# Color Management with ICC Profiles: Can't Live without It so Learn to Live with It

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Abstract

Managing and controlling color, from scanner to monitor to output devices, are serious issues for the printing and imaging industries. Accurate color control is vital for predictable quality of final product, whether printed or displayed. Costs of controlling color are significant. Printing has become much more science than art and any company, especially those involved in printing and other media, must have a presence on the World Wide Web. Thus, controlling color between input, display and print is more important than ever. As a result, spectrophotometers and colorimeters are now necessary tools throughout the industry. Color management systems have been developed to utilize these measurement devices to characterize the color of input, display and output devices. These hardware and software tools have not yet solved all problems of color reproduction, but have made possible quantification, which is the essential ingredient for controlling quality. Here we review color management, ICC profiling and the important players in this technology.

## Introduction

The issue of managing and controlling color, from scanners to monitors to digital printers/proofers and finally to printing presses, is a serious one for the printing and imaging industries. Accurate color control is vital in order to have a predictable quality of final product, whether it be printed on a substrate or displayed in an image editing program or a Web browser, and ultimately to satisfy customer expectations. The costs involved in controlling color for the designer/publisher/printer are both soft (time spent by employees during pre publication, hard or soft proofing, film or plate output for printing presses, and on press), and hard (wasted ink and substrate used in makeready, as well as time wasted in jobs that do not meet final customer specifications).

Great strides have been made in the printing industry in recent years toward applying scientific methods in the pressroom, as well as in the prepress area. Printing has become much more science than art and every company, especially printing and media companies, must have a presence on the World Wide Web. This makes controlling agreement between displayed and printed color more important than ever.

The advent of digital video and computer-generated animation (Figure 1) has further compounded the problem. Accurately matching color, between computer CRT and LCD displays, Analog monitors, Cinematic projection, companion books and wearing apparel, present an apparently insurmountable challenge. To meet this challenge, standards have been established and Color Management methods have been developed. Essential to utilizing these methods are spectrophotometers and colorimeters, which were virtually unheard of by printers twenty years ago. These have now become necessary tools in all media industries [1-4].

Figure 1. A snapshot from Toy Story II, a computer generated animation from Disney and Pixar.

To address the issues of accurate color control throughout the production process, color management [3,4] systems have been developed. The International

Color Consortium (ICC) was formed in 1993 by Adobe, Agfa, Apple, Kodak, Microsoft, Sun Microsystems and Silicon Graphics [3-6] to define the standards for color device characterization. This device characterization is presented in terms of specially formatted files, which have come to be called profiles. The latest version [7] of the ICC specification has been reviewed recently in this magazine by McDowell [8].

Unfortunately, the use of color management systems has not yet solved all of the problems of color reproduction. However, it has made possible the quantification of problems. As always in quality control, with quantification comes the ability to control and, with control, quality management becomes possible.

## Some Important Issues

A large part of the problem of handling color lies in the inherent differences between the mechanisms by which different input, display and output devices perceive color [9-13]. Computer displays, scanners and digital cameras are generally based on the Additive Color Theory [14-16] and are represented in terms of differing amounts of Red, Green and Blue (RGB). On the other hand, printing ink on substrate is based on the Subtractive Color Theory [14,15,17], which generally employs differing levels of Cyan, Magenta, Yellow and Black (CMYK). The problem is further complicated by the fact that the same RGB image looks different on different monitors, even ones that are nominally identical. Growing acceptance of Liquid Crystal Display [18] (LCD) monitors, in addition to the standard Cathode Ray Tube (CRT) monitors, further complicates the situation. Furthermore, the two color models span different portions, or gamuts, of the visible color space [14-17]. Some colors representable in the RGB space cannot be printed in CMYK space, and vice versa. In particular, highly saturated primary colors are readily displayed, but cause serious problems in printing.

Ambiguities in handling color start first when electronically inputting color into the workflow. Whether using scanners or digital cameras, each device sees color differently. Even nominally identical devices show slight, but measurable differences in captured color. Imagine scanning a saturated solid red patch, such as a corporate color. Scanner A may report (Figure 2) the color in terms of RGB (Red, Green and Blue) as (250, 0, 3), while Scanner B reports it as (240, 5, 3). A digital camera may indicate the patch should be (235, 10, 7). Because the CCDs (Charge Coupled Devices) used in scanners and digital cameras are fundamentally different than the phosphors used on CRT (Cathode Ray Tube) displays and filters used for LCD displays, none of the reported colors will be correct on any monitor.

Likewise, different digital printers, proofers and printing will produce different looking results when printing the same CMYK values (Figure 3). This results because these devices employ different printing processes, different inks and print on different paper.

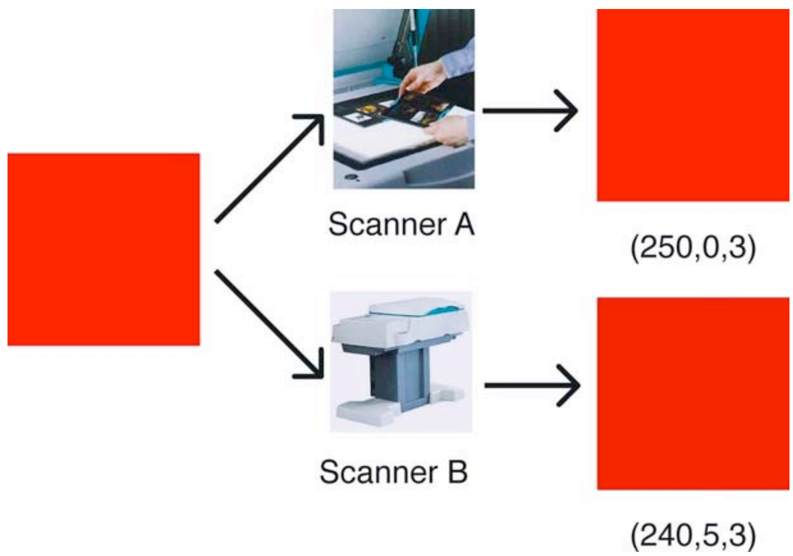


Figure 2. Different scanners report different RGB values for the same scanned original.


