Color Management White Paper 3

Color Spaces & Color Translation

In previous LaCie White Papers we saw that color representation was not absolute, but essentially device-dependent. Color management systems depend on, among other factors, reliable color models or spaces, which allow accurate and predictable color correspondence between devices: generally RGB peripherals (displays, cameras, and scanners) and CMYK peripherals (printers, plotters, and output devices).

Transformation technologies allow correspondence between various peripheral color spaces through the use of advanced translation processes.

Color Models

A color model is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four values or color components. RGB and CMYK are well known color models. Color models are abstractions and cannot describe a specific color without first defining the scale or reference. Without any associated mapping function to an absolute color space, they are more or less arbitrary color systems with little connection to the requirements of any given application.

CIE Color Models

In order to provide a better understanding of colors, the CIE (International Commission on Illumination), the international authority on light, illumination, color, and color spaces, established standards in the 1930s for several color spaces representing the visible spectrum. This made comparisons possible among the varying color spaces of different viewers and devices.

The CIE conducted a series of tests on a large number of people in order to define a hypothetical average human viewer and his/her response to color that they called the "standard observer." Since the human eye has three types of color sensors that respond to different ranges of wavelengths, a full plot of all visible colors is a three-dimensional figure.

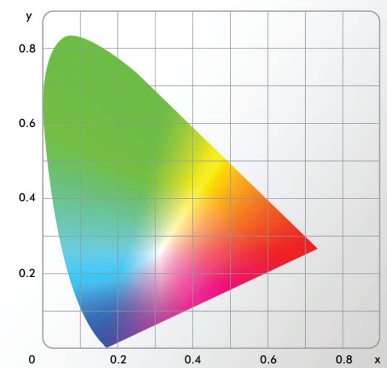
CIE-XYZ

The CIE developed the "XYZ color system", also known as the "standard color system." It is still used as a standard reference for defining colors perceived by the human eye, and as a reference for other color spaces. Like the RGB color model with additive primaries, CIE-XYZ uses 3 spectrally defined imaginary primaries: X, Y, and Z which are the representation of color (electromagnetic waves) that may be combined to describe all colors visible to the "standard observer."

CIE xyY

In order to effectively represent a three-dimensional figure on a two-dimensional sheet of paper, the CIE transformed the three-dimensional color space into two artificial dimensions of color (collectively called chromaticity) and one of intensity. They then took a two-dimensional slice through this space at the level of maximum intensity. This slice became the chromaticity diagram also called "The CIE xyY Chromaticity Diagram" (fig.1).

The CIE xyY Chromaticity Diagram

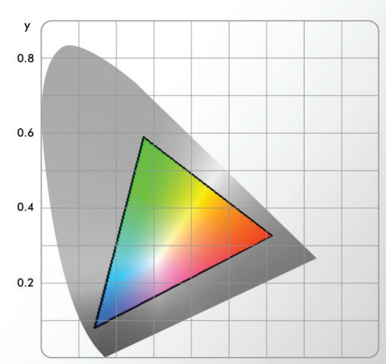


(fig. 1)

The colors depicted depend on the color space of the device on which you are viewing images. The gamut of all visible colors on the CIE plot is a tongue-shaped figure. The curved edge corresponds to the colors of the visible spectrum and the straight edge (the purple line) corresponds to non-spectral shades of purple. Less saturated colors appear in the interior of the figure, with white at the center.

A gamut is commonly represented as an area in the CIE 1931 Chromaticity Diagram as shown below (fig.2). The curved edge represents the monochromatic colors. Gamut areas typically have triangular shapes because most color reproduction is done with three primaries.

An Example of RGB Gamut



(fig. 2)

The chromaticity diagram is a tool for specifying how the human eye will experience light within a given spectrum. It cannot specify colors of objects (or printing inks), since the chromaticity observed while looking at an object depends on the light source as well. The cut-offs at the short- and long-wavelength side of the diagram are chosen somewhat arbitrarily; the human eye can actually see light with wavelengths of up to about 810nm, but with sensitivity that is many thousands of times lower than with green light.

The CIELAB Color Model (L*a*b*)

The Lab color model (fig. 3) was developed by the CIE in 1976 in order to improve color representation. It is the most complete color model used conventionally to describe all the colors visible to the human eye. It is a three-dimensional color space in which color differences perceived to be equally large also have equal distances between them. This difference can be expressed in delta-E (DE).

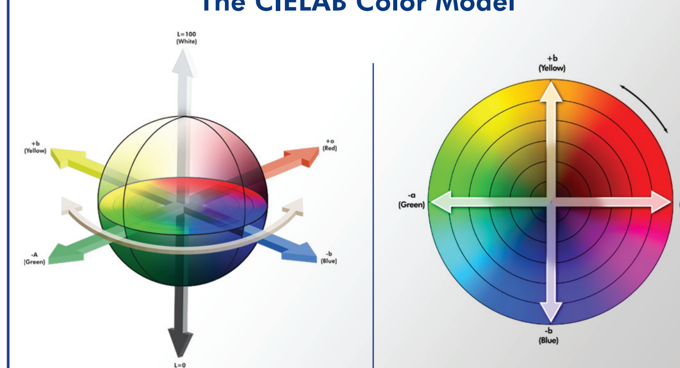
Delta-E is a mathematical description of the distance between two colors. It provides a measurement of both hue and density changes. To calculate the delta-E of two colors, their L*a*b* values are required. Delta-E is the distance between the two points in the L*a*b* color space.

