Understanding Color Management

Every imaging device has its own "personality," the color imaging will only produce accurate results if we take into account the personal characteristics of each device.

BY ABHAY SHARMA

Why do we need color management? Why do we have a problem with matching and controlling colors in digital imaging? Why can't we just scan a picture, look at it on the screen, and print it out and have the color match throughout? The answer is that every imaging device has its own particular characteristics. Color imaging will only produce accurate results if we take into account the personal characteristics of each device.

Each scanner or digital camera captures the same scene slightly differently. Each printer prints the same digital file in a different way. We need to quantify and compensate for device variability. Included in this variability is the issue of color gamut. No device can reproduce all colors.

Device Characteristics

Scanner Variability: An image from a scanner will generally be an RGB image in which each pixel in the image is specified by three numbers corresponding to red, green, and blue. If you use different scanners to scan the same sample, you will get different results.

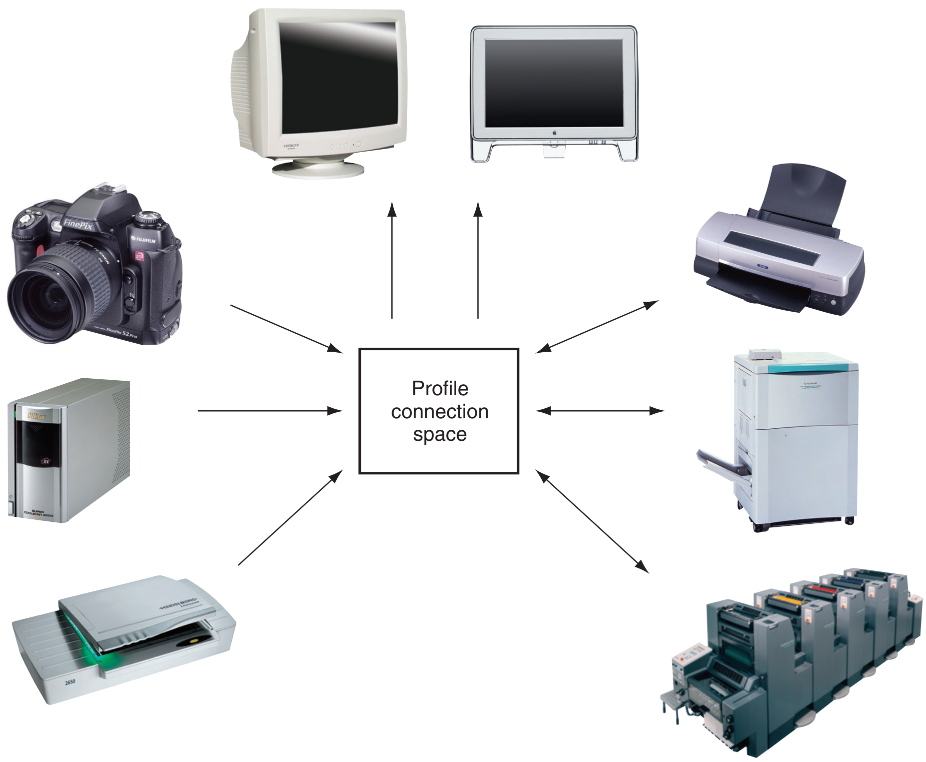
Printer Variability: Device variability also occurs when we print an image. If you sent the CMYK image to three printers, each device would receive these CMYK instructions, which tell the printer to drop varying amounts of cyan, magenta, yellow, and black ink on the paper. Because of the differences in the printing systems printed results can be dramatically different.

There is also variation among monitors. Thus, we see that there is variability in every part of the imaging chain. To get accurate color, we need to know about the device being used to scan, print or display an image. Color is controlled by knowing about the behavior/characteristics of a device.

Two Methods of Color Control

Two ways to make allowances for device characteristics are the old way, which is closed-loop color, and the new way, which is known as open-loop color—color management.

