# The New Challenge for Color Management in Digital Printing

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## Abstract

*Since eight industrial leading companies formed the International Color Consortium (ICC) in 1993, color management based on ICC profile has become the de-facto standard for color reproduction in digital printing. Today, ICC profile and color management are hot research topics. However, it will become more difficult to describe the role or benefits of color management for any specific user in the near future because Microsoft, one of the eight founder members of the ICC, quitted the consortium last year and started to develop the next generation color management system based on scRGB rather than Profile Connection Space (PCS) recommended by ICC. This is a new challenge for ICC to greater uptake of ICC color management in the digital printing industry. This paper aims to address this challenge and its impacts on color management in digital printing industry and ICC. It first analyzes the differences between the color management architectures based on PCS and scRGB used by Microsoft's New Generation Windows Color Architecture (NGWCA). It then discusses the new features of Microsoft's NGWCA. Finally, it discusses an opportunity of further R&D for the next generation color management solutions, and proposes some future research and development directions such as color profile format specification, color appearance modeling, gamut mapping methods, and profile verification to address the challenge in the next generation of color management.*

## Introduction

In the last generation (12 years), the research on color management focused on device independent approach.[1,2] This stemmed from the fact that all the color-reproducing devices handle color differently. Color management is a means of ensuring that color data is processed consistently and predictably throughout the entire workflow. In order to create, promote and encourage the standardization and evolution of an open, vendor-neutral, cross-platform color management system architecture and components, the International Color Consortium (ICC) was established in 1993 by eight industry vendors including Adobe Systems Inc., Agfa-Gevaert N.V., Apple Computer, Inc., Eastman Kodak Company, FOGRA (Honorary), Microsoft Corporation, Silicon Graphics, Inc., Sun Microsystems, Inc., and Taligent, Inc. The ICC has published a standard defining the structure of ICC profiles.[13] ICC profiles have been widely accepted in many color imaging software applications and systems. Today, ICC profiles and color management is a hot research topic in digital printing. The intent of the International Color Consortium profile format is to provide a cross-platform device profile format.

However, there are still some problems for the ICC. The ICC Profile specification is often interpreted differently by different vendors.[5,6,9] This results in poor interoperability. The current ICC Color Management Module (CMM) model is also questioned due to the trade-off between the flexibility of color communication and optimization of performance of color reproduction for device to device.[8] The limitation of the current color encoding spaces for PCS is another challenge for the ICC.[4] These issues caused Microsoft, one of the eight founder members of ICC, to quit the consortium last year and started to develop the next generation color management system based on scRGB.

We think that Microsoft's new development is a key milestone for color management. It symbolizes the start of a new era for color management. The impact of Microsoft's new development is one of the key issues discussed in recent ICC annual meetings. This challenge can be transformed into opportunities for us to work together to improve the existing standard for color management. Furthermore, we propose several further research areas for the next generation of color management.

## Device-Independent VS Device-Dependent Color Spaces

### *PCS – Device-Independent Color Model*

The international standard specifying the profile format defined by the ICC[13] is based on an unambiguous reference color space CIE XYZ or CIELAB defined by CIE which is internationally accepted. CIE XYZ or CIELAB has been selected by the ICC to define the Profile Connection Space (PCS). The PCS is used as a reference for color transformation between different devices for consistent color reproduction. Fig.1 shows color transformation methods using PCS as a common interface for color specification between devices.

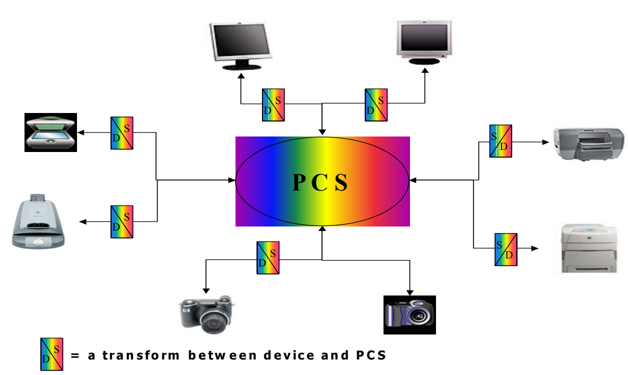


*Figure 1. Workflow based on PCS*

For digital printing, Color Management is the communication of the associated data required for unambiguous interpretation of color content data, and application of color data conversions as required to produce the intended reproductions. The color content may consist of text, line art, graphics, and pictorial images, in raster or vector form, all of which may be color managed. Color management considers the characteristics of input and output devices in determining color conversions for these devices. There are two types of transformations, AToBi and BToAi (where i=0, 1, and 2), defined in the ICC standard. AToBi defines the color transformation from a device to PCS, while BToAi for color transformation from PCS to a device.

