

Supporting Both Preferred and Predictable Reproduction with ICC Profiles

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Color management using International Color Consortium (ICC) profiles today can fail to provide the user with predictable results due to the lack of specification of the details of the color management process. Ongoing work in the ICC is aimed at correcting this limitation by specifiying the baseline process by which color management is accomplished. However, the need to provide a standard mechanism for preferred reproduction continues to elude us. This is because many of the decisions that determine the result of reproduction are inherent in the choice of profiles. What is called for is an extension to the profile definition that provides for the necessary decisions to be made later on in the workflow. A model is proposed that splits the work of the ICC profile into two parts. Preferred reproduction is supported by measurement-only profiles. Predictable reproduction is handled by standard ICC profiles.

Conflicting Needs

One need look no further than previous Color Imaging Conferences to see the tension between the need for preferred color reproduction and the need for predictable reproduction. Several authors have tried to find solutions within the ICC architecture to meet both needs at once. Robert Poe argued for basic appearance preserving profiles and special profiles for printing and publishing.[1] Jack Holm proposed three possible models "in which proprietary approaches and conventional color management can be integrated." The paper discusses many of the ideas that are discussed below, such as on-the-fly profile generation, measurement only profiles, and a two-stage model.[2] He concludes, "There is a need to obtain consensus on the exact nature of an open systems structure that allows both proprietary and open approaches to be employed."[3] This paper proposes a model whereby the tension between the two needs is resolved and proprietary and open systems work in harmony.

The Mechanics of Profile Creation

Device profiles contain the data needed for a color management system (CMS) to do the color mapping. This information is in the form of color transformation data that is determined by profile building programs. The color transformation data is constructed by a process that combines sets of input and output color values along with the expected viewing conditions for images in a manner that produces the best result as determined by the manufacturers of the profile building program. Depending on the device being profiled, either the input or the output values are physical measurements. For a printer, the input values are the command signals sent to the device and the output values are measurements of the color that results when said command values are sent to the printer. For a scanner, the input values are measurements of colored patches on a target, the output values are the digital values obtained when scanning said target.

The input and output data are used to construct a color transform. Typically, the transform either takes data values from device control space to a color appearance space or in the opposite direction. For example, the ICC uses a mutually agreed-upon color appearance space based upon the use of CIELAB or CIE XYZ values under a well-defined viewing condition. This is known as the "Profile Connection Space." Construction of a color transform requires the selection of a color appearance space and of a color appearance model. There are several appearances spaces and even more appearance models to select from. Furthermore, both appearance spaces and appearance models are in a state of rapid evolution. It is not clear when or if this volatility will stabilize.

There are many different ways to produce and to represent the color transform in a device profile. Some examples include: a color look-up table, a polynomial function derived from a least-squares fit, or a sequence of single- and multi-variate transforms of arbitrary complexity. Since one of the goals of the profile-building program is to reduce the overhead of the CMS during the processing of an image, the transform data is then heavily optimized. The profile building process often includes special, proprietary functionality. The special functionality may be to implement a more accurate mapping from device input space to appearance space or to provide a preferred reproduction of the input device space. Because of all of these factors, profiles that are built for the same device and are produced by different profile building program may yield very different results when used in any specific CMS.

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In order to serve a useful purpose, profiles need to have a standard format. This allows different CMS's to be used with any profile and it also allows profiles built with different profile building programs to be used together within a CMS. The ICC has been instrumental in defining and standardizing such a format to allow for the interchange of images from one computer to another.

Workflow

The ICC profile format is based on the assumption that the person who placed the image data into its file had the best notion of what the desired appearance of that image should be. This person is considered to be the "author" of that image. Note that the author of the image is not necessarily the photographer.∗ The author is also assumed to know the best color appearance space for the image and the best mathematical model for mapping device data into appearance space. This is illustrated in Figure 1, below. We see that a photographer captures the image. Later, an author (who may be someone other than the photographer) previews the image on a display. The author saves the image in a file and tags it with an ICC device profile. If the image came from a digital camera, that might be the profile for the capture device. If the image were scanned in, it would be the profile for the scanner. Or the author may choose to modify the image. If he does, then he may use either the profile for the original capture device or the profile for his monitor. In any case, the profile indicates the preferred reproduction of the image.[1] Anyone using the image subsequently is expected to use that embedded ICC profile to reproduce the author's preferred reproduction.

