COLOR THEORY BASICS FRED DRURY

On the one hand you don't need to be a color theory expert to make a good print. But on the other hand, color theory can help you understand some the differences between what your eyes see, what the digital camera records, and what gets printed by your inkjet printer. If you have any questions about this article, you can email me at: fred@marklandimaging.com

Color spaces are a scientist's objective way of describing color. As is the case with image evaluation, it's useful to think of colors both subjectively and objectively. From a subjective viewpoint colors may be muted, monochromatic, vibrant, cool, warm, earth-toned, etc. All these terms (and many more) are descriptive without being specific. Describing colors objectively requires a system (more commonly referred to as a 'color space') which provides for all possible colors in an absolute and measurable way. Many useful color spaces are possible.

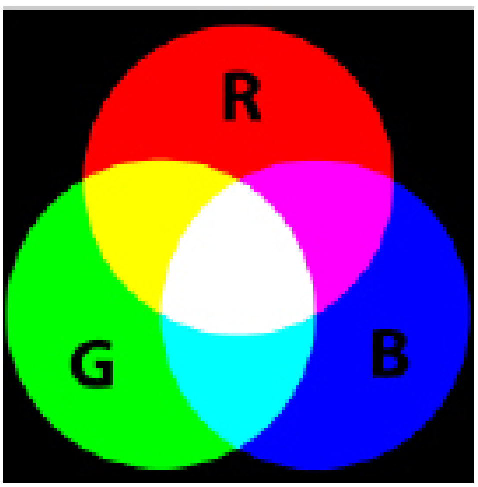

***Figure 1**: Additive color mixing: adding red to green yields yellow; adding all three primary colors together yields white.*

The best known objective system is the RGB color space (**Figure 1**); it measures color in three components, red, green and blue. The RGB color space emulates human vision. The rods and cones in the human vision system see colors in terms of red, blue and green. In RGB, if there is no light reflected from a subject, that absence of color is seen as black. As light is ***added***, color is seen; for that reason the system is said to be '***additive***'. If an object reflects red light, the object is 'seen' as 'red'. If an object reflects equal amounts of red, green and blue light, the object is seen as gray. If an object simultaneously reflects maximum values of red, green and blue, the object is seen as 'white'. In all of these respects, the RGB color space is similar to human vision. Most of the devices photographers use (film cameras, digital cameras and scanners) are RGB devices; they measure color in red, green and blue components and combine the component colors additively.

Printers however deal with color in a very different manner. They use the CMY color space (**Figure 2**). Printers start out with a white (or almost white) sheet of paper, upon which they lay down ink. In this case the absence of color is 'white' and laying down equal amounts of the component colors is intended to produce 'gray'. Similarly, laying down maximum amounts of the component colors is intended to produce 'black'. This is a '***subtractive***' color system; color is '***subtracted***' in order to move from black to white, the reverse of the additive system.

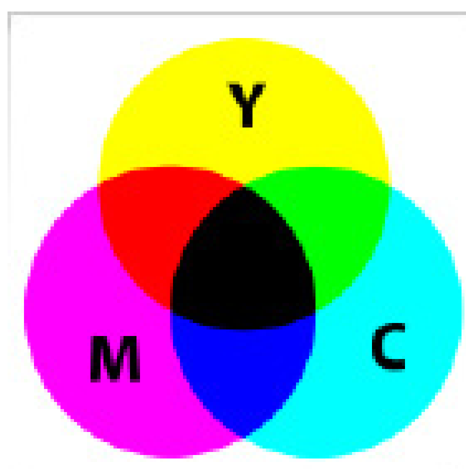

***Figure 2**: Subtractive color mixing: adding magenta to yellow yields red; adding all three primary colors together yields black (in theory).*

A most important relationship between the CMY and RGB color spaces is the interaction between colors and their compliments. Combinations of any two colors in one color space produce the compliment of the third component color in the other color space. For example (**Figure 3**), laying down equal amounts of magenta and yellow ink with a printer produces the compliment of cyan (the third component color), which is red. Similarly, laying down equal amounts of cyan and yellow produce green, and equal amounts of cyan and magenta produce blue. Note: this description is oversimplified: because no 'perfect' cyan ink has ever been found, black is therefore added to the CMY system (making it CMYK). The black ink is used to produce darker tones of all hues.

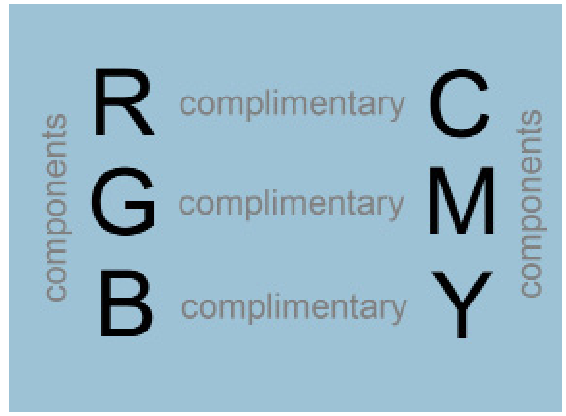

Figure 3 *shows how the RGB and CMY color spaces are related. Red is the compliment of Cyan, and so forth. Mixing and two colors (from one color space) produces the compliment of the remaining color in that color space. In other words, if you mix Red and Green, that will produce Yellow ... which is the compliment of the third color (Blue) in the RGB color space.*

In the RGB color space, this principle of complimentary colors can be used to answer the question: what happens when an object reflects equal amounts of red and green light? The answer is that the result is 'seen' as the 'compliment' of the remaining component (blue), which is 'yellow'. Similarly, an object seen as 'magenta' is one that reflects equal amounts of red and blue, and a 'cyan' object is one that reflects equal amounts of green and blue.

