Defining and Communicating Color: The CIELAB System

We are surrounded by an infinite number of colors that individuals perceive differently and which can be described quite subjectively. Precise communication of the colors that we see, and of those which we desire to reproduce, requires objective color definition standards, exacting numeric measurement systems, and universal communication protocol. This article will briefly survey fundamental color perception theory which forms the foundation of three dimensional colorimetry (the science of measuring color), introduce the device independent CIE color models[1], and then discuss the CIELAB color characterization system—universally used in all facets of the graphic arts.

Color scientists have defined the three basic dimensions, or *colorimetric properties*, of color characterization as hue, saturation/chroma, and lightness. These three dimensions are also known as *tristimulus data*—perceptual attributes of color that allows the brain to interpret and conceptualize the signals it receives through visual stimuli.[2] Nearly all color characterization models (also known as color order systems) incorporate the perceptual color attributes of hue, saturation/chroma, and lightness; and assign numeric coordinates that define each of the three elements of a color in relation to independent lightness and chromatic axes existing in theoretical three-dimensional color space.

Hue is the simple response that we give to the question, “What color is this?” We may name the hue of a color red, blue, fuchsia, pink, purple, etc. Although technically infinite in number, hues are generally described and classified

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[1] The RGB and CMYK color models are viewer/device dependent because the range (gamut) of each is dependent on the color capturing or rendering capabilities of the respective viewer or device. The CIE models/systems are unambiguous, absolute, and device independent—i.e., not tied to, influenced by, or dependent on, the characteristics or capabilities of any color capturing or rendering device.

[2] Tristimulus is not to be confused with trichromacy. The retina of the human eye contains two types of light sensitive cells—rods and cones. Rods are sensitive to motion and degrees of lightness, whereas cones are the receptors that detect color. There are three types of cone cells, each sensitive to either short, medium, or long electromagnetic wavelengths (i.e., each having a peak or dominant sensation response to either blue, green, or red light). Therefore, we say that the perception of color is based on a *trichromatic* response of the cone cells (the theory of trichromacy). Tristimulus relates to the associative response of the brain as it receives information from the rods and cones and then interprets the stimuli (i.e., the color data) in relation to three dimensions: hue, saturation/chroma, and lightness. Three dimensional color models such as LCH and CIELAB are based on tristimulus data.

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according to dominant wavelengths of light and occupy ordered positions around the continuum of the theoretical color wheel. Hues are commonly specified by familiar names describing broad tonal families of the visible spectrum. The ordered classification of hues follows a pattern of orientation which aligns with the order of colors observed when white light is passed through a glass prism or as we see in a rainbow: red, orange, yellow, green, blue, indigo, violet. Pure white, neutral gray, and black posses no hue. Figure #1 demonstrates the ordering of hues around the familiar *color wheel* continuum.

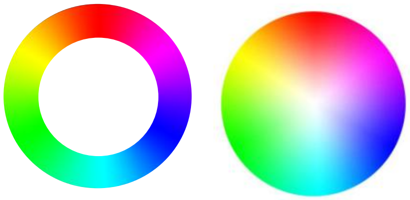

Figure #1

The **saturation** of a color describes its degree of purity in relation to neutral gray and is a direct determinant of a color's intensity. Color saturation is often *similarly* referred to as chroma.[3] Together, saturation and chroma determine the "colorfulness" or purity of a hue. For example, a clean, pure *red* has a high level of saturation whereas a dirtier/duller *red* (red contaminated with a portion of its opposite hue—causing the "red" to move closer to neutral gray) has a lower level of purity/saturation. As a color (hue) becomes more saturated (i.e., more pure), it becomes less gray. Conversely, as a color becomes progressively desaturated it gradually loses its identity; eventually reaching neutral gray (purely neutral gray has a saturation value of zero)—see figure #2. Brilliant, vivid, intense colors are achieved with high levels of saturation. As we later illustrate in figure #3, all colors exist in a theoretical three-dimensional sphere. Opposing colors (i.e., hues) reside directly across from each other with neutral (achromatic) gray occupying the center of the sphere. When colors move farther away from each other, toward the outer perimeter of the saturation axis, opposites become purer as they are positioned at a greater distance from neutral gray. As colors blend together toward the center of the sphere and progressively approach gray, we note that they become less pure, therefore having reduced saturation. The relationship between saturation and chroma exists in part because pure, more saturated hues have a high level of chroma.