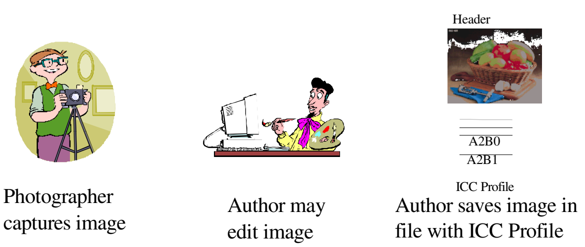

Figure 1. The current ICC model

But consider the alternative workflow shown in Figure 2. Here the photographer captures the image and saves it in a file. The photographer tags the image with an ICC device profile. He then puts the image into an archive or a stock photography bank. Later, an author selects the image from the archive, modifies it, and uses it to create a compound document. In this scenario, the photographer does not know how the author intends to use the image. The author knows the preferred reproduction of the image, but the photographer does not.

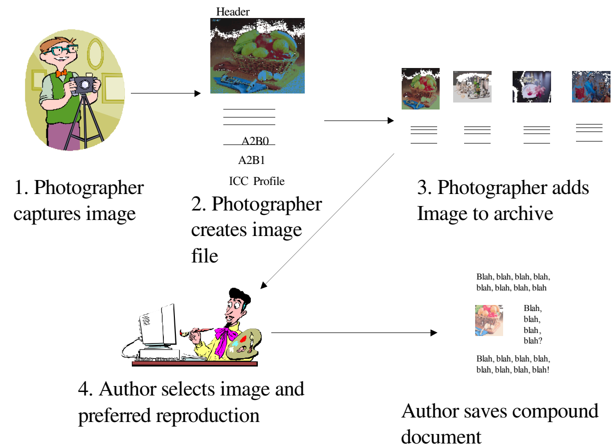

Figure 2. Model using achive/photo bank

At this point, tagging the image with an ICC device profile may cause different kinds of problems. First, the author may not be able to use the ICC profile at all. The ICC profile format has gone through several revisions since its introduction in 1994. If we imagine the author living decades in the future, we can imagine that the ICC profile format may have changed dramatically and such an out-of-date format might not be supported. Or the ICC profile format may not exist any more. Second, even if the author can use the device profile, it might be based on a color appearance space or color appearance model that is incompatible or less than optimal when used with that supported on the author's output device. Combining profiles created with different color appearance models generally do not work as well as combining profiles all created with the same model. Third, it may be that the implementation of the appearance model used in the source profile (say, with a 9x9x9 color lookup table) is not sufficiently accurate to meet the needs of the author. Finally, even if the source and reproduction profiles work together, the preferred reproduction that the photographer used in creating the embedded profile might not be the one that the author would prefer. For example, the tone reproduction may emphasize midtones, when the author is more interested in the shadow detail. Or the author might prefer a colorimetric rendering and the profile supports the photographer's notion of a preferred reproduction.

A New Model

We propose a new model that consists of using both standard ICC profiles and a new type of profile called a

∗ For simplicity, we have used photographs as the type of image in all our examples. However, the same color management issues apply for all types of images, including line art, spot colors, illustrations, etc.

"Measurement Only Profile." We will first introduce the concept of Measurement-Only Profiles (MOPs). Then we will discuss how the use of MOPs would affect the use of baseline ICC Profiles (BPs). Finally, we will provide a scenario showing how MOPs and BPs could be used together.

Measurement Only Profiles

Rather than representing the device characteristics in the form of pre-digested, optimized color transforms, a MOP contains the actual input and output color data along with the viewing conditions encoded in a standardized ASCII text format. The proposed format is an extension of the ANSI/CGATS IT8 file format.[5] Currently, IT8-7/1 and 7/2 files contain measurement data, and 7/3 files contain device control values. We need to allow files that include both the input and output data. In addition, MOPs require tags that specify the viewing conditions under which the device measurements were made. This is necessary partly because CIE XYZ values vary depending on the illumination. Figure 3, below, illustrates what the extensions would look like.

