Exploiting Pseudocolor in ICC Workflow Analysis

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Abstract

An ICC device profile contains information that describes a device's color behavior. A profile contains separate lookup tables that may be used depending on how image data is to be rendered. An ICC device profile contains lookup table structures for perceptual, colorimetric, and saturation rendering intents. This paper describes how the one-dimensional and multi-dimensional lookup tables within these structures can be systematically altered to create a "probe" output profile. When the probe profile is used in a color transform, wrong colors are deliberately produced, but in a systematic way, so that an investigator can visually check which color lookup table (rendering intent) within the profile is actually applied. Such a profile can be used as a workflow analysis tool and in evaluating profile quality where it is necessary to ensure that the system is using a specific lookup table.

In printer-based workflows such as prepress proofing, a number of color conversions take place. The probe profile creates specific output colors and/or lightness levels, so that one can determine which rendering intent is used for rendering (when outputting to a device) and which is used for proofing (when simulating the colors produced by one device on another).

Data is presented to show how a probe profile can be engineered and how it can be used to evaluate sequences of color transforms in commercial software applications. In particular the following applications are analyzed: –Adobe Photoshop, GretagMacbeth iQueue, and EFI's Best Designer Edition Color RIP.

Introduction

The principles of a color-managed workflow are now well established[1]. Color management is a way of controlling color in digital imaging using specialized software, hardware, and some systematic procedures. A color management system uses input and output device profiles to convert device dependent image data into and out of a central, device independent profile connection space (PCS). Device characterization information is stored in profiles such that an input profile provides a mapping between input (usually RGB) data and the PCS, and an output profile provides a mapping between the PCS and output (usually CMYK) values. An ICC device profile thus contains data describing relationships between device signals (such as RGB or CMYK) and the colors produced or sensed by the device (in the PCS, i.e., CIE XYZ or L*a*b* space). The International Color Consortium (ICC) specifies the profile's data format. Each profile contains a number of data records, called "tags." Some of the tags, such as those containing color lookup tables, provide data used in color transformations.

To transform colors from one device to another, gamut mapping is often required[2]. For example, when we transform colors from an input device (transparency scanner) to an output device (printer) a larger color gamut must be mapped to a relatively smaller color gamut. Depending on the situation, different gamut clipping or compression methods are used. These are known as rendering intents, and in ICC terminology there are four "official" intents—perceptual, colorimetric (relative and absolute), and saturation. Different rendering intents impart different "looks" to the reproduced results.

An ICC device profile (such as a printer profile) contains lookup tables for converting from device signals to L*a*b* (A2Bx tags), and tags for converting to device signals from L*a*b* (B2Ax tags). (Some profiles use XYZ instead of L*a*b*.) Today's profiles contain three sets of these lookup tables, which are used for different rendering intents—A2B0 and B2A0 (perceptual), A2B1 and B2A1 (colorimetric) and A2B2 and B2A2 (saturation). This was not always the case. For example, in one early version of the ICC profile format specification, scanner profiles had only one lookup table structure (denoted by the A2B0 tag). By 1998, A2B1 and A2B2 tags for the scanner profile were mentioned in the ICC specification but were "undefined-". In the 2001 major revision of the ICC specification (Specification ICC.1:2001-12, Version 4.0), the A2B0, A2B1 and A2B2 tags for the scanner and other profiles were explicitly defined. The current ICC specification (Specification ICC.1:2003-09, Version 4.1.0) now allows all

profiles to contain sets of lookup tables for different rendering intents via new data types, known as lutAtoBType and lutBtoAType. A profile that complies with a pre-Version-4.0 ICC specification is commonly called a "Version 2 profile" since the major revision field within such a profile's header has the value 2.

