

A System Design for Color Conversions

Jean Aschenbrenner, Reinhard Hohensee, and Yue Qiao

IBM

Boulder, Colorado

Abstract

In a complex printing environment, color conversions occur at many diverse places throughout the system. In an Advanced Function Presentation printing environment, color conversions occur on Postscript data, on image data and on text and graphics. It is particularly important to produce consistent colors across all data paths for both device-dependent and device-independent color spaces.

As an example, an EPS file may be RIPped in the Infoprint Manager (IPM) print server and converted to image which is sent to the printer. Or the EPS may be imbedded in an Intelligent Printer Data Stream and RIPped in the printer. Thus, color conversion within the EPS might occur during application design (using an ICC Profile), within the IPM print server or inside the printer. The color conversion task includes handling SWOP and Euroscale as well as controlling toner saving.

This paper will discuss:

- ◆ Methods used to make the color conversions more consistent
- ◆ Multiple methods which may be used to control color conversions
- ◆ Verification procedures

Introduction

Advanced Function Presentation (AFP) environments are complex. There are many sources of data, many different color spaces and many places where the color can be converted.

This paper discusses our experiences in developing color management for the high-end color printer Infoprint Color 130 Plus. The diagram to the right shows the data paths through an AFP system. The Intelligent Printer Data Stream (IPDS) is used to send data to the printer. Print Services Facility (PSF) merely repackages data into IPDS data. Colors in the data stream may be converted to printer CMYK in one of several places:

- ◆ Application generation software using the ICC Profile
- ◆ Infoprint Manager (IPM) print server:
 - PostScript RIP
 - Image Transform
- ◆ IPDS rasterizer (RIP) in the printer
- ◆ PostScript RIP which is part of IPDS rasterizer

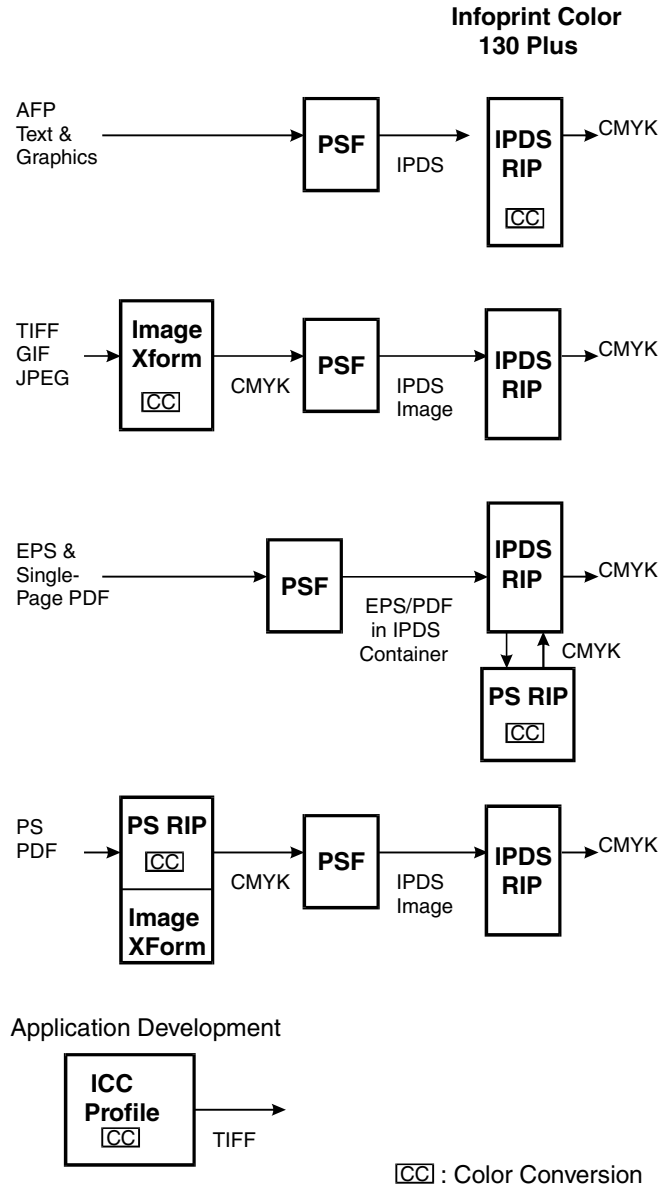


Figure 1. AFP Data Flows with Color Conversions

The AFP system handles several different types of data:

- ◆ Traditional IPDS data: text, graphics, bilevel image

- ◆ TIFF/GIF/JFIF image that is converted to IPDS full-color image by the Image Transform
- ◆ PostScript/PDF which is converted to IPDS full-color image using the PostScript RIP in IPM
- ◆ EPS/PDF which is wrapped in IPDS object containers and processed by the PostScript RIP in the printer.

The goals of this color management system are:

- ◆ To render device-independent colors accurately (within the limits of the printer's gamut).
- ◆ To render colors consistently regardless of where the color conversion occurs.
- ◆ To perform color conversions without adversely affecting performance.

