1

Introduction

Objectives

- Explain and define color management.
- Describe the older, closed-loop method of color control.
- List the activities of the International Color Consortium (ICC).
- Describe the three Cs of color management – calibration, characterization and conversion.
- Introduce RGB/CMYK colorspaces and Yxy/L*a*b*.
- Introduce typical color management workflows.
- Describe the benefits of a color management system.

1.1 Why Do We Need Color Management?

What is color management and why do we need it? Why can't we just use a digital camera to take a picture, view the image on a display, print it out, and have the color match throughout? The answer is that every imaging device is different and every device has its own particular characteristics.

To understand device characteristics, consider an analogy of making microwave popcorn, Figure 1.1. Through trial and error, it is possible to determine that a home microwave needs, for example, exactly two minutes to pop all the kernels without burning any. For a higher wattage, office microwave however, two minutes is too long, and it is determined that the cook time must be adjusted and reduced to one-and-a-half minutes. In a student apartment, using a weak mini-microwave, it is determined that three minutes is needed to create the perfect snack. In all instances we can achieve the same result – a perfectly popped bag of popcorn – but we must adjust the cooking time to take into account the wattage and settings of each microwave, in other words, the characteristics of each device.

In digital imaging, we may have an image with a yellow lemon, Figure 1.1. We seek to create this yellow color on different devices. Each printer prints in a different way, with different ink or toner and each device may use different media. To create this yellow color on different devices we must take into account the characteristics of each device.

Understanding Color Management, Second Edition. Abhay Sharma.

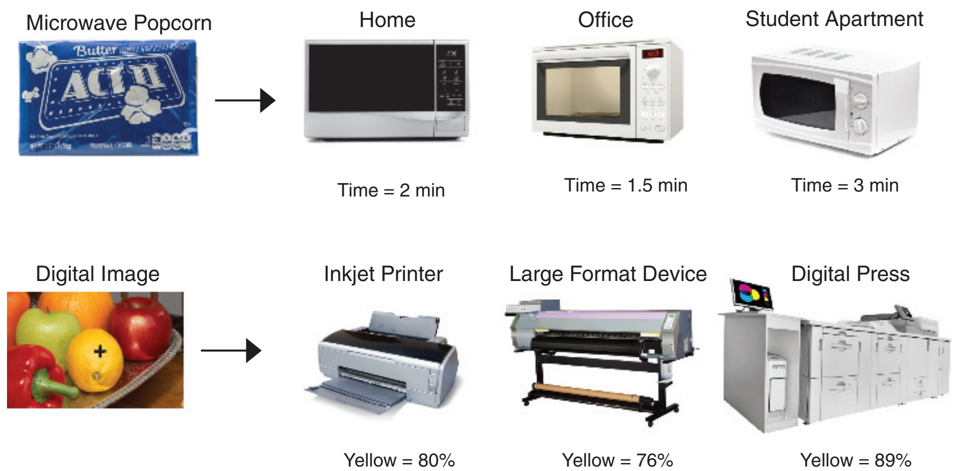


Figure 1.1 Microwave popcorn needs different cook times on different appliances. Similarly different printing systems require different pixel instructions – color management is all about creating different instructions to get the same color on different devices.

In the same way that we adjust the cooking time of popcorn to accommodate the characteristics of each microwave oven, similarly we must adjust the printing instructions to take into account the characteristics of each printing system.

The amount of ink is expressed in units of percent, such as 40%, 50%, 60%, etc. (In this context % is simply an amount and not a percentage.) In Figure 1.1, an inkjet proofer may need 80% of yellow ink, while a large format device may have a very strong yellow ink set, so it may need only 76% of yellow ink to create the same color. A digital press may require 89% of yellow toner to create the same "lemon yellow".

So we see that in order to achieve the same color on different devices it is necessary to send different instructions to each device. In the case of popcorn it may be easiest to determine the required cooking time simply via trial and error, but for an image we need a more sophisticated approach as we must consider not just yellow, but green and blue and orange and all the other colors that can be present in an image. And of course we must extend the process beyond printers to include any device in a color imaging system, including images viewed in a web browser, or a tablet device, or printed using an offset printing press, etc. *Color management is a technology that enables the computation of appropriate pixel instructions on a device by device basis.*

Color management is a digital technology framework that can be used to compute device-specific instructions and thereby control color among different devices in an imaging system. *Color management is defined as the use of hardware, software, and processes to control and adjust color among different devices in an imaging system.*

Color management is not just the technology, it is not a physical item on a store shelf that you can go and buy, color management is all about systems, processes, software, measuring instruments – a whole philosophy – a systematic framework for color control – a way of life!

This chapter provides an introduction to color management, what it is, and how it works.

1.2 Closed-loop Color Control

A fundamental issue with color imaging is that each device behaves differently, which means that we cannot send the same pixel values to different devices; we must adjust the pixel values in order that they are appropriate for each device. There are two ways of making these adjustments, the traditional way is called *closed-loop color*, and the new way is *open-loop color*, more commonly referred to as color management.

Affordable devices for color imaging are a relatively recent development that have come about because cheaper digital systems have brought the technology within the reach of the mass market. During the 1970s and 1980s, digital color was the preserve of high-end systems such as those sold by Crosfield Electronics, Hell, and Dainippon Screen. The same manufacturer would provide a color imaging suite that included the monitor, software, scanner, proofer, and so on. These were closed-loop systems in which all devices were designed and installed by one vendor.

An example of a closed-loop system is shown in Figure 1.2. The image was always acquired from a photographic scanner (perhaps a drum scanner), it was always displayed on the same monitor, and the images were destined for one type of print process, e.g. an offset print condition, that was emulated by a proprietary proofing system such as ColorArt or Chromalin. In this closely controlled situation it was relatively easy to obtain the color we wanted. However, two important conditions had to be met: a fixed workflow and skilled personnel.

In closed-loop systems it was necessary to have a trained scanner operator. Through many hours of use, the operator would gain knowledge about the characteristics of a particular scanner and the required tone curve corrections needed. Images were acquired directly into cyan, magenta, yellow, and black (CMYK), as appropriate for a known print condition.

To obtain optimum results, the operator generated a set of actions that were necessary to apply to scanned images. Typically, this set of corrections would vary depending on such things as whether the image was low key or high key, whether it had dominant skin tones, which customer the job was for (and their color preferences), and how the job was to be printed. Color corrections were based on the operator's experience, and the operator would use CMYK values shown by a dropper tool to make adjustments, Figure 1.3.

Along with a skilled operator, the other requirement of a closed-loop system was a fixed workflow. That is, it was necessary to know where the image came from, how

Figure 1.2 In the old days, digital color was the preserve of high-end systems, where the same company, such as Crosfield Electronics, would provide a color imaging suite that included a drum scanner, monitor, software, and proofing system.

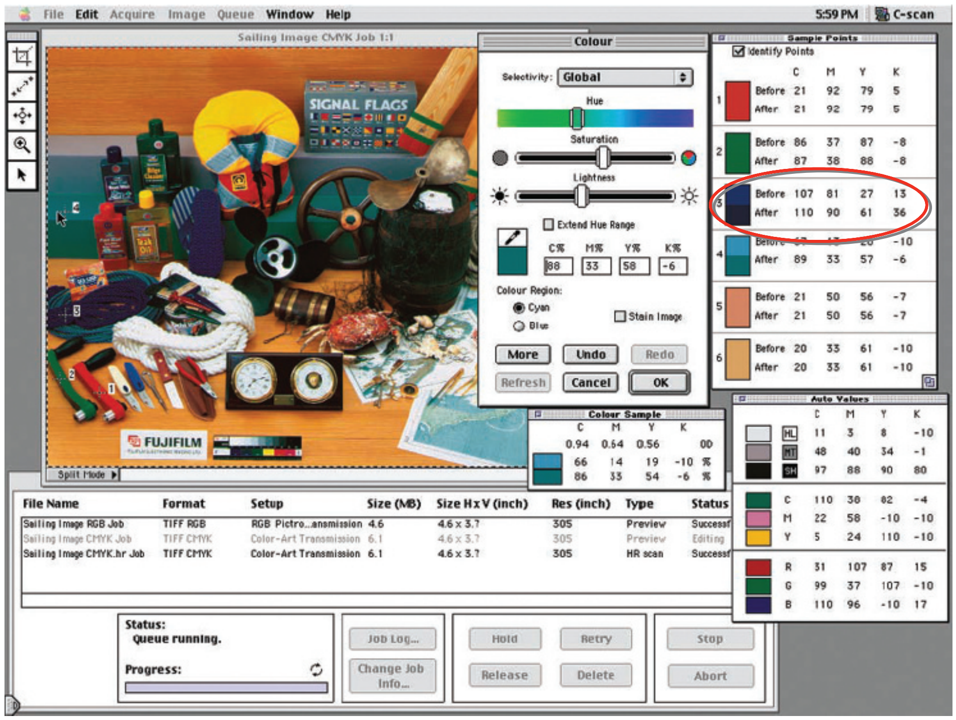


Figure 1.3 In closed-loop systems experienced operators edited images not on visual appearance, but using CMYK pixel values – this required considerable experience. Image shows C-scan software from FFEI.

it would be viewed, and how it would be printed. The relationship between devices was learned through a lengthy, iterative process, and it was not easy to swap devices. If images arrived from a different scanner system, or were to be sent to a different printing configuration, a job would have to be reworked.

There were other issues with this way of working. The image edits were stored in proprietary file formats and were not portable among different software systems. It was difficult to upgrade or change products without losing many man hours of customized style files.

In summary, we see that imaging devices have always exhibited some variability and specific color characteristics. The way of dealing with these characteristics in the older, closed-loop way of working was to "learn" the characteristics of each device through trial and error. Today's requirements make closed-loop color appear very expensive, inflexible, proprietary, and personnel dependent.

1.3 Need for an Open System

For many years, closed-loop color worked very well and was able to achieve high-quality results. The operator learned the device characteristics and then compensated for the devices' behavior. Why is it not possible to simply extend that way of working to today's environment?

In modern workflows, images come from a number of places, are viewed on different displays, and are sent to different printer and other output systems. Consider a scenario in a modern prepress facility that uses closed-loop color. Suppose we have an in-house photo studio and an operator who is experienced with editing product shots from a particular digital camera. The company has an inkjet printer, and all images are printed on this device. When images are captured, the operator adjusts them so that they print correctly on this printer.

Now suppose the company's business grows and it creates a second studio bay and acquires a different camera make and model. Initially the color of the new camera's images may not be perfect. However, over time the operator will learn the "characteristics" of the new camera system and will know how to adjust images that originate from that source. Next, suppose the company starts to use an external freelance source. Again, the operator will need to learn the unique characteristics of this external source and eventually will be able to appropriately adjust images that originate from the freelance photographer. The company does well and the volume of business means that the company has to install another printer. It chooses a laser toner device.