Modern color management workflows consist of complex color pathways involving RIPs, soft proofing and press proofing configurations. Typical workflows involve a number of profiles used sequentially. Often application software and a CMM are involved in processing image data.[3,4] When profiles are concatenated using software and underlying color management modules (CMM) it is useful to know which rendering intent lookup table is being used at each stage of the process. The profile described in this research can be used to probe which parts of the profile are actually being used in a color managed workflow and to determine whether the system is actually carrying out the user's intent, as specified via the software's user interface. This research describes a procedure for creating a special "probe" profile that dramatically alters the color of the image in a systematic way, allowing a user to determine which lookup tables are used in processing image data.

In a proofing scenario for example, a press profile is used, followed by a proofer profile. By using a probe profile one can determine which rendering intent is used in outputting to press, and which is used for simulating the press color output on the proofing device.

Researchers and practitioners often need to evaluate the quality of profiles.[5] Before assessing the quality of a profile it is necessary to understand how the profile is used in a particular workflow. For example, a colorimetric accuracy test may be conducted, and in this instance it is essential to verify that the absolute colorimetric rendering intent is being used to process image data.

A probe profile, as described in this research, is useful for investigating CMM functionality. Generally, two or more profiles are presented to the CMM. It is of interest to understand how the CMM applies user instructions in choosing which lookup table to use in each of the concatenated profiles. The Apple CMM, for example, uses the rendering intent specified by the first profile to color match to the second profile, the rendering intent specified by the second profile to color match to the third profile, and so on through the series of concatenated profiles.[6] So we see that in this CMM, the rendering intent can appear to "flow forward." A probe profile can be used to determine such details in instances of undocumented CMM behavior.

An ICC profile contains a header, a tag table, and tag data. One of the entries in the profile header is a rendering intent field. The rendering intent in the profile header can be used to control which lookup table is to be used in a transform. Often application software, such as Photoshop, ignores the setting in the profile header and provides the user with a GUI selection for rendering intent. A probe profile can be used to verify whether an application is ignoring or honoring the rendering intent tag in a profile header.

Procedure

This research describes a procedure for creating a special "probe" profile. This profile syntactically conforms to the ICC specification, but has been specially constructed to create dramatically altered colors. The probe profile creates specific output colors and/or lightness levels when various combinations of the rendering intent tables are used.

In an ICC profile, color transformation is done via a lookup table (A2Bx or B2Ax tag), which may be in either the Version 2 format (lut8Type or lut16Type) or the Version 4 format (lutAtoBType or lutBtoAType), as shown in Figures 1 and 2.

Both Version 2 and Version 4 lookup table tags consist of multiple components, which provide parameters for color transformations. For example a profile can contain color conversion matrices, 1-dimensional lookup tables, and multi-dimensional lookup tables. In this research, a profile is constructed that deliberately produces wrong colors, but in a systematic way, so that an investigator can visually check which lookup table (rendering intent) within the profile is actually being used.

There are many significant differences between Version 2 and Version 4 ICC profiles. Although the details are outside the scope of the present discussion, both specifications allow for a number of components that may or may not be used in a given color transformation. The Version 2 data structure, Figure 1, has a matrix, a set of 1-dimensional lookup tables, a multi-dimensional lookup table (CLUT), and a final set of 1-dimensional lookup tables.[7] The Version 4 "forward" (A-to-B) data structure, Figure 2, has a set of 1-dimensional lookup tables, a matrix, another set of 1-dimensional lookup tables, a multi-dimensional lookup table, and a final set of 1-dimensional lookup tables. The Version 4 "inverse" (B-to-A) structure has the same blocks cascaded in the opposite order, improving composite transform accuracy when the forward and inverse transforms of a profile are cascaded.

