Linotype-Hell

Technical Information

Color Space Conversion

The role of color space conversion in the process of scanning and reproducing a color image begins the moment an image is captured by a scanner and continues through the point at which it is output on film. For the purpose of this article we will discuss conversions between three types of color systems: RGB, CIE, and CMYK.

The RGB (Red, Green, & Blue) and CMYK (Cyan, Magenta, Yellow, & Black) color models have been described in greater detail in the Linotype-Hell Technical information piece entitled Color in Printing. For some background information on the CIE (Commission Internationale de l'Eclairage), please refer to Color Spaces and PostScript Level 2.

CIE as a reference color space

Most scanners acquire color in the form of RGB data. The majority of non-photographic printing methods employ CMYK inks or toners. In a closed system, where the characteristics of both the scanner and the printing method are well-defined, conversions may be made from RGB to CMYK through tables that maintain a reasonable level of color consistency. The process becomes somewhat more difficult as you add monitors, other scanners, proofing devices or printing processes that have different characteristics. It becomes critical to have a consistent yardstick, if you will, a means of converting between different color systems (and back again) without a loss in color fidelity. This is what CIE provides. Let's start with some background on CIE, and then we will look at how it can be applied in an open system.

Measuring color

Light reflected off of, or transmitted through a colored object can be measured by the wavelengths of light that are reflected or transmitted. For example, Figure 1 shows the wavelengths of light that might reflect off of a variety of different colored objects.

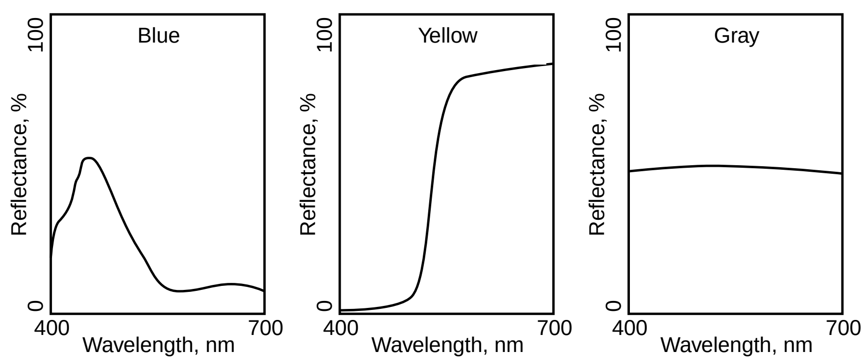

Figure 1 - Light reflected off of an object can be represented by a spectral reflectance curve which shows the amount of reflectance in each portion of the spectrum. The curve for a blue object (left) shows the greatest reflectance just under 500 nanometers (in the blue portion of the spectrum). The curve for a yellow object (center) starts increasing around 525 nanometers. The curve for a gray object (right) stays at virtually the same level throughout the spectrum. (Source: Billmeyer & Saltzman, Principles of Color Technology.)

While knowing these wavelength values is interesting, it doesn't provide a very handy method for describing color since wavelength values mean very little to most people. A more useful system would be one that used numerical values in a manner consistent with human perception.

CIE XYZ

In 1931 the CIE, an international commission on Illumination, decided to run a series of tests on color mixing to help quantify human color perception. They asked participants to match the color of a test light by adjusting the intensity of three superimposed red, green, and blue lights. By recording and plotting these intensity values, the commission was able to come up with a mathematical representation of the way humans perceive color. This mathematical representation is called the CIE standard observer. As part of this research, standard light sources were also chosen so a measure of standardization would exist for both light source and observer.

The work that the CIE did with the standard observer allows spectral curves like the one shown in Figure 1 to be converted into three values: X, Y, and Z (the so-called tristimulus values). The problem with CIE XYZ is that X, Y, and Z don't correspond well to common visual attributes (hue, for example). However, X, Y, and Z can be manipulated in one fashion or another to make them easier to visualize or conceptualize. This is what has been done with subsequent versions of CIE standards.