Figure 3. The same CMYK value printed on different printers will look different.

In the early days of Color Electronic Prepress systems (CEPS), high-end drum scanners were used with a single printing press in a closed-loop [3] system (Figure 4). Highly trained skilled specialists adjusted scanner characteristics for color separations and halftones based on press characteristics. Using visual observations and some measurement instruments on carefully chosen test targets, they were able to achieve good color "matching". When the company traded in the old printing press on a new one, the scanner operator had to start all over again. Color separations intended for an offset press were not correct for a gravure press and vice versa.

Today everybody has a scanner, computer and a color printer. Electronic images come from different places including the Internet, digital cameras, computer generated art and different scanners. They are displayed on different CRT and LCD monitors on Macintosh and PC computers. They are intended for multiple purposes; printed on different printers, proofers and presses and to be read on screen with different applications from CD-ROM, DVD disks and Web pages. This intertwined network of connections is illustrated in Figure 5. This situation can only be handled by an open color controlled system. The necessity of accurately handling these different color devices has led to the development of color management systems[3].

Figure 4. Illustration of a closed-loop color management system.

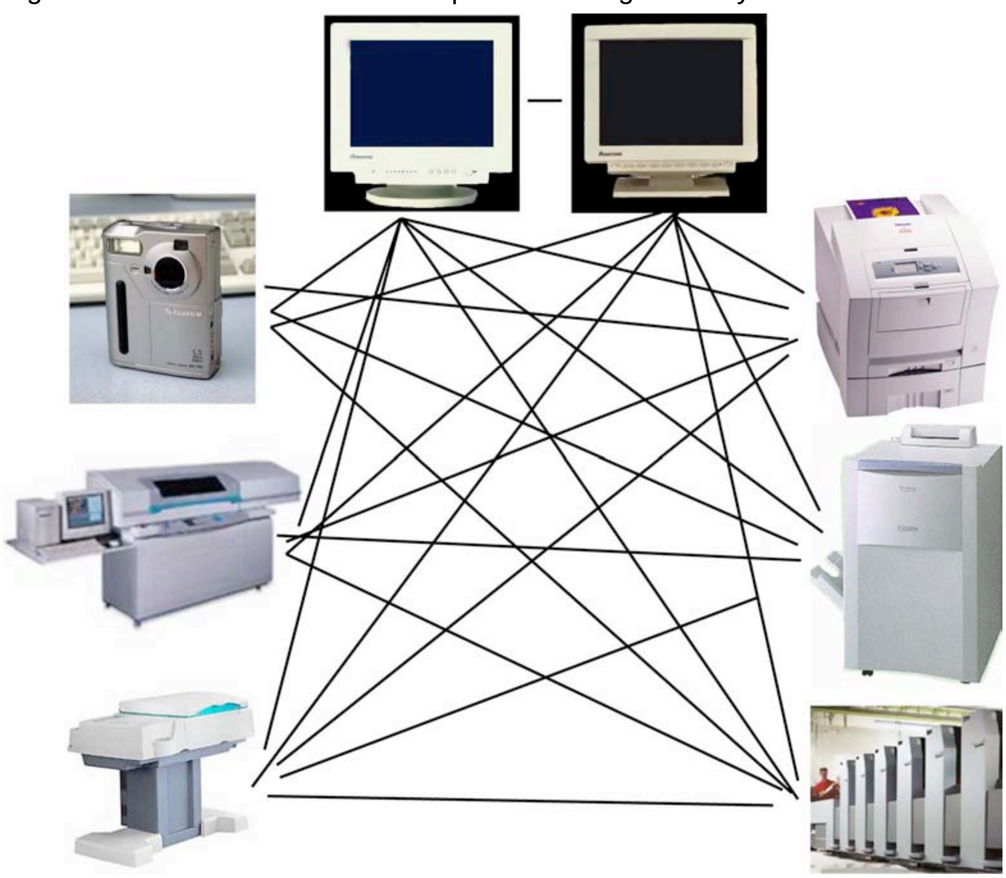

Figure 5. Illustration of an open Color Management System.

The color managed system is achieved by make use of a universal device independent color Profile Connection Space (PCS). A special type of computer file, called a Profile, characterizes the behavior of the device in terms of the PCS and specifies how to pass into and out of the PCS (Figure 6). The PCS can be thought of as analogous to the Hub city airport used by airlines to route passengers to and from different destinations. Just as a new city can be added to the airline's service area, a new device can be added to the mix by merely specifying a profile that gets color information into and out of the PCS.


Figure 6. Open Color Management System with central Profile Connection Space (PCS).

## Color Spaces and Tolerancing

As stated above, Scanners, Digital Cameras and Monitors use the additive color theory and the RGB color space. Digital Printers, Proofers and Printing Presses use the subtractive color theory and the CMYK color space. These are all examples of device dependent color spaces. As such, they cannot be used as the PCS. The first device independent color model was developed by the Commission Internationale de l'Eclairage (CIE) in 1931 [(19)]. This space, called the tristimulus space is defined by coordinates X, Y and Z. X is a redness coordinate, Y is a greenness coordinate and Z is a blueness coordinate.

The tristimulus values are very useful, being very easy to directly measure with colorimeters and spectrophotometers. However, unit variations in tristimulus values do not scale uniformly with human visual sensitivity. This deficiency led the CIE to define a new color space, the L*, a*, b* color space in 1976 [(20)], which has been called a uniform color space. This space, often called CIELAB, is equivalent to the tristimulus space. For a given illuminant, the L*, a* and b* values are given by

$$L^* = 116f(Y/Y_I) - 16 \tag{1a}$$

$$a^* = 500[f(X/X_I) - f(Y/Y_I)] \tag{1b}$$

$$b^* = 200[f(Y/Y_I) - f(Z/Z_I)], \tag{1c}$$

where $X_{I,}$ $Y_I$ and $Z_I$ are the tristimulus vales of the illuminant and

$$\begin{aligned} f(x) &= x^{(1/3)}, \; x > (6/29)^3 = .008856\ldots \\ &= (29/6)^2 x/3 + 16/116, \; x < (6/29)^3. \end{aligned} \tag{1d}$$

Being device independent, CIEXYZ or CIELAB are candidates for the PCS. In fact, profiles generally use either CIEXYZ or CIELAB as the PCS.

