HDR imaging and color constancy: Two sides of the same coin?

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ABSTRACT

At first, we think that High Dynamic Range (HDR) imaging is a technique for improved recordings of scene radiances. Many of us think that human color constancy is a variation of a camera's automatic white balance algorithm. However, on closer inspection, glare limits the range of light we can detect in cameras and on retinas. All scene regions below middle gray are influenced, more or less, by the glare from the bright scene segments. Instead of accurate radiance reproduction, HDR imaging works well because it preserves the details in the scene's spatial contrast. Similarly, on closer inspection, human color constancy depends on spatial comparisons that synthesize appearances from all the scene segments. Can spatial image processing play similar principle roles in both HDR imaging and color constancy?

Keywords: High-Dynamic Range (HDR) Imaging, color constancy, intraocular scatter, veiling glare

1.0 INTRODUCTION

Silver halide photography has a fixed response to scenes. Films count photons, and that results in a count-dependent optical density. The response range (film's sensitivity to light), and the film's density are set in the film factory. Digital imaging makes it possible to display wider ranges of scene radiances caused by variations in illumination. If we turn to imaging hardware solutions, we can improve the range of the light sensors, increase the number of digital quantization levels, improve the emission range of displays, and we might make accurate reproductions over a greater range of light. Active pixel processing has led to techniques that can increase the range of measurement to 10 log units.[1-3] Raw formats in commercial cameras make it possible to access 16-bit scene renditions.[4] Seetzen et al. used an unsharp mask technique to illuminate a high-resolution LCD display with an out-of-focus, modulated, array of LED illuminators.[5] The Dolby embodiment has a 5 log unit range with 1500 cd/m2 screen luminance.[6] The question becomes: "How much of the 10 log unit range of the sensor response, and the 5 log units range of displays can we use in imaging?

2.0 MEASUREMENTS OF VEILING GLARE LIMITS CAMERAS AND HUMAN OBSERVER

Jones and Condit measured the range of light in 128 outdoor scenes and cameras' response to them.[7] They measured the range on the camera's film plane. They showed that the optical veiling glare (scattered light), not sensor signal-to-noise, determines the usable dynamic range of cameras. They subsequently designed negatives that captured all the information above the glare limit, roughly 4 log units. (The use of high-contrast print paper causes the loss of scene detail in prints.) Recent measurements of the veiling glare limits in cameras and in human vision show a strong scene-dependency. Camera optics add an unwanted fraction of the scene's light to the wanted image of the scene on the sensor.[8] This unwanted glare is present in all multiple exposures, and makes calculations of scene radiance from camera images unreliable.[9]

Further, intraocular glare limits the range light falling on the retina.[10-12] As with cameras, the range of usable light for humans varies with the scene content. It is about only 1.5 log units with a maximum white background; around 2 log units with 50% background; and slightly over 4 log units with a no-light background. Optical veiling glare limits the range of scene radiances we can capture accurately; and intraocular glare limits the image of the scene's range on the retina.

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3.0 TWO VISION PARADOXES

Nevertheless, digital HDR imaging dramatically improves scene rendering. There must be reasons, other than accurate scene rendition, that account for the success of HDR imaging. We can turn to two important, but paradoxical observations. First, artists since the Renaissance have rendered HDR scenes in the low-dynamic range of paintings. Second, humans see details in shadows over 4 log units, using optic nerves that can transmit only 2 log units of range.[13]

4.0 TWO OPPOSING MECHANISMS

The resolution of these paradoxes is that human spatial image processing counteracts the effects of glare. Humans have two independent and opposing spatial mechanisms. The optical mechanism, intraocular veiling glare, reduces the luminance range on the retina, while the neural mechanism, spatial image processing, increases the apparent differences. Figure 1 shows the classic simultaneous contrast experiment with two identical scene luminance gray patches. The one surrounded by white has more glare than the gray-in-black. If retinal luminance predicted appearance, then the gray-in-white must appear lighter than the gray-in-black. However, human's spatial image processing, *simultaneous contrast,* makes the lower contrast gray-in-white look darker. In this case, contrast overcompensated for glare.