Now the (slightly frustrated) employee has to make different changes to the image, depending on whether the image is going to be printed on the inkjet printer or the new color laser device. The operator tries to keep track of all of these device-specific conversions. Then the boss comes in and asks for an image to be created that is to be sent to a client's location for the client to view on their monitor and print on their printer. At this point the operator gives up and starts muttering things about using color management!

A closed-loop system does a compensation for each device-to-device translation, and therefore the closed-loop color system works best only for a small number of devices. Today, with many different input and output devices, the closed-loop system of trying to compensate for the behavior of each device on a device-by-device basis is impractical as it leads to a multitude of "connections". The other prerequisite of closed-loop color is a skilled operator.

As the conditions for a closed-loop system (a fixed, small number of devices and skilled personnel) disintegrated something had to be done to get consistent, accurate color. The answer is an open-loop system, also known as a color management system. A color management system changes the pixel values in an image – behind the scenes, and without direct user input.

1.4 A Color Management System

Today, color is managed in an open-loop system, that we refer to as a *color management system*. Today images are captured with digital cameras and smartphones, are viewed on tablets, laptops and monitors, and sent to online portals and publications. Images destined for print have a wide range of printing technologies to choose from, spanning offset publication printing to packaging and large format systems for signage applications. Given this scenario of images coming from many different devices and going to many different forms of output, a closed-loop solution is largely impractical.

A color management system provides an elegant solution to the issue of color control. Instead of trying to understand the relationship between every device and every other

Figure 1.4 Airlines use a hub system to connect passengers between different cities. This is efficient as it reduces the number of flights needed to cover many destinations.

device, a color management system employs a central connecting space. Consider an airline analogy to understand how modern-day color management works.

Airlines have developed the concept of a "hub and spoke" system, depicted in Figure 1.4. Flights from cities served by an airline fly into and out of a central hub (e.g. Chicago O'Hare). Suppose a passenger wants to fly from City A to City B. The passenger catches a flight from City A into the central hub and then catches a connecting flight from the hub to City B. It is thus possible to get from City A to City B even if there is no direct flight between A and B.

If every city had to be directly connected to every other city, this would require a huge number of flights. A big advantage of the hub and spoke system is that it dramatically reduces the number of flights needed to cover many destinations. The other advantage of the hub and spoke system is that it is very simple to add a new city to the route. All that is needed is a single flight from City C into the central hub and instantly City C is connected to Cities A and B and the rest of the airline's network.

How does this analogy relate to color management? Modern-day color management uses a central hub system to communicate color between devices, as shown in Figure 1.5. The official name for the central hub is the Profile Connection Space. A file, called a color profile forms the "spokes" of the system. A color management system uses color profiles to connect devices into and out of, the central connection space.

If you are a traveling passenger, and seek to enter the airport terminal, you must have a boarding pass, similarly for an image to be part of a color managed system it must have a color profile. Thus, we need a scanner profile for a scanned image, a digital camera profile for a camera image, a monitor profile for an image to be displayed on a monitor,

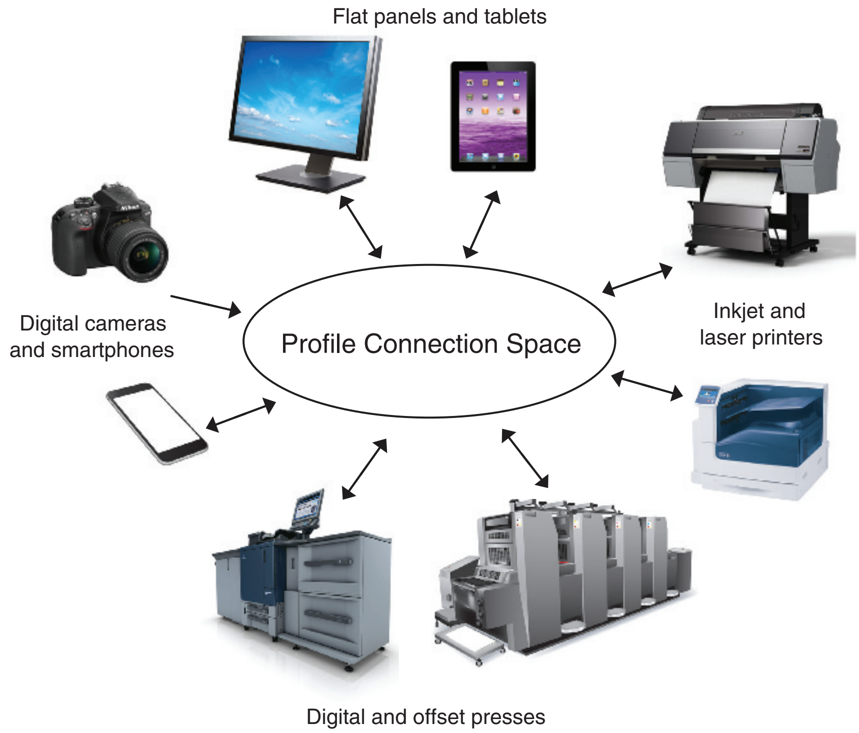


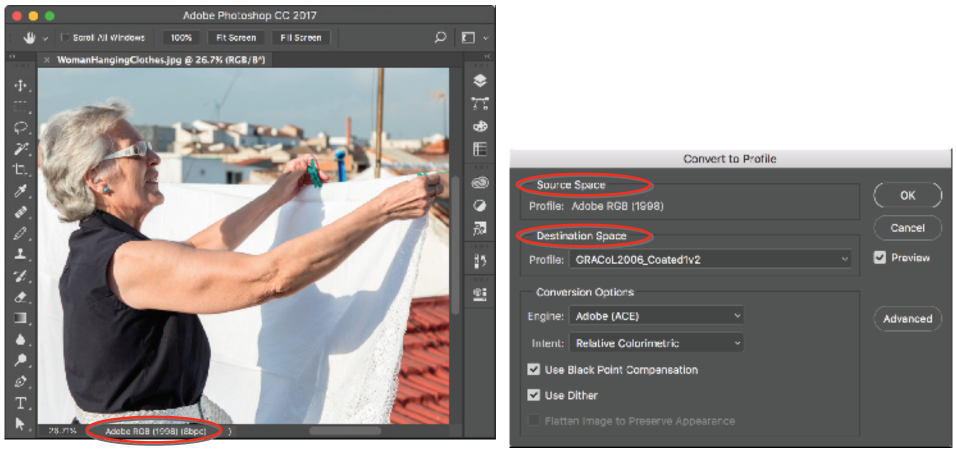
Figure 1.5 A color-managed system uses the Profile Connection Space to connect many devices via device profiles. This figure is the single most important schematic to understand in color management. *Source:* Konica Minolta Business Solutions, Ingram Image, Epson®, Xerox® and Nikon Corporation. Image from Konica Minolta Business Solutions, reproduced with permission. Images of iPad and LCD panel licensed by Ingram Image.

and a printer profile for a printed image. *The device color behavior is encapsulated by a profile, so as an image completes its journey, into and out of the central hub, the pixel data in the image is automatically adjusted by the profile to take into account the characteristic behavior of each device.*

In Figure 1.5, note the arrows, leaving the Connection Space going to an inkjet proofer and laser printer; the action of the profiles is to adjust and alter the pixel values for each device, exactly what we need to happen from the earlier popcorn analogy.

Color management can only work if every image has a profile. By simply opening an image in Adobe Photoshop, it is possible to see that an image has an associated profile, in this example the name of the profile is "Adobe RGB (1998)", Figure 1.6a.

Another feature of a color-managed process is the source and destination profile. In the airline analogy, passengers fly into and out of a central hub, similarly in color management we need to know where the image is coming from and where it is going to. Color management operations require the user to specify a source and a destination profile. The source and destination profiles are clearly illustrated in a Photoshop dialog, Figure 1.6b. This figure shows a commonly used RGB to CMYK "travel plan", where an image is starting from a source space with a profile called "Adobe RGB (1998)" and



(a) (b)

Figure 1.6 (a) Adobe Photoshop clearly indicates the image's profile at all times. © Eduardo López/ Adobe Stock. (b) Every color management operation requires the user to specify a source and destination profile.

is traveling to its destination indicated by a profile called "GRACoL_2006_Coated1v2". (RGB and CMYK are abbreviations for red, green, blue, and cyan, magenta, yellow and black, respectively.)

Color has become "plug and play" – just as it is easy for an airline to add a new city to its route map, in color management it is easy to add a new device to a workflow. All that is needed is a single profile. The profile connects the device to the central connection space which immediately makes the characteristics of the device known to all other devices in the system, making it is easy to add, delete or change devices.

A city can sometimes be one person's starting point, but it could be another passenger's final destination. In Figure 1.5 we see that most processes are connected by a double-ended arrow. A smartphone could be used to capture images for input to a color managed workflow, but it is also often used to view content from a color managed process.

In summary we can say that device variability has not been eliminated, but in an open-loop color management system, profiles and the Profile Connection Space are used to deal with device variability. A color management system connects different types of color imaging devices and provides a way to alter the underlying pixel values in an image as images flow seamlessly between different color imaging devices.

Figure 1.5 is the single most important diagram to understand in color management. This figure provides the conceptual basis for all color management operations as discussed throughout this text.

1.5 Color Management Workflows

A *workflow* describes a path involving different devices and operations. A color management workflow can consist of input, output, and display devices connected to a central connection space via profiles, Figure 1.5. There are a number of ways of processing images through such a system.

A fundamental function in color management is *accurate viewing* of an image. In this scenario, the image from a digital camera or smartphone is brought into the central space and then sent to a monitor. This process is accomplished using software that applies a source profile (the camera profile) and a destination profile (the monitor profile) to the data in the image.

On the way in, the camera profile provides information relating to the capture device's color characteristics and on the way out the image is adjusted to take into account the particular monitor being used to view the image. The end result is a color-correct rendition of the starting image. If the image is sent by e-mail to a customer, the customer can also accurately view the image. In this scenario, the same camera profile is associated with the image, but on the way out the customer is using their own monitor and so must have their own monitor profile. In this instance, the image pixel data is adjusted to take into account the customer's monitor being used to view the image.

The real power of color management is evident in printer-based workflows. Color management facilitates *accurate printing*. This is where the image from a digital camera is brought into the central space and then sent to the printer. In this case the software applies the input profile (as before), but instead of a monitor profile the system uses an output profile. The printed result is thus color managed and may be similar to the original, given limitations of the destination printing system.

Next, consider the common situation in which you are looking at your image on your screen and are ready to print it. Using profiles, you can determine whether or not your image colors are going to be changed by the printer.

Soft proofing involves previewing the printed image on a monitor so that we can get a color-accurate preview of what the printed result will look like, Figure 1.7. In this scenario, the image is brought into the central connection space using the input profile. The image is then 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 finally sent to the monitor. A soft proof is very useful in that simply by choosing a printer profile, you can immediately see on the screen what your print is expected to look like.

Figure 1.7 In a process known as soft proofing, the image on your screen matches the printed output displayed in a desktop viewing booth. Reproduced with permission of JUST Normlicht®.