As stated above, the CIELAB space more uniformly represents the human perception. Thus, the difference between two colors is usually reported as the Cartesian distance in L*a*b* space. This distance is generally denoted by $\Delta E$, which is defined by

$$\Delta E = \sqrt{(L_1^*-L_2^*)^2+(a_1^*-a_2^*)^2+(b_1^*-b_2^*)^2}, \tag{2}$$

for the distance between colors $L_1^*a_1^*b_1^*$ and $L_2^*a_2^*b_2^*$. Generally, a $\Delta E$ value of around unity or less means that the two colors are indistinguishable to essentially all human observers.

## Instruments

Measurement devices used to characterize color are densitometers, colorimeters and spectrophotometers.

Reflection densitometers measure the light reflected from the printed sample. The reflection density is defined as

$$D = -\log_{10}(R/I), \tag{3}$$

where R is the intensity of light reflected and I is the intensity of incident light. Color information can be obtained by determining the density of light passed through red, green and blue filters.

Colorimeters and spectrophotometers can actually measure CIE coordinates. Generally, they measure X, Y, Z and calculate the L*, a*, b* values with built in electronics. In addition, spectrophotometers actually measure the spectrum of light reflected from or emitted from the sample.

## ICC Profiles

In this section, we illustrate how ICC profiles function. First, we consider input profiles. Suppose that a digital camera, a drum scanner and a professional flatbed scanner each capture the same red patch discussed earlier. Each device sees the color differently within its color space as illustrated in Figure 7. The effect of the profile is to map all three to the same color in the PCS.

To make an input profile a standard target such as the standard IT8.7/1 (for color transparency scanning) or IT8.7/2 [21] (for color reflective scanning) illustrated in Figure 8. The different patches in this target have known colorimetric values, either provided by the manufacturer or custom measured by the user. The profile making software creates a mapping between device RGB values and L*a*b* values, using the known values for the patches. Usually, this mapping involves a parameterized fitting function. This function is then used to create a lookup table that is stored in the profile. The input profile created by this process is then used to interpret the color of all originals scanned or photographed with the device.

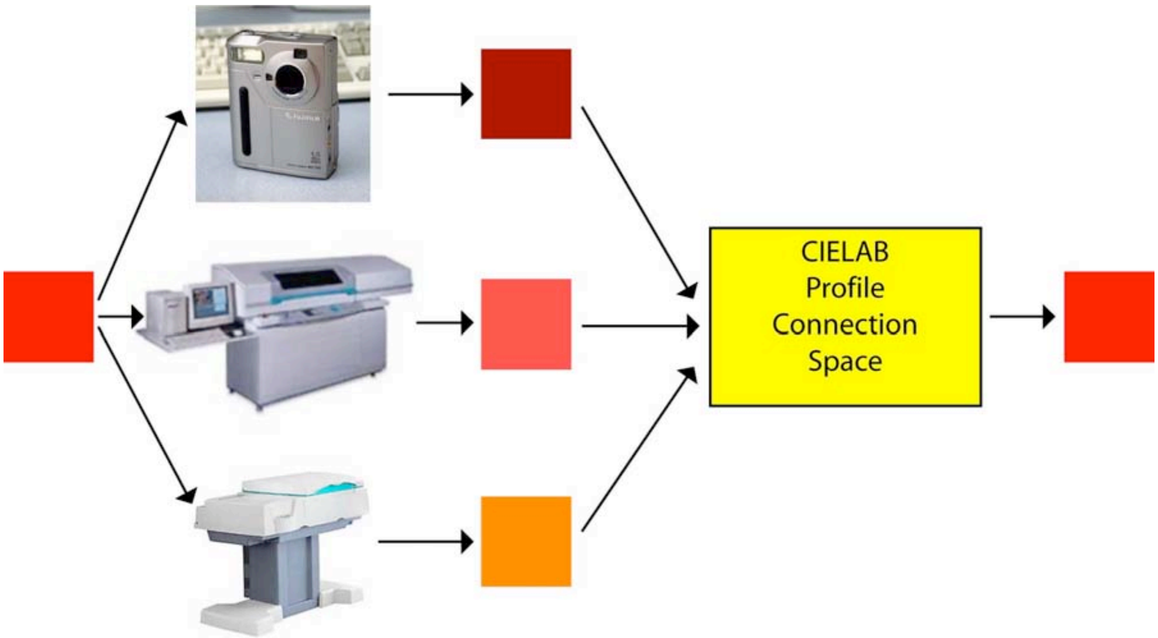


Figure 7. The effect of an input profile is to transform the color in the input device's color space to the correct color in the PCS.