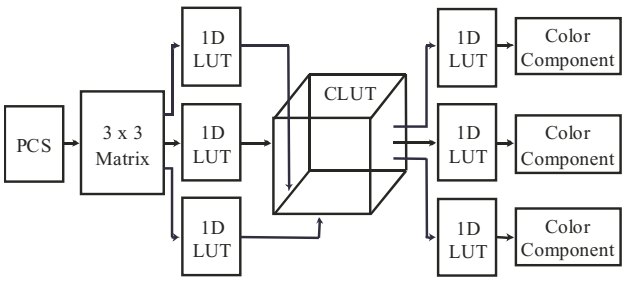

Figure 1. Version 2 ICC profiles have a number of components that can be used for color transformations. Parts of this lookup table structure were systematically altered to create the "probe" profile.

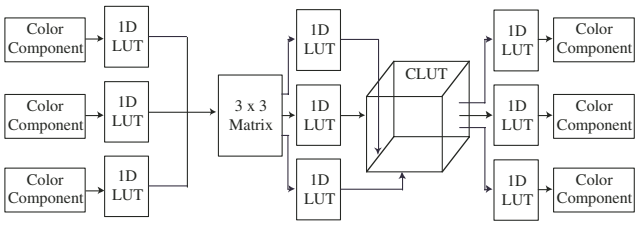

Figure 2. Version 4 ICC profiles can use a new lookup table data type (lutAtoBType) that provides another set of 1-dimensional lookup tables. An inverse form (lutBtoAType) is also provided, in which the same blocks are cascaded in the opposite order.

The aim of this research is to produce a profile with altered tags that clearly indicate which rendering intent is used in the color transformation. To create this profile, the multi-dimensional lookup tables in the B2Ax tags of a Version 2 profile were constructed so as to pass the (inverted) PCS L* channel data directly to all four CMYK output channels. This approach has been used in other situations such as in the creation of duotone imagery.[8] In addition, the B2Ax output 1-dimensional lookup tables were arranged such that only one of them (a different one for each intent) passes its input through (identity mapping), and the others are set to zero. The mappings are diagrammed in Figure 3. When used in a workflow, this profile creates a cyan image when the B2A0 table (perceptual intent) is used, a magenta image when the B2A1 table (colorimetric intent) is used and a yellow image when the B2A2 table (saturation intent) is used. This mapping of rendering intent to output color is somewhat arbitrary, of course, and may be changed to suit the user. Mapping the lightness information in this manner retains a semblance of the original image while creating a monotone rendition in a dramatic and thus immediately recognizable color.

It is possible to repeat the procedure for the device to L*a*b* (A2Bx) lookup tables. However, if data is processed sequentially through the B2Ax and the A2Bx lookup tables of the same profile, as in a proofing scenario, it will be difficult to interpret the image due to the compound effect of the specially altered lookup tables. Therefore, we have adopted the following strategy. One of the 1-dimensional output lookup tables in the A2Bx tag controls the PCS L* channel. This lookup table was variously set to produce output in the range 60-100 L*, 30-60 L*, 0-30 L* for A2B0, A2B1, A2B2 respectively. Thus, the three 1-dimensional output lookup tables in the A2Bx tag created a light (A2B0), medium (A2B1) and dark (A2B2) image. By altering the 1-dimensional output lookup tables in the A2Bx tag we change the lightness of the image and this is clearly evident in the superimposed gamut plots for this profile, Figure 4. Here, the multi-dimensional color lookup tables in the A2Bx tags are based on color measurements of a real device.

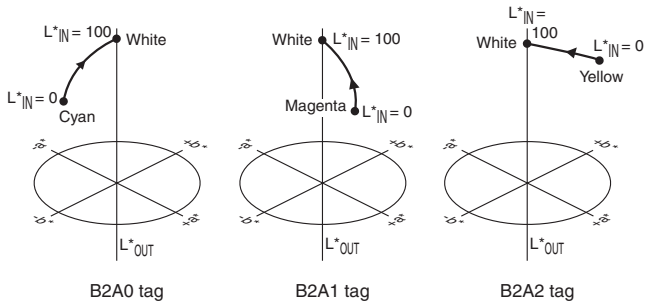

Figure 3. The probe profile's B2Ax tags map input lightnesses to pure C, M, or Y tints, depending on the rendering intent.