The advantage of using PCS is to reduce the complexity of color transformation among devices. If there is no PCS, a separate transformation would be required for each pair of devices. For a system with n devices, it would be necessary to provide a transformation between each device and every other one, a total of n*(n-1) transformations would need to be defined and n new transformations would be defined when a new device is added into the system. By using PCS, only n–1 transformations need to be defined and only one new transformation needs to be defined if a new device is added. The limitations of the PCS are the assumption of color appearance models mix and match without quality degradation, and the difficulty of verifying and editing third-party profiles.

### *scRGB – Device-Dependent Color Model*

The scRGB color space is intended to address the high-end consumer market problems of integrating virtual realistic solutions with more traditional perceptual imaging solutions. It is designed for relative scene radiance, wide dynamic range, extended color gamut, and extended bit precision RGB colors as a color space used in computer systems and similar applications by defining encoding transformations. It is an extension of sRGB and it is considered compatible with sRGB. It complements current color management strategies such as ICC, CMYK, and sRGB, by enabling a method of handling color in the operating systems, device drivers and the Internet that utilizes a simple and robust equipment independent color definition. This color space is well suited for graphics arts RGB workflows, professional digital photography, computer gamuts, and computer graphics. Fig. 2 shows a typical workflow using scRGB. In this diagram, the scRGB is used as a color space based on a raw RGB space with automatic white balancing to D65, optional scene processing and white level determined by the image itself. This allows for easy transformation into sRGB.

The main advantage of scRGB is to allow work in a large gamut, wide dynamic range linear space. This reduces the computation cost for color transformation from device to device by simply using 1D LUT conversion. The increased bit precision allows improvements in banding, contouring, and signal-to-noise issues.

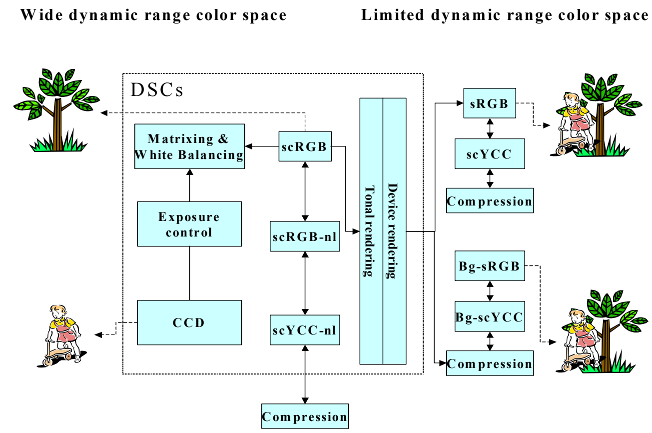


*Figure 2. A workflow using scRGB*

The scRGB color space allows for negative values, which has some significant advantages. Taking an example for gamut encapsulation, one might consider display gamut to be shaped like apples, with the bulk of the color gamut in the bright colors due to the additive nature of the devices. Similarly one might consider printer gamut to be shaped like pears, with the bulk of the color gamut in the shadow colors due to the subtractive nature of the devices.

The key disadvantage of scRGB is the additional bits for each color channel. This causes the performance and memory limitations due to a higher bit precision space.

## Microsoft's New Generation Color Architecture

The next version of the Microsoft® Windows® client operating system, codenamed "Longhorn", which is targeted to be available in 2006, incorporates the new color Architecture[3,4] to better support current and future printing devices and operations. The new architecture adds new features that improve the current Windows Graphics Device Interface (GDI) by using the Longhorn presentation engine, code-named "Avalon", for its graphics processing.

The new Windows Color Architecture which is based on scRGB is able to handle large color gamut, large bit precision, and extended tonal range. Some new features are discussed in the following subsections.

### *Color Infrastructure and Translation Engine*

The new color infrastructure is designed for "Longhorn" XML-based Device Model Profile (DMP) which is easer to understand, verify, and read in comparison with the current ICC Profile format. It also supports legacy ICC profiles. The Color Translation Engine (CTE) provides core system services for color transformation. It provides a single color appearance model and high, wide, and deep color processing pipeline. It provides baseline device models for display devices like CRT and LCD monitors, input devices such as scanner and digital camera, and RGB and CMYK printers. It also provides reference Gamut mapping models to handle color transformation from one space to another based on pictorial, colorimetric, and saturation intents.