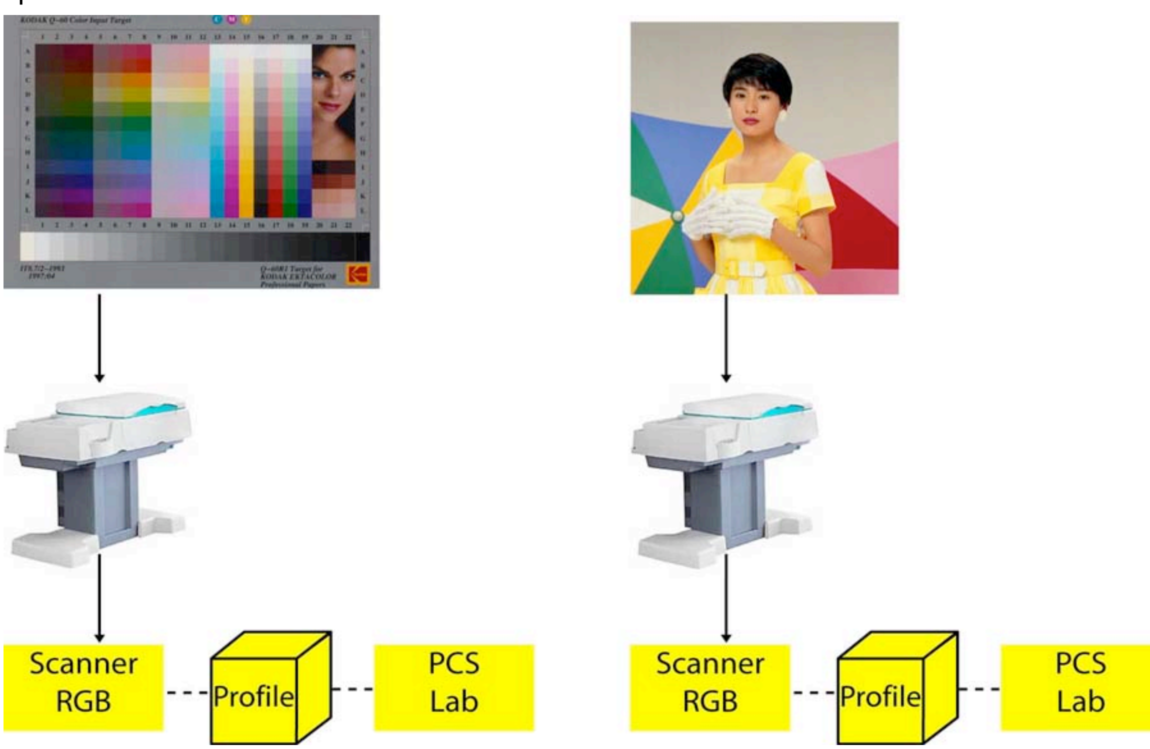


Figure 8. Making an input profile using a standard target and using it to scan an actual photograph.

Monitor profiles and output profiles are constructed by measuring colors displayed or printed. For monitor profiles, a colorimeter, such as the X-Rite Monitor Optimizer, or a spectrophotometer, such as a GretagMacbeth Spectrolino, is attached to the screen by suction cups (Figure 9). A set of 40-50 RGB values is displayed and the colorimetric values are recorded. These are used to construct the monitor profile. Monitor profiles are generally characterized by white point color temperature, gamma ($\gamma$) value and tristimulus values for the Red, Green and Blue primary colors. The white point is interpreted as the temperature of a perfect Planckian Black body radiator (22) that produces the same relative tristimulus values (the Y value is usually normalized to 100). Generally color temperatures of 5000 K ($D_{50}$) and 6500 K ($D_{65}$) are used to simulate "natural" daylight under different assumed conditions. The $\gamma$ value is an exponent that is used to characterize the nonlinear response of phosphor brightness to electron energy (voltage) in a CRT monitor.


Figure 9. X-Rite DTP92 Monitor Optimizer.

For output profiles, it is necessary to print a file of know CMYK values, such as the IT8.7/3 (23) or the newer IT8.7/4 (24) (Figure 10). The printed patches are then measured with a colorimeter or spectrophotometer, such as the GretagMacbeth Spectroscan. Much like the case with input profiles, a mapping between CMYK values and L*a*b* values is generated and used to populate lookup tables in the profile. The mapping is more complicated in this case, because in order for it to be one to one and invertible, some sort of GCR (Gray Component Replacement)(25,26) or UCR (UnderColor Removal) (25,27) prescription must be specified to make the effective CMYK space a function only of three variables. Specifying the L*a*b* value for a given CMYK value is no problem, because that is what is specifically measured. However, specifying the CMYK value for a given L*a*b* requires a constraint on the CMYK values. It is important that the output profile be reversible, so that transforming between CMYK and L*a*b* and then back again to CMYK yields the same (or equivalent) color values. This feature is crucial for any digital proofing, hard or soft (on monitor). Sometimes, an annealing process must be applied to assure this reversibility (28).

Numerous utilities are available to view the contents of ICC profiles. *ColorSync Profile Inspector* (written in 1994 by Steve Swen and Friends) for Classic Macintosh Operating Systems, ProfileInspector for Mac OS X Operating Systems and ICCinspect (from Iphoto), for Microsoft Windows Operating Systems, allow users to view the contents of ICC profile tags. These are very useful for interpreting the behavior of profiles. The ColorSync Utility, distributed with Mac OS X, displays the tags present in a profile, but not the content of the tags. It does, however, have some useful features including Profile First Aid and Device association with profiles. Ben Griffin's Profile Editor (written in 1995) actually enables editing of some profile tags under Mac classic operating systems.

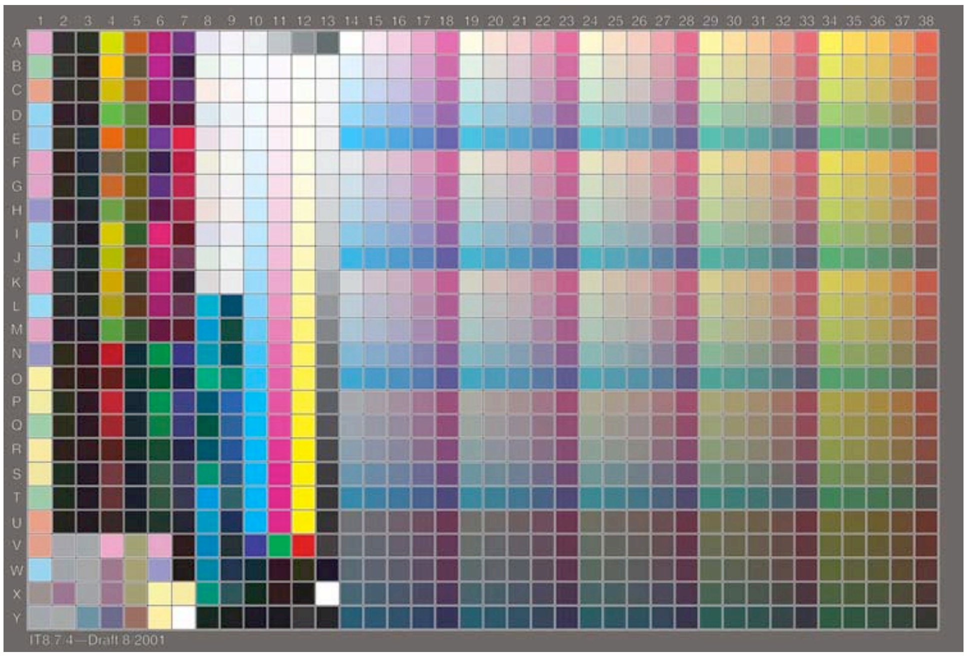


Figure 10. The new IT8.7/4 output target.

