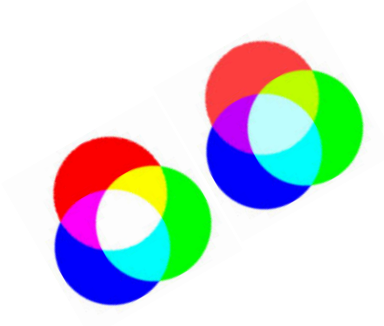


Graphics

MANAGING COLOR

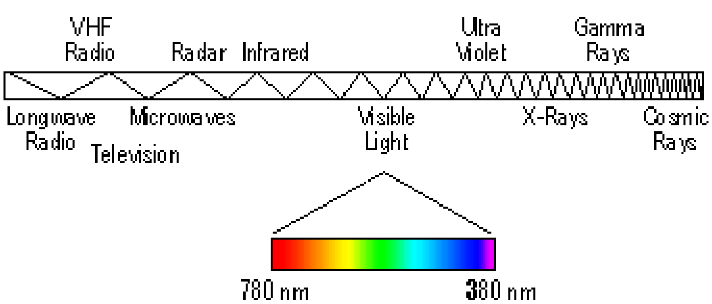
Information Sheet No. 518

Light and Color

What is Light?

Our Sun emits electromagnetic radiation across a spectrum ranging from radio waves to gamma rays. A small section of this spectrum, from 380nm (nanometers) to 780nm in wavelength, forms what we call light. Light is that part of the electromagnetic spectrum that our eyes can detect.

Diagram 1: Electromagnetic radiation from the Sun.



What is Color?

White Light

White light is a mixture of all the wavelengths that the human vision system is capable of detecting. We generally think of daylight as white. However daylight is not always white. Because it is filtered by the Earth's atmosphere it changes color depending on the angle at which the light is entering the atmosphere in relation to our position on the Earth. Particles in the atmosphere also have an influence. For instance, where there is an abundance of moisture particles in the air we may see a blue tint to a view.

Color

Color is the sensation produced in us when electromagnetic radiation, of certain wavelengths within the range 380nm to 780nm, reflects from objects into our eyes where electro-chemical reactions cause signals to be passed to our brains. These signals are interpreted by our minds as colors. That is, colored light only appears to us where there is a predominance of wavelengths from just part of that spectrum.

It is when the objects we look at absorb part of the spectrum to which we are sensitive that we perceive the color of an object. For instance, if an object absorbs those wavelengths corresponding to the colors red and green then we perceive blue. If an object absorbs those wavelengths corresponding to the colors green and blue then we perceive red.

All of the colors in the spectrum that we can perceive, ranging from red at one end to blue at the other, can be made by mixing light of just three colors: red, green and blue.

This can be demonstrated by taking three white light sources, of equal power, and placing red, green and blue filters over them. If the lights are set up so that they shine discs of light onto a white board, in a triangular arrangement, and where the colored circles overlap each other at the centre, there will appear six colored patches and a white, or neutral, patch at the centre.

If the power of one light, say the red one, is decreased then the other two, green and blue, dominate. A mixture of green and blue makes cyan. So the centre patch will appear a light cyan instead of neutral and the colors that include some red light will appear slightly less red and slightly more cyan.

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Color Temperature

We have invented a range of light sources for ourselves. These include candles, gaslights, tungsten filament bulbs, fluorescent tube lights, electronic flash lighting and so on. We generally think of these light sources as providers of white light but they actually vary quite widely in color.

However if there is at least some level of all the wavelengths which make up the light which illuminates a scene, our minds are able to adapt, even if that light differs quite markedly from white. This ability to adapt allows us to differentiate between say subtly different shades of blue even under quite yellow light such as that emitted by a domestic tungsten filament bulb.

The ability to adapt to lighting conditions has obvious advantages but the perception of color (even in white light) is a highly subjective process and this poses problems for the accurate communication of color. Standards and ways of measurement are needed so that colors, which are certain wavelengths of electromagnetic radiation, can be accurately communicated.