As has already been mentioned, the absence of any color is black. If an object reflects a very small amount of red light, the object is said to be nearly black with a hint of red. If the object reflected a very large amount of red light, the object is said to be bright red. These are two 'tones' of red. For a color system to be absolute and measurable there needs to be a quantitative system which in this case defines the tonal range between the absolutes of black and white.

Film is an analog system; the range from black to white is continuous. Between any two grays, there will always be another gray which is 'in between' the two. The difference will always be measurable even if not visually significant. Consequently, for an analog system there are an infinite number of tones between black and white.

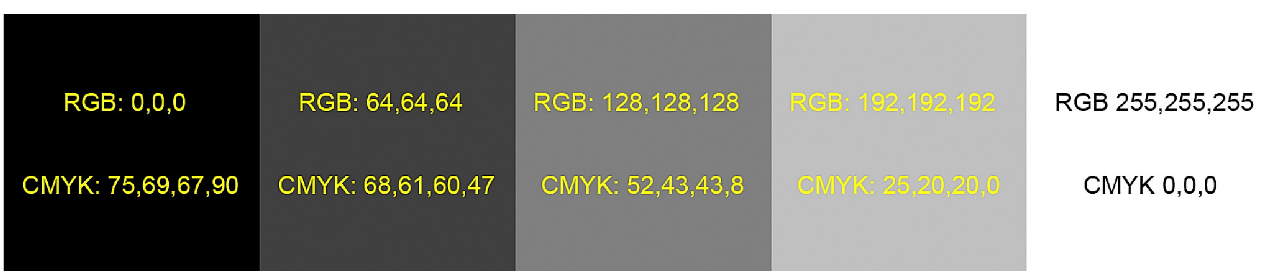

Figure 4 *is a comparison of RGB and CMYK values for different grays. Beginning on the right the first two conversions from RGB to CMY work without any black ink. The third conversion almost works, but the last two require substantial black ink contributions. The bottom line is that black ink is essential for all dark colors.*

In a digital system the tonal range is discrete. There are only as many tones as the system definition will permit. For example, if only a single bit is used to define tonality, then there can only be two tones in the system, the bit is either 'on' of 'off' (i.e. silhouette); no other alternative exists. If two bits are used to define tonality, then there are four possible tones (2^2): off-off, on-off, off-on, and on-on. For most of its history Photoshop has defined its tonal range as an 8-bit system meaning a maximum of 2^8 or 256 tones. Photoshop now uses a 16-bit system so many more tones (2^{16} or 65,536) are possible. Most digital cameras are now either 12-bit or 14-bit devices. However only in recent years have printers become available that can print more than 8-bits.

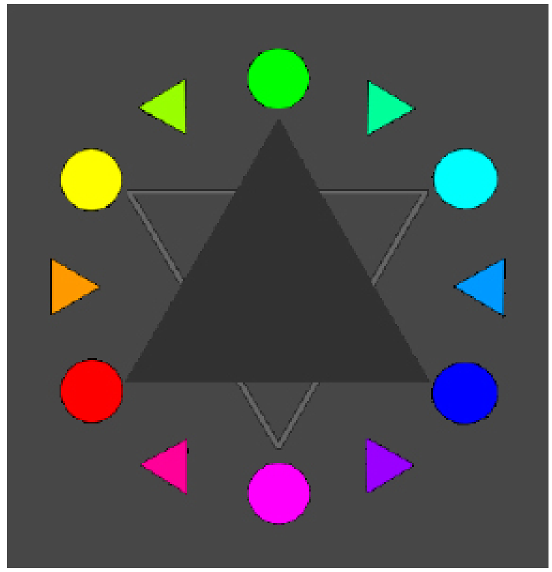

***Figure 5**: The triangles inscribed in the center show the interrelationship between the RGB (black) and CMY (gray) color spaces. Colors opposite one another (see inset) in the figure are said to be 'complementary'.*

The task of photographers is to reproduce what humans see with their eyes. This is a very significant challenge for many reasons. First of all we have two eyes which mean that we see stereoscopically; we 'see' depth. On the other hand, the camera (usually) has only one eye. The second technical challenge is the far greater dynamic range of the human eye. Our eyes are both adaptive and non-linear 'devices'. They are adaptive meaning that the retina adjusts to light conditions. Our eyes are also non-linear. Halving the light level does not reduce our ability to 'see' by half. The combination of these capabilities means that we can 'see' a dynamic range of something like 20 stops. By comparison, cameras can record light values across a far smaller dynamic range, something like 5-7 stops. The third challenge has to do with color; we cannot display many of the colors we can see, and we cannot print even all of the colors we can display. The bottom line is that there are a lot of very significant reasons why what comes out of the printer cannot look exactly like what we saw in real life! Ansel Adams dealt with these same issues by doing what he called 'previsualiztion'; that challenge remains!!

Next month, I'll begin a series of columns dealing with preparing images for, and printing images on inkjet printers.