Color Conversions in General

In IPDS data, the following color spaces are supported:

- ◆ Device CMYK
- ◆ SMPTE-C RGB
- ◆ CIE Lab
- ◆ IPDS named colors (about 20, not discussed here)

Note that server-level AFP (which includes support for TIFF, PDF, ...) supports a much wider range of color spaces but conversions are done before the data is sent to the printer. In addition,, the PostScript RIP in the printer supports all the normal PS color spaces.

The PostScript RIP supports the following spaces for full color:

- ◆ DeviceCMYK
- ◆ DeviceRGB
- ◆ CIEBasedABC
- ◆ CIEBasedDEFG

The CIEBased spaces include a color profile which tells how to convert the input color space to CIEXYZ. A color rendering dictionary (CRD) for Infoprint Color 130 Plus is then used to convert from CIEXYZ to printer CMYK.

The ICC Profile for Infoprint Color 130 Plus converts from CIE Lab with a white point of D50 into printer CMYK. By using a second ICC Profile which converts from the input color space to CIE Lab, all input color spaces are supported.

A color conversion into CMYK printer space involves some setup calculations (converting white points, linearizing, ...), a color look-up table (LUT) , and post-LUT calculations (transfer curves, CMYK to C'M'Y'K' conversions). The LUT is usually used to convert from a 3-component color space (e.g. Lab, RGB) to a 4-component space (CMYK). It is implemented as a 3-D array. To limit the amount of memory used for the array, a sparse array is used. Common sizes that Infoprint Color 130 Plus uses are 17x17x17 or 33x33x33. For 4-component input spaces, a 9x9x9 array is sometimes used. To convert a color which does not fall on a node of the array, interpolation is used.

A critical part of the system is the generation of the color look-up tables. For CIE Lab, this is a complicated process involving:

1. Analyzing halftone screens for primaries and linearizing tone reproduction curves
2. White point conversion
3. Applying gray component replacement by using UCR and UCA
4. Lightness compression and gamut mapping
5. Interpolation to create the LUT
6. Installing the LUT in color conversion code
7. Testing

This process requires printing color swatches and measuring output. Note that 'printing colors' is a significant task when developing a new printer. It may not be possible early in the development cycle. It depends on a printer which can print reliably, on halftone screens that have been finalized, and on the existence of a system for properly calibrating the printer. It requires a well-tuned, well-calibrated printer with the proper paper.

Several guidelines were followed to ensure that the look-up tables are essentially the same everywhere:

1. The same input range for L, a, and b is assumed.
2. The same table size is used (e.g. 33x33x33).
3. The tables use the same increments between nodes.
4. The tables are generated using the same algorithm for a given rendering intent.
5. The tables are generated for the same 'standard' media white point.

Much of our testing was designed to compare color conversions across multiple paths. The data tested included color swatches (e.g. MacBeth Chart and regular sparse grid of full color space) as well as photographic images. Some of the techniques we used included:

- ◆ Print rectangles; measure output
- ◆ Display output using PhotoShop and ICC Profile; read CMYK values
- ◆ Modify conversion code to print out CMYK values
- ◆ Psychophysics tests: print photographic images; many observers visually compare pairs of output with original image

CIE Lab

CIE Lab is the basic device independent color space supported by Infoprint Color 130 Plus. CIE Lab was selected since it is more uniformly linear than CIEXYZ. In AFP data it is assumed to have a white point of D50. The user is responsible for converting the input CIE Lab colors to this white point. The basic LUT, which is used everywhere in the system, converts from CIE Lab into printer CMYK.

Input CIE Lab colors in the IPDS data stream go directly into this LUT. If a different white point is specified in a TIFF file or PS data stream, the input data would need to be converted to have this white point before the LUT is used.

The CIELab LUT is used in essentially identical form for many conversions.

- ◆ In IPDS rasterizer & Image Transform, it is used directly.
- ◆ In PS:
 - Input color profile converts input to CIEXYZ.
 - CRD converts CIEXYZ to have D50 white point.
 - CRD converts this CIEXYZ to CIELAB
 - CRD LUT is used to convert to printer CMYK
- ◆ Using ICC Profile:
 - Input color profile converts input to CIELab with D50 white point.
- LUT is used to convert to printer CMYK

The Infoprint Color 130 Plus system supports two rendering intents:

- ◆ Relative Colorimetric
- ◆ Perceptual

Rendering intents define the approach used to map out-of-gamut colors into the available printer gamut. The rendering intent can be specified within the PS data stream, in the IPM user interface, or in the GUI for application development tools like Quark or PhotoShop. In the Infoprint Color 130 Plus color conversions, gamut mapping is incorporated into the look-up table. Therefore, there are two versions of the CIELab:CMYK LUT, one for each rendering intent.

There is no way to specify rendering intent in the IPDS data stream. This is not a problem since IPDS text, graphics and bilevel image do not need to be converted using a perceptual intent so a default of Relative Colorimetric is used. Full color images are color-converted before being sent to the printer and there are controls available when they are being converted.

RGB

RGB which is specified in IPDS data is assumed to be SMPTE-C with a white point of D65. Conversion of RGB in IPDS data involves:

1. Linearizing the R,G,B by raising to the power 2.2
2. Converting to CIEXYZ using a 3x3 matrix
3. Converting to a white point of D50
4. Converting CIEXYZ to CIELab
5. Using LUT to convert Lab to CMYK.