Closed-Loop Color: Digital color once was the preserve of high-end systems. The same manufacturer would sell a system that included the monitor, software, scanner, output, and so on. The



A color management system connects all devices into and out of a central connection space—the profile connection space—to communicate color between devices.

image was acquired from one scanner, it was displayed on the same monitor, and images were destined for one type of print process. In this controlled situation, it was relatively easy to obtain the color we wanted. However, two important conditions had to be met: skilled personnel and a fixed workflow. As the conditions for a closed-loop system disintegrated, something had to be done to get consistent, accurate color. The answer is an open-loop environment.

Open-Loop Color Management: Modern-day color management uses a central hub system to communicate color between devices, as shown in the above illustration. In today's workflows, images come from a number of places, are viewed on different displays, and are printed on different printer technologies. Instead of connecting every device to every other device, a color management system connects all devices into and out of a central connection space—the profile connection space (PCS). This illustration is the single most important diagram to understand in color management. It provides the conceptual basis for all color management.

In color management, every device must have a profile. A golden rule of color management is image + profile. In a typical workflow, images from a scanner may be "brought into" the profile connection space using the scanner profile. To print the image it would be "sent out" from the connection space to a printer using a printer profile. Thus, color management operations require a source and a destination profile—we need to know where the image is coming from and where it is going.

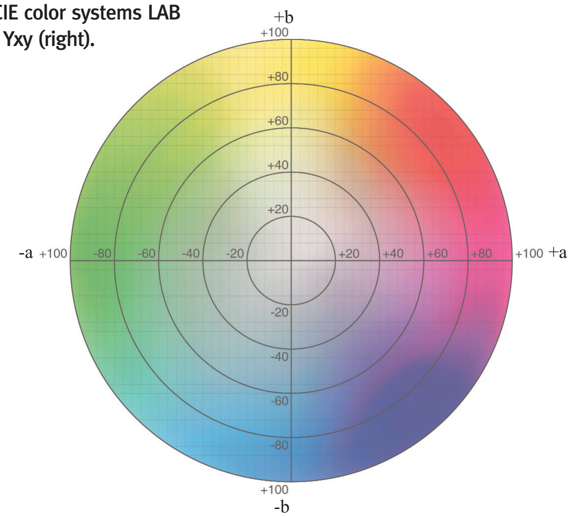
In color management it is easy to add a new device to the workflow. All that is needed for a new device is a single profile that connects the device (and its images) to the central space. A profile describes the characteristics of a device, thus as soon as a device and its profile are available to the network, the characteristics of the device become known to all other devices in the system.

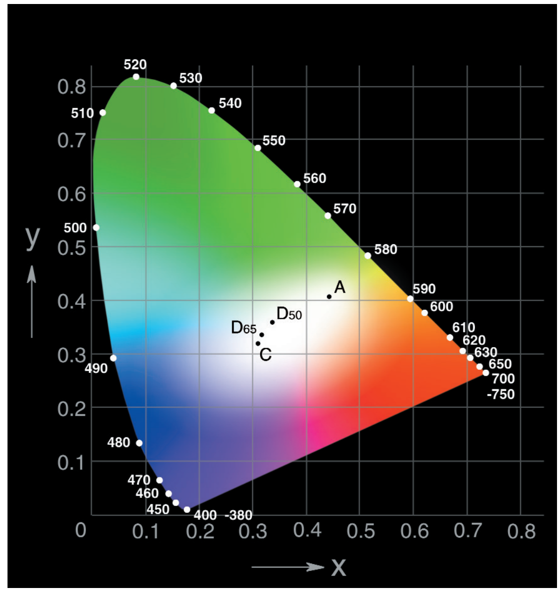
Color Spaces

Color specification falls into two main categories—device-dependent color and device-independent color.

Device-Dependent Color: RGB values from a scanner are not a universal truth but are dependent on which scanner was used to scan the original. Such values (including CMYK values for printers) are known as device-dependent color values because the colors you obtain are dependent on the device being used. There is nothing wrong with specifying a pixel value in terms of RGB or CMYK. As scanners use red, green and blue filters, they truly generate RGB pixel values when they scan an image. Similarly CMYK instructions are appropriate for most printers. RGB and CMYK are instructions for a device and are necessarily in units that the device can understand and use.

