Color Construction*

Donald D. Hoffman

A Commentary on Brown's paper

Backgrounds and illuminants: The yin and yang of color constancy

Over a wide range of viewing conditions, our experience of an object's color varies little. This "color constancy" is a striking achievement of human vision, and raises a much-debated question: What is the proper theoretical framework for understanding color constancy?

Several approaches have been considered. The most common has been to estimate the spectral composition of the illuminant, and to compensate for it while estimating the colors of object surfaces. An example of this approach is any model based on a variant of the "Grey World" hypothesis: the assumption that the average reflectance of surfaces in a visual scene is grey. This hypothesis allows one to estimate the spectral composition of the illuminant by simply computing how the space-averaged light from a scene deviates from grey. Another approach uses the assumption that illuminants and reflectances in nature can adequately be represented by linear models of low dimension, say two or three dimensions each. This assumption, when true, allows one to compute the reflectances and illuminants in a scene, thereby giving color constancy.

In his paper "Backgrounds and illuminants: The yin and yang of color constancy" Richard Brown pursues a third approach, which urges careful attention to the evolutionary constraints on perception, and therefore to the ecological properties of the environment to which perception, and in particular color perception, might be adapted.

Careful attention to ecology can uncover shortcomings of the standard approaches. Brown notes that careful study of the reflectances of natural scenes reveals that the Grey World hypothesis is, in general, false. Furthermore, careful study of reflectances and illuminants in nature reveals that they are not adequately represented by linear models of low dimension. Although the standard approaches are attractive for their computational simplicity, that simplicity apparently derives from unrealistically simplified representations of the natural ecology of reflectances and illuminants, and therefore such approaches are unlikely to perform adequately for natural scenes. They are, in consequence, unlikely to be adequate models for human visual performance.

---

* A commentary in *Colour: Mind and the Physical World,* edited by D. Heyer and R. Mausfeld (Eds.) Oxford University Press, 2003, 273–274.

Brown also uses his ecological approach to suggest interesting directions to explore for biologically plausible accounts of color constancy. He notes, for instance, that for luminance, the variation of intensity in natural illuminants is much larger than in natural reflectances, whereas natural reflectances exhibit much larger variation than natural illuminants in both the blue-yellow and red-green dimensions of MacLeod-Boynton color space. He suggests that the luminance and color-opponent channels in human vision are adapted to these differences, and that this adaptation is helpful, though not the entire solution, for color constancy. Thus Brown's ecological approach is useful both in pointing out shortcomings of existing approaches to color constancy, and in suggesting new directions of exploration for more adequate accounts. However Brown himself does not propose such an account.

I agree with Brown that an ecological approach to color constancy is required, one that gives due attention to the properties of natural visual scenes and the perceptual problems faced by the visual system. Brown's analysis of the chromatic and luminance properties of natural reflectances and illuminants, and their relation to human color opponent channels, is an important step in this direction. But I also suggest, and I suspect Brown would agree, that the scope of such analyses must be made much wider. A demonstration I first saw from Jan Koenderink will help to make this point. The demonstration is available online at this URL:

http://aris.ss.uci.edu/cogsci/personnel/hoffman/Applets/Grid/Grid.html

On the left, in this demonstration, I have arranged a set of 49 squares with systematically varying chromaticities. On the right I have simply randomly rearranged the positions of the same 49 squares. However the two sets of squares appear different in several respects. The set of squares on the left appear to be illuminated by several different colored light sources. The squares themselves do not appear flat, but slightly scalloped, concave or convex. Moreover each square does not appear of uniform brightness, but appears lighter on one side and darker on the other. In contrast, the set of squares on the right appear to be illuminated by a single white light source. The squares appear perfectly flat and each of uniform brightness. And there appear to be browns and tans, colors which do not appear in the set of squares on the left.

This demonstration illustrates that the visual construction of colors is done in concert not only with the construction of the chromatic properties of light sources, but also in concert with the construction of the 3D shapes of surfaces. And this makes sense when one considers that realistic reflectance models must, in general, take into account the angle of incidence and reflection of light with respect to the local normal of the surface, i.e., such reflectance models must incorporate the 3D geometry of the surface. So the problem of color constancy cannot be divorced from the problem of constructing 3D surface shapes, and therefore the ecological considerations that motivate our theories of color constancy must be extended to include 3D shape.

Not only does 3D shape interact with our construction of colors, so also does apparent motion (Cicerone, Hoffman, Gowdy, and Kim, 1995; Wollschlaeger, Rodriguez, and Hoffman, 2001). A demonstration of this is available online at this URL:

http://aris.ss.uci.edu/cogsci/personnel/hoffman/Applets/Outline/java.html

In this demonstration, there are many small colored dots scattered at random over a white background. All of the dots are one color, say, red, except for those dots which happen to lie inside a virtual disk and are colored, say, green. As the virtual disk moves from one frame to the next some dots change color, depending on whether they are now inside or outside the disk, but no dots ever move. The perceptual effect is quite striking. One sees a uniformly colored disk gliding across the display. The chromatic properties of this disk depend on the speed of its apparent motion (Cicerone et al., 1995). Note that in this display one sees the green color spreading over regions that a spectral photometer would reveal are white. So this demonstration illustrates that the problem of color constancy cannot be divorced from the problem of constructing object motions, and therefore the ecological considerations that motivate our theories of color constancy must be extended to include object motion.

And this raises my last point. Once we focus on the fact that the colors we see depend not only on illuminants and reflectances, but also on 3D shape, motion, and other factors as well, is it really useful to pick out color constancy as the object of study? The perceptual phenomena we place under the rubric of color constancy are part of a much wider range of phenomena, and perhaps not a natural part. We might do better to focus on the principles of color construction more generally rather than on color constancy in particular. The phenomena now called color constancy might then fall out as a special case.

1. C.M. Cicerone, D.D. Hoffman, P. Gowdy, J. Kim. (1995). The perception of color from motion. *Perception & Psychophysics,* 57(6), 761-777.
2. D. Wollschlaeger, A.M. Rodriguez, D.D. Hoffman. (2001). Flank transparency: Transparent filters seen in dynamic two-color displays. *Perception,* 30, 1423-1426.