## Gamut and Rendering Intent

When working in a color managed workflow with ICC profiles, it is important to remember the "Three Cs" of Color Management [3]. These are calibration, characterization and conversion. Calibration is the process of ensuring that the device in question conforms to a specified state or condition. The profiling process characterizes the color behavior of the properly calibrated device.

Conversion is what is needed for applications to convert between different device color spaces. This is required in order to display or print scanned images or to preview (soft proof) what the printed image will look like on a calibrated and characterized output device. Varying degrees of support for these conversions are available in Photoshop, InDesign, QuarkXPress, Illustrator, FreeHand and PageMaker. Of these, Photoshop 6 and 7 are the most advanced and the easiest to manipulate and probe. In addition, there is some degree of support at the operating system level from Mac OS 9.2.2 (or earlier), Mac OS X and Windows 98/Me/2000/Xp.

The conversion process also depends intimately on the Color Management Module (CMM) [3] of the system. The CMM accepts color data and translates them to another color space using the device profiles. It is like a language or dialect translator that interprets the profile information. Different CMMs will produce different results, even with the same profiles [29, 30]. CMMs are available from Apple, Adobe, Heidelberg, Kodak and X-Rite. Currently, only the Apple CMM is available for Mac OS X.

In order for the CMM and applications to convert between device spaces, it is necessary to recognize that different devices sample different volumes, or gamuts [31], of the full human visible color space. Thus, it is necessary to determine how colors that are outside the color gamut of one device are mapped to the color space of that device. This process is generally called gamut mapping and the strategies for gamut mapping are referred to as *Rendering Intents*. The latest ICC specification [7], version 4.0.0, defines four rendering intents; perceptual, media relative colorimetric, saturation and ICC absolute colorimetric. These are illustrated in Figure 11.

Perceptual Rendering – According to the ICC, the exact gamut mapping for perceptual intent is vendor specific. It generally involves compromises, such as trading off preservation of contrast in order to preserve detail throughout the tonal range. It is most useful for general reproduction of images, particularly pictorial or photographic-type images.

Media Relative Colorimetric – According to the specification, this intent re-scales the in-gamut, chromatically adapted tristimulus values such that the white point of the actual medium is mapped to the PCS white point (for either input or output). It is especially useful for colors that have already been mapped to a medium with a smaller gamut than the reference medium (and therefore need no further compression).

ICC Absolute Colorimetry - The ICC specifies that for this intent, the chromatically adapted tristimulus values of the in-gamut colors are unchanged. This is useful for spot colors and when simulating one medium on another (proofing). Note that this definition of ICC-absolute colorimetry is actually called “relative colorimetry” in CIE terminology, since the data have been normalized relative to the perfect diffuser viewed under the same illumination source as the sample. Profiles do not contain a separate transform for the ICC-absolute colorimetric intent. When this intent is needed, it is generated using the media-relative colorimetric intent and scaling the PCS values by the ratio of the destination profile white point values to the source profile white point values.

Saturation Rendering – As noted by the ICC the exact gamut mapping of the saturation intent is vendor specific and involves compromises such as trading off preservation of hue in order to preserve the vividness of pure colors. It is useful for images, which contain objects such as charts or diagrams.

Since the Perceptual and Saturation rendering intents are vendor specific, only the colorimetric rendering intents for a given device can be meaningfully compared between different profile making vendors. Thus, in the following section, where we discuss profile quality, we employ absolute colorimetric rendering.

