# Color Management Overview

**Graphics & Animation**

**2005-07-07**

Apple Inc.
© 2004, 2005 Apple Computer, Inc.
All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, mechanical, electronic, photocopying, recording, or otherwise, without prior written permission of Apple Inc., with the following exceptions: Any person is hereby authorized to store documentation on a single computer for personal use only and to print copies of documentation for personal use provided that the documentation contains Apple's copyright notice.

The Apple logo is a trademark of Apple Inc.

Use of the "keyboard" Apple logo (Option-Shift-K) for commercial purposes without the prior written consent of Apple may constitute trademark infringement and unfair competition in violation of federal and state laws.

No licenses, express or implied, are granted with respect to any of the technology described in this document. Apple retains all intellectual property rights associated with the technology described in this document. This document is intended to assist application developers to develop applications only for Apple-labeled computers.

Every effort has been made to ensure that the information in this document is accurate. Apple is not responsible for typographical errors.

Apple Inc.
1 Infinite Loop
Cupertino, CA 95014
408-996-1010

Apple, the Apple logo, ColorSync, Mac, Mac OS, and New York are trademarks of Apple Inc., registered in the United States and other countries.

Simultaneously published in the United States and Canada.

**Even though Apple has reviewed this document, APPLE MAKES NO WARRANTY OR REPRESENTATION, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THIS DOCUMENT, ITS QUALITY, ACCURACY, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE. AS A RESULT, THIS DOCUMENT IS PROVIDED "AS IS," AND YOU, THE READER, ARE ASSUMING THE ENTIRE RISK AS TO ITS QUALITY AND ACCURACY.**

**IN NO EVENT WILL APPLE BE LIABLE FOR DIRECT, INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES RESULTING FROM ANY DEFECT OR INACCURACY IN THIS DOCUMENT, even if advised of the possibility of such damages.**

**THE WARRANTY AND REMEDIES SET FORTH ABOVE ARE EXCLUSIVE AND IN LIEU OF ALL OTHERS, ORAL OR WRITTEN, EXPRESS OR IMPLIED. No Apple dealer, agent, or employee is authorized to make any modification, extension, or addition to this warranty.**

**Some states do not allow the exclusion or limitation of implied warranties or liability for incidental or consequential damages, so the above limitation or exclusion may not apply to you. This warranty gives you specific legal rights, and you may also have other rights which vary from state to state.**

# Contents

# Figures

# Introduction to Color Management Overview

**Note:** This document was previously titled *Color and Color Management Systems.*

This document provides a general introduction to the basics of color and color management. Read this document to learn about:

- Color perception
- Color spaces
- The values used to describe color
- Color conversion and color matching
- The role of color management systems

Color management is the process of maintaining consistent color among devices. Different imaging devices such as scanners, displays, and printers work in different color spaces, and each can have a different gamut (the range of colors a device can display). Color displays from different manufacturers all use RGB colors but may have different RGB gamuts as a result of the device type and its age. Printers and presses work in CMYK space and can vary drastically in their gamuts, especially if they use different printing technologies. Even a single printer's gamut can vary significantly depending on the ink or type of paper in use. It's easy to see that conversion from RGB colors on an individual display to CMYK colors on an individual printer using a specific ink and paper type can lead to unpredictable results.

## Who Should Read This Document

This document provides the conceptual foundation developers need to understand ColorSync developer documentation. You should be familiar with the concepts in this document before you read *ColorSync Manager Reference*.

The information in this document is also useful for anyone who works with color and wants to understand the challenges of maintaining consistent color from input device (scanner, digital camera) to output device (monitor, printer, printing press).

If you don't know what ColorSync is, before you read this document, read the short overview of its features on the Apple website:

http://www.apple.com/macosx/features/colorsync/

## Organization of This Document

This document is divided into these chapters:

- "Color: A Brief Overview" (page 9) discusses color perception and additive and subtractive color systems.
- "Color Spaces" (page 11) describes how different peripheral devices represent color and the values used to represent color.
- "Color Management Systems" (page 19) discusses the color matching problem and how color management systems maintain consistent color among devices.

## See Also

For information on ColorSync, Apple's standards-based solution for color management, see:

- *ColorSync Manager Reference*, provides a complete reference for the ColorSync Manager application programming interface.

For more information on color theory and color spaces, see:

- Bruce Fraser, Fred Bunting, and Chris Murphy. *Real World Color Management*, first edition. Peachpit Press, 2003.
- Roy S. Berns. *Billmeyer and Saltzman's Principles of Color Technology*, third edition. Wiley-Interscience, 2000.
- James D. Foley, Andries van Dam, Steven K. Feiner, and John F. Hughes. *Computer Graphics: Principles and Practice in C*, second edition. Addison-Wesley, 1995.
- Roy Hall. *Illumination and Color in Computer Generated Imagery*. New York: Springer-Verlag, 1988.
- R.W.G. Hunt. *Measuring Colour*, third edition. Fountain Pr LTD, 2001.
- Günther Wyszecki and W.S. Stiles. *Color Science: Concepts and Methods, Quantitative Data and Formulae*, second edition. John Wiley & Sons, 2000.

