

The Next Generation of Color Management System

Tim Kohler
MediaFlex
Campbell, California

History

In the beginning, color management was relegated to the professionals. The craftsmen who toiled at their printing presses, creating printed reproductions of original photographs or transparencies. They used their skill and a color filter pack to generate a set of color separations that would produce a color reproduction. Early on, they used their experience to judge whether or not the films would yield the desired reproduction. There was no way to visually judge the result until they were printed. In those days, things were slower[1] and there was plenty of time to make separations. A set of four film halftones could take up to a day to create.

As technology and science progressed, so did the pace at which color was reproduced. Color proofing systems were introduced to allow the separator to check the films prior to printing. Then came the electronic color scanner.[2] Now, the separator could produce films in a matter of 30 minutes. Analog scanners gave way to digital scanners. The data from the scanner could now be stored on a magnetic tape that could be loaded into a computer for manipulation, allowing even further control of color.

Take a moment to consider where this technology has led. Previously, color was reproduced without ever looking at it. Then we had a system where color was reproduced on a cathode ray tube or on a color proofing material. These tools allowed the color reproducers to "see" the color they were reproducing before the "actual" reproduction was made. The image "data" had changed from simple streams of photons moving through layers of acetate to streams of photons that were split into multiple different forms, most of which were converted to the vibration of electrons. Now we have computers connected through networks. This allows the electrons to vibrate over long distances or even to be transformed into electromagnetic radiation of a non-visible sort. The main upshot of this is more than the convenience of not having to cart a magnetic tape around the prepress room. This allows the prepress rooms to be separated by miles or oceans.

Each person involved in producing this separation, which now takes only a few seconds to create, views a reproduction of the reproduction. Traditionally, the viewing was done under D50 lighting in a brightly lit room. Now, it is done in an office on a CRT, or perhaps, printed on a digital proofing machine.

The Need for Color Management

Meanwhile, the rest of the color reproduction industry has been busy. Computers went from green text screens to 24-bit color displays. Printers went from noisy, monochromatic line printers to color laser printers and photo-realistic inkjet printers. Color scanners have come down in price from millions of US dollars to less than US$100. The machine on which I am writing this document is displaying an image of a white piece of paper with text appearing as type. Clearly, this is not news to anyone. In fact, there are very few people whose life allows them to avoid computers and that is one of the reasons we have this industry called color management. Where once a person went to a printshop with typewritten copy and a handful of slides, they now do it themselves and are able to reproduce their own copies on their own inexpensive printing equipment or they can send vibrating electrons to the printshop for conversion back in to colors. Perhaps they are in a hurry and they just make the vibrating electrons available to anyone with web browsing computer. And, chances are, the person is in a hurry. Equally likely is the chance that they have not had the experience of looking at dot sizes through a loupe or measuring color bars. They expect that the color reproduction will be handled for them automatically.

In the printing industry, the same thing is happening. However, instead of expecting the color reproduction to be handled automatically, the printers know better. They want to control the colors exactly. They want to use numbers to get a match between the print and the proof. And, they want to have seamless control of the color as it passes through each device on the way to the press. They are willing to pay for it, although they would much rather pay in money than in time. Like the captain of a modern submarine, graphic artists can run by the numbers, but periodically, human nature requires them to surface and look at the colors on a CRT.[3]

This situation requires a system that can handle color transformations in a manner that can be invisible and at the same time in a manner that allows in-depth customization. The present day answer to this problem is the International Color Consortium's[4] color profile. This profile is designed to contain information for each individual color-rendering device. The information describes the color behavior of the device and includes any customized manipulations. When one is reproducing colors from one device to another, two profiles are used, one profile for each device. A Color Manipulation Module (CMM) transforms the color data. This transformation can be caused to occur by the operating system, the device driver, an application, or the device itself. This is illustrated schematically in figure 1. Each ICC profile contains a transform between the input or output color and the Profile Connection Space (PCS), ideally a standardized color space with standardized viewing conditions.

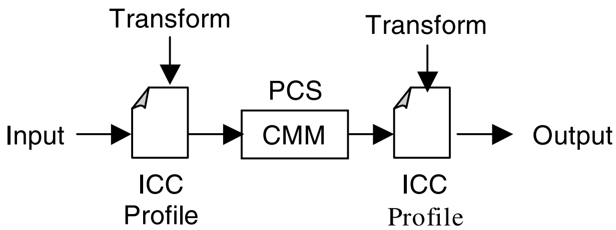

Figure1. The ICC System

The Need for a Major Change

The ICC is in place and has been working for at least six years. However, as has been stated many times before, by many authors, there are problems.[5] The ICC system has a number of problems that were either not foreseen or were not solvable at the time. This has created a situation where the system is ingrained in many products and the makers of those products are understandably reluctant to change anything that might cost money or harm quality. This situation has been in stalemate primarily because anything that is considered a major change is "put-off" until "the next major revision". It is difficult to make a major revision in a deployed standard without some confidence that the change is for the better. This paper describes an attempt to design the next-generation of the ICC. The issues that were considered and the resulting decisions will be described. Some interpretation about how this architecture can be used to yield the "right" amount of user control/vendor differentiation will also be made.