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AMBIENT_XYZ 98.6 100 108.6
SURROUND_XYZ 19.7 20 21.7
BACKGROUND_XYZ 19.7 20 21.7
LUMINANCE_OF_ADAPTING_FIELD 20
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Figure 3. Sample of extension tags for IT8 file

Alternatively, spectral measurement data can be used in the MOP. In that case, the same measurement data can be used for many different viewing conditions. The viewing conditions could be changed either by modifying the IT8 file, or by allowing the user to specify desired viewing conditions through a user interface.

A CMS that makes use of MOPs would generate the color transforms 'on the fly.' This could be done either by creating an ICC profile based on the information in the MOP or by processing the MOP directly. The fact that we are constructing the appearance model-based transform of the input device 'on the fly' provides the second reason to include source viewing conditions. Most appearance models require additional information beyond device measurements to creating appearance data. Examples of this additional information are those used in CIECAM97s: ambient illumination luminance and chromaticity, surround luminance, background luminance and chromaticity, and luminance of the adapting field.6 As we cannot predict all the values that future appearance models may need, they must be prepared to use default values for any information not included in the IT8 file.

MOPs address archival issues in two ways. First, only the raw measurement data is stored. From this, any characterization may be made. The characterization information will not become obsolete, even if the ICC profile format evolves or is replaced. Second, the data is stored in a format that is likely to be understandable for a long time to come. CIE XYZ values have been in use since 1931. ASCII has been a standard for more than 25 years. Given the amount of data encoded with these formats, it is very likely that people will have tools to use them in the foreseeable future.

MOPs allow the author, rather than the archivist, to determine the preferred reproduction. The author can select the color appearance space, the appearance model, and the precision used for both the source and destination devices, as well as the gamut mapping technique used. For most consumers, the CMS or device driver built into the author's system will determine these selections automatically. But the CMS is now in control of all the relevant factors.

Because the device characterization information is sent unprocessed from sender to receiver along with the image, the receiver's CMS is able to build a set of transformations that are most appropriate for use with the output device selected, the capabilities of the receiver's computer platform, and the capabilities of the CMS software. This provides a ready mechanism for vendors of CMS software to differentiate their individual approaches without requiring special information to be embedded in the device profile. It also allows users without special CMS-specific profiles to take full advantage of any given CMS.

ICC profiles have pre-built transformations because creating transforms on the fly is computationally expensive. However, several factors mitigate this expense. When the ICC profile format was first devised, a 100Mhz processor was only available in high-end graphics workstations. Today, consumer PCs are shipping with 1 Ghz processors. This improvement in processor speed makes formerly intractable problems tractable. Transforms can be cached once they are created, so we would not have to pay the computation overhead for every image used.

We believe that MOPs can provide for the needs of those who wish to create a preferred reproduction. They can easily be used in local closed-loop systems, as they support the functionality of today's IT8 files. They can also be used in distributed closed-loop systems, as long as image's creator is willing to forgo some authorial rights regarding decisions about the preferred reproduction of images. And they can be used in both proprietary and standards-based systems.

Changes to Standard ICC Profiles

What then, do we see as the future role of ICC profiles? Briefly, they will become the mechanism for *predictable* color reproduction. Once someone has "authored" an image, that is, once they have selected the optimal reproduction, then it is important to have a mechanism to guarantee that the image will be reproduce faithfully. The reproduction may be made over the Web, on press, or by any other mechanism. These profiles would be Standard ICC Profiles (BPs).

This can be achieved by clearly defining all aspects of the creation and use of ICC profiles. An effort to this end is underway within the ICC's Research Implementation Working Group (the group formerly known as the

"Reference Implementation Working Group"). The group's charter is to create a "baseline" architecture and implementation for both ICC profiles and color manipulation modules (CMMs). This baseline will support both colorimetric and appearance-based reproductions. It would use a standard gamut-mapping algorithm. In the new architecture, gamut mapping is done by the CMM, not in the color lookup tables built into the profiles. We believe the CMM can do a better job of gamut mapping, because it will have access to the gamut information for both the source device or source image and the reproduction devices. The ability to perform gamut mapping in the CMM is also necessary for MOPs, because the MOPs contain information about the device's gamut, but no mapping information.