Color management uses well-defined CIE color systems LAB (left) and Yxy (right).





Device-Independent Color: If RGB and CMYK are not reliable descriptors of color, what is? CIE (International Commission on Illumination) systems are reliable measurement systems. The CIE organization has over the years specified a number of color measurement systems. CIE systems use a measuring instrument to sample a color and produce a numeric result. The measuring instrument, for example, does not need to know about the printer that produced the sample, it just measures a color patch. Thus CIE measurements are independent of any particular printer, scanner, or monitor, and we can say they are device-independent measurements. CIE systems are standardized and dependable systems, so when a color is specified by one of these systems it means the same thing to any user anywhere.

CIE systems form the basis for color management. Two CIE systems popular in color management are shown above. The LAB system is used in profile generation and is also used in Photoshop. The Yxy system is often used to analyze and compare the color gamut of different devices. The CIE LAB (L*a*b*) system specifies a color by its position in a 3D color space. The coordinate L* stands for lightness, a* represents the position of the color on a red-green axis, and b* represents the position of the color on a yellow-blue axis. In the Yxy system, a color is specified by its x and y coordinates on a graph called the chromaticity diagram.

LAB and Yxy are device-independent color metrics that are not related to any specific device. A CIE value can more accurately be thought of as a description or specification of a color as viewed by a human observer. CIE systems (especially LAB) are important ways to measure and specify color and are used implicitly and explicitly in many color management operations.

Internal Color Scale

Because scanners produce different RGB values, each scanner has its own internal color scale. Thus, the pixel values are specified according to a particular scanner. We cannot simply hand these numbers on to a printer without providing some information about the scale on which they are based. If we simply pass on a set of RGB values, there is no guarantee the printer will correctly interpret them.

We would have the same problem with printers—each printer would have its own CMYK color space. Working with each device's individual color scale is difficult and largely impractical.

Device Profiles

Instead of trying to convert data from every device to every other device, we relate each device to a central scale. If we are presented with an RGB pixel value, we want to know what color it really refers to. We use a profile to interpret the color represented by RGB pixel values. A profile provides data that allows us to evaluate what color the pixel values represent. A profile relates device dependent RGB values to device-independent, unambiguous LAB values. Thus, a profile contains data to convert between the RGB value each scanner produces and the LAB number for that color. Each scanner will need to have a different profile and the profile must accompany the image from that scanner to allow its device-dependent RGB values to be correctly interpreted. The correct interpretation of the RGB scan values greatly improve an image, giving it much better contrast, enhanced tone reproduction, vivid saturated colors, and generally better overall color reproduction, as shown in the images to the right.

When you print an image, the process is reversed. You specify an LAB color and the profile establishes the necessary CMYK instructions specific to that printer to produce that color.

International Color Consortium (ICC)

The framework for the profile connection space and the format of profiles is specified by the ICC, a regulatory body that supervises color management protocols between software vendors, equipment manufacturers and users. Today's color management is basically "ICC-color management."

Inside a Profile

Profiles are an essential part of any color management system. A profile can be embedded in an image or be used as standalone files. Profiles allow the correct interpretation of image data (pixel values). Because the ICC specifies a standard profile format, profiles are neither vendor specific nor platform specific. The same profile can be accepted by various software programs and operating systems. Software such as Photoshop, QuarkXPress, and InDesign can use images with device profiles from any manufacturer and for any device. The same profile can be used on Mac and Windows. Because profiles have a standard format, there are a number of "profile inspector" utilities that can be used to view the content of a profile.

Profile-Making Software

A profile is needed to link an image to the central connection space, thus to implement color management it is necessary to have an ICC profile for each device in your imaging chain. There are three main ways to obtain a profile for your device: Custom, Generic, and Process.

