Technology Brief 23
Spectral and Spatial Filtering

Filtering is applied in electrical systems, sound systems, optical systems, mechanical systems, and more. It is so ubiquitous that we often are unaware of the filtering that occurs in every day life. This Technology Brief provides an overview of how filters are applied in sight and photography, and how this affects what we see. There are two major types of filters in what we see—***spectral filters*** that control color and ***spatial filters*** that control smoothing and edges.

Spectral Filters

Our eye is, itself, a spectral filter. The colors we can see range in wavelength from about 750 nm (400 THz, red) to 400 nm (750 THz, violet). Other frequencies, such as the ultraviolet (UV) and infrared (IR), are not detectable by the human eye. Thus, our eye is a spectral bandpass filter with a bandwidth of about 350 THz. But we do not see all colors equally well. Our eye's frequency response is nonlinear. **Figure TF23-1** shows the relative response of the eye to different colors of light. The eye is more sensitive to colors in the yellow-green region than to red and blue colors. This is why neon-yellow clothing provides high visibility under both dim and bright conditions (**Fig. TF23-2**).

Figure TF23-2: The eyes are a nonlinear bandpass filter. Greenish yellow provides high visibility in both dim and bright conditions because of the nonlinear sensitivity of our eyes to this color. (Credit: Agoora.co.uk.)

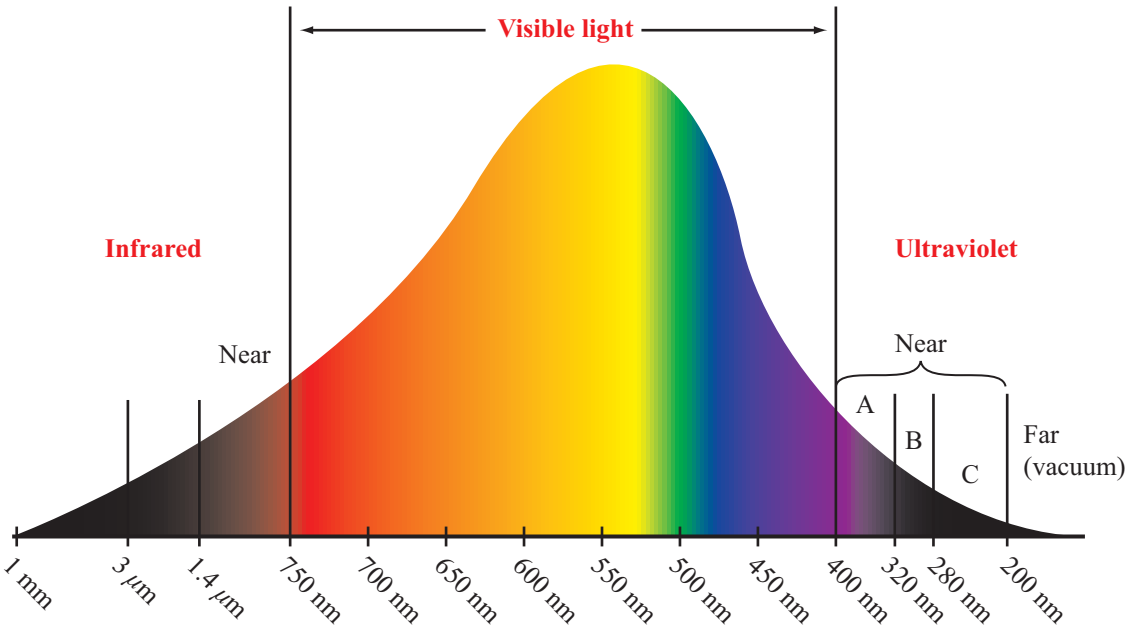

Figure TF23-1: Visible, infrared, and ultraviolet parts of the electromagnetic spectrum.