# Color: A Brief Overview

Color is a sensation and, therefore, a subjective experience. The sensation of color is one component of the visual sensation, caused by the sensitivity of the human eye to light. Light can be perceived either directly from light sources (such as the sun, a fire, incandescent or fluorescent bulbs, television screens, and computer displays) or indirectly, when light from these sources is transmitted through or reflected by objects. Color sensation is also affected by how the brain processes information and is specific to each individual. Thus color perception is a very complex phenomenon.

The foundation of the color reproduction process is trichromatic color vision, which describes the capacity of the human eye to respond equally to two or more sets of stimuli having different visible spectra. This means that two or more visible spectra may exist that will be perceived as the same color, a phenomenon known as metamerism. Because of this property, spectral color reproduction, a very expensive and impractical process, can be replaced by trichromatic color reproduction, a process that is much cheaper and easier to control.

Trichromatic color reproduction induces the illusion of a color using various amounts of only three primary colors: either red, green, and blue mixed additively or cyan, magenta, and yellow mixed subtractively. Additive and subtractive colors are described in "Additive and Subtractive Color" (page 10). Trichromatic color reproduction is the fundamental mechanism used in the majority of color reproduction devices, from television, computer display and movie screens, to magazines, newspapers, large posters, and small pages printed on your desktop printer.

Computers enable you to control color digitally and many peripherals have been developed for acquiring, displaying, and reproducing color. As a result, there is a need for a mechanism to maintain color control in an environment that can include different computer operating systems and hardware, as well as a wide variety of devices and media connected to the computer.

## Color Perception

The eye contains two types of receptors, cones and rods. The rods measure illumination and are not sensitive to color. The cones contain a chemical known as Rhodopsin, which is variously sensitive to reds and blues and has a default sensitivity to yellow. The color the eyes see in an object depends on how much red, green, and blue light is reflected to a small region in the back of the eye called the fovea, which contains a great majority of the cones present in the eye. Black is perceived when no light is reflected to the eye.

Even the conditions in which color is viewed greatly affect the perception of color. The light source and environment must be standardized for accurate viewing. When viewing colors, people in the graphic arts industry, for example, avoid fluorescent and tungsten lighting, use a particular illuminant that is similar to daylight, and proof against a neutral gray surface.

Color images frequently contain hundreds of distinctly different colors. To reproduce such images on a color peripheral device is impractical. However, a very broad range of colors can be visually matched by a mixture of three "primary" lights. This allows colors to be reproduced on a display by a mixture of red, green, and blue lights (the primary colors of the additive color space shown in Figure 2-4 (page 14)) or on a printer by a mixture of cyan, magenta, and yellow inks or pigments (the primary colors of the subtractive color space shown in Figure 2-4 (page 14)). Black is printed to increase contrast and make up for the deficiency of the inks (making black the key, or K, in CMYK).

## Hue, Saturation, and Value (or Brightness)

Color is described as having three dimensions. These dimensions are hue, saturation, and value. Hue is the name of the color, which places the color in its correct position in the spectrum. For example, if a color is described as blue, it is distinguished from yellow, red, green, or other colors. Saturation refers to the degree of intensity in a color, or a color's strength. A neutral gray is considered to have zero saturation. A saturated red would have a color similar to apple red. Pink is an example of an unsaturated red. Value (or brightness) describes differences in the intensity of light reflected from or transmitted by a color image. The hue of an object may be blue, but the terms dark and light distinguish the value, or brightness, of one object from another. The 3-dimensional color spaces based on hue, saturation and value are described in "HSV and HLS Color Spaces" (page 13).

## Additive and Subtractive Color

The additive color theory refers to the process of mixing red, green, and blue lights, which are each approximately one-third of the visible spectrum. Additive color theory explains how red, green, and blue light can be added to make white light. Red and green projected together produce yellow, red and blue produce magenta, and blue and green produce cyan. With red, blue, and green transmitted light, all the colors of the rainbow can be matched.

The subtractive color theory refers to the process of combining subtractive colorants such as inks or dyes. In this theory, various levels of cyan, magenta, and yellow absorb or "subtract" a portion of the spectrum of white light that is illuminating an object. The color of an object is the result of the color lights that are not absorbed by the object. An apple appears red because the surface of the apple absorbs the blue and green light.

Monitors use the additive color space, output printing devices use the subtractive color space.

# Color Spaces

A color space describes an environment in which colors are represented, ordered, compared, or computed. A color space defines a one-, two-, three-, or four-dimensional environment whose components (or color components) represent intensity values. A color component is also referred to as a color channel. For example, RGB space is a three-dimensional color space whose stimuli are the red, green, and blue intensities that make up a given color; and red, green, and blue are color channels. Visually, these spaces are often represented by various solid shapes, such as cubes, cones, or polyhedra.

For additional information on color components, see "Color-Component Values, Color Values, and Color" (page 18).