For performance improvement, steps 1-5 are collapsed into a single LUT. This LUT is used by both the IPDS rasterizer and the Image Transform, so RGB conversions are consistent in these two places.

However, we did not achieve complete color consistency with RGB color because PostScript uses DeviceRGB which is device-dependent. PostScript conversion of RGB is simple: $c=1.0$ -red; $m=1.0$ – green; $y = 1.0$ – blue; $k = \min(c,m,y)$ where red, green and blue are the values obtained after black generation BG(k) and undercolor removal UCR(k).

CMYK SWOP & Euroscale

Infoprint Color 130 Plus supports CMYK SWOP and Euroscale because it may have customers with input that was created in these color spaces. A customer may have a TIFF image or an EPS which uses SWOP. He may be including it in a job which was created using CIELab. So the SWOP/Euroscale designation is on an **object** basis, not a job basis.

The user interface for IPM's PostScript RIP and Image Transform allows the user to specify SWOP or Euroscale. In IPDS data, the object container which holds the EPS/PDF data can have an attribute attached which indicates that CMYK colors are SWOP or Euroscale. Legacy IPDS text, graphics, and image were not created using SWOP/Euroscale so the IPDS architecture does not include a way of specifying SWOP/Euroscale for them.

To support SWOP/Euroscale, the Infoprint Color 130 Plus has two LUTs which are 4D to 4D transformations. They take a CMYK color and convert it to C'M'Y'K'. The conversion involves only LUT access and interpolation. In the Image Transform, the conversion is done directly. In both of the PS RIPs, if SWOP or Euroscale is indicated, after the normal PS color conversion occurs, a call is made to a function which is an extension to the PS RIP. This function uses the same LUT as the Image Transform and converts CMYK to C'M'Y'K'. This conversion is done only if the original color space was CMYK.

Toner Saver

The Infoprint Color 130 Plus supports toner saver. The purpose is to use less ink and thus to decrease the cost of printing. This is a **job** level attribute and applies to ALL data which is printed. In IPM, the PS RIP and Image Transform have access to this attribute. In IPDS architecture, there is a command which controls toner saver.

Two levels of toner saver are supported: NONE and SOME. Actually, when the LUTs for Lab and RGB are created, as much black ink as possible is used while still producing accurate color. These LUTs are used when NONE is specified. The goal for SOME toner saver is to have minimal impact on color accuracy yet to use additional black ink.

Typically, toner saver would be implemented after converting the original color into CMYK. A 4D-to-4D LUT with interpolation would be used to convert from CMYK to C'M'Y'K' (toner saved). This would adversely affect performance. This approach is used only if the input color space is CMYK. When it is used for CMYK data in the PS RIP, the implementation is the same as that for SWOP.

For other color spaces, SOME toner saver is incorporated directly into a new version of the LUT. So, for instance, in PostScript there are four CRD's:

- ◆ Relative Colorimetric without Toner Saver
- ◆ Relative Colorimetric with Toner Saver
- ◆ Perceptual without Toner Saver
- ◆ Perceptual with Toner Saver

The appropriate CRD is selected by control logic. Similarly, the Image Transform has four CIELab LUTs. The IPDS rasterizer has only two since it does not support the Perceptual rendering intent.

For RGB conversions, the IPDS rasterizer and the Image Transform each have two LUTs for converting SMPTE-C to CMYK (with and without toner saver). The PS RIP handles toner saver for RGB by allowing control of Undercolor Removal (UCR) and Black Generation (BG).

Toner saver is not supported in the ICC profile. Nor is it supported for SWOP/Euroscale color spaces.

Conclusion

To achieve consistency between color conversions in different parts of the system, the Infoprint Color 130 Plus uses essentially the same color look-up table for each color conversion.

To aid performance during color conversion, multiple steps in the color conversion process are collapsed into one color look-up table. In IPDS data, text and graphics color conversions are simplified by allowing a limited number of input color spaces. Performance is also controlled by doing color conversions offline, in the Infoprint Manager.

To satisfy customer requirements, the Infoprint Color 130 Plus supports SWOP, Euroscale and toner saving.

References

1. Adobe Systems Inc., *PostScript Language Reference Manual*, Addison Wesley, 1990.
2. IBM Corporation, *Intelligent Printer Data Stream Reference*, S544-3417-05, 1996.

Biography

Jean Aschenbrenner is a senior software engineer in the Printing Systems Division of IBM in Boulder, CO. She joined IBM in 1984 and did VLSI and card design for the printer control engine. Since 1993 she has been working on microcode and is part of the rasterizer team for the high-end common control unit. She has coordinated work on color management on IBM's high-end color printers.

Jean received her B.A. in Mathematics from Mount Holyoke College (1970), her M.A.T. from Wesleyan University in Connecticut (1971), her B.S. in Electrical Engineering from Colorado University (1983) and her M.S. in Computer Science from National Technological University (1994). She is a member of Phi Beta Kappa honor society and of IS&T.