A very big time (and money) saver is *press proof*. This process simulates a printing press result on a local desktop proofer, so that you can see what an image will look like before thousands of copies are printed. In the press proof scenario, the image is brought into the central space via the input profile. The image is then processed to the press profile, brought back in from the press, and finally sent out to a local inkjet proofer. The inkjet device provides a rendition of the printed product and therefore provides a preview of the printed result that can be used to detect any problems with the print job. As the inkjet proof is produced in conjunction with the characteristics of the printing press it accurately represents the capability of the printing press and can be used as a hard-copy proof for customer sign off, safe in the knowledge that the press can achieve the colors shown.

Any device used to simulate the results of another printer is called a *proofer*. In color management, any output device can be used as a printer or proofer. The difference between a printer and a proofer is the sequence in which the profiles are used. The first device in the process is the printer, and the second device becomes the proofer. Care should be taken in choosing a suitable proofer. The proofer should be able to reproduce all colors received from the printer device. Thus, not all printers are suitable proofers.

Printer profiles can be used for *print-to-print matching*. Print-to-print matching is often used where a brand product must be reproduced in a magazine advertisement, flyer insert, product label, store display, etc. In print-to-print matching, output profiles are used to create the same "look and feel" on different print processes. The sequence of profiles used in this situation would be, for example, a camera image with a source profile and a digital press and offset press as the destination profiles.

In order to avail of the benefits of a color managed system, all that is needed is a profile for each device and user knowledge about the sequence in which to apply the profiles. With this information any user can exploit the many useful features of a color managed system.

1.6 ICC – International Color Consortium

Today when we refer to color management we actually mean "ICC color management". The framework for the Profile Connection Space and the format of profiles, is described by the International Color Consortium (ICC). The ICC is a regulatory body that supervises color management protocols between software vendors, equipment manufacturers and users.

In the early 1990s a number of leading color technology companies were developing applications for desktop color publishing. Because there was no common color management framework for systems to use, each application had to align itself with a specific hardware vendor.

New systems were introduced regularly, and there was no compatibility between systems and no consistency among results. When a desired feature was missing from a chosen solution, users wanted to "mix and match", i.e. purchase parts of the system from different vendors. The technology was evolving, and there was no system to support the new way of working. The entire industry was threatened.

(a) (b)

Figure 1.8 (a) The birth of the ICC is generally accepted to have been at a meeting in Palo Alto, in 1993. (b) Today, representatives from ICC member companies meet twice a year. ICC meeting in progress, Munich, February 2016. Reproduced with permission of ICC.

At this time, Apple Computer had been working on a color management project called ColorSync™. The ColorSync philosophy was simple. Just as the operating system knows about things such as resolution and bit depth of a monitor, or the mapping of letters on a keyboard, there should be some way to succinctly describe the color capabilities of a device. ColorSync is an OS-level technology that facilitates the communication of color information among multiple hardware and software components. It is an open-platform system that all vendors can link into. Many vendors were interested in adopting or interfacing with this system, but were secretive about their intentions.

The birth of the ICC is generally accepted to have been at a FOGRA (German graphic technology research association) meeting in Munich, in 1992. After the normal program, the FOGRA organizers invited guests to continue discussions in a small meeting room. In this meeting vendors talked openly about ColorSync and their interest in a unified color management system. The shroud of secrecy was lifted, and the Apple ColorSync Consortium was formed with the first official meeting in 1993 at Sun Microsystems in Palo Alto, depicted in Figure 1.8a.

The Apple ColorSync name was soon dropped from the title, as everyone was in agreement that the consortium should be truly platform independent. A totally independent organization emerged called the International Color Consortium (ICC). The industry has greatly benefited from being able to use the ColorSync model as the basis and framework for modern color management systems and is indebted to the farsightedness of Apple Computer for readily offering its technology to the community.

The eight founding members of the ICC were Adobe, Agfa, Apple, Kodak, Taligent, Microsoft, Sun, and Silicon Graphics. Today, the ICC is open to all companies who work in fields related to color management. Members must sign a membership agreement and pay the dues, which are currently $2500 a year. Different membership categories are available to universities with color imaging programs and to individuals.

The ICC has over 70 member companies who elect a roster of officers from within their ranks. The NPES (Association for Suppliers of Printing, Publishing and Converting Technologies) provides administrative support to the ICC in the form of mailing lists, web sites, organization of meetings, and issuance of an annual report. The ICC web site – www.color.org – provides a useful repository of ICC profiles, a number of profiles for testing, and informative White Papers. The site is widely used and receives 14,000 hits per month.

The work of the ICC is conducted via conference calls and the consortium also meets in person, in different worldwide locations, three times a year. The ICC meeting in February, 2016 in Munich, Germany is shown in Figure1.8b. Normally a member company or organization provides local assistance or an ICC meeting may be held in conjunction with a relevant conference such as the IS&T Color Imaging Conference. At any given meeting, only a subset of the membership is in attendance.

The main work of the ICC is done in groups, each dedicated to looking at a specific issue. Currently there are working groups for Architecture, Displays, Graphic Arts, Profile Assessment, Medical Imaging, and Specification Editing. Each group works on ways to solve problems and tackle user issues. Often the groups need to overcome obstacles posed by the proprietary nature of modern digital imaging systems or patent issues.

The outcomes of the ICC deliberations are communicated to users and vendors via the ICC profile specification. The specification is a technical document that describes the structure and format of ICC profiles and is the main "biblical" document for the ICC. The ICC specification continues to change and evolve, the current version of the specification is always available from the ICC web site. At the time of writing there are the following versions of the specification in use.

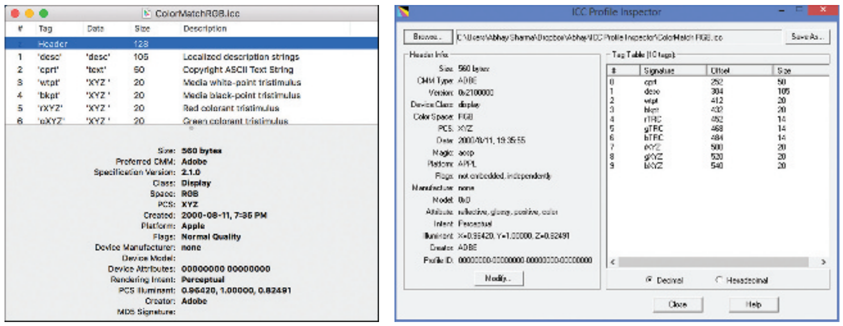
- Specification ICC.1:2001-04 (Version 2), previous major revision, still supported by many vendors.
- Specification ICC.1:2010-12 (Version 4), most widely used version, published in 2010.
- Specification ICC.2:2016-07 (Version 5), released in 2016, not yet in widespread use.

Profiles generated according to each version of the specification are labelled accordingly, thus you may meet a Version 2 (v2) profile, or Version 4 (v4) profile, etc.

The specifications are also submitted via appropriate national and international committees to be published as international standards, ISO 15076 (v2 and v4) and ISO 20677 (v5).

The ICC has created a universal system for color management that has revolutionized and hugely benefited the whole industry. Proprietary systems have been relegated in favor of an open architecture that ensures convenience and seamless interoperability for the end user. One of the reasons that the current system works so well is that the whole community – suppliers, users, operating systems – has come together to agree on the structure, format and contents of an ICC profile. The use of proprietary information in an ICC profile is actively discouraged, so in general there is no, or very little, proprietary information in an ICC profile.

As day-to-day color management involves many different companies and products it is important that profiles made by one company can be used for devices made by another manufacturer and connected by the user in third party application software – all on the Windows or Mac operating systems. As profiles are all made according to the ICC specification, this means that it doesn't matter who made the profile and where we want to use it; profiles work for all devices, on all software, and in all operating systems. The format is so open that if you are a Mac user – double click on any profile and it will open up, Figure 1.9a. On Windows, an ICC profile can be opened and its contents can be viewed with a free utility, Figure 1.9b.



(a) (b)

Figure 1.9 ICC profiles are platform independent, so profile contents can be viewed using (a) MacOS system software called *ColorSync Utility* or (b) a Windows utility called *ICC Profile Inspector*.

An ICC profile is a computer file that can vary in size from 4 kB for a simple monitor profile, to an 8 MB printer profile. Profiles can be embedded in an image or be used as standalone files. In terms of the construct of a profile, all devices are considered equal – i.e. the ICC does not distinguish between the profile for a $100 desktop inkjet printer or that for a $1 million offset printing press.

The ICC framework allows companies to develop new products or write new software without the worry of which platform or system to support. ICC color management has enabled quicker time to market and ensured a level playing field. A smaller start-up company has equal access as a behemoth imaging company, encouraging competition and entrepreneurship.

The ICC framework allows for expansion into new technology areas. New devices and systems that were not envisaged at the time of the creation of the ICC nevertheless can be easily accommodated by the ICC's open architecture. Color reproduction on tablets, smartphones and in web browsers; in 3D printing, and in vehicle wraps can all be easily modeled by ICC profiles. New expanded gamut ink sets, using more than CMYK, such as orange, green and violet, do not require any new ICC modules.

Apple's ColorSync technology was the first and best system-wide implementation of a digital color management system and forms the basis for modern-day ICC color management. Because of this historical connection, and because ColorSync continues to be a well-integrated and well-supported part of macOS, this is often the preferred platform for color management.

ICC color management is here today, and is here to stay, it is not going away anytime soon, which is justification for the reader to understand color management and how it works.

1.7 RGB and CMYK Color Specification

In color management we encounter color specification in RGB and CMY (or more commonly CMYK). Devices operate using one or the other of these basic color sets, as shown in Figure 1.10.

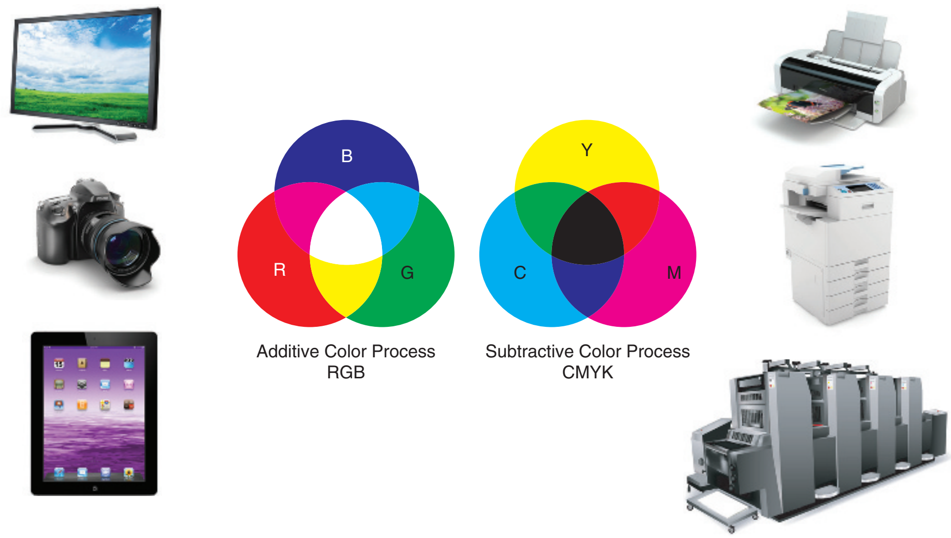


Figure 1.10 Color imaging devices reproduce colors using either the additive RGB color set (red, green, and blue) or the subtractive CMYK color set (cyan, magenta, yellow and black). LCD Panel: © Denis Tabler/Shutterstock.