Kelvin

The color of a light source can be measured in Kelvin (K). If the light is 'reddish' relative to white then

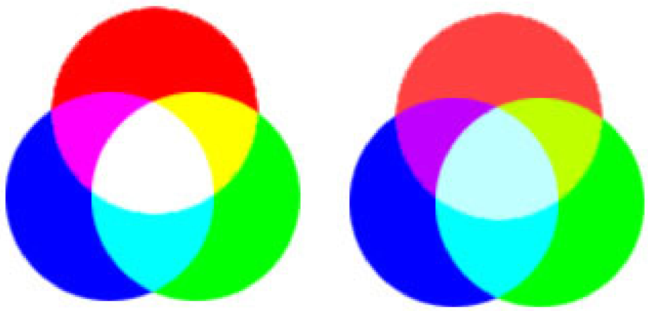


Diagram 2. RGB discs, equal (left) then less red (right)

the color temperature is said to be low. If the color of the light is 'blueish' it is said to be high.

Table 1.

Light Sources and their Kelvin Values

Candle	2000K
Light Bulb	3000K
'Daylight'	5500K
Electronic Flash	6500K
Blue Sky	15000K

When viewed, or measured, objectively the same item appears as different colors when illuminated by each of the different light sources in table 1. For instance a red apple against a green background, illuminated by candlelight, will appear bright, saturated red in color. The same apple, illuminated by electronic flash, would appear as a less saturated red as there are less of the red wavelengths in the higher temperature light to reflect. The inverse is true of the green background.

Photographers often wish to capture images as if they were illuminated by daylight of around 5500K. They deal with the problem of nature failing to oblige with the right light by measuring the light incident upon their subjects and then, if needs be, by placing compensating filters on their lenses. They do this because the film they use to capture images is totally objective, it cannot compensate as the human mind can, its response to light is fixed in manufacture.

For example, if a scene is lit by candlelight it will be recorded, on film that is manufactured to be 'balanced' for daylight, with an extremely orange cast. When the processed photograph is observed, especially in daylight, it will appear unnaturally orange. The photographer who wants to record the scene as if illuminated by daylight brings the balance back toward normal by placing a blue filter over the camera lens.

The exact color of the filter is determined by measuring light incident on the scene with a calibrated color meter, deciding what color temperature you would have preferred that light to be and calculating the 'shift' in K that needs to be made. The calculation gives a figure that enables the appropriately colored filter to be selected.

This is one of the way in which photographers 'manage' color and their standard, or reference point is most often daylight or 5500K.

Color Management in Digital Imaging Systems

Open and Closed Systems

Before desktop imaging came about, in the late 1980s, high-end computer graphics systems were made as 'closed' systems. That is, they were sold as complete, pre-configured and calibrated systems with all parts coming from one manufacturer. It was the manufacturer's responsibility for ensuring color fidelity throughout the system. It was the responsibility of highly skilled operators of such systems to obtain the best results from the various originals they were given.

For some years now professionals and consumers alike have been able to source individual parts of a computer graphics system, such as scanners, monitors, graphics adapters, proofing devices and printers from a variety of manufacturers. Set-ups put together like this are termed 'open' systems.

Different Color Languages

The devices comprising an open computer imaging system may all process color differently. Each type of device can be thought of as using its own 'language' when interpreting and rendering color. This means that there can be no automatic way of guaranteeing color fidelity throughout a system. Also device characteristics, such as age and wear, and operating conditions such as temperature can affect color rendition. This can lead to disappointment with, for instance, printed output when what was seen on the monitor looked fine, or when a screen representation of a scanned artwork looks markedly different from the original.

Trial and Error

When faced with these facts it might seem that we are in a hopeless situation where only trial and error will enable us to get the results we want. Trial and error might work in the end but will probably be very expensive in both time and materials. Hardware and software developers are moving toward standardizing the way devices handle color but there is still a need for users to employ color management systems. The use of color management systems and regular calibration of equipment reduces the trial and error element to that required for fine-tuning and enables predictable and repeatable results from the various devices in an imaging system.