The Proposal

The goals of developing this new architecture were to remove ambiguity in the color transformations, to create an extendable, but well-defined, baseline, and to maintain compatibility with existing systems. As previously mentioned, the current ICC system has some ambiguities.[6] It was determined that this architecture should, from the outset, attempt to remove the possibility of ambiguities. The baseline concept was introduced. The baseline concept is based on the idea that there should be at least one fully defined color management workflow that will achieve 100% interoperability. This is the unrealized dream of the ICC system: the ability to have full confidence in the color matching results. The baseline system allows the receiver of baseline tagged image data to view the colors intended by the sender without regard to operating system, CMM vendor, profile vendor, or device manufacturer. Along with the above goals, it is important to adoption of this system that those who have already deployed ICC profiles are not abandoned. This means that existing profiles must be able to interoperate with the new architecture, yielding the same or better results as they would have achieved in the current system.

The new architecture can be classified as a "Smart CMM-Dumb Profile" system, that is, the profiles are created with basic measurements and standard transformations and the CMM contains transformations such as the gamut mapping algorithm and color appearance model. Part of designing the baseline model is defining each step in the color reproduction chain. Therefore, in addition to a profile format, a CMM and profile-maker had to be defined as well as the means of characterizing the viewing conditions. Since it is easy to create unforeseen omissions or ambiguities when designing a complex system on paper, it was decided that a working system should be built alongside of the on-paper design. This accomplished a number of things: it provided a test-bed for the new architecture during the design process, it serves as a proof-of-concept, the source code will provide a guide for developers, and it can eventually be migrated to a compliance checking tool. This working system was produced two parts, the profile maker and the CMM library.

Putting it Together

The nuts and bolts of the working system are beyond the scope of this paper, however, a description of the design basics and reason for the design decisions will be given. The first part of the system was the profile. The profiles are a modification of the current ICC profile. The modifications to the profile structure take the form of an extension of the existing, but optional, viewing conditions tag and the addition of a gamut boundary description tag. Basically, viewing conditions tag was made mandatory and additional fields were added to account for the additional information used by many color appearance models. A gamut boundary description (GBD) tag was added to include information about the shape of the device gamut for use by the gamut-mapping algorithm in the CMM. In the current ICC system, there is no defined gamut for the profile connection space (PCS) so any gamut-mapping algorithm that uses the shape of both the input and output gamut was impossible to use. The new system also does not explicitly use a PCS to connect profiles; rather, the CAM color correlates are used.

The profile-maker software was designed to handle a separate profile building technology for each of the possible technologies listed in the ICC technology tag[7]. However, in the current state, three basic technologies are considered: CRTs, printers, and scanners. It is expected that experts from various fields working on the individual technologies will eventually contribute baseline profile making technologies for each of their specialties. The basic profile making methods are well known. The CRT profiling technology is based on the work of Motta & Burns.[8] The printer profiling is based on multidimensional look-up-table based on direct measurements of a series of printed color patches. These data are inverted using Newton's method[9] to produce a colorimetry to device value transformation. The scanner method was based on a polynomial fit to a collection of measured IT8[10] color patches.[11]

The CMM software was built as a library that could be accessed from any software. A test bench program was built to convert TIFF images using the library. The CMM includes the ability to convert from CIE XYZ or to directly use pre-computed CAM97s2[12] values. CIEXYZ values could be calculated from a 3x3 matrix and CAM97s2 could be stored in a device color to CAM look up table. The CMM would perform any color appearance modeling required based on the viewing condition (VC) information included in the profiles. As mentioned above, gamut mapping between the input and the output is performed by the CMM as well. The CMM reads the GBD from both the input and the output profiles and provides that information to the gamut-mapping algorithm. The software was designed such that both the color appearance models and the gamut mapping algorithms are "pluggable", that is, the baseline models serve as a default but other models may be easily interchanged for non-baseline extensions to the architecture. For example, it was useful for development to write a CIELAB color appearance model to provide simple colorimetric transforms.

For the baseline mode, it is proposed that CAM97s2 be used. For gamut mapping, the choice of default algorithm will be based on the results of the work of CIE TC 8-03.[13] Therefore, the full baseline system includes profiles made in the manner described for the baseline profile-maker, a baseline CMM that uses the CAM97s plug-ins and a standard gamut-mapping algorithm.