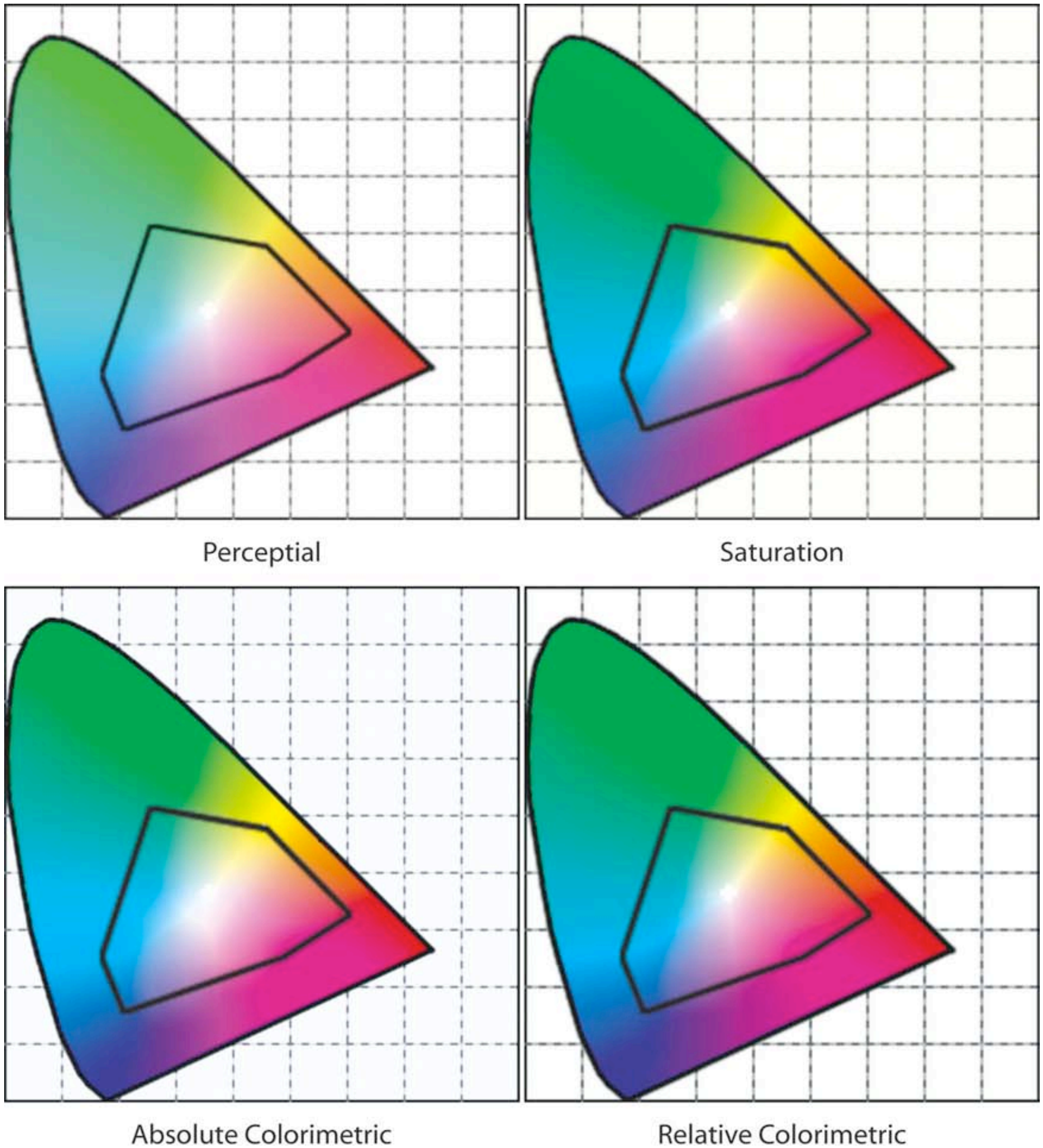


Figure 11. Illustration of different rendering intents for output devices. The outline in the interior represents the printing gamut of a SWOP CMYK device printed on the “standard” coated paper.

## Measures of Profile Quality

Recently [29,30], we introduced some measures for evaluating the quality of ICC profiles. This work was undertaken because no agreed upon method of determination of profile accuracy was available. The distributed document [30], called the *WMU Profiling Review*, provides an independent, scientific assessment of the accuracy of profiles. In the current version of the review, results of 8 packages used to make input, printer and monitor profiles are compared. Updates to the WMU Profiling Review occur bi-annually on January 1 and July 1. Any vendor that would like to be included in future revisions is welcome to contact us [30].

It is important to have a quality measure for ICC profiles, because this indicates how well a device has been characterized and, therefore, how accurate its color is likely to be in a color managed workflow. It is important for software vendors to have a merit figure available and for the industry to agree on how the figure is calculated. Some vendors quote a $\Delta E$ merit figure, and often programs will write out a file with statistics following profile generation. However, there is no indication to tell us how these figures were calculated and whether everybody is measuring the same thing in the same way.

The aim of the WMU Profiling Review is to establish some baseline assessment for ICC profiles and thus assist user choice, raise the standard for profiling software and promote the wider acceptance of ICC color management.

It is inevitable in a survey of this type that some vendors appeared better than others did. However, this should not be taken as an endorsement of any particular product or manufacturer. In addition, whilst accuracy is important other features such as visualization tools and profile editing should be considered when making a purchasing decision.

The assessment of ICC profiles and color reproduction is a complex issue involving everything from color science, psychophysics and image analysis to 'preferred' reproduction styles. The approach adopted in our work is to evaluate the accuracy of profiles using the absolute colorimetric intent. This does not provide an all-encompassing result but does provide an indicative set of metric figures that can be used to make valid cross-vendor comparisons.

Photoshop 6.0.1, Mac OS 9.2.2 and ColorSync 3.0.4 were used throughout this testing.

**Scanner Profiles**

Agfa, FujiFilm and Kodak IT8.7/2 [23] reflection test targets were scanned on a Umax Astra 4000u scanner and profiles were made using normal procedures in the different profiling packages. The methods are detailed in references 29 and 30.

The accuracy obtained for each vendor's program is shown in the table. Manufacturers are ranked in order. Thus, ScanOpen provided the best overall result, whilst the generic profile was worst. How do we interpret these results? A lower $\Delta E$ number is preferable. Profiles with a $\Delta E$ less than 2.0 are very accurate input profiles. The error in these profiles is so small that the differences are probably not even noticeable. For this scanner, the generic profile with a $\Delta E$ of nearly 30 was very poor. Note that just because the generic scanner profile is poor, this does not mean that the Umax scanner is poor. In fact, the scanner is remarkably good for the price.

| *Scanner profile quality* | *Agfa IT8.7/2 Chart* | *FujiFilm IT8.7/2 Chart* | *Kodak IT8.7/2 Chart* | *Final result* | *Price*[1] |
|---|---|---|---|---|---|
| | *Mean (Max) ΔE* | *Mean (Max) ΔE* | *Mean (Max) ΔE* | *Average ΔE* | |
| *ScanOpen 4.0.5* | 0.69 (16.08) | 0.63 (2.51) | 0.69 (7.53) | 0.67 | Bundled |
| *ScanOpen 2.1.0*[2] | 0.99 (15.56) | 1.12 (3.28) | 0.96 (4.99) | 1.02 | |
| *GretagMacbeth ProfileMaker 4.0* | 0.85 (2.87) | 0.99 (10.13) | 1.23 (4.12) | 1.02 | $3,000 |
| *Monaco Profiler 4.0* | 1.19 (9.95) | 0.92 (4.70) | 1.19 (7.10) | 1.10 | $4,250 |
| *Monaco Profiler 3.2*[2] | 4.39(15.00) | 5.04 (8.25) | 4.79 (11.35) | 4.75 | |
| *FujiFilm ColourKit 2.3* | 1.15 (3.72) | 1.23 (4.53) | 1.43 (3.53) | 1.27 | $3,600 |
| *FujiFilm ColourKit 2.2*[2] | 1.17 (3.98) | 1.25 (4.53) | 1.42 (3.66) | 1.28 | |
| *ColorBlind 4.2* | 1.53 (7.13) | 1.95 (8.95) | 1.37 (6.92) | 1.62 | $4,545 |
| *ColorSynergy 4.5* | 2.74 (11.17) | 3.05 (10.09) | 2.79 (10.43) | 2.86 | $1,495 |
| *Kodak Colorflow 2.2.1* | 6.86 (36.33) | 11.20 (59.27) | 6.75 (34.40) | 8.27 | $2,450 |
| *Generic Umax scanner profile*[3] | 29.80 (44.55) | 28.93 (42.03) | 29.38 (46.67) | 29.37 | Free |