Apple's ColorSync technology directly supports several different color spaces to give you the convenience of working in whatever kind of color data most suits your needs. The ColorSync color spaces fall into several groups, or base families. They are:

- Gray spaces, used for grayscale display and printing; see "Gray Spaces" (page 11)
- RGB-based color spaces, used mainly for displays and scanners; see "RGB-Based Color Spaces" (page 12)
- CMYK-based color spaces, used mainly for color printing; see "CMY-Based Color Spaces" (page 14)
- Device-independent color spaces, such as L*a*b, used mainly for color comparisons, color differences, and color conversion; see "Device-Independent Color Spaces" (page 15)
- Named color spaces, used mainly for printing and graphic design; see "Named Color Spaces" (page 18)
- Heterogeneous HiFi color spaces, also referred to as multichannel color spaces, primarily used in new printing processes involving the use of red-orange, green and blue, and also for spot coloring, such as gold and silver metallics; see "Color-Component Values, Color Values, and Color" (page 18)

All color spaces within a base family are related to each other by very simple mathematical formulas or differ only in details of storage format.

## Gray Spaces

Gray spaces typically have a single component, ranging from black to white, as shown in Figure 2-1. Gray spaces are used for black-and-white and grayscale display and printing. A properly plotted gray space should have a fifty percent value as its midpoint.

**Figure 2-1** Gray space

# RGB-Based Color Spaces

The RGB space is a three-dimensional color space whose components are the red, green, and blue intensities that make up a given color. For example, scanners read the amounts of red, green, and blue light that are reflected from or transmitted through an image and then convert those amounts into digital values. Information displayed on a color monitor begins with digital values that are converted to analog or digital signals for display on the monitor. The signals are transmitted to the elements on the face of the monitor, causing them to glow at various intensities of red, green, and blue (the combination of which makes up the required hue, saturation, and brightness of the desired colors).

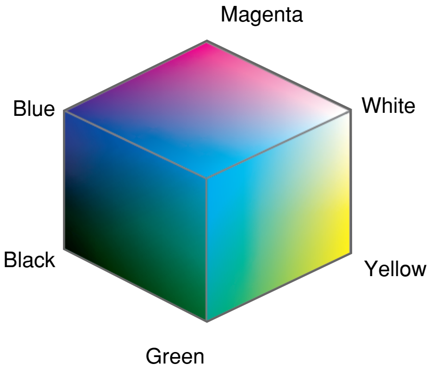
RGB-based color spaces are the most commonly used color spaces in computer graphics, primarily because they are directly supported by most color displays and scanners. RGB color spaces are device dependent and additive. The groups of color spaces within the RGB base family include

- RGB spaces
- HSV and HLS spaces

## RGB Spaces

Any color expressed in RGB space is some mixture of three primary colors: red, green, and blue. Most RGB-based color spaces can be visualized as a cube, as in Figure 2-2, with corners of black, the three primaries (red, green, and blue), the three secondaries (cyan, magenta, and yellow), and white.

**Figure 2-2** RGB color space (Red corner is hidden from view)



## sRGB Color Space

The sRGB color space is based on the ITU-R BT.709 standard. It specifies a gamma of 2.2 and a white point of 6500 degrees K. You can read more about sRGB space at the International Color Consortium site at http://www.color.org/. This space gives a complementary solution to the current strategies of color management systems, by offering an alternate, device-independent color definition that is easier to handle for device manufacturers and the consumer market. sRGB color space can be used if no other RGB profile is specified or available. ColorSync provides full support for sRGB, including an sRGB profile.

Note that as an open architecture, ColorSync is not tied to the use of the sRGB color space and can support any RGB space that the user might prefer. For example, high end users with good quality reproduction devices may find that the sRGB space, which limits colors to the sRGB gamut, is too restrictive for their required color quality.