Color Spaces

Unfortunately we are often not going to be able to faithfully reproduce an object as seen by the human vision system. This is a task of which the available devices and systems are just not capable. Good photographic film comes nearest to the response to light of the human vision system but will capture only a subset of the colors humans can perceive.

While photographic film will outperform computer monitors, monitors can represent more colors than desktop printers and the offset lithographic processes. However another issue is that, as you move down the quality scale, these devices operate in 'color spaces' (their own sets of colors) which often do not entirely coincide. So while a computer monitor operating in the RGB (Red Green Blue phosphors) color space can represent more colors than a printer there are still colors in the relatively small CMYK (Cyan Magenta Yellow Black inks) color gamut that printers use that RGB monitors cannot produce.

A scanner records or samples an image as a set of RGB values. The accuracy of the color measurements taken from the image depends on the scanners manufacture, maintenance and settings. A monitor will display that image to us in a way that depends on viewing conditions, the screen phosphors used in its manufacture, the state of its settings and on its condition. Further, when an image is printed, the colors reproduced and perceived will depend on the inks as well as the paper used to print on and the conditions under which the print is viewed.

A system is required to compensate for the color handling differences between the devices present in a color computer graphics set-up. This system is required to enable predictable and repeatable reproduction of an original image with the output being as close as possible to the original. However it has to be acknowledged at this point that, as this process often involves a chain of devices exhibiting less and less ability to reproduce a wide range of colors, the output may be comprised of a smaller set of colors than that in the original scanned artwork. I other words, some colors may be changed or lost.

Managing Color

A color management system enables devices in a computer graphics system to communicate color information to each other via an intermediary color space.

The CIE Yxy three dimensional color model was developed by the Commission Internationale de l'Eclairage in 1931 (followed by CIE L*a*b* in 1976) and describes all colors visible to humans. It can be thought of as the interpreter that knows all other color languages because it is aware of all the colors in all of the color spaces. It is independent of the imaging devices, a device independent color space. While colors on output devices such as computer monitors may change over time and between manufacturers, colors in the CIE models never change, they are a fixed reference or standard.

Diagram 3. CIE Yxy color space with scanner, monitor and CMYK color spaces.

Device Profiles

In a color management system each device in the imaging process is 'profiled'. For instance to create a scanner profile a reflective (transmissive for film scanners) IT8 or Q60 target is scanned.

The IT8 target is a test page developed by ANSI (American National Standards Institute), the Q60 by Kodak. They both contain colors and grays of known values.

Device profiling software converts the values supplied by the scanner into the CIE color model then compares them with the known target values. The differences between the two sets of values indicates the limits and color distortions of the scanner. Data produced in this process is stored as the device profile. A scanner is an input device and the profile is termed an 'input profile'.

Note: Until recently many organizations were implementing different methods of profile creation. This resulted in the usual confusions and incompatibility issues that are prevalent whenever evolutions take place in the IT industry.

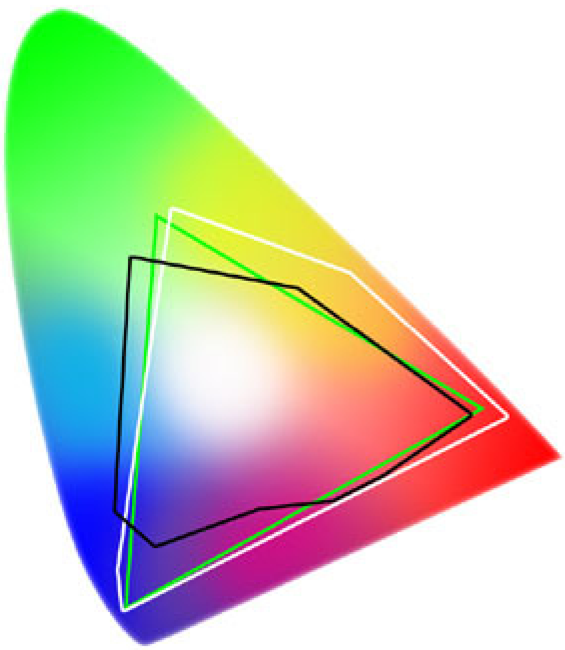
The ICC (International Color Consortium), founded by leading imaging industry members such as Kodak, Adobe, Apple, Microsoft, Agfa, Silicon Graphics and Sun Microsystems, has now developed a standard format for profile creation so that suppliers of hardware and software can ensure that their products communicate effectively about color.

