Light Touch

Colored Shadows and Retinex Vision

When the sun is low at the end of a clear winter day, the long shadows of trees against the snow look violet-blue in comparison to the gold sunlight. As sunset progresses and the sunlight becomes redder, the shadows may look green.[1] A controlled experiment will show that, in general, shadows of objects that are illuminated in colored light will be the complementary colors in the presence of a white light background illumination.

Colored acetate (available at art supply stores) can be used to show this. Cast a shadow using colored light (*e.g.*, a flashlight covered by a colored acetate filter) onto a white wall or sheet of paper in an otherwise normally and brightly lit room. If the filter transmits predominantly red light, the shadow will look a pale green. If the filter transmits green, the shadow will be colored pink. Orange is the complementary color of blue, but "blue" acetate is often really blue-green and its shadow may appear more pink than orange. If you see no color in the shadow, the white light is too bright; either move the colored light source closer to the wall or dim the white light source.

The complementary colors of shadows can be used to code realistic color into black and white transparencies. You will need a camera, black and white film, red and green (or blue) filters, and two overhead projectors to show this. Arrange and photograph a still life scene twice without moving the camera: place a red filter over the camera lens to take the first photograph, and replace the red filter with a green or blue filter for the second photograph. Print the photos onto paper and make overhead transparencies of each using a photocopier.

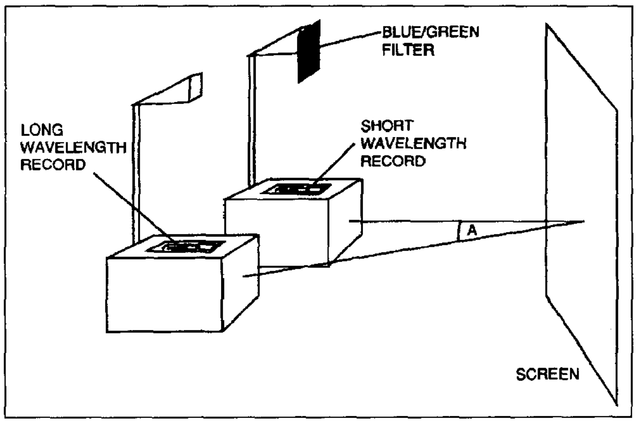

Figure 1. Set-up for viewing color image using two black and white transparencies and a single color filter.

You should have two positive black and white transparencies that, at first glance, look similar. Objects in the actual scene that were red will look pale in the first transparency (corresponding to the red filter) and dark in the second transparency (blue or green filter). Likewise, blue objects in the scene will look dark in the first transparency and light in the second. We will follow Edwin Land[2] and refer to the black and white transparency photographed through the red filter as the "long wavelength record" and the one photographed through the green or blue filter as the "short wavelength record."

Set up the overhead projectors to project onto a screen or a white wall in an otherwise dark room. Put the transparencies on separate projectors and arrange the transparencies so that their images superimpose on the screen. The superposition will be imperfect; this is from distortion in the images since both projectors cannot simultaneously be oriented normal to the screen while projecting a superposition image. However, the distortion can be minimized by keeping the projector-screen-projector angle (see angle A in Fig. 1) as small as possible. With no filters, a black and white superposition image will be observed.

The perception of two or more colors occurs with the introduction of a single color filter. By placing a blue filter over the short wavelength record, the complementary color will appear in the image. An example is shown in Figure 2 for a short wavelength record made with a blue-green filter. When the transparencies are taken off the projectors, but the blue filter is kept in place, a single, uniform (pale blue) color is seen.

The reconstructed colors in the image are likely to be incomplete. This is illustrated in Figure 2. The original scene contained yellows and greens that are absent in the figure. However, it turns out that nearly full color images are obtainable using this method, providing proper care is taken[2,3] *i.e.*, controlling the transmission spectra of the color filters and minding the linearity of the transparencies (not possible using a photocopier for most photographic subjects). When these precautions are taken, striking full color images are reproduced using two black and white long and short wavelength records with a single color filter. (Refs. 2 and 3 contain splendid illustrations.)

The question remains why one should see complementary colors in shadows at all. Recall that the color-sensitive elements in our retinas are the cones. "Blue" cones have a peak spectral sensitivity at 440 nm, but also respond to wavelengths from approximately 375-510 nm. The "green" and "red" cones have peak sensitivities at 535 and 565 nm, respectively. Their sensitivities are quite broad and span

Susan Houde-Walter, *Assistant Professor of Optics at the University of Rochester, is a contributing editor to OPN.* **Greg Pierce** *is Senior Technical Associate for the Institute of Optics, University of Rochester.*

FIGURE 2. PHOTOGRAPH OF RECONSTRUCTED COLOR IMAGE USING BLUE-GREEN FILTER OVER THE SHORT WAVELENGTH RECORD. NOTE THAT THE ORIGINAL SCENE CONTAINED YELLOW AND GREEN IN BACKGROUND.

nearly identical wavelength ranges (roughly 450-630 nm and 460-655 nm, respectively). Land points out that our perception of brightness and color is generally unaffected by the vast range of illumination levels that we encounter in our visual scenery. A black object looks black and a white object looks white, even if the reflected flux from the black object exceeds that of the white object. He explains that the perceived brightness of a scene is normalized somewhere in the retina and cortex ("retinex") to the maximum reflected flux at any point in the scene. This brightness scale normalization is specific to each cone type (red, green, blue); it is independent of the normalization for the other cone types.[3]

Consider the example of the violet-blue shadows in the gold light of the setting sun, and assume for simplicity that the flux from the scattered skylight is white.[4] The gold (*i.e.*, yellow/orange) direct sunlight is in the sensitivity range of the red and green cones. These cones see a high contrast between the shadow and the bright surround since the surround is illuminated by two sources (white skylight and gold direct sunlight), to which both of these cones are sensitive . The blue cones are not sensitive to the direct sunlight, so the surround is apparently illuminated by only one source (white skylight). Consequently, the contrast between the shadow and the surround is much weaker and the shadow appears less dim to the blue cones than it does to the red and green cones. The predominant color assigned to the shadow region comes from the blue cones, while the color assigned to the surround comes from all three cone types. Therefore, shadows on snow-covered ground will be distinctly violet-blue in the gold light of the evening.

References

1. J.W. Von Goethe, *Theory of Colors*, trans. into English by C.L. Eastlake, Cass Publ., London, 1967, p.34 et seq.; *The Nature of Light and Color in the Open Air*, Dover Press, New York, 1954, section 96, p. 134.
2. E.H. Land, "Experiments in color vision," Scientific American, May 1959.
3. E.H. Land, "The retinex theory of color vision," Scientific American, December 1977.
4. Since the shadows can be much more colored, we will ignore the blue of the sky dome; admittedly, this is an oversimplification made to emphasize the physiological effect. In fact, the blueness of the sky does contribute to the blueness of the shadows, but not enough to fully account for their color.

Largest Available Tuning Range...
and Constant Time Delay...

The HRL-100Z, hybrid Ti:sapphire/OPO laser system

- Single Longitudinal Mode
- High Spectral Brightness
- All Solid State

STI OPTRONICS
2755 Northup Way, Bellevue, WA 98004
Phone: (206)827-0460 or 1-800-4TUNING
Fax: (206)828-3517