Chromaticity and Chrominance in Color Definition

Douglas A. Kerr

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ABSTRACT

In connection with the definition of color in such fields as computer graphics, television systems, and digital still photography, we encounter the two similar-looking, and often-confused, terms *chromaticity* and *chrominance*. In this article we illuminate the distinction between these terms.

Color

Color is the principal property of visible light by which a human observer can distinguish different "kinds" of light. It is a subjective property, and in general the color of a light source cannot be determined by simple measurement of any fundamental physical property of the light.

It has been ascertained that to describe a particular color of light we must state three values. Color is thus a "3-dimensional property" in the mathematical (not geometric) sense. In the case of another three-dimensional property, the location of a point in space, many different sets of three variables (coordinates) may be used.[1] Similarly, in the case of color, many different systems of three variables may be utilized. A particular one is often called a *color model*, and its variables are said, in the language of mathematics, to be the coordinates of its three-dimensional *color space*. However, today, especially in photography, the term "color space" means a system for explicitly describing a particular color, based a certain color model, beyond which the exact definitions of its coordinates are specified.

Luminance-chromaticity color models

One model that is well related to the intuitive human perception of color uses these three properties as its color coordinates:

Luminance is the property that describes the "brightness" of the light. (Many people are startled to learn that brightness is a part of color, but it is in the formal sense we are considering here.)

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[1] For example: rectangular (Cartesian) coordinates, cylindrical coordinates, spherical coordinates, geodesic coordinates.

Hue is the property that distinguishes red from orange from blue from blue-green, and so forth.

Saturation is the property that distinguishes red from pink. It is sometimes said to describe the "purity" of the color.

The properties *hue* and *saturation* are said to collectively describe the *chromaticity* of the color of interest. Chromaticity is in fact the property that the average person thinks of as the "color" of light (not realizing that *luminance* is one aspect), the cause of much confusion in the technical discussion of color. Since chromaticity actually embraces two of our "color coordinates", it is a two-dimensional property (in the mathematical sense).

There are other pairs of properties (other than *hue* and *saturation*) that can be used to define chromaticity, leading to different color models within the "luminance-chromaticity" family.

Suppose that we have light of a certain color and that we "attenuate" it by passing it through what a photographer would call a "neutral-density filter". The emerging light will have a lower luminance, but its chromaticity (however it is specified) will be unchanged.

Luminance-chrominance models

In describing different colors of light with electrical signals or digital codes, as in television, computer graphics, and digital photography systems, a different approach is often used. I'll describe an "ideal" form of the concept. Modified versions are actually used in practice

To describe a color under this approach, we visualize making up the color by combining ingredients. The first ingredient is white light[2] having the same luminance as the color of interest. To that we add a "colorant" ingredient, producing the color of interest (without changing its luminance).[3] The definition of the "colorant" is said to be the *chrominance* of that color. The luminance and chrominance together describe the color of interest.

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[2] We recognize that "white light" can mean different things, but for expediency we will not explore that complication further here.

[3] This may seem paradoxical: how can we take light of a certain luminance, add further light to it, and yet not increase the luminance? The short answer is that the "colorant" is not a physical light but a fictional, mathematically-defined ingredient, and it has zero luminance.

Like chromaticity, chrominance can be defined in different ways, leading to different color models within the "luminance-chrominance" family. In any case, two quantities must be used to define chrominance, since the entire definition of the color must involve three quantities (luminance again being the third).

Suppose that we again have light of a certain color and "attenuate" it by passing it through a neutral-density filter. The emerging light will have a lower luminance, and the magnitude ("size") of its chrominance will also be proportionately less. Its chromaticity, as we saw before, will be unchanged. This illustrates an important difference between chrominance and chromaticity.

The reason for the scaling of chrominance can be understood by thinking of mixing a quantity of paint to a certain "tint". We do that by starting with a certain quantity of white paint and adding specified amounts of one or more colorants. If we wish to mix a smaller quantity of paint, we must scale down the amount of colorants accordingly. So it is with chrominance when we are mixing a smaller "quantity" of light (light with a smaller luminance).

Specific color models in the luminance-chrominance family include:

- The **YIQ** and **YUV** models used for analog color TV signal definition.

- The **YCbCr** model used in digital TV signal and digital still image definition, including in the common form of JPEG still image file.

- The **CIE L*a*b*** model used in some digital image editing (sometimes called **CIELab** or even just **Lab**; no, "Lab" isn't short for "laboratory").

- The **CIE L*C*H** model (used in similar situations)

In each case, chrominance is defined by the last two of the three quantities mentioned in the model's name (I and Q, U and V, Cb and Cr, a* and b*, or C* and H). The first quantity (Y or L*) is something like luminance, but is not truly luminance. (See the next section.)

Luma and chroma

In connection with the description of color in television signals and digital images, we encounter the terms *luma* and *chroma*. These usually describe the "signal components" or "digital representations" of a color that are something like *luminance* and *chrominance*.

The use of these terms usually alerts us to another subtlety. The so-called "luminance" component of a television signal does not vary proportionately to the luminance it represents, nor does it follow a "power law" from the actual luminance. Rather, it is derived from a set of R, G, and B values that have been transformed in a nonlinear way from the actual "red", "green", and "blue" coordinates of the color, under what is called "gamma precompensation". (But it is not "gamma-precompensated luminance".) We need not concern ourselves here with the rationale for gamma precompensation. Similarly, the "chrominance" signal is derived from gamma-precompensated values of the underlying "tristimulus" color coordinates.

The same situation is true of other so-called "luminance-chrominance" models (such as YCbCr, L*a*b*, or L*C*h).

The use of the terms *luma* and *chroma* is usually, by convention, a cue that the coordinates they describe are in this situation—derived from nonlinear forms of the underlying "tristimulus" color coordinates.

Another meaning of "chroma"

Since chroma is a two-dimensional property, we can think of it as being plotted on a plane with two axes (which we might choose in different ways, a further subdividing of the repertoire of color models). In any case, the origin of the coordinate system represents "white", which implies "zero chrominance".

We may to choose two Cartesian coordinates (at right angles) to specify chroma, as is done in the Y<u>IQ</u>, Y<u>UV</u>, Y<u>CbCr</u>, and L*<u>a*b*</u> color models (the underlined coordinates describing the chroma of the color—and note that different schemes of nonlinearity are involved here).

Or we may think of polar coordinates, in which the point representing the chroma is described in terms of its distance from the origin (a radius) along with an angle describing its "bearing" from the origin with respect to some reference direction on the plane.

The angle is considered to describe the hue aspect of the chroma, while the radius, which describes the "magnitude" of the chroma, is called—"chroma".

This is in fact the significance of the coordinate "C*" in the CIE L*C*h model, and the coordinate "h*" is the hue (given as an angle).

As you can see, we need to be careful when we encounter the word "chroma". It might mean "a nonlinear form of chrominance", or it might mean "the magnitude of a nonlinear form of chrominance".

For further details

The information in this article is in large part excerpted from the companion article, *Color Models and Color Spaces,* by the same author. The reader who wishes further technical details on this and related topics is commended to that article, as well as to the companion article, *Color*, also by the same author.

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