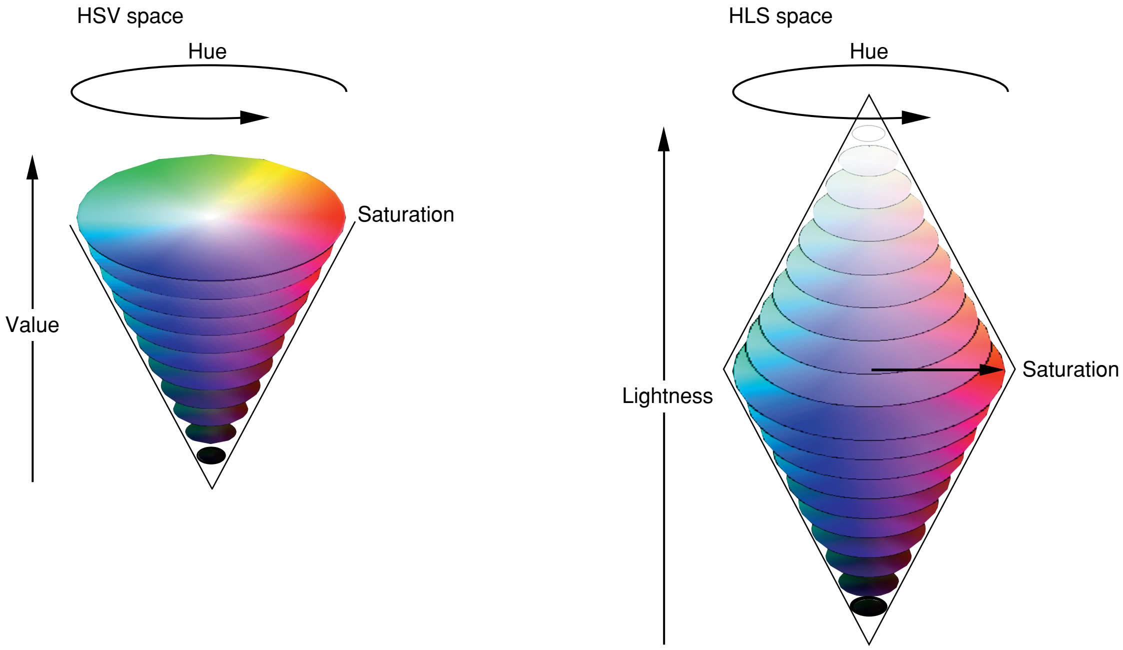
## HSV and HLS Color Spaces

HSV space and HLS space are transformations of RGB space that can describe colors in terms more natural to an artist. The name HSV stands for hue, saturation, and value. (HSB space, or hue, saturation, and brightness, is synonymous with HSV space.) HLS stands for hue, lightness, and saturation. The two spaces can be thought of as being single and double cones, as shown in Figure 2-3 (page 13).

The components in HLS space are analogous, but not completely identical, to the components in HSV space:

- The hue component in both color spaces is an angular measurement, analogous to position around a color wheel. A hue value of 0 indicates the color red; the color green is at a value corresponding to 120, and the color blue is at a value corresponding to 240. Horizontal planes through the cones in Figure 2-3 (page 13) are hexagons; the primaries and secondaries (red, yellow, green, cyan, blue, and magenta) occur at the vertices of the hexagons.
- The saturation component in both color spaces describes color intensity. A saturation value of 0 (in the middle of a hexagon) means that the color is "colorless" (gray); a saturation value at the maximum (at the outer edge of a hexagon) means that the color is at maximum "colorfulness" for that hue angle and brightness.

**Figure 2-3** HSV (or HSB) color space and HLS color space



- The value component in HSV describes the brightness. In both color spaces, a value of 0 represents the absence of light, or black. In HSV space, a maximum value means that the color is at its brightest. In HLS space, a maximum value for lightness means that the color is white, regardless of the current values of the hue and saturation components.

## CMY-Based Color Spaces

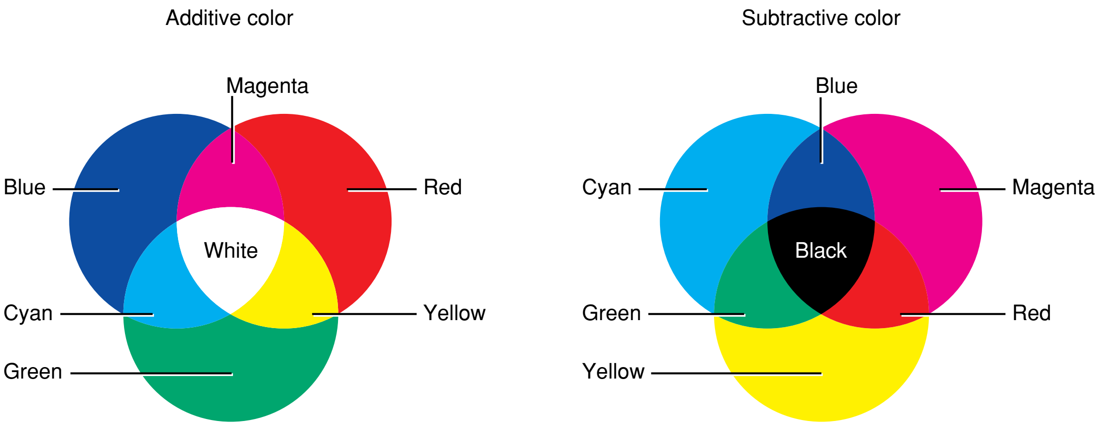
CMY-based color spaces are most commonly used in color printing systems. They are device dependent and subtractive in nature. The groups of color spaces within the CMY family include

- CMY, which is not very common except on low-end color printers
- CMYK, which models the way inks or dyes are applied to paper in printing

The name CMYK refers to cyan, magenta, yellow, and key (represented by black). Cyan, magenta, and yellow are the three primary colors in this color space, and red, green, and blue are the three secondaries. Theoretically black is not needed. However, when full-saturation cyan, magenta, and yellow inks are mixed equally on paper, the result is usually a dark brown, rather than black. Therefore, black ink is overprinted in darker areas to expand the dynamic range and give a better appearance. Printing with black ink makes it possible to use less cyan, magenta, and yellow ink. This may prevent saturation, especially on materials such as plain paper which cannot accept too much ink. Using black can also reduce the cost per page because cyan, magenta, and yellow inks are generally more expensive than black ink. It can also provide a sharper image, because a single dot of black ink is used in place of three dots of other inks.

Figure 2-4 (page 14) shows how additive and subtractive colors mix to form other colors.

**Figure 2-4** Additive and subtractive colors



Theoretically, the relation between RGB values and CMY values in CMYK space is quite simple:

```
Cyan        = 1.0 - red
Magenta     = 1.0 - green
Yellow      = 1.0 - blue
```

(where red, green, and blue intensities are expressed as fractional values varying from 0 to 1). In reality, the process of deriving the cyan, magenta, yellow, and black values from a color expressed in RGB space is complex, involving device-specific, ink-specific, and even paper-specific calculations of the amount of black to add in dark areas (black generation) and the amount of other ink to remove (undercolor removal) where black is to be printed. Therefore, when ColorSync converts between CMYK and RGB color spaces, it uses an elaborate system of multi-dimensional lookup tables, which ColorSync knows how to interpret. This information is stored in profiles, see "Color Management Systems" (page 19).