Some devices create colors using the RGB set (i.e. red, green, and blue). RGB is called the primary (or additive) color set. The technologies that are based on RGB are flat-panel displays, digital cameras, and tablet devices. Cyan, magenta, and yellow (CMY) is the other basic color set. CMY is called the secondary (or subtractive) color set. CMY devices include all printers and presses. In each system the three colorants control a third of the spectrum, thus by the use of varying amounts of RGB or CMY we are able to create a wide range of colors.

In RGB devices, such as a monitor, we can create the primary colors, red, green or blue, using the red, green, or blue elements, respectively. We can also add red, green or blue together to simulate other colors. If we add red and blue this area of the screen will look magenta, if we add blue and green we get cyan and if we add green and red we get yellow. If we add all three colors together the screen will look white, and if we add none of these we get black. Of course we can also add perhaps a bit of red and a bit more of green to make mid-tones and intermediate values. So we see that by controlling the primary R-G-B colorants we can create any color we want.

The other main color model is the CMY model. In the CMY model, for offset printing, for example, we place different amounts of cyan, magenta and yellow ink on the paper to create any of the colors we want. We can add one, two, or three colored inks together and also differing amounts of each ink. If we add yellow and cyan ink we form green, and cyan and magenta ink create the impression of blue, finally magenta and yellow ink makes red. Where we put down all three color inks in one spot this appears as black. If we want to make white, we put down no ink and the paper shows through making white.

In printing, because of the imperfections in inks, pigments, and toners the black formed by the addition of cyan, magenta and yellow is not that deep or vivid, so we artificially introduce a black ink (K), therefore the CMY set is commonly known as

Table 1.1 RGB and CMYK are instructions for a device and therefore only give a general indication of the final color.

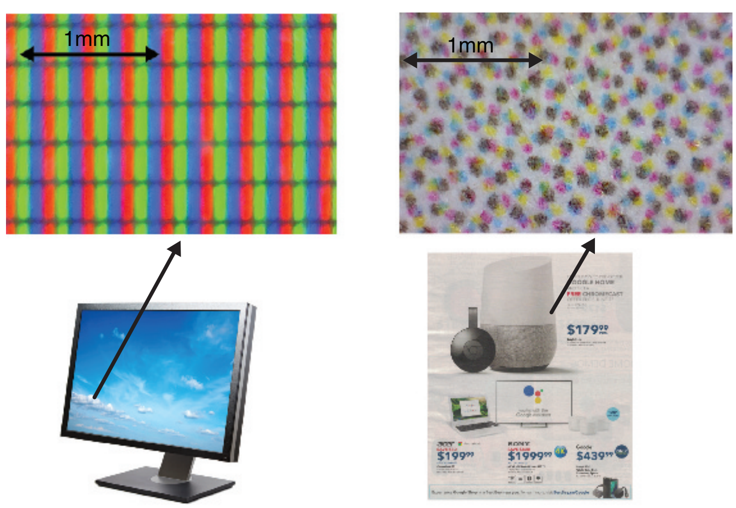
Color Model	Pixel Value	Color
RGB (0–255)	R = 10, G = 200, B = 32	
CMYK (0–100%)	C = 13%, M = 6%, Y = 83%, K = 4%	

CMYK. Black is called “K” due to historical reasons where the black channel was the key or keyline channel and the other physical color separations were aligned to the black channel for registration purposes. (Also if black had been referred to as “B”, it could be confused for blue.) In most printing processes therefore, we add black ink or toner to improve the colors in the image. Nearly every type of printing technology from inkjet printers to digital presses and offset presses, all use the CMYK print model.

You may notice that CMY is “opposite” or complementary to the RGB model. So we talk about yellow as the opposite of blue, as yellow has no blue in it. And similarly magenta is the opposite of green and cyan is the opposite of red.

It is possible to specify a color in either of these color spaces, a color can be specified by describing various amounts of RGB or CMYK. A color description could be, for example, as shown in Table 1.1, R = 10, G = 200, B = 32, on a 0–255 scale, this is a green color, and C = 23%, M = 6%, Y = 83%, and K = 4%, on a 0–100% scale, this is a yellow color.

In the case of RGB, the pixel instructions may be sent to a display, and the display implements these instructions, which results in a displayed color, Figure 1.11a. But the



(a) (b)

Figure 1.11 (a) Flat-panel displays are RGB devices as indicated by the magnified red, green, and blue screen elements. (b) A printed flyer is created with CMYK, indicated by cyan, magenta, yellow and black ink. From normal viewing distances we do not see the individual RGB or CMYK elements which fuse to create a continuous image.

same instructions sent to a different monitor, due to the differences in the display, may create a slightly different color.

In the case of CMYK, these instructions could be inking levels for an offset printing process, the printing plate would transfer, for example, the requested amount of ink onto the paper, Figure 1.11b. But if the same CMYK values were sent to a different printing process, the system may diligently obey the instructions to deposit exactly the correct amounts of ink, but obtain a different color due to the different paper, inks, and printing process it is using. *RGB and CMYK are only instructions for a device, and do not provide a reliable or precise specification of color.*

RGB and CMYK are only instructions for a device and while we can guess at the likely color these instructions will create, the final exact color will depend on the device and its configuration. So while RGB and CMYK are necessarily in units that the respective RGB and CMYK devices can readily understand, they are not really a color specification and are better referred to as instructions for a device. We say that RGB/CMYK are device-dependent color specifications, as the color created will depend on the device and its configuration.

It is OK for a user to create a file in RGB or CMYK, but it is not feasible to use RGB and CMYK when trying to communicate color information across different devices in an open color managed system.

1.8 CIE 1931 Yxy and CIE 1976 L*a*b*

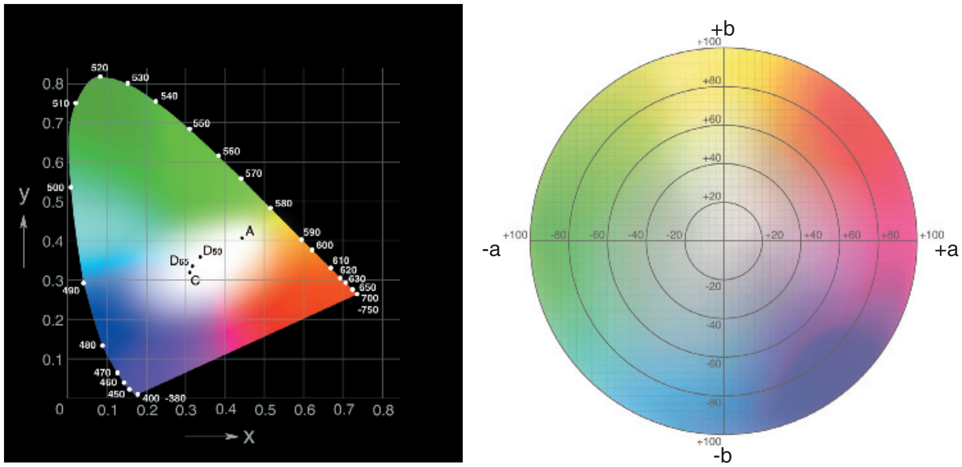
Color specification falls into two main categories: *device-dependent color* (RGB and CMYK) and *device-independent color* (Yxy and L*a*b*). A device-independent color system can be used to communicate color information among many different devices.

The Commission Internationale de l'Eclairage (CIE) defines a number of color systems that are device-independent, which means that they are based on measurement of a sample, irrespective of how it was made. The CIE systems can be thought of as a *descriptor* or *specification* of a color. Over the years, the CIE organization has specified a number of device-independent color systems; the two systems widely used in color management are the CIE 1931 Yxy and CIE 1976 L*a*b* color spaces, Figure 1.12.

The Yxy system is an older system, approved in 1931, and has a horseshoe shape, Figure 1.12a. In the Yxy system, a color is specified by its x and y coordinates on a graph called the chromaticity diagram. In the chromaticity diagram the green color takes up a large area, compressing blue and red into smaller corners.

The L*a*b* system specifies a color by its position in a three-dimensional color space, of which a two-dimensional slice is shown in Figure 1.12b. The coordinate L^* represents 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. Notice in the L*a*b* diagram, how the colors are more evenly spaced – the green does not occupy the whole top of the diagram and the diagram has a more circular shape. In terms of color science, we say the L*a*b* color space is more "perceptually uniform".

Yxy and L*a*b* are device-independent color models that are not related to any specific device. CIE systems use an instrument to measure a color and produce a numeric result. In the L*a*b* system we may have, for example three numbers, L*a*b* of



(a) (b)

Figure 1.12 (a) The 1931 Yxy diagram is horseshoe shaped and has a large area for green colors but compresses blues and reds. (b) The 1976 L*a*b* diagram is much improved and affords all colors equal spacing. ICC color management is based on L*a*b*.

43, 68, 46 for a specific red color. A measuring instrument does not need to know about the printer that produced the sample, it just measures a printed patch. 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. The CIE color systems are described in more detail in Chapter 3, Color by Numbers.

1.9 Color Conversions

How does color management work? Under the hood, color management works by relating RGB input to CMYK output via an L*a*b* interchange. Consider an example of photographing a red object, opening the image in Photoshop, and printing the image, Figure 1.13. A simple red patch was photographed with a Nikon D3200 digital camera and is opened in Photoshop. A digital camera operates in RGB and the image is therefore necessarily in RGB. Photoshop's Info palette indicates that the cursor is on a pixel with RGB value of 173, 4, 37 (the sample is very red and so has a high R value).

Each camera has its own characteristic response, thus the RGB pixel values would be different if we used a different Nikon model, or a Canon or Sony camera. Instead of directly sending the RGB values to the printer, color management works by converting the device RGB values into device-independent L*a*b* values, as displayed in the Info palette. The camera RGB values are converted from RGB to L*a*b*, using the camera profile, in this example the profile is "Adobe RGB (1998)", as indicated in the lower part of the figure. The L*a*b* values are an unambiguous description of color and are used to convey the color requirements to a printer system. In this example, the L*a*b* values for this red are $L^* = 43$, $a^* = 68$, and $b^* = 46$.