It would still be possible for vendors to create non-standard profiles using the ICC format. This is necessary for backward compatibility with current ICC systems. This also might be useful as a simple way to handle MOPs. They could be used to produce ICC profiles and the results handled the same way BPs are.

Using MOPs and BPs Together

Figure 4 shows a typical scenario for using MOPs and BPs together in a professional environment. As before, the photographer captures an image. The image is tagged with the MOP of the capture device. It is then stored in an archive. Some time later, an author selects the image from the archive. He determines a preferred reproduction and proofs it to be sure it works well in print. Once he is satisfied, he replaces the MOP embedded in the image with a BP. The document then travels to the printers who use that BP and a BP for their press. In this way, the author is in control of the preferred reproduction. The press operator is responsible for accurately reproducing that desired reproduction.

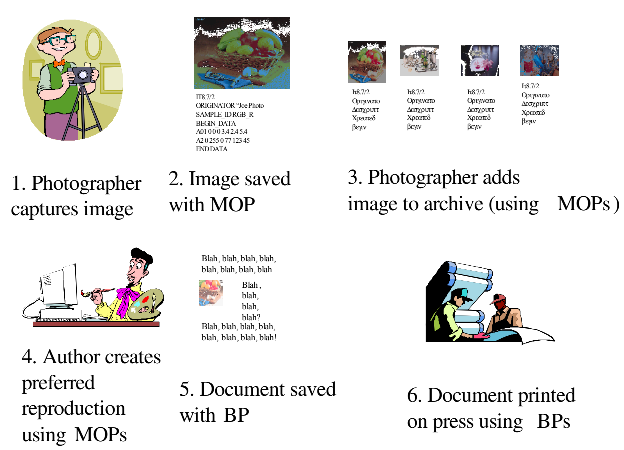

Figure 4. Using MOPs and BPs together

These same tools, MOPs and BPs, also work well in a consumer workflow. Consumers also use stock images. They also combine them with imagery they have created themselves. These images are still combined into documents--perhaps for printing in a business report, perhaps for distribution on the Web. The main difference is that consumers would need a new generation of software tools that tagged files using an appropriate selection of MOPs or BPs. Digital cameras and scanners could tag images with a MOP. Consumer display tools such as Adobe's PhotoShop™ could save for archiving with a MOP or for publication with a BP. Document editing tools and page layout tools would by default save final documents with BPs to ensure a predictable reproduction. A reasonable selection of default settings would make color management transparent to typical consumers; a few additional controls would let sophisticated users meet their own needs.

Standard Color Spaces

Before adopting any change to current practice, it is worthwhile to examine alternative solutions. One possibility would be to transport original images in a standard color space rather than keeping them in device space tagged with a MOP. The problem with this is that there is currently no accepted standard space with a large enough gamut to capture the information that is typically found in, for example, slide film. The IEC's sRGB standard[7] is gaining wide acceptance, but under most interpretations it is limited to the gamut of a cathode ray tube. Work is being done to revise the standard to support a broader gamut, but that work is not yet complete. There are several other standards being proposed at this time, such as sRGB64,[8] RIMM[9] and ROMM[10] RGB, ISO RGB,[11] but again, none are yet international standards. So we cannot depend on stability in these proposals. Furthermore, color management techniques would be required to convert from the original capture device space into the standard color space. We would still be subjected to the problems, discussed above, that we might not like the engineering decisions made in the choice of conversion technology at capture time. By performing the conversion at a later time, a more appropriate choice of conversion technology can be made. In general, it seems best to maintain the captured image in the original device space.

Summary

Our new model splits the work of the ICC profile into two parts. Preferred reproduction is supported by measurement-only profiles. Predictable reproduction is handled by standard ICC profiles. Separating the functionality makes each component easier to implement. The MOP allows unambiguous communication of device color information. As an added advantage, it is likely to be a convenient format for image archiving. The details of preferred image reproduction can be localized in one system. This allows for the user to select between proprietary systems. Once an appealing result has been created, standard ICC profiles handle the aspects of distributing work and allowing predictable color reproduction.

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