# Device-Independent Color Spaces

Some color spaces can express color in a device-independent way. Whereas RGB colors vary with display and scanner characteristics, and CMYK colors vary with printer, ink, and paper characteristics, device-independent colors are not dependent on any particular device and are meant to be true representations of colors as perceived by the human eye. These color representations, called device-independent color spaces, result from work carried out by the Commission Internationale d'Eclairage (CIE) and for that reason are also called CIE-based color spaces.

The most common method of identifying color within a color space is a three-dimensional geometry. The three color attributes, hue, saturation, and brightness, are measured, assigned numeric values, and plotted within the color space.

Conversion from an RGB color space to a CMYK color space involves a number of variables. The type of printer or printing press, the paper stock, and the inks used all influence the balance between cyan, magenta, yellow, and black. In addition, different devices have different gamuts, or ranges of colors that they can produce. Because the colors produced by RGB and CMYK specifications are specific to a device, they're called device-dependent color spaces. Device color spaces enable the specification of color values that are directly related to their representation on a particular device.

Device-independent color spaces can be used as interchange color spaces to convert color data from the native color space of one device to the native color space of another device.

The CIE created a set of color spaces that specify color in terms of human perception. It then developed algorithms to derive three imaginary primary constituents of color—X, Y, and Z—that can be combined at different levels to produce all the color the human eye can perceive. The resulting color model, CIEXYZ, and other CIE color models form the basis for all color management systems. Although the RGB and CMYK values differ from device to device, human perception of color remains consistent across devices. Colors can be specified in the CIE-based color spaces in a way that is independent of the characteristics of any particular display or reproduction device. The goal of this standard is for a given CIE-based color specification to produce consistent results on different devices, up to the limitations of each device.

## XYZ Space

There are several CIE-based color spaces, but all are derived from the fundamental XYZ space. The XYZ space allows colors to be expressed as a mixture of the three tristimulus values X, Y, and Z. The term tristimulus comes from the fact that color perception results from the retina of the eye responding to three types of stimuli. After experimentation, the CIE set up a hypothetical set of primaries, XYZ, that correspond to the way the eye's retina behaves.

The CIE defined the primaries so that all visible light maps into a positive mixture of X, Y, and Z, and so that Y correlates approximately to the apparent lightness of a color. Generally, the mixtures of X, Y, and Z components used to describe a color are expressed as percentages ranging from 0 percent up to, in some cases, just over 100 percent.

Other device-independent color spaces based on XYZ space are used primarily to relate some particular aspect of color or some perceptual color difference to XYZ values.

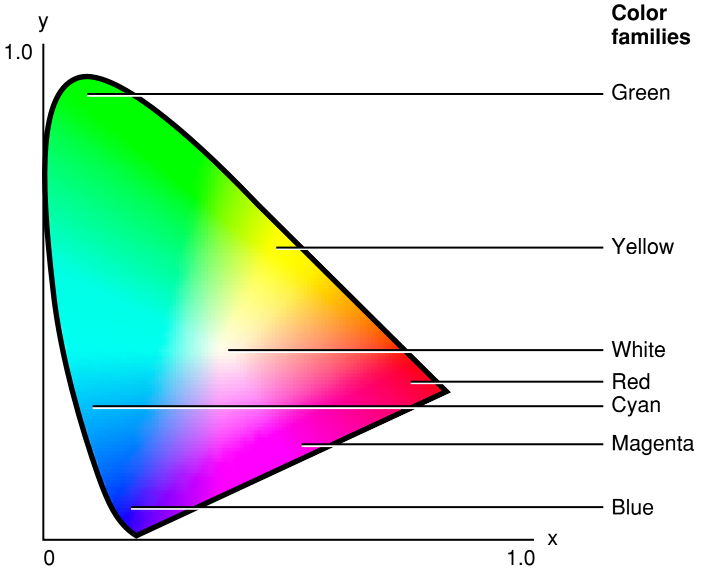
## Yxy Space

Yxy space expresses the XYZ values in terms of x and y chromaticity coordinates, somewhat analogous to the hue and saturation coordinates of HSV space. The coordinates are shown in the following formulas, used to convert XYZ into Yxy:

```
Y = Y
x = X / (X+Y+Z)
y = Y / (X+Y+Z)
```

Note that the Z tristimulus value is incorporated into the new coordinates and does not appear by itself. Since Y still correlates to the lightness of a color, the other aspects of the color are found in the chromaticity coordinates x and y. This allows color variation in Yxy space to be plotted on a two-dimensional diagram. Figure 2-5 shows the layout of colors in the x and y plane of Yxy space.