CIE L*a*b* and CIE L*u*v*

A number of transformations have been proposed to improve upon CIE XYZ. CIE L*a*b* (also known as CIELAB), CIE L*u*v* (also known as CIELUV) and CIE L*C*h° are three of the most common[2]. All of these systems place a color in a mathematically definable space through the use of coordinates.

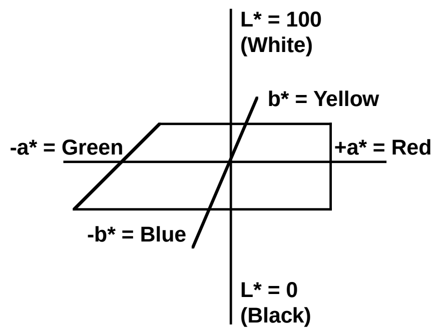

*Figure 2 - CIE L*a*b* diagram.*

Colors in the CIE XYZ color space are not uniformly distributed. Greens and yellow occupy a much larger portion of the space than reds and blues. To improve on this, a non-linear transformation may be applied to make CIE XYZ more uniform. (Both CIELAB and CIELUV are non-linear transformations of CIE XYZ.) The goal is to make equal numerical values represent equal color differences (although neither CIELAB nor CIELUV is perfect in that respect).

In addition, CIELAB and CIELUV use an opponent coordinate system based on a black/white axis, a green/red axis and a blue/yellow axis to place color in space. CIELAB is shown in Figure 2. (See Color Spaces and PostScript Level 2 for a fuller description of opponent color spaces.)

[1]CIELAB and CIELUV are pronounced like the words 'see-lab' and 'see love'. The individual characters in CIE L*a*b* and CIE L*u*v* are said in the following manner: 'c-i-e-l-star-a-star-b-star' and 'c-i-e-l-star-u-star-v-star'. CIE L*C*h° is usually referred to as 'c-i-e-l-c-h'.

CIE L*C*h°

While CIELAB and CIELUV are more uniform, many people find it hard to understand the concept of a blue/yellow and a red/green axis. However, people generally do like color spaces that use hue, chroma, and value. (These are the coordinates that the Munsell Color System uses. See the box on the following page for some common synonyms.) CIE L*C*h° provides hue, chroma and value, but does it in a way that is based on CIE standards.

CIE L*C*h° may be derived from either CIELAB or CIELUV. CIE L*C*h° uses lightness, hue angle and chroma to place colors in the space. (See Figure 3.) Since the numbers for lightness, hue angle and chroma are derived from L*, a*, and b*, this is simply a different way of displaying the same data. However, this does make it much easier to compare CIE L*C*h° values with

Common Color Terms and Synonyms[2]

Hue	Chroma	Value
Dominant wavelength	Colorfulness	Lightness
Hue angle	Color Strength	Luminance
Common hue terms:	Saturation	*Common value terms:*
Red, green, blue, yellow,	Vividness	*Light, medium, dark*
orange, purple, etc.	*Common saturation terms:*	
	Strong, vivid, moderate, grayish	

[2]Within the same category, there are very subtle differences between the meanings of some of these terms. This is often due to the way the terms are mathematically defined. For a more in-depth discussion, please see Billmeyer and Saltzman's Principles of Color Technology.

Two other color terms that may come up in a discussion of hue, chroma and value are chromaticity and brightness. Chromaticity is used to describe both hue and saturation, as in the horseshoe-shaped CIE chromaticity diagrams. Brightness is also a measure of two factors: lightness and saturation. The following adjectives describe brightness: brilliant = light and strong, deep = dark and strong, pale.= light and grayish. In addition, the term brightness may be used to account for the intensity of a light source. For example, an object appears brighter in direct sunlight than in the shade, but this is a result of the light source rather than the object itself.

systems that use color swatches (such as the Munsell** System and the Pantone Matching System**).