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[3] Saturation and chroma are similar in concept but have different precisely defined technical applications which are beyond the scope of this discussion (also see footnote 4).

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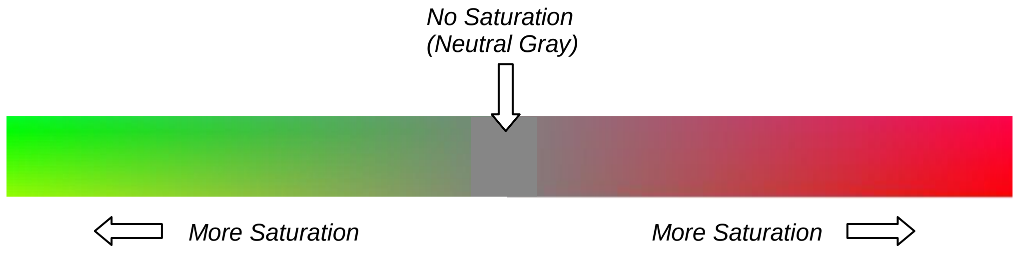

Opposing Hues

Figure #2

The **lightness** (also referred to as luminance or value)[4] of a color describes its relative brightness; i.e., its luminous intensity (e.g., light red compared to dark red). The lightness *value* is achromatic, meaning that the associated numeric reference data gives no information about a color other than how light or dark that color is. Lightness can be thought of as adjusting the level of light with a variable dimmer switch! Same color, just lighter or darker within the continuum of common hue and saturation/chroma. Note the effect of varying lightness using a hue of red:

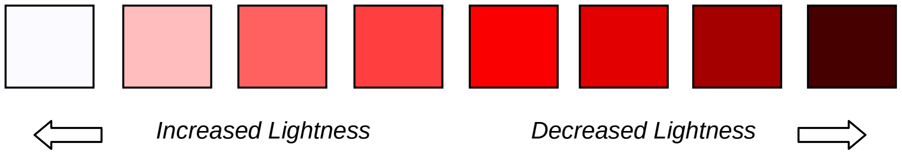

Figure #3 graphically demonstrates the tristimulus properties of color as they exist within a theoretical three-dimensional sphere. Pure, vibrant hues reside around the outer edges (i.e., the “equator” of the sphere). Moving toward the center, the colors approach gray as they become desaturated or less pure. As colors move inward and become desaturated, the hues become less dominant—with no hue dominating the center of the sphere. Points along the vertical axis of the sphere indicate the lightness and darkness of the color. The lightness extremes of white and black reside at opposite ends of the “poles.” At the center of the sphere we find neutral gray; the point where equal amounts of desaturated hues of color converge with lightness positioned at the midpoint between black and pure white. Hues are measured by their angle position in relation to the central axis (0-359° --beginning at a point in the *red* area of the spectrum). Saturation and lightness are each measured as percentages. Saturation is measured outward, and specified as a percentage of distance from the center

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[4] As is the case with saturation and chroma, the terms lightness, luminance, and value are not exactly synonymous. All have precise definitions, and each is used for specific purposes in technical applications. In common usage, these terms are often interchanged and used imprecisely and incorrectly. It is beyond the scope of this article to delve into the precise meanings and technical use of these terms.

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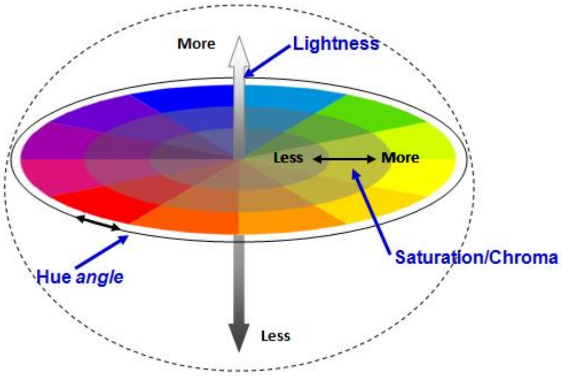
axis. Lightness is quantified as a percentage from darkness to maximum lightness (diffuse white).