When we print an image, the process is reversed, that is, we specify an L*a*b* value and an ICC profile determines the necessary CMYK instructions specific to each printer

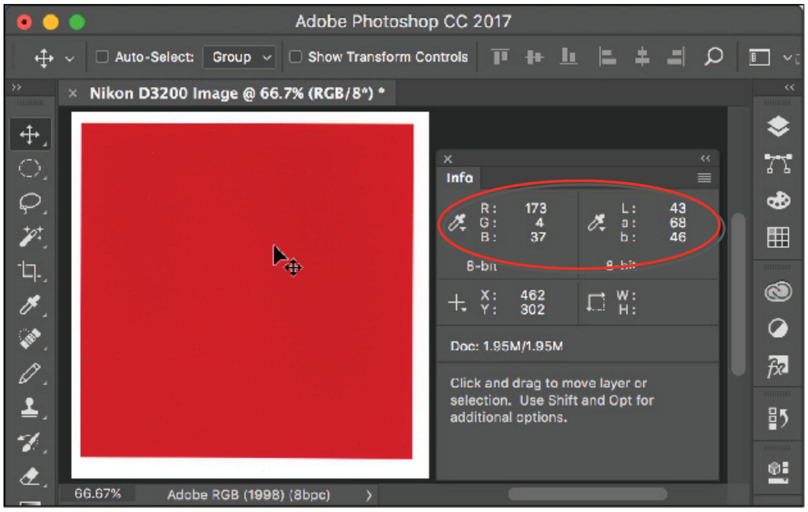


Figure 1.13 ICC-aware applications such as Adobe Photoshop are able to convert RGB pixel values into L*a*b*.

to produce that color, Figure 1.14. Each printer profile receives the same L*a*b* instructions ($L^* = 43$, $a^* = 68$, and $b^* = 46$) and each profile is used to determine the appropriate amount of CMYK inks that will create this color. We see that the same red color with L*a*b* value of $L^* = 43$, $a^* = 68$, and $b^* = 46$, is created by CMYK instructions that vary by printer type. This experiment was conducted in the School of Graphic

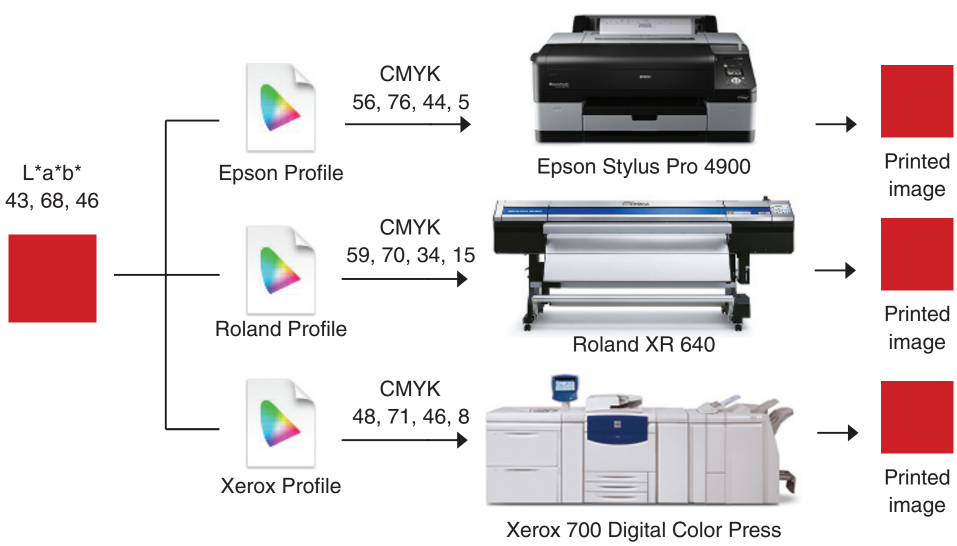


Figure 1.14 A red image was sent to different printers at Ryerson University. L*a*b* values are converted into CMYK instructions by each device's ICC profile, such that each printer creates the same red color. *Source:* Epson and Xerox. Image from Roland DGA Corporation, reproduced with permission.

Communications Management at Ryerson University using real devices. This process "accommodates" the specific color characteristics and behavior of each individual printer.

In summary, devices can only deal with device-dependent RGB or CMYK, so images from a digital camera are necessarily in RGB and image data being sent to a printer is necessarily in units a printer can accept, i.e. CMYK. However in the middle, L*a*b* is used as a common interchange space and is used to communicate color information from source to destination all the while compensating for input device characteristics via the RGB to L*a*b* conversion, and for printer characteristics during the L*a*b* to CMYK conversion.

1.10 Three Cs of Color Management

Practical color management processes can be defined in terms of three hierarchical Cs: *calibration, characterization*, and *conversion*, as shown in Figure 1.15. Throughout this text we will make and use profiles according to three Cs of color management.

Calibration involves establishing a fixed, repeatable condition for a device. For a monitor this may mean adjusting the brightness and contrast settings. For a printer, this means agreeing on a media type and printer resolution setting. Anything that alters the color of the image must be identified and "locked-down." Calibration involves establishing some known starting condition, a means of monitoring that condition, and having the ability to return a device to its calibrated state should it drift.

After a device has been calibrated, its characteristic response is studied in a process known as *characterization*. In color management circles, characterization is commonly referred to as "profiling". During the profile generation process the color characteristics of a device are studied by sending a reasonable sampling of color patches in a test chart to the device and measuring the device's response. During characterization the color characteristics and gamut of the device are ascertained, and this information is stored in an ICC device profile.

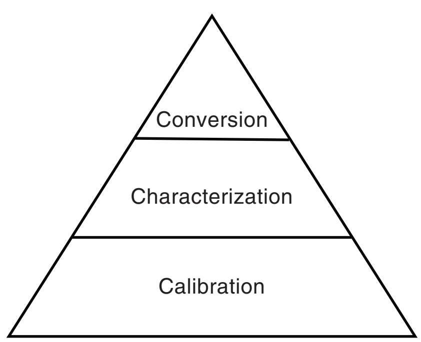


Figure 1.15 Color management operations can be described in terms of the three Cs. Calibration refers to creating a fixed baseline. Characterization refers to "profiling". Conversion happens when we use profiles to convert image data from RGB to CMYK. The calibration process should provide a solid foundation for characterization and conversion.

After a device has been calibrated and characterized, it is time to use the profiles to acquire, print, or display images. The third C of color management is *conversion*, a process in which images are converted from one color space to another using device profiles. Typically for a camera-to-printer scenario this may mean using a camera profile and a printer profile. The conversion process typically relies on application software (e.g. Photoshop), system-level software (e.g. macOS ColorSync), and a color management module (e.g. Adobe CMM).

The three Cs are hierarchical which means that each process is dependent on the preceding step. A stable calibration is the foundation of color management, that is, the device must be consistent and not drift from its original calibration. If the calibration changes this can shake the whole pyramid as the characterization becomes invalid which detrimentally affects the results of the conversion.

Nearly every color management process can be described in terms of the three Cs, therefore it is useful throughout this text to refer to operations in terms of calibration, characterization, and conversion.

1.11 Profile Types

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.

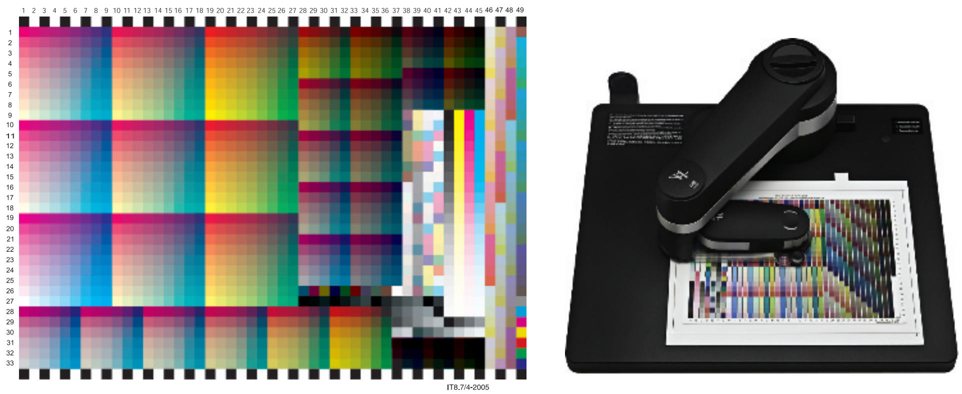
- *Custom profile*: Make a custom profile for your device using a measuring instrument, test chart, and profiling software.
- *Generic profile*: Use a generic profile as supplied by the vendor, e.g. Epson SureColor P7000 profile for use with Epson Premium Photo Luster Paper.
- *Standard profile*: Consider your device to be represented by a standardized condition, e.g. sRGB or GRACoL or FOGRA51.

Users should be aware of the different types of profile available in order to evaluate the best type of profile for a particular scenario. In general we seek a profile that is easiest to acquire, yet still delivering the accuracy and quality for the intended purpose.

1.11.1 Custom Profiles

A *custom* profile refers to a profile that is made specifically for your device and the state it is in. Creating a custom profile is what most users think of when they refer to "profiling". Many discussions in color management circles revolve around the choice of software and hardware to make custom profiles and the nuances of the differences of a custom profile from different vendors.

The procedure to make a custom profile is based on the three Cs of color management – calibration, characterization and conversion. To make a printer profile, for example, the user *calibrates* the device, and then *characterizes* the system by printing and measuring a test chart, Figure 1.16a. Depending on the device you are profiling (an RGB printer, a CMYK printer, a multi-color printing process, etc.) there are a range of test charts to choose from. The IT8.7/4 is a chart with 1617 patches that is commonly used for profiling a CMYK printing process, Figure 1.16a. Figure 1.16b shows how the X-Rite i1iO spectrophotometer would be used to measure a test chart in order to create a



(a) (b)

Figure 1.16 (a) The IT8.7/4 is a widely used test chart for printer profiling, with 1617 patches of different CMYK combinations. (b) Custom profiles are made by measuring the test chart, using for example the X-Rite i1iO spectrophotometer. Figure (b) reproduced with permission of X-Rite, Incorporated.

custom printer profile using profile making software. *Conversion* of image data happens in a software application such as Adobe Photoshop or a printer's RIP.

The advantage of a custom profile is that it takes into account the behavior of your specific device and the condition it is in. Custom profiling can deal with custom and non-standard media that you may wish to use. Custom profiling tends to be used for special circumstances as it requires a meticulous approach, technical knowledge, and an investment in measuring hardware and profiling software. An advantage of a custom profile is that it can fully utilize the color gamut of the device, an issue of special relevance in printing systems, that have an inherent small color gamut.

Custom profiling is an important operation in color management, and therefore custom profiling of digital camera, monitor, and printers is dealt with in separate chapters in this book (Chapters 6, 7, and 8).

1.11.2 Generic Profiles

Many inkjet and digital press manufacturers provide a *generic* profile that represents the average color characteristics of a device when printing with a specified printer model, print resolution, ink set and media. A vendor may select some representative devices from the production line to determine a generic profile. Generic profiles are typically available from the manufacturer's web site or provided within a software package, print driver, or downloadable update, Figure 1.17.