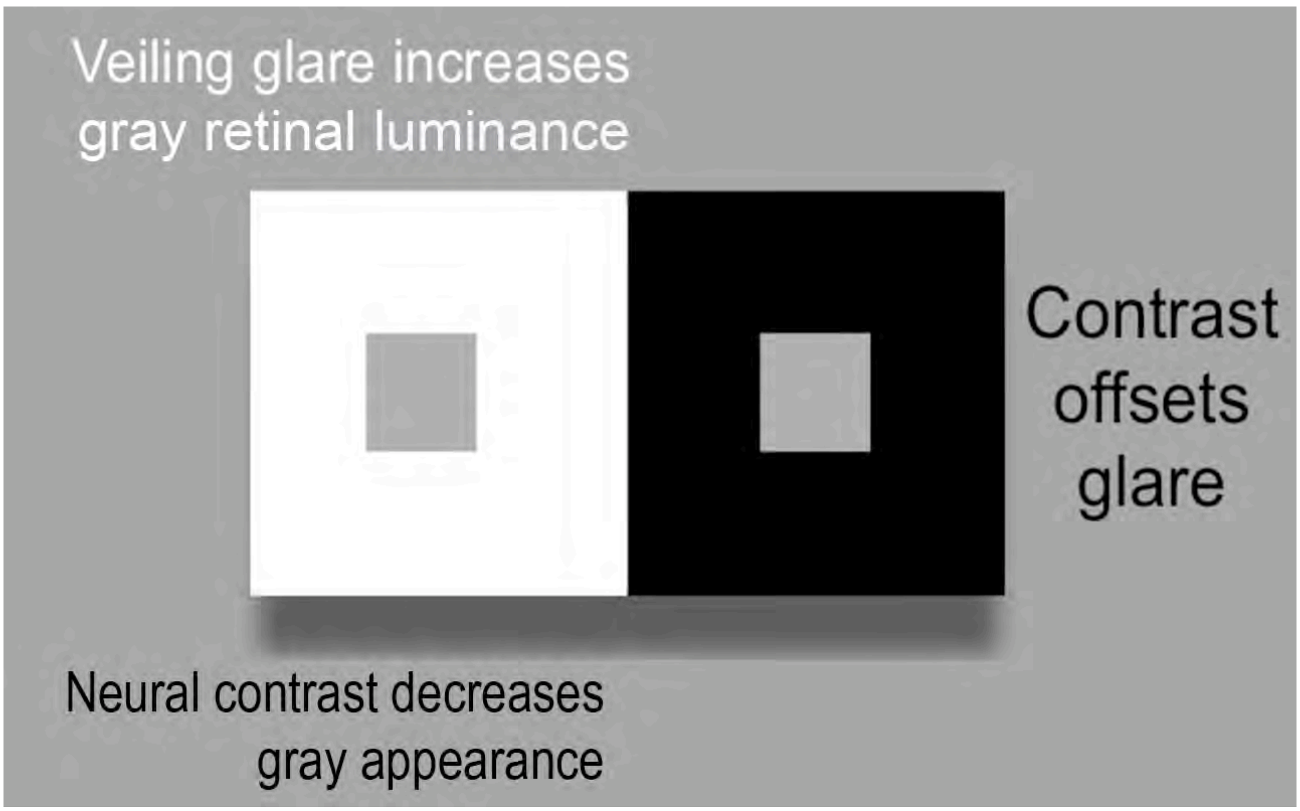

Figure 1. Two opposing spatial mechanisms control the appearance of gray patches.

Glare distorts the luminances of the scene in the image on the retina. It lowers retinal contrast. Simultaneous, or neural spatial processing works to counteract glare. The lower ***actual contrast*** image appears to have higher ***apparent contrast***. Both glare and simultaneous contrast are spatial processes and depend on the contents of the entire scene.

5.0 COLOR CONSTANCY IS SPATIAL PROCESSING

Color constancy is usually considered to be unrelated to HDR scene rendition. Unlike films that have fixed spectral sensitivities, humans see objects with constant color appearances from variable spectral stimuli. Traditional explanations have used pixel-based normalization, similar to white balancing a camera. Many assume that retinal cones adapt to changes in illuminations, so as to discount the illumination, so that appearances correlate with reflectances.

Such hypothetical mechanisms can account for flat 2-D Mondrian test targets, but fail to predict the variable appearance of constant paints in complex illumination on 3-D Mondrians.[14] Figure 2 shows photographs of two identical 3-D Mondrians: one in nearly uniform illumination, and the other in directional (HDR) illumination. Adaptation, or any other single pixel process, cannot predict colors in 3-D Mondrians.[15] Other studies with variable spectral illumination show that the small departures from perfect color constancy are predicted by spatial comparisons.[16] Color constancy depends on spatial comparisons that synthesize appearances from all the scene segments.[17]

Figure 2. The pair 3-D Mondrians, made with 11 paints, viewed at the same time in the same room. The left is in nearly uniform illumination, while the right is in directional HDR illumination. Appearances vary with illumination, despite constant reflectances.

6.0 ACCURATE HDR REPRODUCTION: NOT POSSIBLE AND UNNECESSARY

At first, we think that High Dynamic Range (HDR) imaging is a technique for improved recordings of scene radiances. However, on closer inspection, glare limits the range of light we can detect in cameras and on retinas. All scene regions below middle gray are influenced, more or less, by the glare from the bright scene segments. Instead of accurate radiance reproduction, HDR imaging works well because it preserves the details in the scene's shadows. Seeing high-contrast details in the dim light of shadows is key to improved HDR appearances. Spatial image processing preserves this information, but distorts accurate reproduction. Similarly, human color constancy, also on closer inspection, depends on spatial comparisons that synthesize appearances.

7.0 COINCIDENCE?

The combination of the development of extended range cameras and displays with studies of human color vision covers a very large range of topics. Are there real advantages to thinking in such an inclusive manner? The *two sides of the same coin* analogy suggests that the coin's two different pictures convey different information from the same object. At times, it can be helpful to study problems from different perspectives. What one learns from one approach can be transferred to the other. The Dark Side of Color question is: Will it be helpful to integrate the spatial properties of HDR imaging with those of color constancy?

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