**Figure 2-5** Yxy chromaticities in the CIE color space

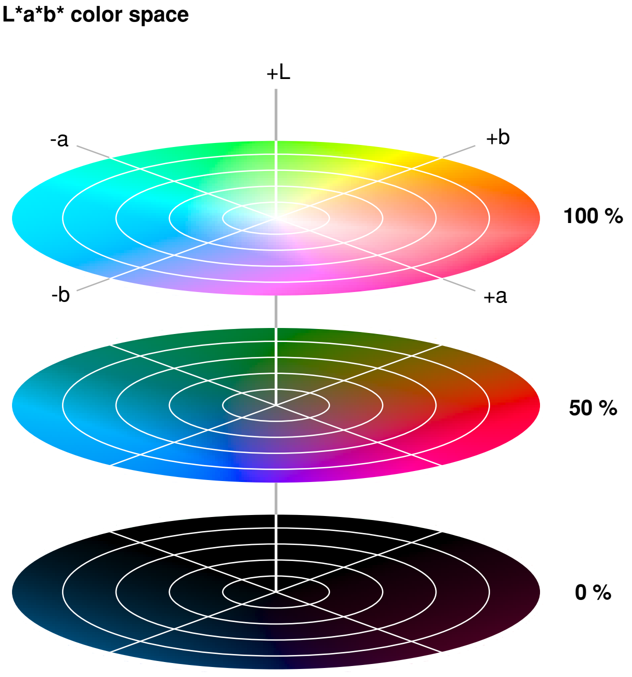


## L*u*v* Space and L*a*b* Space

One problem with representing colors using the XYZ and Yxy color spaces is that they are perceptually nonlinear: it is not possible to accurately evaluate the perceptual closeness of colors based on their relative positions in XYZ or Yxy space. Colors that are close together in Yxy space may seem very different to observers, and colors that seem very similar to observers may be widely separated in Yxy space.

L*u*v* space and L*a*b* space are nonlinear transformations of the XYZ tristimulus space. These spaces are designed to have a more uniform correspondence between geometric distances and perceptual distances between colors that are seen under the same reference illuminant. A rendering of L*a*b space is shown in Figure 2-6.

**Figure 2-6** L*a*b* color space



Both L*u*v* space and L*a*b* space represent colors relative to a reference white point, which is a specific definition of what is considered white light, represented in terms of XYZ space, and usually based on the whitest light that can be generated by a given device.

**Note:** Because L*u*v* space and L*a*b* space represent colors relative to a specific definition of white light, they are not completely device independent; two numerically equal colors are truly identical only if they were measured relative to the same white point.

Measuring colors in relation to a white point allows for color measurement under a variety of illuminations.

A primary benefit of using L*u*v* space and L*a*b* space is that the perceived difference between any two colors is proportional to the geometric distance in the color space between their color values, if the color differences are small. Use of L*u*v* space or L*a*b* space is common in applications where closeness of color must be quantified, such as in colorimetry, gemstone evaluation, or dye matching.

## Indexed Color Spaces

In situations where you use only a limited number of colors, it can be impractical or impossible to specify colors directly. If you have a bitmap with only a few bits per pixel (1, 2, 4, or 8, for example), each pixel is too small to contain a complete color specification; its color must be specified as an index into a list or table of color values. If you are using spot colors in printing or pen colors in plotting, it can be simpler and more precise to specify each color as an index into a list of colors instead of an actual color value. Also, if you want to restrict the user to drawing with a specific set of colors, you can put the colors in a list and specify them by index.

Indexed space is the color space you use when drawing with indirectly specified colors. An indexed color value (a color specification in indexed color space) consists of an index value that refers to a color in a color list. Color values are defined in "Color-Component Values, Color Values, and Color" (page 18).

## Named Color Spaces

In a named color space, each color has a name; colors are generally ordered so that each has an equal perceived distance from its neighbors in the color space. A named color space provides a relatively small number of discrete colors.

Color systems using named color spaces have existed for many years. Graphic artists and designers using named color systems can "see" the real color by looking at a color chip or swatch. Printing shops can reproduce a specified color accurately.

Named color systems are useful for spot colors, but they have several drawbacks:

- They are not useful for images, which require a continuous range of colors.
- They are highly device dependent and proprietary.
- Colors are tied to medium-specific formulations.
- Applications that use these systems require a device-specific database for each supported printer, making it difficult to add additional devices.

## Color-Component Values, Color Values, and Color

Each of the color spaces described here requires one or more numeric values in a particular format to specify a color.

Each dimension, or component, in a color space has a color-component value. An unsigned 16-bit color-component value can vary from 0 to 65,535 (0xFFFF), although the numerical interpretation of that range is different for different color spaces. In most cases, color-component intensities are interpreted numerically as varying between 0 and 1.0. An exception occurs for the a* and b* channels of the Lab color space, where values ranging from 0 to 65,535 are interpreted numerically as varying from -128.0 to approximately 128.0.

Depending on the color space, one, two, three, or four color-component values combine to make a color value. For HiFi colors, up to eight color-component values combine to make a color. A color value is a structure; it is the complete specification of a color in a given color space.

# Color Management Systems

Color management is the process of ensuring consistent color across peripheral devices and across operating-system platforms. Members of the computer and publishing industries developed color management systems (CMSs) to convert colors from the color space of one device to the color space of another device. A color management system gives the user the ability to perform color matching, to see in advance which colors cannot be accurately reproduced on a specific device, to simulate the range of colors of one device on another, and to calibrate peripheral devices using a device profile and a calibration application.