To use a generic profile, the user obtains the exact media, uses a specific printer make and model, loads the calibration file to create the correct environment, and then selects the provided ICC profile in a software dialog. Normally a re-calibration and verification may be performed to ensure the supplied profile does indeed match the local configuration. In the example shown in Figure 1.17, if a roll of Epson Premium Luster Photo Paper is used in an Epson Stylus Pro 9900 inkjet proofer, then a ready-made generic profile for this paper type can be chosen from a drop-down menu in EFI Fiery XF.

(a) (b)

Figure 1.17 Out of the box, generic profiles are very convenient. A ready made profile is available within EFI Fiery XF, when using Epson Premium Luster Photo Paper with an Epson Stylus Pro 9900 printer. *Source:* B&H. Reproduced with permission of B&H Photo Video and Pro Audio.

A generic profile can be very accurate when the behavior of the printing system is well controlled, and all parameters are known. It is clear to see that use of a generic profile is very convenient as there is no need to make an ICC profile yourself, yet the user is still able to have a profile specific for their printing condition. Generic profiles are now widely used in inkjet printing and proofing and digital press devices.

1.11.3 Standard Profiles

Examples of standard profiles are sRGB, Adobe RGB, GRACoL, SWOP, etc. *Standard* profiles are ICC profiles that are based on published specifications, reference printing conditions, or international standards, and represent a convenient and practical way of managing color and communicating color information. To use a standard profile we say that a device is operating according to a standard process and then adopt a standard ICC profile for that device. If your press, for example, operates according to SWOP specifications, then in prepress and proofing, you can use a SWOP profile as your press profile, without having to create a custom profile for your press.

A number of standard profiles are available such as sRGB or Adobe RGB for RGB systems such as cameras and displays, and GRACoL, SWOP and FOGRA profiles for CMYK printing systems. Most application software and RIP systems already include standard profiles, Adobe Photoshop, for example includes a number of RGB and CMYK standard profiles. Standard profiles are readily available from public web sites such as Idealliance, FOGRA, ICC, etc.

A standard profile is a very convenient way to communicate color information, there is no need to keep track of, or wait for the printer to share a custom profile. The designer can use a public-domain, standard profile during creation of the artwork, and prepress can create a color proof using a standard profile.

sRGB is a widely used RGB profile for flat-panel displays, web browsers, and tablet and mobile devices. Like all standard profiles, the sRGB profile is based on the real response of a class of device. sRGB is based on an older monitor technology, devices that were based on cathode-ray tube (CRT) type displays. Figure 1.18a shows the three-dimensional gamut of different profiles in the L*a*b* color space. A number of different cathode-ray tube (CRT) monitor gamuts are shown. Note how they are all

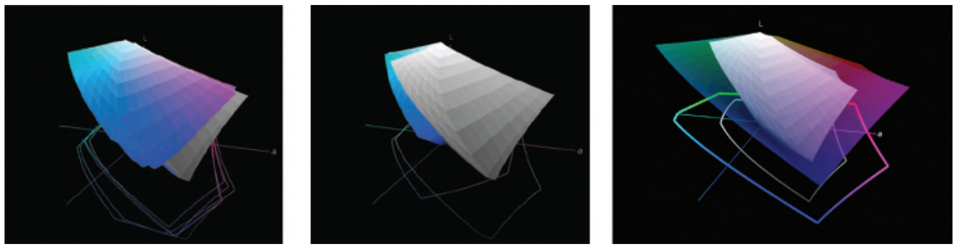


Figure 1.18 (a) sRGB (in gray) is based on the average of different CRT monitors. (b) sRGB gamut (in gray) is very different to an LCD flat-panel display (in blue). (c) The new Rec. 2020 profile for video and HDTV, has a larger color gamut when compared to sRGB (in gray).

very similar and how, on average, sRGB (in gray) is fairly representative of a typical CRT display. sRGB is based on legacy CRT devices, nevertheless it has now been accepted as a standard profile for many types of RGB imagery such as smartphones, tablets and Internet applications.

Using a standard profile has its limitations. Often a device may differ from a standard process. Figure 1.18b shows the response of sRGB compared to the gamut of a liquid-crystal (LCD) flat-panel display. The sRGB capability is shown as the gray volume and the LCD gamut is shown by the colored volume. The gamut of sRGB is based on CRT-type devices and is very different and therefore not representative of the response of an LCD flat-panel display. An LCD panel can display some colors, for example in the blue part of the color space.

In order to address the issue of the small sRGB color gamut, a replacement standard RGB profile is now available called Rec. 2020. The International Telecommunication Union (ITU), provides a document called a Recommendation (Rec.). Rec. 709 was first approved in 1993 and provides the chromaticity coordinates for the sRGB profile. Rec. 2020 is a 2015 recommendation for a much larger color gamut profile, as adopted by the video and broadcast industries. The Rec. 2020 RGB profile is available for use, and is provided within macOS, over time it is expected that the Rec. 2020 profile will replace the Rec. 709 (sRGB) profile as an RGB standard profile.

Standard profiles are very common in CMYK applications. A printing press is a complex machine that operates at high speed, as an example, Figure 1.19 shows a 4-color Heidelberg offset press. It is often difficult to use custom color management tools on an offset press, and we find that users are not interested in having a multitude of profiles for each individual press condition. A printing press can be operated so that it produces density/L*a*b* values that are in accordance with accepted standards for printing, known as *reference printing conditions*. Instead of profiling each individual press, it is more convenient to run a press according to a specific reference printing condition and then for the designer, prepress and proofing to use a standard profile that represents this condition.

Committees of printers, print buyers, and suppliers have worked together to develop standardized profiles based on different reference printing conditions. These datasets are based on experimental press runs, so they represent results that can be achieved in real life. There are a number of readily available standard profiles for different printing

Figure 1.19 A standard profile such as GRACoL or FOGRA51 is used to represent the color characteristics of a printing press such as this 4-color Heidelberg Printmaster 74, sheetfed, offset press. *Source:* Heidelberg. Reproduced with permission of Heidelberg®.

conditions as specified by SWOP for magazines printed by web offset lithography and gravure, GRACoL/FOGRA for commercial printing and SNAP/WAN-IFRA for newspapers. Standard profiles are invaluable in many parts of commercial printing and proofing, as discussed in detail in Chapter 8, Press and Printer Profiling.

In summary we see that users are not interested in having a long list of device profiles for every small change of paper or printing condition, and the color community has realized that as RGB devices and CMYK print processes fall into well-defined "baskets" it is more convenient and efficient to use standard profiles.

Standard profiles are realistic because they have been created from actual device data. Standard profiles are freely available for all to use, and are readily available from web sites such as Idealliance, Fogra, ICC, etc. or already installed in software, e.g. Adobe Photoshop. As long as a standard profile is a good representation of your device, it provides flexibility and convenience. An issue is that a device may be capable of a color gamut that exceeds the standard, in this instance we are losing some color ability of the device. In general we see that many users consider the efficiency and advantage of using a standard profile far outweighs the small loss in color gamut.

1.12 Color Gamuts

One of the main reasons for disappointment in color imaging is "what you see is not what you get", in other words the printed image does not match what we saw on the screen. A

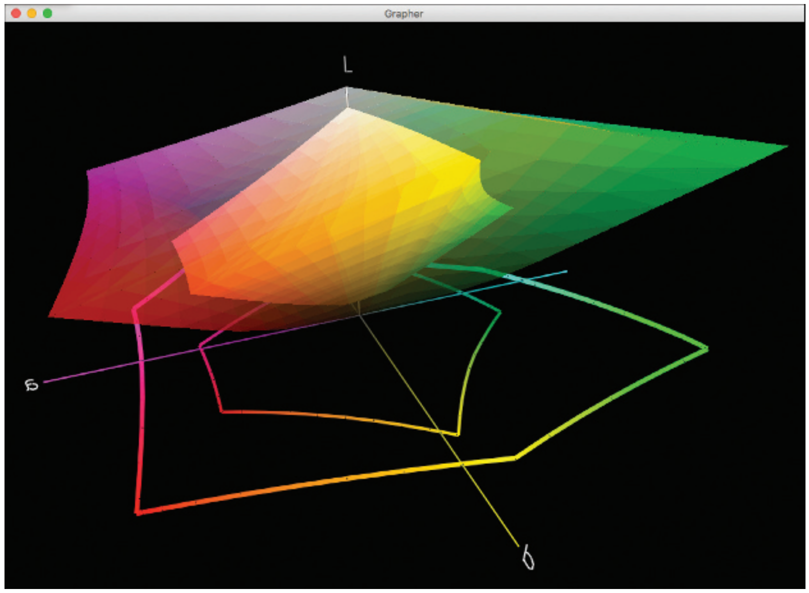


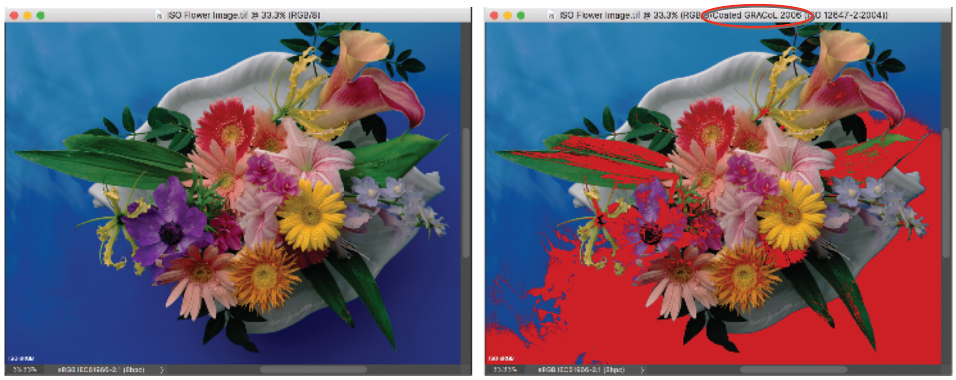
Figure 1.20 The gamut of an RGB monitor (bigger volume) is much larger than that of a CMYK print process (smaller volume), so there are many colors that may be captured by a digital camera, or that we may see on a screen, that cannot be printed.

major issue at play is differences in device color gamuts. The *color gamut* of a device is defined as the range or extent of colors a device can produce. Digital cameras, displays, and printers employ different imaging technologies and therefore have differing color gamuts. The gamut of a device is measured during the profiling process which means that profiles contain gamut information. Gamut information can be extracted from a profile and visualized in 3-dimensional software. A monitor and printer color gamut are compared in Figure 1.20.

Because imaging devices work in totally different ways (RGB or CMYK), they may not be able to create an identical range of colors. We can make a broad distinction between devices in the RGB and CMYK category. Most print processes use CMYK inks in a subtractive color imaging process, and therefore in general, printers and presses have a smaller color gamut than additive RGB color devices such as digital cameras and flat-panel displays.