Figure# 3

There are several numeric based models or systems for measuring, specifying, and categorizing colors by assigning reference points that define hue, saturation, and lightness. Three dimensional color specification systems must include methods to individually assign data points to the three components of color in relation to independent axes. One axis will separately characterize lightness/brightness while two axes form a chromatic plane where numeric coordinates define the actual *color*.

CIE Color Systems

In 1931, the Vienna based international standards body, the International Commission on Illumination (***CIE****: Commission Internationale d'Eclairage*), devised a mathematical model for the purpose of numerically describing all color visible to the human eye—the CIE XYZ Color Space. CIE XYZ became the basis of several successive more refined colorimetric systems for the measurement and specification of color. In addition to CIE XYZ, systems include CIE LUV (L*u*v*), CIE LAB (L*a*b*), and CIE LCH (L*C*h°). Unlike RGB and CMYK color models, color definitions characterized by CIE systems are unambiguous, absolute, and device independent—i.e., not tied to, influenced by, or dependent on, the characteristics or capabilities of any color capturing or rendering device.

Published in 1976 by the International Commission on Illumination, the CIELAB system has become the universally accepted colorimetric reference system for quantifying and communicating color. CIELAB is the reference color model used by the paper making and graphic arts industries. CIELAB forms the foundation of color management and is generally the ICC profile connection space used for gamut mapping. The basic architecture and operating premise of CIELAB is based on scientific theory demonstrating that the brain translates retinal color stimuli into distinctions between light and dark (lightness), and between mutually exclusive zones of opposing colors: red/green, and blue/yellow. We call this the "principle of *color opposition correlation"* due to the fact that a color cannot be red <u>and</u> green or yellow <u>and</u> blue. Ever see a greenish red?

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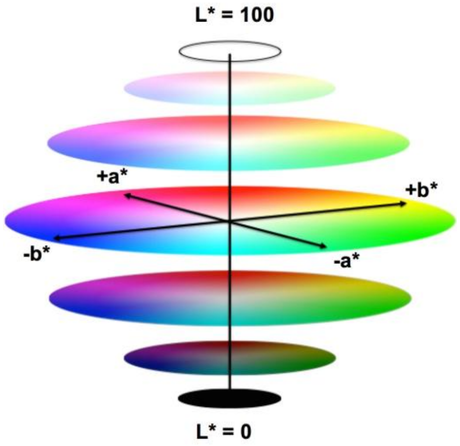
The coordinates of CIELAB are L*a*b*[5] but the color system is often informally referred to simply as *L-a-b.*

Much like its predecessors, CIELAB provides a system to triangulate and precisely define and specify any color reference point within the theoretical sphere containing all visible color.

The CIELAB color system contains one “channel” for lightness (L*) and two channels for color (a* and b*). In the three dimensional model, the chromatic a* axis extends from green (-a*) to red (+a*), and the chromatic b* axis extends from blue (-b*) to yellow (+b*). The lightness dimension, represented by L*, ranges from 0 (pure black) to 100 (diffuse white). The point at which the a* and b* axes cross, at the L* value of 50, is pure, balanced, neutral gray. See figure #4.



Figure# 4

When numerical values are applied to each dimension, any visible color can be “triangulated” or exactly pinpointed within CIELAB color space. This allows color data to be precisely transferred within color management workflows and accurately communicated for discussion and reproduction purposes worldwide.

As illustrated in figures #4 and #5, along with the color opponent indices (a* and b*), the CIELAB model naturally incorporates the tristimulus distinctives of hue and saturation/chroma (along with lightness).

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[5] The CIELAB coordinate axes L*a*b* are stated: “L-star,” “A-star,” and “B-star.”