A color management system includes:

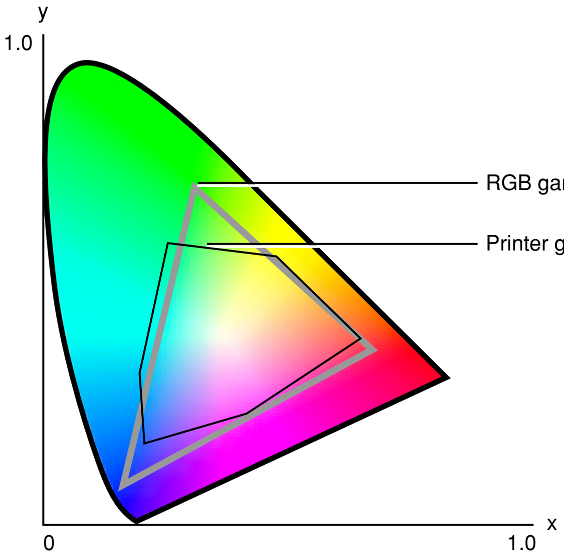
- Collections of color characteristics. These collections are given various names, such as color tags, precision transforms, or profiles.
- A color management module (CMM). This is a mathematical engine that performs the color matching among, and transformation between, collections of color characteristics.
- A system component for invoking color matching. ColorSync is Apple's implementation of the ICC specification, providing system-level color management of images, documents, and devices.

## The Color Matching Problem

When an image is output to a particular device, the device displays only those colors that are within its gamut. Likewise, when an image is created by scanning, all colors from the original image are reduced to the colors within the scanner's gamut. Devices with different gamuts cannot reproduce each other's colors exactly, but careful shifting of the colors used on one device can improve the visual match when the image is displayed on another.

Figure 3-1 (page 20) shows examples of two devices' color gamuts, projected onto Yxy space. Both devices produce less than the total possible range of colors, and the printer gamut is restricted to a significantly smaller range than the RGB gamut. The problem illustrated by Figure 3-1 is to display the same image on both devices with a minimum of visual mismatch. The solution to the problem is to match the colors of the image using profiles for both devices and one or more color management modules. A **profile** is a structure that provides a means of defining the color characteristics of a given device in a particular state.

**Figure 3-1** Color gamuts for two devices expressed in Yxy space



**Color conversion** is the process of converting colors from one color space to another. **Color matching**, which entails color conversion, is the process of selecting colors from the destination gamut that most closely approximate the colors from the source image. Color matching always involves color conversion, whereas color conversion may not entail color matching.

## Profiles

Color matching or color conversion across different color spaces requires the use of a profile for each device involved. Profiles provide the information necessary to understand how a particular device reproduces color. A profile may contain such information as lightest and darkest possible tones (referred to as white point and black point), the difference between specific "targets" and what is actually captured, and maximum densities for red, green, blue, cyan, magenta, and yellow. Together these measurements represent the data which describe a particular color gamut.

Profiles are documents containing data that describe how to transform colors from device color space to an intermediate color space. This file format allows for the description of a wide variety of devices and is regularly updated with improvements. If needed, you can extend the data format to suit your software's purpose.

Profiles can contain different kinds of information. For example, a scanner profile and a printer profile have different sets of minimum required tags and element data. They can also contain optional and private tagged elements which can contain custom information used by particular color management modules. However, all profiles have at least a header followed by a required element tag table. The required tags may represent lookup tables, for example. The required tags for various profile classes are described in the International Color Consortium Profile Format Specification. To obtain a copy of this specification, or to get other information about the ICC, visit the ICC Web site at http://www.color.org/.

## Source and Destination Profiles

The profile that is associated with the image and describes the characteristics of the device on which the image was created is called the **source profile**. Displaying the image requires using another profile, which is associated with the output device, such as a display. The profile for that device is called the **destination profile**. If the image is destined for a display, color matching requires using the display's profile (the destination profile) along with the image source profile to match the image colors to the display gamut. If the image is printed, color matching must use the printer profile to match the image colors to the printer, including generating black and removing excessive color densities (known as undercolor removal, or UCR) where appropriate.

## Profile Connection Space

A **profile connection space** (PCS) is a device-independent color space used as an intermediate when converting from one device-dependent color space to another. Profile connection spaces are typically based on spaces derived from the CIE color space. ColorSync supports two of these spaces, XYZ and L*a*b.

## Profile Classes

There are a variety of classes, or categories of profiles, each of which plays a role in the color matching process. They include:

- Device profiles
- Color space profiles
- Abstract profiles
- Device link profiles
- Named color space profiles

A **device profile** characterizes a particular device: that is, it describes the characteristics of a color space for a physical device in a particular state. A display, for example, might have a single profile, or it might have several, based on differences in gamma value and white point. A printer might have a different profile for each paper type or ink type it uses because each paper type and ink type constitutes a different printer state. Broadly speaking, there are three kinds of device profiles—input, display, and output. Input device profiles characterize scanners and digital cameras. Display devices profiles characterize monitors and LCD panels. Output device profile characterize printers, printing presses, and film recorders.

A **color space profile** contains the data necessary to convert color values between a PCS and a non-device color space (such as L*a*b to or from L*u*v, or XYZ to or from Yxy), for color matching. Color space profiles provide a convenient means for CMMs to convert between different non-device profiles.