Differences between the RGB and CMYK color gamuts, mean that sometimes you can see a color on your screen but your CMYK printer will not be able to reproduce that color. A digital photographer may work on a colorful set of images but the colors when printed will often be different (usually duller) to what was seen on the screen.

Due to the fundamental physics of the situation (CMYK inks that work in a subtractive imaging process creating a smaller color gamut), even a perfectly color managed process may not be able to create a screen to print match. Color management cannot eradicate the problems of gamut limitations, but it can show you what to expect. Color management helps in gamut compression by predicting and showing you the expected result. Color management allows everybody – the photographer, designer, operator,



(a) (b)

Figure 1.21 The Photoshop preview mechanism uses a stain to show you which areas of the original image (a) are out of gamut of a GRACoL print process (b). Color management cannot eradicate gamut limitation issues, but it can warn you of potential problems.

customer – to see an accurate preview of the expected results, and to therefore have realistic expectations of the likely outcome.

The Photoshop preview mechanism allows you to see what the image will look like on different printers or printing processes, Figure 1.21. As ICC profiles contain information about the printer's color gamut, simply by selecting the appropriate profile in color-aware software such as Adobe Photoshop it is possible to see a rendition of the printed image. You could, for example, easily see what your image will look like on a color laser printer or Epson SureColor P7000 inkjet printer or on a SWOP printing process. All of this can be accomplished without printing a single image, and you do not even need the actual printers; you only need their profiles to do this type of simulation. So color management can't solve the problem of gamut compression, but it can provide an accurate warning of which colors will be affected and in what way.

1.13 Rendering Intents

Color management provides another way to help in "managing" gamut limitations. If a color cannot be printed, a color management system helps us find the best replacement. The user can select from different approaches to finding a replacement color. The methods used to find a replacement are called rendering intents and typically the rendering intent for a color conversion is specified in application dialogs, such as in Adobe Photoshop, Figure 1.22.

The ICC has specified four standard gamut compression schemes, called *rendering intents*. The official terms for the rendering intents are perceptual, relative colorimetric, absolute colorimetric, and saturation. Let's look at rendering intents as related to different image types.

Perceptual rendering is used to process photographic-type images, as shown in Figure 1.23a. This intent processes the colors in an image so that the printed reproduction is pleasing. This process tends to alter the color from the original, and therefore there is no guarantee the reproduction will be accurate when compared to the original.

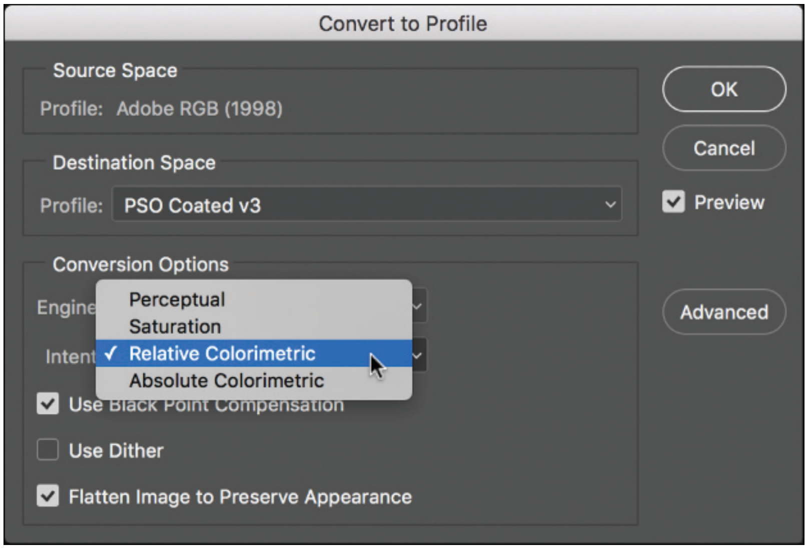
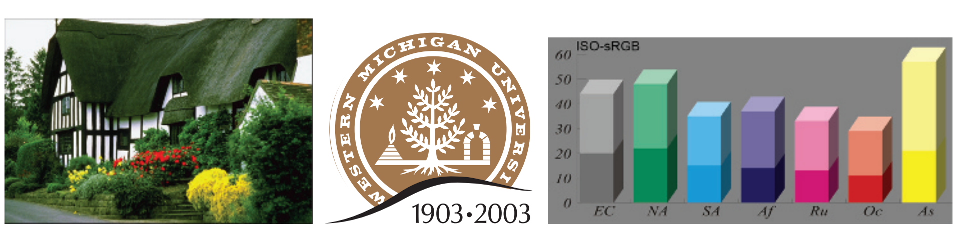


Figure 1.22 There are four different rendering intents that the user can choose during image conversion, as shown here in Adobe Photoshop.

In fact, perceptual rendering is very likely to change the color of an image from original to reproduction. This sounds like a poor option, but in doing this sort of gamut compression, the relationship between colors is retained and this creates the best-looking and pleasing image.

The colorimetric intents are used in instances where we desire the highest accuracy in the reproduction. There are two colorimetric intents – absolute and relative. Consider a fighter plane analogy to explain relative and absolute rendering, Figure 1.24a. An F-22 fighter jet has two speeds – the speed relative to the refueling tanker and an absolute speed relative to the ground. In some situations the relative speed is important in others the absolute speed may be relevant. When the fighter jet is approaching the refueling tanker for example, their relative speed is critical.

In color management we may use absolute or relative color measurements, based on the situation. When doing a side-by-side comparison, when creating a proof for a



(a) (b) (c)

Figure 1.23 Different rendering intents are used with different types of image, (a) photographic images (b) logos and (c) business graphics.

(a) (b)

Figure 1.24 (a) The F-22 fighter jet has two speeds, a speed relative to the refueling tanker and an absolute speed with respect to the ground. *Source:* U.S. Air Force. (b) In color management we have relative and absolute colorimetry, in a side-by-side evaluation, we would use absolute colorimetry. Courtesy of David Arculus.

press run, we would normally use the absolute colorimetric intent, Figure 1.24b, however when reproducing an image across different similar media, perhaps an image in different print publications, then relative colorimetry may be appropriate.

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, as the precise color of the graphic is irrelevant. This intent is used for business graphics such as graphs and pie charts, for which it is important to have bright, vivid colors to make the graphic stand out and be well understood, Figure 1.23c. Because of the behavior of this intent, it is primarily used for business graphics and is not often used to process images.

The descriptions for rendering intent are generalizations. The best rendering intent will depend on the image content and the source and destination device gamuts. If you don't know which intent to use, many programs will allow you to preview your results using different intents and choose the one that looks the best. For a one line answer to "which intent should I use?", relative colorimetric rendering will be the best choice in most situations.

In summary, devices create color using different technologies, therefore each device is expected to have a different color gamut. If a device is not able to reproduce a color due to gamut limitations color management allows us to see this effect and we can use different rendering intents to direct how a replacement color should be found. Rendering intents and gamut mapping are important concepts that permeate many areas of printer color management and are discussed in more detail in Chapter 8, Press and Printer Profiling.

1.14 Color Accuracy

Color management can give you color accuracy. What does this mean? Color accuracy means that you get the colors you expect to get.

With a color management system you can scan an original, print it, and have the colors in the reproduction match the original. In this instance accuracy refers to a color match between original and reproduction.

Often we may not seek an exact "accurate" match between scene and reproduction. The colors in a red rose seen in an expansive garden setting need not be exactly the same when an image of the scene is viewed later on a laptop device. In fact an image is usually pleasing and more acceptable when the colors are different from scene to reproduction, as it is necessary to account for differences in the viewing conditions as experienced by a human observer. In this situation there is no interest in having numerical accuracy between the original and it's reproduction.

In another example, using a digital camera, it is entirely conceivable that your print process cannot reproduce all the colors that were in the original. Some colors cannot be physically reproduced by your printer. We have seen that using a soft proofing process, a color management system can show you the nearest replacement color it will use. A color managed system will then accurately print what it has shown you.

So accuracy in this situation does not refer to an exact match from original to reproduction because this is either physically not possible or is not desirable, instead accuracy means that you will get what you saw in the preview; in other words you get what you expected, there are no hidden surprises. So we can say that color management can provide color accuracy and by color accuracy we mean getting the colors you expect to get.

1.15 Late-binding Workflows

The gamut of RGB images captured from digital cameras is relatively large. If an image is converted to a printer CMYK colorspace, that has a smaller gamut, the out of gamut colors may be brought into gamut, via gamut compression. When RGB images are converted into a CMYK printer or press colorspace, this limits the images' color gamut to the gamut of the chosen CMYK process. Gamut compression is irreversible because once you have compressed the colors in the image, there is no way to get them back. Suppose you change your mind and decide not to print to that printer? Unfortunately, in this scenario it is too late; your image colors are changed forever.

A situation could occur in which an image is intended for a newspaper with a very small gamut, with the images processed accordingly. Then someone decides that the same content is to be printed in a glossy magazine or published online. The glossy magazine or an online version are capable of displaying a large color range. If the images were processed to the gamut of the newspaper they would have lost most of their colors and would not look very colorful when sent to the other output mediums.

In previous years, images would be scanned and directly converted to CMYK. In traditional color reproduction, in order to see the final result, the image was "committed" to a particular process at a very early stage. In fact it was so routine to scan images to CMYK that in some systems it was difficult to get RGB images from a scanner.

In older ways of working it was necessary to convert to CMYK in order to see the final result. In modern color management, it is preferable to retain an image in its original color space, usually RGB. In modern color management we should retain an image in its original colorspace and use ICC profiles with color-aware applications, such as Photoshop, to preview or prepare a copy of the image for different CMYK or other final output destinations. To visualize the effect of the print gamut we can simply preview in CMYK, as described earlier in Figure 1.21. And to process an image for print, we can process copies of the RGB image to different output processes only when needed and even then by using copies of the RGB image, leaving the original unchanged.

In order to retain the full color gamut of an original image, a workflow recommendation is to retain an image in its original RGB colorspace, in a so-called “RGB workflow” or “late-binding” workflow. RGB images are not committed to a print process and therefore are not gamut compressed.

Today, late-binding color management workflows happen more or less automatically, however users trained in a more conventional approach may retain the bad habit of processing content to CMYK.

1.16 Spot Colors and Proprietary Systems

Before we leave this introductory chapter it is prudent to mention some non-ICC color systems, by choosing two examples – Pantone and GMG.

There are a number of non-ICC, commercial color solutions available. These proprietary systems, however often have some connection or interface to an ICC color management workflow. Often a proprietary system will have some way of interacting with ICC programs, perhaps via sharing a common color specification, such as L*a*b*.

The Pantone system is a method widely used to specify and reproduce spot colors, Figure 1.25. In commercial printing, if a special color is required, a separate printing plate is produced containing a spot color. The actual hue of the color can be designated within the Pantone Matching System, as shown in Figure 1.25. The ink for this color is premixed and matches the swatch in the fan booklet, that the designer and prepress operator can refer to. Digital equivalents of the numbered patches are available within programs such as Adobe Photoshop and Illustrator.