Profiles are created for each device in the imaging system.

A monitor profile (display profile) is made by displaying patches of known colors on screen which are measured with a colorimeter or a spectrophotometer. The color that is displayed might be measured as differing slightly from the color that should have been displayed. A range of colors are displayed and measured and a profile for that monitor is created. The rest of the devices in the system, whether they be input or output devices, are now aware of the behavior of the monitor.

Other devices such as printers and film recorders are also profiled (output profiles) and the whole system, by using the device independent CIE color space as a translator, is enabled to communicate, up and down the work flow, about the way color is handled at various stages.

Device profiles are often available from device manufacturers or are included in the color management system software that you choose to use. It is however



Key: Black = CMYK; White = Scanner; Green = Monitor

best to produce profiles for the actual device rather than use a generic one. Even devices with the same model number and specification may differ in performance.

Some devices may even have several profiles - for instance, a printer may have one for each type of ink being used or type of paper being printed on.

Color Management Modules

Within the color management system is a color management module. This is the software that is responsible for considering the device profiles then mapping device gamuts to one another. For instance, it maps colors within the gamut of an input device, such as a scanner, but outside the gamut of a destination device, such as a monitor, so that out of gamut colors are reproduced on the monitor as near as acceptably possible to the original. The color information in the file is not changed but is translated between the devices in the system.

Diagram 4. The Kodak Q60 color input target.

Color management systems may support color management modules in addition to their own. There are several major players in this field including Linotype-Hell, Kodak and Agfa. However there is some evidence of convergence in that Apple and Microsoft seem to be leaning toward operating system level integration of the Linotype-Hell color management module.

Rendering Intents

There are several different ways that the translation process performed by the color management module can be conducted. Four are outlined below:

Perceptive - this method adjusts the destination color space when any colors in the input color space are outside of it. The visual relationship between colors is preserved but the resulting color space is contracted and results in all colors being shifted. This method may not give a truly accurate match with the original but, because the visual relationships between colors are maintained, out of gamut colors are not clipped on the border of the target gamut.

Absolute Colorimetric - Colors that cannot be displayed in the target color space are lost, clipped on the gamut boundary.

Relative Colorimetric - this method does not change colors that are within the overlapping color

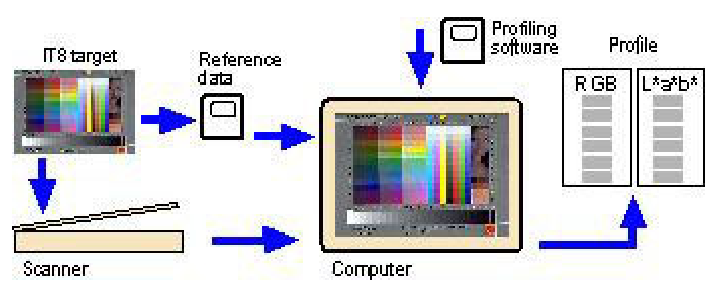


Diagram 5. Creating a scanner profile.

spaces of the devices. It changes only those which are outside. A color which falls outside the gamut of a destination color space is assigned a color which exists in the destination color space i.e. colors which were different in the source color space may become the same in the destination space.

Saturation - this method retains the original saturation characteristics of the colors and is most suitable for graphics with bright saturated colors.

Summary

CMS Workflow

Considering the above, it can be seen that a single matching process performed in a color management system can be condensed into three basic steps.

Color values in the color space of device A are converted to device independent values.

The device independent values are converted into device B color space values.

This is done while the input and output color spaces are compared using data from the device profiles, then output is made according to the chosen color management module.