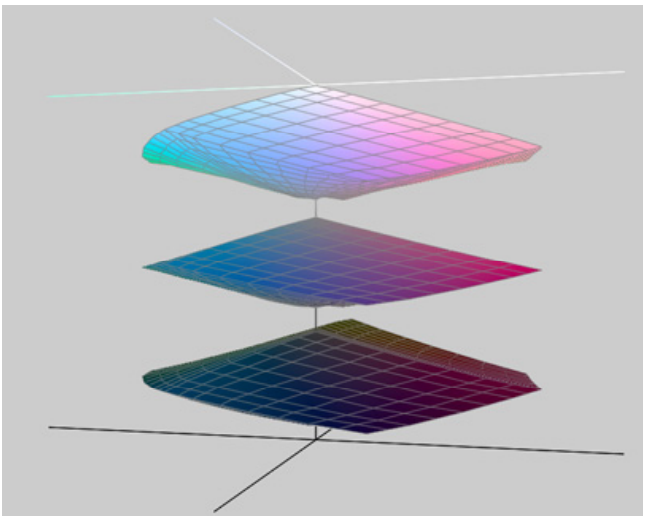

Figure 4. Gamut plots from the A2B0 (top), A2B1 (middle) and A2B2 (bottom) lookup tables are superimposed to demonstrate how the 1-dimensional tables responsible for PCS L can be used to make images of different lightness.*

Thus by interpretation of the primary color (cyan, magenta, yellow) and the lightness level (light, medium, dark) of a processed image, a single profile can be used to simultaneously probe which rendering intent is used in the A-to-B and B-to-A transforms of a proofing workflow.

Experimental Results

In a typical workflow there may be a number of profiles and a number of color transforms, in which a profile may be used more than once. For the purposes of this discussion we assume a situation involving an input profile, a press profile and a proofer profile. A probe profile was created using the procedure described above. The probe profile was used to determine which rendering intent is used for the rendering path (when outputting to a device) and which is used for the proofing path (when simulating one device on another).

A probe profile was used to analyze three commercially available software applications: — Adobe Photoshop, GretagMacbeth iQueue and Best Designer Edition RIP.

Adobe Photoshop

One of the entries in the header portion of an ICC profile is a rendering intent field. The rendering intent in the profile header can be used to control which lookup table is to be used in a transform. Application software such as Photoshop additionally provides the user with a GUI selection for rendering intent. The probe profile was used to determine whether Photoshop uses the rendering intent set in the profile header. The rendering intent tag in the header of a printer profile was changed, but this did not affect the image created in the application. The probe profile thus showed that Photoshop ignores the rendering intent tag in a profile header.

Further tests were done to establish which A2Bx lookup table was used in Photoshop during soft proofing where a CMYK image is converted via the A2Bx lookup table for display on a monitor. To do this CMYK images were displayed and a note was made of whether the image was cyan, magenta or yellow and whether it was light, medium or dark. Table 1 shows that in earlier versions Photoshop used the same lookup table in the A-to-B and B-to-A transform. In other words, Photoshop simply used the inverse of the B-to-A transform. Later versions of Photoshop are "hard-wired" to always use the A2B1 (relative colorimetric intent) lookup table for the A-to-B transform.

Table 1. Which Rendering Intent Does Photoshop Use to Preview CMYK Images?

Photoshop 5.0.2	Inverse of B2Ax transform
Photoshop 5.5	Inverse of B2Ax transform
Photoshop 6.0.1	Relative colorimetric intent
Photoshop 7.0	Relative colorimetric intent
Photoshop 8.0 (CS)	Relative colorimetric intent

GretagMacbeth iQueue

GretagMacbeth iQueue 140 (v1.02) is a workflow tool for the automated application of profiles to images and PDF files. The probe profile was used to show that once again the application, in this instance iQueue, ignores the rendering intent tag in the profile header.