**Abstract profiles** allow applications to perform special color effects independent of the devices on which the effects are rendered. For example, an application may choose to implement an abstract profile that increases yellow hue on all devices. Abstract profiles allow users of the application to make subjective color changes to images or graphics objects.

A **device link profile** represents a one-way link or connection between devices. It can be created from a set of multiple profiles, such as various device profiles associated with the creation and editing of an image. It does not represent any device model, nor can it be embedded into images.

A **named color space profile** contains data for a list of named colors. The profile specifies a device color value and the corresponding CIE value for each color in the list.

### Embedded Profiles

Profiles can be embedded within images. For example, profiles can be embedded in JPEG, EPS, TIFF, and PICT files and in the private file formats used by applications. Embedded profiles allow for the automatic interpretation of color information as the color image is transferred from one device to another.

Embedding a profile in an image guarantees that the image can be rendered correctly on a different system. Although profiles can be several hundred KB or even larger, the typical RGB profile is around 500 bytes.

## Color Management Modules

A color management module (CMM) uses profiles to convert and match a color in a given color space on a given device to or from another color space or device, perhaps a device-independent color space. When colors consistent with one device's gamut are displayed on a device with a different gamut, a CMM attempts to minimize the perceived differences in the displayed colors between the two devices. The CMM does this by mapping the out-of-gamut colors into the range of colors that can be produced by the destination device. The CMM uses lookup tables and algorithms for color matching, previewing, color reproduction capabilities of one device on another, and checking for colors that cannot be reproduced.

### Rendering Intents

Rendering intent refers to the approach taken when a CMM maps or translates the colors of an image to the color gamut of a destination device—that is, a rendering intent specifies a gamut-matching strategy. The ICC specification defines a profile tag for each of four rendering intents: perceptual matching, relative colorimetric matching, saturation matching, and absolute colorimetric matching.

**Perceptual matching** is typically used for photographic content. All the colors of one gamut are scaled to fit within another gamut. Colors maintain their relative positions. Perceptual matching usually produces better results than colorimetric matching for realistic images such as scanned photographs. The eye can compensate for gamuts differences and when printed on a CMYK device, the image may look similar to the original on an RGB device. A side effect is that most of the colors of the original space may be altered to fit in the new space.

**Relative colorimetric matching** is typically used for spot colors. Colors that fall within the overlapping gamuts of both devices are left unchanged. For example, to match an image from the RGB gamut onto the CMYK printer gamut, only the colors in the RGB gamut that fall outside the printer gamut are altered. Allows some colors in both images to be exactly the same, which is useful when colors must match quantitatively. A disadvantage is that many colors may map to a single color, resulting in tone compression. All colors outside the printer gamut, for example, would be converted to colors at the edge of its gamut, reducing the number of colors in the image and possibly altering its appearance. Colors outside the gamut are usually converted to colors with the same lightness, but different saturation, at the edge of the gamut. The final image may be lighter or darker overall than the original image, but the blank areas will coincide.

**Saturation matching** is typically used for business graphics. The relative saturation of colors is maintained as well as can be achieved from gamut to gamut. Colors outside the gamut of the destination space are usually converted to colors with the same saturation of the source space, but with different lightness, at the edge of the gamut. Can be useful for some graphic images, such as bar graphs and pie charts, when the actual color displayed is less important than its vividness.

**Absolute colorimetric matching** is most often used in proofing. This type of matching preserves the native device white point of the source image instead of mapping to D50 relative. Absolute colorimetric matching is most often used in simulation or proofing operations where a device is trying to simulate the behavior of another device and media. For example, simulating newsprint on a monitor with absolute colorimetric intent would allow white space to be displayed onscreen as yellowish background because of the differences in white points between the two devices.

## ColorSync

ColorSync is Apple's platform-independent color management system that provides essential services for fast, consistent, and accurate color calibration, proofing, and reproduction. In Mac OS X, ColorSync is fully integrated into the operating system. In most cases, color matching occurs behind-the-scenes, without any effort required on the part of applications. As soon as a device is connected to the computer, Mac OS X registers at least one profile for the device. ColorSync uses the registered profiles to ensure color matching throughout the digital workflow.

The ColorSync Manager is the application programming interface (API) to color matching services in Mac OS X. Only those developers who require color matching support beyond what Mac OS X provides automatically need to use this API. Some typical reasons for using the ColorSync Manager API include:

- You are a hardware vendor and want to register a profile for your scanner, camera, or printer.
- Your application supports creative professionals for whom color fidelity is essential. Your application may need to support soft proofing, preparation of materials for printing press, or other custom color tasks.

You can find detailed information on how ColorSync works in Mac OS X and guidance on whether your application needs to use the ColorSync Manager API by reading Technical Note TN2035 ColorSync on Mac OS X.

# Document Revision History

This table describes the changes to *Color Management Overview*.

| Date | Notes |
|---|---|
| 2005-07-07 | Added link to technical note on ColorSync in Mac OS X. |
| 2004-10-05 | Changed the title from "Color and Color Management Systems" to make it more consistent with the titles of similar documentation. No other changes. |
| | Changed the title from *Color and Color Management Systems* to make it more consistent with the titles of similar documentation. No other changes. |
| 2004-05-27 | First version. |
| | The contents of this document were previously published as a chapter in *Managing Color With ColorSync*, a book that targets color management in Mac OS 9 and earlier. |