[1] The price quoted is for the full product that will make input, monitor and printer profiles.

[2] The ranking of the profile and the price is based on the latest release of the software. Older versions of the software are included for reference only.

[3]The generic profile was provided as part of the Umax scanner driver, Umax VistaScan 3.5.4.

Table 1. Results for scanner profiles.

## Display Profiles

Eight monitor profiles were tested to see if they were able to achieve a requested gamma and a requested white point. A Mitsubishi Diamond Plus CRT was used on a Power Mac G4. Monitor profiles were made using different measuring instruments as shown in the table and if offered a choice, the user requested a $\gamma$ of 1.8 and white point of $D_{65}$. After each profile was made it was selected as the system display profile. Using Photoshop, a series of patches were displayed on the monitor so that the actual white point and actual $\gamma$ of the display could be measured.

Macintosh monitor profiles are distinguished by the use of a 'vcgt' tag that is used to store the correction that converts the factory setting into the user desired settings. Vcgt stands for video card gamma tag and has been part of the MacOS since ColorSync 2.5. In terms of the $\gamma$ value, the monitor profiling results fell in to two camps. Profiles with a vcgt tag produced a $\gamma$ of 1.8 as requested by the user, whilst profiles without a vcgt produced a $\gamma$ of around 3.0, which is the inherent gamma of the display. The difference between the color of the profiled monitor and the desired white point of $D_{65}$ was calculated for each vendor and is shown in the table. The ΔE on a monitor should not be considered as critical as that for a scanner. A monitor profile can be colorimetrically accurate for any white point, even if its white point isn't exactly the same as the target whit point.

| *Monitor profile quality* | *Measuring instrument* | *Achieved gamma (Target was 1.8)* | *ΔE difference in white point from a target of $D_{65}$* | *vcgt tag* |
|---|---|---|---|---|
| *GretagMacbeth ProfileMaker 4.0* | Gretag*Macbeth* Spectrolino | 1.81 | 0.58 | Yes |
| *Monaco Profiler 4.0* | Spectrolino | 1.85 | 0.68 | Yes |
| *FujiFilm ColourKit 2.2* | X-Rite DTP92 | 1.77 | 3.35 | Yes |
| *Mitsubishi monitor generic profile* | None | 2.99 | 3.83 | No |
| *Kodak Colorflow 2.2.1* | None | 2.98 | 3.97 | No |
| *ColorSynergy 4.5* | Spectrolino | 2.99 | 4.07 | No |
| *X-Rite Colorshop 2.6.2* | DTP92 | 1.76 | 5.81 | Yes |
| *ColorSync Monitor Calibrator 3.0.4* | Visual | 2.03 | 12.76 | Yes |

Table 2. Results for Display profiles.

## Printer Profiles

Printer profiles contain three all three rendering intents – perceptual, colorimetric and saturation. Each intent has a forward (Profile Connection Space to Device) and reverse (Device to Profile Connection Space) look-up table. In this test, the forward and reverse parts of the absolute colorimetric intent were evaluated. The methods for testing the forward and reverse modes are detailed in the reference.

Whilst photographic images are normally processed using the perceptual intent, the colorimetric intent is used during the facsimile reproduction of images, during soft proofing, when images are evaluated on a monitor and during proofing when press images are 'returned' to the PCS and printed on a proofing device. The colorimetric intent may also be used when legacy CMYK images are opened. Therefore, although the colorimetric intent is not normally used to process photographic images it is used in number of very significant ICC workflows and as such is a good indicator to use for profile accuracy evaluation.

| *Printer profile quality* | *HP Designjet 20ps*[1] | *Epson Stylus Pro 5000*[2] | *Final*[3] |
|---|---|---|---|
| | *Mean ΔE Range* | *Mean ΔE Range* | *Mean ΔE Range* |
| Gretag*Macbeth ProfileMaker 4.0* | 2-4 | 2-4 | 2-4 |
| *FujiFilm ColourKit 2.3* | 2-4 | 2-4 | 2-4 |
| *PrintOpen 4.0.5* | 2-4 | 2-4 | 2-4 |
| *Monaco Profiler 4.0* | 2-4 | 2-4 | 2-4 |
| *Kodak Colorflow 2.2* | 4-6 | 4-6 | 4-6 |
| *ColorSynergy 4.5* | 6-8 | 10-12 | 8-10 |
| *Generic profile* | 12-14[4] | 12-14 | 12-14 |

[1] HP Designjet using the HP RIP v 1.1 SP2 with HP Premium Photo Paper Glossy, batch C6039A

[2]Epson Stylus Pro5000 using Fiery RIP SPv1.3 in CMYK mode with Epson Photo Paper, batch Y1JL0U744

[3]The final result is an average of four mean ΔE results.

[4]The HP generic profile was part of the HP driver and was called HPGb2_out. The Epson generic profile was downloaded from www.cgs.de/de/icc.html.

Table 3. Results for Printer profiles.