Pantone and spot color reproduction is dealt with in detail in Chapter 9, Spot Colors and Expanded Gamut Printing.

Figure 1.25 PANTONE® is a proprietary system that relies on specification of color using printed swatches in different fan books called GUIDEs. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

GMG ColorProof is a system from Germany that consists of software and output modules for various printing devices and processes. This product is a proofing and printing solution that manages color for different output processes. While the system has many features in common with the ICC system – for example, it uses an L*a*b* framework, and it uses lookup tables – it operates within its own proprietary ecosystem. It is useful for the reader to be aware that there are a number of "non-ICC" systems that may be cost-effective in different applications and specific workflow scenarios, such as spot color management or package printing.

1.17 Benefits of Color Management

Fundamentally color management allows us to match color across different devices and media, so that a Disney character, or Coke red, matches from printed advertisement to billboard to supermarket shelf.

ICC color management provides a framework that can be used to communicate color information throughout the production chain, Figure 1.26. Traditionally jobs have originated from the photographer or client, have been passed to the designer or layout department and then over the wall to prepress and finally to press. Each department works in its own silo and does not communicate color information – upstream or downstream. Problems occur when a designer, for example, chooses from an enormous palette of colors, and the press cannot hit those colors.

The ICC framework breaks down barriers allowing all participants to preview and edit and approve color. This makes sure that the customer is aware of what is, and what is not possible, there are no surprises and there are no inflated expectations, in other words, "WYSIWYG" color – what you see is what you get.

Today, efficiency in color communication is further improved through the use of an agreed ICC profile, such as GRACoL or SWOP or FOGRA. When all parties agree to design, edit, proof and print to a given profile, the designer can create a soft proof with this profile, the prepress operator can create a press proof and in the press room, the colors can be achieved on press. An ICC profile gives us an elegant container in which to store a device's color characteristics. An ICC profile is readily accepted in all software and across all operating systems.

Color management provides a number of efficiencies which save time and money. Photographers can move away from the trial and error way of working, and in terms of color, get very close, very quickly. Correct settings for ink limits and black channel generation in large format inkjet printing can offer savings for ink usage when printing

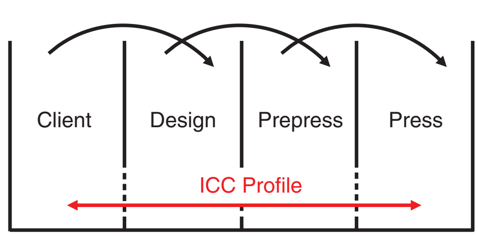


Figure 1.26 Traditionally, each part of the workflow was rigidly divided. Color management can break down traditional barriers and allow color information to be shared throughout the production process.

larger banners and signs. A color managed system allows a press operator to quickly obtain the correct color, which leads to time savings and reduced paper and ink waste.

Color management is a game changer for proofing, it is no longer necessary to use an expensive traditional proofing system, instead there is the ability to use an inkjet device to create a contract color proof. Inkjet devices do not need a skilled technician to make proofs and with a color management system a proofer can be located on-site at customer locations and remotely controlled. The cost of a contract color proof is reduced from $150 to $15.

Color management offers flexibility. Color management allows a job to be split between different devices to deliver the completed job quicker to the client, or to print locally and avoid shipping, for example in Toronto and Ottawa branches of the same company. In a recent real world example an offset press job was 100 sheets short. Instead of finding and re-mounting the printing plates the shortage was addressed via color management by printing the missing sheets on a digital press, quickly creating samples that the customer agreed were an acceptable color match.

Color management addresses the issue of the inexperienced end user. Today, color is being used in many different market segments from consumer to prosumer to full-time professional. We may say that the industry is largely de-skilled, with most users lacking a background in color theory and practice. A color management system removes the need for the user to have many years of color experience. Sophisticated color science processes are embodied within an ICC profile and may include bicubic interpolation, preferred color appearance, black and white point mapping, gamut compression, etc. The user does not need to have an understanding of these complex processes as the ICC architecture manages this behind the scenes, allowing the user to focus on image and editorial content.

Color management is a measurement-based technology, and we see that hand-held instruments such as spectrophotometers are commonly used in day-to-day operations. Humans can get tired and make different color judgements at the end of the day, compared to in the morning, in this situation a system based on instrumentation and measurement provides consistency and repeatability. A spectrophotometer rarely has different readings between the start and end of a long shift!

Numbers-based color management creates easy pass/fail instructions that remove the need for evaluation by a color expert. It is no longer necessary to do an in-person press OK. During a press OK, a print buyer visits the printer and approves the color and signs off on the press sheets for a job. In the new color management paradigm there is no longer the need to visit a remote printer location, instead simple measurement of control patches on the edge of a press sheet verifies if the numbers (and therefore the color) meets the job specifications. Via measurement of control patches there is never a discussion about whether the printed colors are within the job specification, the customer cannot refuse the shipment as all color results can be easily verified. Color management creates a protocol for remote monitoring and verification which allows non-time-sensitive jobs to be printed in China or India.

Numbers-based color management allows for pass/fail metrics that are easy to incorporate into standard operating procedures and documentation. A facility can develop a simple numbers-based tick box that allows a job to be checked and allowed to proceed. Creating and maintaining numbers-based documentation allows a facility to apply for external validation to become a “certified facility”.

Color management provides a framework for a statistical approach to managing color, measuring the performance of each device and tracking this on control charts with warning limits and action limits. Data analysis can evaluate production time vs. down time, throughput, and provide accurate data to enable equipment "end-of-life" decision making.

A color-managed system allows you to get the best color from your devices by calibrating and maintaining the device, and knowing proper controls and settings. Use of color management ensures that the device is using its full color gamut and producing good quality color. Color management provides a way to establish a good baseline and a way to get back to that baseline should devices drift.

One of the significant advantages of modern color management is that it creates the ability to buy different products from different vendors and to upgrade or replace devices with ease and convenience. Color management enables "plug and play" color. It is easy to add another device, even another type of printing technology – perhaps a laser device alongside an inkjet proofer. New devices and their software all speak the same ICC language and are all immediately up and running with no more than plugging in and calibrating.

Color management saves money as it improves productivity with less manual color adjustments, removes the need for endless iterations, and avoids late detection of costly mistakes. Color management allows a user to have a methodology to fix color issues, creates faster turnaround times, and produce work that meets customer expectations which results in happy and satisfied customers. Customers will have confidence in your work, trust that you can reproduce color accurately and consistently, be confident that they will get what they expect, and that any repeat orders will match the color of the original shipment. A facility that has a correct color implementation has organizational "color confidence", which has invaluable monetary value.

Color management is a way of working, a "philosophy", a systematic approach to color. In establishing a color managed system, you will be able to bring everyone into a common color system in terms of their understanding and working methods. You will need to educate and guide (and sometimes coerce) your customers and your employees, colleagues and your company's management.

Today color management is already part of every digital imaging system. On most systems, every image, icon, desktop, is color managed and can't be turned off. If you delete the system ICC profiles on macOS, by dragging them to the trash, for example, they are immediately replaced. Adobe Photoshop insists on an ICC profile for every image, there is no such thing as an "untagged" image. Color management is part of every digital imaging system and is difficult to turn off. As color management is already installed, there is nothing to install or upgrade, it is already there!

Color management does not require a user to write a new rule book or develop any new processes or procedures. Color management is well established and well documented, there are products, tutorials, workshops, short courses, and color consultants to assist and educate the user. The user does not need to re-invent the wheel, we have a successful ICC color management technology, tried and tested and widely accepted in every market segment, throughout the world.

After this long list of benefits of color management, one wonders how did I manage for so long? After implementation of color management most users would never look back and return to their old way of controlling color.

1.18 Summary

A fundamental issue with color imaging is that each device has its own unique characteristics. We would not expect all microwave ovens to need two minutes to cook a bag of popcorn perfectly – the devices are from different manufacturers, some brand new, some old, each appliance will need a slightly different cooking time. In the same way, in digital imaging, it is unrealistic to expect that we can just send the same image data to different devices and expect the color to match throughout.

In color imaging, in the past, a manual, closed-loop approach was used to manage color. Today however, with many different sources for images and many different destinations, a more sophisticated approach is needed.

Modern color management systems use profiles to automatically manage color across a range of input, display and output devices and systems.

Practical color management can be represented by a reference diagram, Figure 1.5 in which image data is converted into or out of, a central connection space. A number of operations were described that demonstrate the power and ability of a color management system in different capture, prepress and press environments.

This chapter described color management in terms of the three Cs – calibration, characterization and conversion. Calibration referred to establishing a fixed, measurable baseline. Characterization is more commonly known as “profiling” in which a test chart is printed and measured. Conversion is the application and use of profiles to convert image pixel data in a program such as Photoshop. Importantly it was shown that the three Cs are hierarchical, and that anything that alters the calibrated state, such as device drift, can undermine the foundation of the other processes thereby eventually reducing the accuracy of the color conversion.

Today’s color management is essentially “ICC color management”. This chapter provided an insider’s view to the ICC and its procedures, describing the current versions of the ICC Specification, and describing the work of the ICC working groups and international meetings. For the first time we have a system that is accepted and supported by the whole color and imaging community. This universal color management system puts enormous power in the hands of the end user and allows functionality that was inconceivable in older ways of working.

In this chapter we noted that RGB and CMYK are device instructions and not necessarily accurate descriptors of a color. In order to communicate color information across many different devices and systems, we need a universal way of specifying color that does not rely on a particular device and the age or condition it is in. Yxy and $L^*a^*b^*$ provide device-independent descriptors of color. $L^*a^*b^*$ is used in the Profile Connection Space at the heart of a color management system.

Color management is only possible if every device has a profile, so in this chapter, custom, generic and standard profile types were described. Traditionally most emphasis has been on making a custom profile, however the trend in recent years has been to move towards good quality generic and standard profile types.

Color gamut was defined as the range of colors a device can produce. Due to differences in the physics of the imaging process-additive vs. subtractive color synthesis-RGB camera and display devices usually have a larger color gamut compared to CMYK printing processes. It was shown that color management cannot eradicate the color changes that may occur due to gamut limitations, but it can warn you by staining the colors that are out of gamut and also allow the user to choose different rendering intents based on the content in your image.

Color management works best if you stay in the image's original color space and use simulation tools to predict the look of the image on any number of devices and thereby process copies for different destinations. Color management is most powerful in a "decide later" workflow, or a late-binding workflow. The optimum color management workflow is one in which an image is retained in its original format (with all colors) and copies are processed for various jobs.

Implementation and efficient use of color management provides a long list of benefits, including saving time, money, and materials. There are many technical, financial and customer satisfaction benefits to using color management. If used carefully and intelligently, color management works, and works very well.

This chapter has provided a general overview to the topic of color imaging and color management. In the rest of the book we provide detailed explanation for each of these concepts, in order that the reader can genuinely *understand color management*.