In the iQueue application there is the ability to set only two rendering intents—one for the input profile and the other for the output profile. In a typical printer scenario, there are however three profiles – the input profile, the press profile and the proofer profile. There are four color transformations in a press proof scenario—input profile (A2Bx), press profile (B2Ax), press profile (A2Bx), and proofer profile (B2Ax). The probe profile was used to determine that the rendering intent set in the application for the "input profile" governs the transform used in the B2Ax conversion of the press profile. The rendering intent set for the "output profile" governs the rendering intent used in both the press profile (A2Bx) and the proofer profile (B2Ax) transforms. Thus we see that some assumptions must be made when we are trying to configure four color conversions but have only two places where we can specify the rendering intent.

Best Designer Edition RIP

Best Designer Edition 3.0.1 is a RIP tool that can be used to print and proof images on various printers including Epson and HP inkjets in CMYK mode. The probe profile was used to show that the Best RIP ignores the rendering intent tag in a profile header, in common with the other applications described above.

In the Best RIP there is the ability to set only two rendering intents—one for RGB (the input profile) and the other for CMYK (the output profile). Consider again a typical press proofing scenario. The sequence of color transformations in a press proof scenario is input profile (A2Bx), press profile (B2Ax), press profile (A2Bx), and proofer profile (B2Ax). In the Best RIP these are described as the RGB (input) profile, the CMYK (press) profile and the Paper (proofer) profile. The probe profile was used to determine that the rendering intent set in the application for the RGB profile governs the transform used in the B2Ax conversion of the press profile. The rendering intent set on the CMYK profile governs the rendering intent used in both the press profile (A2Bx) and the proofer profile (B2Ax) transforms. Thus we see that the Best RIP, in common with the iQueue application uses the rendering intent specified for a profile to color match to itself and to the next profile in the sequence. We see that this procedure requires the user to make assumptions when trying to configure four conversions using a software GUI that only provides two places in which to specify the rendering intent.

Conclusions

This research describes an experimental method and tool, where a single profile is used to probe both the A2Bx and B2Ax lookup tables in an ICC profile. A number of parts of a profile are constructed in a systematic manner to create a diagnostic tool that can be used to analyze and verify rendering intent usage in color management workflows. The probe profile was used to demonstrate that several widely-used color processing applications ignore the rendering intent tag in an ICC profile header.

Our study has shown that a probe profile can be used to reveal how the functionality of CMYK image preview in Adobe Photoshop has changed from Photoshop 5 to Photoshop CS. We also found that software applications such as GretagMacbeth iQueue and Best Designer Edition color RIP use the rendering intent specified in the GUI and

associated with the first profile to determine which lookup tables from the first and second profiles in the chain will be incorporated into the composite color transform.

An example probe profile is being made available to users via the ICC web site (www.color.org).

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Biographies

Abhay Sharma received his B.S. degree in Imaging Sciences from the University of Westminster, UK and a Ph.D. in Physics from King's College, London. He worked in the Colour & Imaging Technology research group at FujiFilm Electronic Imaging, UK before joining Western Michigan University as an Associate Professor in color imaging. He is a member of the ICC and chairman of the ICC working group that is looking at the issue of profile quality assessment. He has recently published a book entitled *Understanding Color Management*, and is a member of IS&T and the Optical Society of America.

John Dalrymple received the M.S.E.E. degree from Oregon State University in 1981. At Tektronix' Color Printing and Imaging Division from 1990 to 1998, he developed color management tools and utilities, as well as process control firmware for phase-change inkjet printer products. In 1998, he joined the Digital Imaging Systems department at Sharp Laboratories of America, Inc., where he develops algorithms and tools for color profile generation, profile quality evaluation, and color workflow analysis. He is a member of IS&T and the ICC Profile Assessment Working Group.