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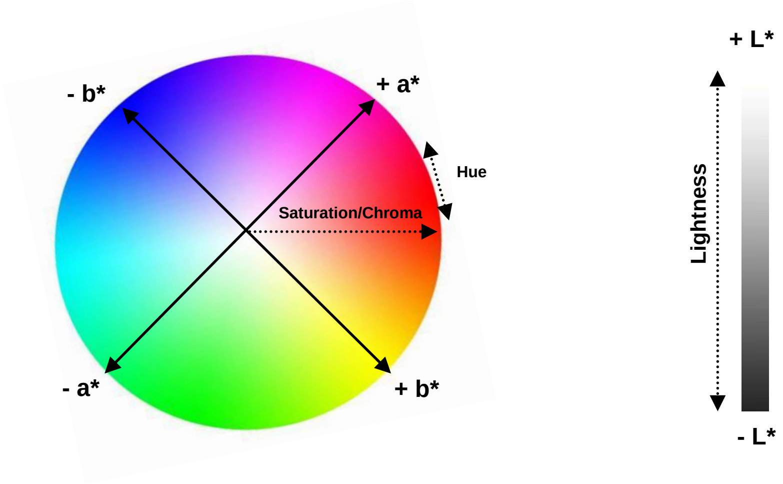

Figure# 5

Quantifying Color Differences

Color differences can be computed as the relative distance between two reference points (i.e., between two mathematically specified colors) within a color space (e.g., CIELAB). This difference is typically expressed as delta E (ΔE) and is calculated by comparing reference and sample *L*a*b** values to pinpoint how far apart two colors reside within a color space. One drawback of delta E data is that simple delta E calculations will quantify the magnitude of a color difference but do not necessarily indicate the direction of the difference.

The widely used Delta E 1976 (CIE 76) utilizes a simple linear formula to calculate the distance between two points of color. More recently developed formulae, Delta E 1994 (CIE 94) and Delta E 2000 (CIE 2000), are designed to closely correlate with the non-uniformities of human perception by building in certain *perceptual* tolerancing methodologies—primarily in the low saturation to neutral gray areas. The CMC tolerancing method, developed by the Colour Measurement Committee of the Society of Dyers and Colourists**,** is constructed in a similar manner to the CIE 94 and CIE 2000 methods but is based on the L*C*h color model (rather than CIELAB). It should be noted that delta E data are meaningless unless the specific calculation formula is specified.

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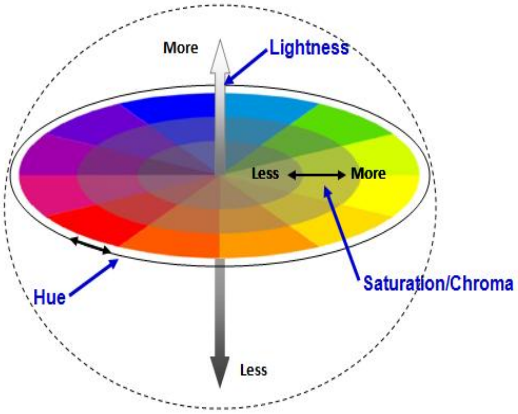
In Summary:

<u>The three *tristimulus* components of color</u>:

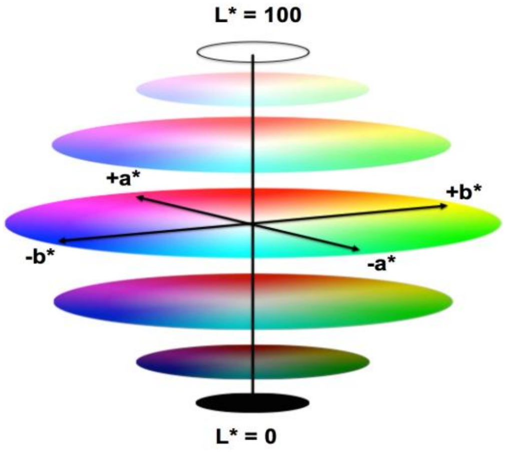
- Hue
- Saturation/chroma
- Lightness/luminance



<u>The CIELAB color model</u>:

L* = Lightness (also referred to as luminance); the lightness or darkness of a color
a* = red to green (+a = redder, -a = greener)
b* = yellow to blue (+b = yellower, -b = bluer)

Where the two "color" axes intersect = neutral gray



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