In discussions of color space conversion, you are very likely to hear about CIE XYZ, CIELAB, CIELUV, and CIE L*C*h°. These systems are used by some color systems and scanner vendors, as well as by vendors of measurement equipment like colorimeters and spectrophotometers.

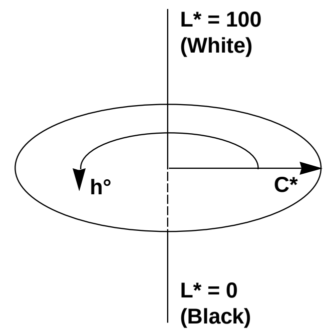

*Figure 3 - CIE L*C*h° diagram. Where L* = Lightness, C* = Chroma, and h° = hue angle*

The process

Let's take a moment to look at the conversions in an image reproduction process. (See Figure 4.)

Input values from a scanner, digital camera, or video camera come in as RGB. With software like LinoColor*3.0, which uses CIE, the color space conversion from RGB values into CIE values is done by a three-dimensional look-up table (LUT) with interpolation. (See the Linotype-Hell technical information piece entitled The Scanning Process for more information on look-up tables.) The quality of this look-up table is of critical importance. The characteristics of the source scanner and the film material must be understood. One way to do this is through the analysis of a test image (usually one with numerous color patches like Kodak's Q60). Measuring the test image with a spectrophotometer reveals CIE values for each color patch. The spectrophotometer CIE values can then be compared with the data from the scanner.

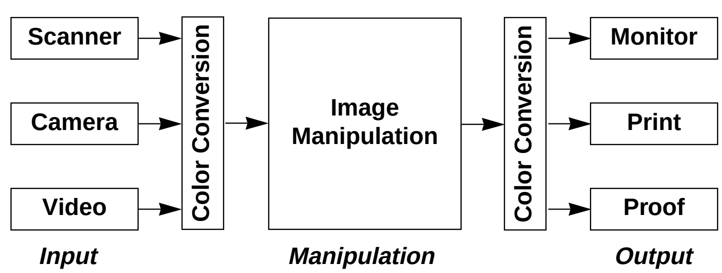

Figure 4 - The role of color conversion in the reproduction of a color image.

Initially, the data from the scanner will be RGB, but by using a preliminary look-up table, a first pass translation of the data can be made. The preliminary look-up table can then be corrected to give more accurate results based on the readings from the spectrophotometer. This procedure characterizes the scanner for the film material that the test image is on. A similar test must be made for the conversion process to CMYK values for printing or proofing, and also for RGB values on a monitor.

Of course, few people are in a position to do this kind of testing, so manufacturers of equipment must provide look-up tables not only for conversion from RGB, but also for conversion to CMYK. Adjustments to these tables need to be made for each scanner, film material, and printing process involved.

Color communication

Another advantage of using a CIE system is in the distribution of color files between users. CIE brings us closer to true device independence. If, when a file is created, there is some CIE measurement of the scanner RGB, then those files may be more accurately rendered. PostScript** Level 2 facilitates this through its use of the CIE standard. And, a TIFF CIE file format is currently being developed by Aldus.

Conclusion

The use of a CIE color space bases color space conversions on a consistent yardstick. The use of CIE L*C*h° makes the difficult concepts of CIE easier for people to grasp. On top of that, look-up tables based on production conditions make the process more predictable. And, CIE brings us a large step forward in terms of device independent color.

Comments

Please direct any questions or comments to:

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Appendix: Color references

The most comprehensive source of information on color science is Principles of Color Technology by Fred W. Billmeyer and Max Saltzman (John Wiley and Sons, New York, 1981).The first two chapters alone provide a wealth of information to newcomers to color, and yet the book goes into a depth of detail that is useful to dedicated students of color.

Two good overviews of color communication are contained in illustrated booklets by the following color measurement equipment manufacturers:

- A Guide to Understanding Color Communication, X-Rite
- Precise Color Communication, Minolta

Request these booklets from your local X-Rite or Minolta representative.

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