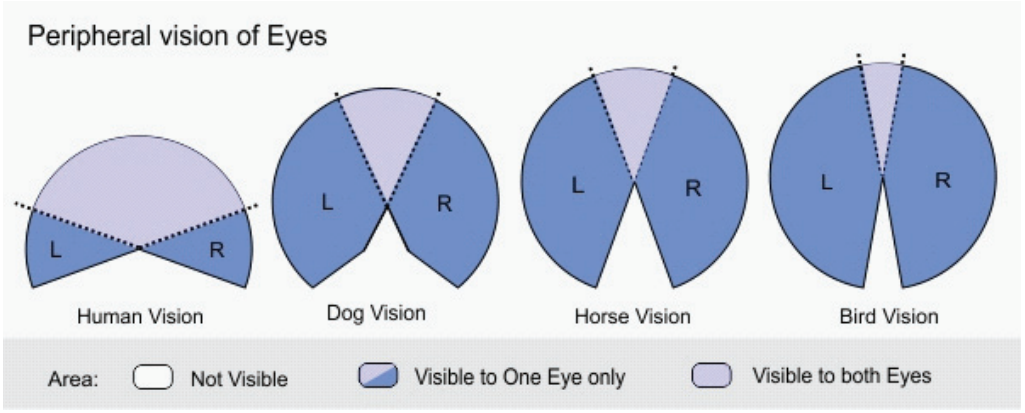

Figure TF23-3: Field of view (spatial filter) for humans, dogs, horses, and birds. (Courtesy of Wordpress.com.)

Our eyes are also a spatial filter. Humans can see across an angular range of about 180°, including a narrow range where we focus and see colors, and a much wider peripheral field of view where vision is not as clear and colors are more limited (**Fig. TF23-3**). The field of view is controlled mainly by the placement of the eyes on the head. Some birds have 360° fields of view. Some animals (horses, for instance) do not see directly in front of them, but have broader fields of view that let them see along both of their sides and even almost behind them. Prey animals tend to have larger fields of view than predators, whose eyes have more focus in front of them.

Tinted lenses and photo editing are spectral filters that can selectively filter out various parts of the optical spectrum (**Fig. TF23-4**), acting as band pass or band reject filters. Gray tinted lenses are most common,

(a) Grey filter

(a) Amber filter

(c) Rose filter

(d) Blue filter

Figure TF23-4: Color filters. (Credit: SunglassWarehouse.com and Krista Ward.)

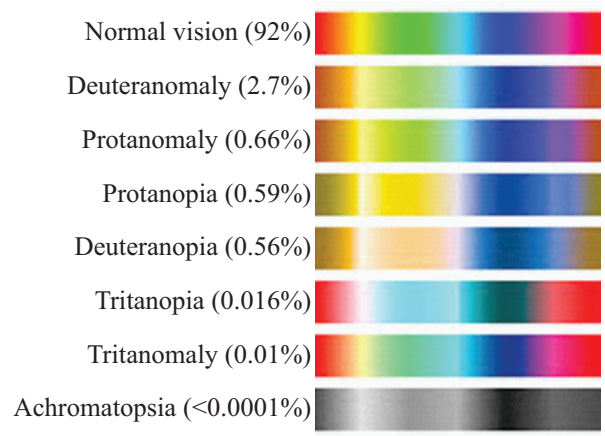

Figure TF23-5: Percentage of people with various types of color blindness.

because they absorb all colors roughly equally, thus reducing the overall brightness with minimal change to the color vision. They act like optical attenuators. Amber or brown lenses reduce brightness, but they also absorb (filter out) blue and UV light. The blue hues in an image often appear to us as hazy or blurry, so absorbing this range brings out the apparent contrast and sharpnes in an image, and absorbing UV helps reduce the risk of cataracts. Yellow lenses, often used in ski goggles, absorb almost all of the blue light, making the image appear bright and sharp, but colors are significantly distorted. Green lenses also absorb the blue range, thus enhancing contrast and sharpness, and they have the highest color contrast. Purple and Rose colored lenses give emphasis to objects outdoors against green and blue backgrounds, thus raising the contrast in an image, especially in low light conditions. These images are often perceived as more beautiful, and seeing the world "through rose colored glasses" has become synonymous with optimism.

Color blindness is a natural type of filtering that occurs when the eyes are less sensitive to color. **Figure TF23-5** shows color filtering and the incidence of different types of color blindness in people.

Spatial Filters

When we use a camera to record a digital image, we want that image to reflect what we see in real life. Or do we?

(a) Lowpass filtering is a smoothing (averaging) operation

(b) Edge detection is highlighted by high-frequency spatial filtering

Figure TF23-6: (a) Lowpass filters remove small imperfections and (b) highpass filters accentuate edges.

Photoshop™ and other photo editing tools allow us to control just how "real" our photos appear. One common spatial filter applied to images after the fact is a smoothing filter. This allows us to remove blemishes from the skin by smoothing or averaging the skin tones as in **Fig. TF23-6**. Smoothing (or blurring) is, effectively, a spatial lowpass filter. By contrast, a highpass filter emphasizes the outline and provides edge detection. It makes things less blurry. Things that change suddenly (edges) represent the high-frequency spatial content in an image.