Output profiles were generated and tested for HP Designjet 20ps and Epson Stylus Pro 5000 inkjet printers. The results are summarized in Table 3. It is reassuring to note that, in many cases, vendors achieve similar results across both printers despite each device having a different RIP and print process. The results produced by the first group of vendors, with an average ΔE of 3.0 – 5.0, are very good. In general, the forward process shows greater error than the reverse. It is possible to speculate that the forward test involves printing and measuring and therefore is more subject to instrument variability. The number of grid points used in the profile may also be an issue if, for example, the forward look-up table has more nodes in the look-up table while the reverse table is more sparsely populated.

## Summary

We have reviewed fundamentals of color management and ICC profiles. As we have seen, such a system is needed for today's production workflow with multi source digital color content and cross-purposed output. It provides needed flexibility and is not as dependent on the skills of the users as were previous closed-loop systems. It seems complicated at times, but color management is the only way to provide the controls needed to have critical colors viewed faithfully at all stages and for all purposes.

Managing color is essential for all methods of visual communication, especially color printing, gravure in particular. Obtaining an ICC output profile for the Gravure Press is an essential component of fingerprinting a (gravure) press [31].

## References

1. C. Bak, "Color: From Art To Science", *In-Plant Graphics*, Oct. 1997, p33
2. H. Tolliver, "Quantifying Color", *American Inkmaker*, Oct. 1997, p16
3. R.  M. Adams and J. B. Weisberg, *The GATF Practical Guide to Color Management*, GATFPress, Second Edition, 2000.
4. S. Brues, *Postscriptum on Color Management*, GretagMacbeth, Second Edition, 2000.
5. P. Green, *Understanding Digital Color*, 2nd Edition, GATFPress, 1999, Chapter 7.
6. ICC home page, http://www.color.org.
7. ICC, Specification ICC.1:2001-12, *File Formats for Color Profiles* (version 4.0.0), downloadable from http://www.color.org.
8. D. McDowell, "Color Management: What's New with the ICC?", *Gravure*, April 2002, 50-54.
9. K. C. Williamson, "A Soft Proofing Study", *GATFWorld*, Nov./Dec. 1997, p23
10. M. Samworth, "Toward True Color Management", Part 1-3, *Flexo*, Sept., Oct., Nov. 1997, p74, p64, p57
11. D. C. Rich, "Today's Color Management Systems: The Application of Advanced Technology To the Science of Color", American Inkmaker, Oct. 1997, p33
12. J. Mertens, "Color Management Using CIELab", *Flexo*, Oct. 1997, p60
13. X. Zhang and B. A. Wandell, "A spatial extension of CIELAB for digital color-image reproduction", *JSID*, **5/1**, 61 (1997)
14. P. Green, *Understanding Digital Color*, 2nd Edition, GATFPress, 1999, Chapter 1.

15. P. Pfiffner and B. Fraser, *How Desktop Publishing Works*, Ziff-Davis Press, 1994, Chapter 11.
16. T. E. Schildgen, *Pocket Guide to Color with digital applications*, Delmar, 1998, chapter 3.
17. T. E. Schildgen, *Pocket Guide to Color with digital applications*, Delmar, 1998, chapter 4.
18. J. Widman, Ed., “Flat-Panel Power”, *Publish Extra*, Summer, 1998.
19. *CIE Proceedings* 1931, Cambridge University Press, Cambridge, 1932.
20. CIE, *Recommendations on Uniform Color Spaces, Color-Difference Equations, Psychometric Color Terms,* Supplement No. 2 of CIE Publ. No. 15 (E-1.3.1) 1971, Bureau Ventral de la CIE, Paris 1978.
21. ANSI IT8.7/2-1993 (ISO 12641), *Graphic Technology - Color Reflection Target for Input Scanner Calibration* (see http://www.npes.org/standards/order.html for ordering information), P. J. Groff and Frank V. Kanonik, Test Images for Printing, GATFPress, 1990, p 13.
22. M. Planck, *Verh. d. deutsch phys*. Ges., **2**, 202, 237, 1900. *Ann. d. Physik,* (4), **4**, 553 (1901).
23. ANSI IT8.7/3 *Graphic technology* **–** *Input data for characterization of 4-color process printing*, also published as ISO 12642:1996 (see http://www.npes.org/standards/order.html for ordering information).
24. ANSI IT8.7/4-200X, *Input data for characterization of 4-color process printing of packaging materials*, CGATS STF2 N 088. (Downloadable from http://www.npes.org/standards/newarea/subcommittees.html)
25. J. A. C. Yule, “Theory of Subtractive Color Photography III; Four-Color Process and the Black Printer”, *J. Opt. Soc. Am*., **30**, 322-331 (1940).
26. G. G. Field, “Color Variability Associated with Printing GCR Color Separations”, *TAGA Proceedings*, 145-157, (1986).
27. J. A. C. Yule and F. R. Clapper, “Undercolor Removal Requirements of the Black Printer”, *Graphic Arts Mon*., **32**, No. 5, 153-166, (1960), J. A. C. Yule, “Special Methods of Undercolor Removal”, Graphic Arts Mon., **33**, No. 12, 42-46 (1961).
28. A. Sharma, M.P. Gouch, and D.N. Rughani, “Generation of an ICC profile from a proprietary style file”, J. Imag. Sci. Tech, 46, 26. 2002
29. A Sharma and P D Fleming, “Evaluating the Quality of Commercial ICC Color Management Software”, Presented at TAGA Annual Technical Conference,

North Carolina, April 11-14, 2002. To be included in the *Proceedings* of the Conference.

30. A Sharma and P D Fleming, “Measuring the accuracy of ICC profiles and color management software”, *WMU Profiling Review 2.0*, July 1, 2002. This can be obtained by sending an e-mail to abhay.sharma@wmich.edu with “Subscribe WMU Profiling Review” in the subject line.
31. M. R. Pointer, “The Gamut of Real Surface Colors”, *Color Research and Application*, **5**, no. 3, 145-155 (1980).
32. R. Wiesmann, "Fingerprinting: The Rising Phoenix", Six part series, *Gravure*, June 2002-April 2002. See also http://www.gaa.org/fingerprintcentral.html.