Custom Profiles: Color management is mostly done with custom profiles. A custom profile refers to a profile that is made specifically for your device and the state it is in. To make a custom profile, you need a test chart, a measuring instrument, and profile-

An image without and an image with a scanner profile. Notice how a profile improves the appearance of the image. The image was scanned on a Fuji Quattro scanner with a profile made in Fuji ColourKit profiling software.

making software. Profiling a device involves creating a map between device-dependent RGB/CMYK and device-independent LAB. Thus, all profiles—monitor, scanner, or printer—require that these two sets of data be available.

Custom-made profiles are the most accurate type of profile because they describe the characteristics of your device and the state it is in. Custom profiling is one of the most important operations in color management.

Generic Profiles: Manufacturers usually supply a generic profile for a device, but the profile may not accurately represent the device you have in front of you. A custom profile generated for your device is likely to give you better results. There is one good use for a generic profile, however, color management operations cannot be initiated without a profile: and a generic profile can be used as a starting point because the profile will be of the correct type and description for the device.

sRGB, SWOP, and Other Process Profiles: Another option is to use a process profile. One popular way of working is to say your device is representative of a typical process, so you can justify using a process profile. A number of process profiles are available such as sRGB for monitors and SWOP for printers. If you believe your monitor is average, you can use an sRGB profile as your monitor profile.

Process profiles are very common in commercial printing. A printing press can be run so it produces density values that are in accordance with accepted standards for printing, known as "reference printing conditions." Some of the common settings include SNAP, GRACol, and SWOP. If your print process operates according to SWOP specifications, in a color managed workflow, you can use a SWOP profile as your printer profile. As long as a process profile is a good representation of your device, process profiles provide flexibility and convenience to end-users.

Device Gamuts

A color gamut is defined as the range of colors a device can produce. The gamut of a device is part of the device's characteristics and is derived during the profiling process. Thus, profiles contain information about a device including its gamut.

Some devices create colors using RGB—the primary (or additive) color set. The technologies that use RGB are computer monitors, flatbed scanners, slide scanners, slide writers, and large-screen video projectors. CMY (commonly known as CMYK because printer technologies also use black ink) is called the secondary (or subtractive) color set. The CMYK set is used by nearly all output devices. An accepted generalization is that RGB systems have a larger color gamut and can cope with more colors than CMYK systems. As images are passed into and out of the central connection space, they may be sent to a device with a small color gamut. Thus we have to deal with colors that are out-of-gamut of the destination process. Color management provides a number of ways to deal with out-of-gamut colors.

Rendering Intents

Gamut issues affect many color management operations. Images from a scanner or digital camera will have colors a printer cannot reproduce. If a color cannot be printed, we would like a color management system to find a replacement. The ICC has specified four color-replacement schemes, called rendering intents: perceptual, relative, absolute, and saturation.

Perceptual Rendering Intent: Perceptual rendering is used to process photographic-type images. This intent processes colors in an image so that the printed reproduction is pleasing. Perceptual rendering is likely to change the color of an image from original to reproduction, but the relationship between colors is retained and this creates the best-looking images.

Relative and Absolute Colorimetric Intent: The colorimetric intents are used in instances where we desire the highest accuracy in color reproduction, for example in logos where color is critical.

Saturation Intent: The saturation intent makes the image more colorful by utilizing the full gamut of the destination device. This intent has total disregard for any genuine representation of color. This intent is used for business graphics such as graphs and pie charts, for which it is important to have bright, vivid colors.

Version 4 Profiles

The rendering intents just described have until now been primarily associated with printer profiles. Following the Version 4 revision of the ICC specification, it is now possible to create rendering intents for all types of profiles (scanner, monitor, and printer). Many vendors are now starting to incorporate different rendering intents in their monitor and scanner profiles.

Three Cs of Color Management

The whole process of color management can be neatly defined in terms of three Cs—Calibration, Characterization, and Conversion. Calibration involves establishing a fixed, repeatable condition for a device. Anything that alters the color of the image must be identified and "locked-down." Calibration involves establishing some known starting condition and some means of returning the device to that state. After a device has been calibrated, its characteristic response is studied in a process known as characterization. In color management, characterization refers to the process of making a profile. During the profile generation process, the behavior of the device is studied by sending a reasonable sampling of color patches (a test chart) to the device and recording the device's response. Thus, the typical behavior, gamut and characteristics of the device are ascertained, and this information is stored in the device profile. Creating a profile is the characterization part of the process.