### Color Process Pipeline (CPP)

The "Longhorn" color processing pipeline is designed for 16 and 32 bits per channel (bpc) based on scRGB. All color transformation and calculation are performed using 32 bits float number. This enables not only to process high precision camera RAW data with no compromising, but also to transfer colors from the digital cameras to printing devices without losing any color information.

The CPP also supports multi-channel for non-display pipelines such as 16 bpc CMYK and n-channel color with alpha.

### Device Control Infrastructure (DCI)

The DCI provides bi-directional communication and control of color information between system and device drivers. It aims to coordinate color management policy with optimization of device capability and performances. It provides control mechanisms for display, capture and printer devices.

### Color Policy Infrastructure (CPI)

The CPI provides functionality for setting of general, input, and output color policy rules. It also allows users to edit, modify, and delete rules.

## The Opportunity for Color Management in Future

The challenge of Microsoft's new Windows Color System brings us an opportunity for rethinking the standard for next generation color management. The ICC has discussed this issue in its annual meetings in May 2004, November 2004 and Feb 2005. It has closely monitored the new development of color management from Microsoft. There is no significant resolution being reached yet. We have identified several opportunities after studying new Windows Color System and the limitations of the current ICC profiles.

### XML-based Color Profile Format

Extensible Markup Language (XML) allows specific markups to be created for specific data. It is strong in intelligence, adaptation, maintenance, linking, simplicity and portability. We do believe that there is an advantage to specify ICC profile using XML. Since Microsoft has moved in this direction, ICC should consider this in the future revision of its profile specification.

### Visual Model

Color visual modeling for color management is another prospective area for further investigation. There are several color appearance models,[12] but most of them are fairly complex and their suitability for color management is still needed to be comprehensively evaluated.

The development of simpler and really applicable models of color perception and their incorporation into color transformation algorithms for color management to improve performance is also a desirable research goal. This is particularly relevant to the color transformations defined in BToAi anid AToBi (where i=0,1,2) tags in an ICC Profile.

### Gamut Mapping Model

Color output devices are typically capable of producing only a limited range of colors defined as their gamut. An image usually contains colors out of the gamut of the target output device. A gamut mapping model defines the transformation of the image colors to lie within the gamut of a target device. The objective of gamut mapping is to obtain a reproduction that appears identical to an "original" image. The ICC defines fixed PCS as reference color space without specifying its boundary. This causes profile creators and CMMs to guess its boundary differently. A standard gamut-mapping model is really needed to standardize the mapping process in order to maintain color consistence.

### Profile Verification

The verification of ICC profiles is a complex area involving color science, psychophysics, stochastic process and image analysis. Most recent researches focus on tests and measurements of the accuracy of colorimetric transformation of ICC profiles.[7] Evaluation of ICC profiles based only on colorimetric transformation is not enough. The visual judge for appearance of final printouts is critical in most cases.

Several issues are related to verification of ICC profiles, especially, CMYK output profiles. Selection of a test target is important for verifying an ICC profile. Using the same test patches for verification and creation of a profile may be misleading to the users. Different Delta E formula gives different values for the same inputs. How to interpret those results is also a tough task. The accuracy of an ICC profile depends on error propagation of the measuring device. The systematic and random errors are important for judging the performance of the profile. It is possible to minimize those errors through adoption to measure the differences of colors instead of measuring the color itself. While verifying an ICC profile, the different implementation of CMM should also be considered. A practical method for verification of ICC profiles for digital printing is critical for digital printing due to the pressure of time-to-market.

## Discussion and Conclusion

In early this century, digital printing has been growing at a truly amazing rate. As color becomes an engineering process rather than an art, it has also become a significant tool and requirement for digital printing. The just built-up color management standard has been challenging by Microsoft's development of new Windows Color System. This challenge, we believe, would cause the start of research and development for the next generation color management solutions, which have been transiting from single color reference model to multiple color reference models in order to handle more complex work flow for color reproduction. For example, the PCS-based color management workflow may not be applicable to the scenario described in Fig. 2 for the modern RGB printing process.

We regard the challenge as an opportunity for the vendors to work together to improve the existing standard for the next generation color management. In order to overcome the problems in the last generation, we propose some further research areas such as new color profile format specification, color appearance modeling, gamut mapping methods, and profile verification. We expect that this paper may trigger further research in color management for digital printing in the near future.

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## Author Biography

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*He recently presented two focal papers at NIP 20.*