processing and vision.

7. CONCLUSIONS

The "impossible" illusions discussed here are great fun. They catch our interest because they violate our cognitive experience. Balls don't roll up hill; papers don't change appearances when we slide them around the table. The magic here is the skill of the magician. They use the human tools for generating sensations to portray impossible things.

- The careful selection of a monocular point of view can startle us.
- Making a brown tile be the local maxima in a shadow can make it yellow.
- Arranging invisible gradients to make highly visible edges makes seemingly uniform papers change tone.

As we saw in the HP 945 Retinex photographs, low level spatial processing can generate changes in output that mimic vision. These illusions follow the tradition of painting and photography, They synthesize the desired rendition of the scene by using the spatial building blocks of human sensation. In these cases they used these sensations to violate our perceptual predictions.

8. ACKNOWLEDGEMENTS

The author appreciates the help of Mary McCann in formulating these experiments.

REFERENCES

[1] McCann J. J., and Rizzi, A., [The Art and Science of HDR Imaging], Wiley, Chichester, (2012).
[2] Land, E. H., and McCann, J. J., "Lightness and Retinex Theory," J. Opt. Soc. Am. 61, 1-11 (1971).
[3] Sinha, P., "Brightness induction from unseen cues," Perception (in press).
[4] http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html
[5] Sobol, R., "Improving the Retinex Algorithm for Rendering Wide Dynamic Range Photographs," J. Electronic Img. 13, 65-74 (2004).