The third C of color management is conversion, a process in which images are converted from one color space to another. The conversion process relies on application software (e.g., Photoshop), system-level software (e.g., ColorSync), and a CMM (e.g., Adobe CMM). The three Cs are hierarchical—each process is dependent on the preceding step. Thus characterization is only valid for a given calibration condition.

Color Management Workflows

Workflows typically involve source and destination devices and color management operations such as image conversions or processing. A color management system can consist of input, output, and display devices connected to a central connection space via profiles. There are a number of ways of processing images through such a system.

The real power of color management is evident in printer-based workflows. This is where the image from a digital camera or scanner is brought into the central space and then sent to the printer. In this case, the software applies the input profile, and the system uses an output profile. Typically, this operation converts the image from RGB to LAB and then from LAB to CMYK. The printed result is thus similar to the original image.

Soft proofing involves previewing the printed image on a monitor to get a color-accurate preview of what the printed result will look like. In this scenario, the image is brought into the central connection space using the input profile. The image is processed through the output profile, which imbues the image with the look and feel of the printer. From the printer space, the image is brought back into the central space and sent to the monitor. Simply by choosing a printer profile, you can immediately see on the screen what your print will look like.

The press proof process simulates a printing press result on a local desktop printer. The image is brought into the central space via the input profile. The image is processed to the press profile, brought back in from the press, and finally sent out to a local inkjet printer. The inkjet device provides a rendition of the printed product, providing a preview of the printed result that can be used to detect any problems with the print job.

RGB Versus CMYK Workflow

In modern color management, it is preferable to retain the image in its original color space, usually RGB. The advantages of working in RGB are:

- RGB images are three-channel images and have a smaller file size compared to four-channel CMYK counterpart.
- There are more Photoshop filters in RGB mode than in CMYK mode.
- RGB images are not “committed” to a print process and are therefore not gamut compressed.
- Working in RGB reduces the number of color conversions to which an image may be subjected.

The gamut of RGB scanners is relatively large. If the image is converted to a printer CMYK that has a smaller gamut, any colors in the RGB set but not in the CMYK set must be thrown away. This process is irreversible. Suppose a client wants an Internet version of a printed catalog. It is possible to take the processed CMYK images back to the connection space and then to web RGB, however, you don’t have as many colors and are not fully exploiting the capabilities of the display medium. It would be better to take the input RGB data to web RGB.

In color management you do not have to commit to a particular print process to see what the printed image will look like. It is not necessary to convert the image from RGB to CMYK. It is possible to simulate this process. Software allows you to preview and even edit the image as if it were in the destination space.

Why Do We Need Color Management?

Color management gets us very close, very quickly. It removes the need for endless iterations. There are of course many instances where a particular image will need further editing and “tweaking.” Color management provides a way to get to a good baseline from which to make further, aesthetic changes. At the end of the day color management saves time and money—the bottom line with which few can argue. Color management provides flexibility, the ability to proof at remote locations, and the ability to use inkjet printers instead of high-end proofers. In the final analysis it facilitates a quicker, less expensive workflow, which is what counts.

Understanding Color Management by Abhay Sharma

This article is excerpted from chapter 1 of Abhay Sharma’s popular *Understanding Color Management.* The book provides an in-depth look at CIE color systems; quantifying color difference; measuring instruments; and scanner, camera, monitor, press and printer profiles, as well as Apple utilities and color management in Photoshop. Additional key features:

•Show how to make and use profiles for monitors, scanners, and printers.

•Describe how to set up and use color management in Photoshop.

•Include updates on Version 4.0 ICC profiles.

•Examine color management in Mac OS X.

The book is available for purchase through IPA. Please email donna@ipa.org for further information. Sharma, in conjunction with IPA, has conducted a series of color management webinars and ICC Profiling webinars that have been archived and are available on-demand or on CD. Go to www.ipa.org/webinars for more information or to order the webinar series.