It is important to note that an average viewer will only notice differences above 5-6 delta-E. Only a trained eye would notice differences from 3-4 delta-E. The human eye, however, is much more sensitive to changes in gray levels and mid-tones; a difference of 0.5 delta-E may then be noticeable.

Each color can be precisely designated using its specific "a" and "b" values and its brightness - "L." The three parameters in the model represent the luminance of the color – "L" (the smallest L yields black) its position between red and green - "a" (the smallest a yields green) and its position between yellow and blue – "b" (the smallest b yields blue), scaled to a reference white point.

The advantage of this color space, however, is its device-independence and its resultant objectivity. The same combination of a, b and L always describes exactly the same color. For these reasons, CIELAB is commonly used as a reference for the color translation process in ICC systems.

The CIELAB Color Model



(fig.3)

Color Spaces

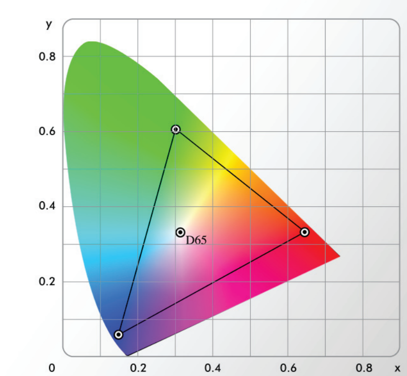
Color spaces derive from color models and provide additional necessary scale or reference information. For example, the sRGB color space or Adobe RGB color space (1998) both define a scale that makes color representation possible. They both derive from the RGB color model and offer a quantitatively measured three-dimensional geometric representation of the colors that can be seen or generated using the RGB color model.

sRGB Color Space

sRGB color space, or standard RGB (Red Green Blue), is an RGB color space created by Hewlett-Packard and Microsoft, and has been adopted by many industry leaders (fig 4). sRGB defines the red, green, and blue primaries as colors where one of the three channels is at the maximum value (255) and the other 2 are at zero, with a gamma value set to 2.2. sRGB was initially designed to match CRT monitors (in 1996). It is generally used for images that are intended to be shown on the Web.

The strength of sRGB is its wide diffusion in the graphic arts world. It has become a reference for professionals as well as the reference space for Windows. Nevertheless, publishing professionals frequently criticize it because of its narrow color gamut. Some colors that are visible, even some colors that can be reproduced in CMYK, cannot be represented by sRGB.

The sRGB Color Space

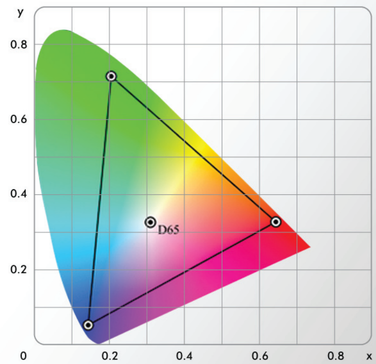


(fig. 4)

Adobe RGB Color Space (RGB 1998)

The Adobe RGB color space was developed by Adobe Systems in 1998 and was designed to encompass most of the colors achievable on CMYK color printers. However, this color space must be used in conjunction with devices such as computer displays, which use RGB colors. The Adobe RGB color space encompasses roughly 50% of the visible colors specified by the L*a*b* color space, improving upon the gamut of the sRGB color space, primarily in cyan-greens. Color spaces and color models are key references in color management policies. They are used in the color translation processes detailed in fig. 5.

The Adobe RGB 1998 Color Space



(fig. 5)

Color Translation

An ideal color management system (CMS) should work transparently across all operating systems and software packages regardless of the peripherals used. Due to color representation differences, various translation mechanisms are required. Device- and platform-independent references make accurate translation mechanisms possible. CIELAB and CIE XYZ color spaces are key elements in this process.

The International Color Consortium (ICC), an industry consortium created in 1993 by eight industry leaders, has defined a cross platform, open system for color management that is widely used nowadays. Apple ColorSync for Mac OS X and ICM for Windows are examples of an ICC compliant CMS.

It is based on the following elements:

- **A Color Matching Module (CMM)**, which is software embedded in the graphics application software, operating system and/or hardware driver. The CMM addresses tables within the profiles that describe how conversion should occur. Each profile contains multiple tables, allowing translations from the device space to the Profile Connection Space (PCS).

- **A Profile Connection Space (PCS)**, which is the standard reference space into or out of which the color data is transformed. This PCS is either a L*a*b* or CIE XYZ color space.

- **Color Profiles (ICC profiles)**, which are a description of how a particular device reproduces color. This is achieved by describing the color space of the device to the color management system. Profiles can be obtained by performing calibration and profiling with ICC compatible tools (such as the LaCie Blue eye pro for LaCie Monitors). They can be embedded in a document or loaded in an application.

- **A Rendering Intent**, referring to the way the CMM (Color Matching Module) handles out-of-gamut colors during a conversion from one color space to another. The International Color Consortium specification includes four different rendering intents: Perceptual, Relative Colorimetric, Saturation and Absolute Colorimetric, based on the concept of gamut mapping.

LaCie's Color White Paper #4 explains in depth how these elements work in a color management workflow.

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