Three Modes of Interoperability

One important factor in the success of a standardized system depends on how well the system encourages interoperability. In addition, the success depends on how companies can increase revenue from products based on that system. In view of this, the new architecture was designed to include both a well-defined baseline as well as the flexibility to expand that baseline. There are three modes of interoperability that are proposed: the baseline, the consistent CMM and the proprietary CMM.

The baseline method is as described earlier. This mode would be used by workflows that require full interoperability. For example, an online photo gallery would want to be confident that the images that were being viewed or printed had the appearance desired by the artist. Another example would be a graphic artist sending their work to a service bureau. The artist wants the service bureau to produce output that has the same appearance as the output made in the artist's studio. This method is illustrated in figure 2. The profiles contain information based on measurements of the device colors and viewing conditions. The baseline GMA and CAM are used by the CMM.

The consistent CMM approach would be the case where the processing done by the CMM is standardized. The profiles, however, could be made in any manner desired by the user. This approach has value for markets such as the printing industry. The printing industry desires a well-defined CMM but requires the freedom to make adjustments to the color profiles.[14] This method is illustrated in figure 3. The profiles are still made up from measurement data, however, there is not restriction for how the data are measure or modified be for putting them in the profile.

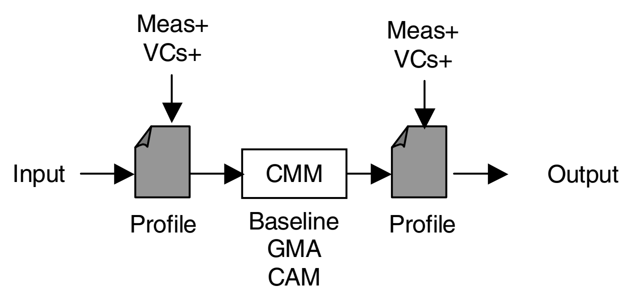

Figure3. The Consistent CMM Method

Finally, there are cases where the ability to perform proprietary color matching is desired. In this case, the profile making, the CMM and GMA are all flexible. This is likely the case for reproductions made in closed systems where the user or driver software is in full control of the entire process. This is often the case in host based printing on desktop printers. This method is illustrated in figure 4. Again, all of the inputs to the system are left unspecified and maybe modified or replaced by proprietary counterparts.

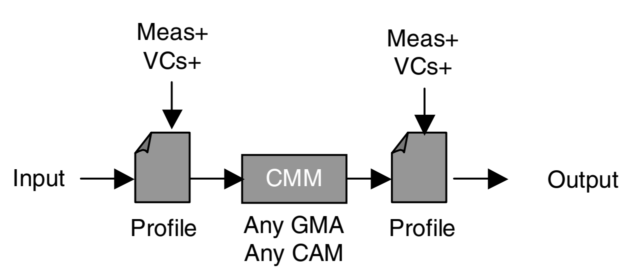

Figure 4. The Proprietary Method

Conclusions

A new architecture for color management has been presented. The advantages of this architecture are that it improves the interoperability of profile based color management while, at the same time, preserving the flexibility for proprietary solutions. The system is based on the "Smart CMM" concept where the CMM takes the dominant role in producing color transforms and the profiles are simply based on measurements. The new architecture features a plug-in system for both color appearance models and gamut mapping algorithms in the CMM. This architecture specifies a baseline mode of operation for compliance. This mode is useful for situations where full interoperability is desired. Alternatively, the baseline can be modified or extended for special features or vendor differentiation.

References

1. Gleick, J., Faster: The Acceleration of Just About Everything, Pantheon Books, 1999
2. Southworth, M., *Color Separation, 3rd Ed.* Graphic Arts Pub., Livonia, 1989.
3. Gallery, D. V., *"Clear the Decks"*, Morrow, New York, 1951.
4. International Color Consortium, http://www.color.org/
5. Dispoto, G. & Stokes, M., Limitations in communicating Color Appearance with the ICC profile Format, *Proceedings of the 3rd IS&T/SID Color Imaging Conference*, Scottsdale, 1995.
6. Kohler, T., ICC Achievements and Challenges, *Proceedings of the International Colour Management Forum*, Derby, 1999.
7. International Color Consortium Specification ICC.1:1998-09 - File Format For Color Profiles
8. Burns, R., Motta, R., & Gorzynski, M., CRT Colorimetry, Part I: Theory and Practice*, Color Res. & Appl.*, **18**, 299-314, 1993.
9. Ralston, A. & Rabinowitz, P., A First Course in Numerical Analysis, 2nd Edition, McGraw-Hill, New York, 1978.
10. ANSI Standard IT8.7/2-1993 - Graphic Technology - Color reflection target for input scanner calibration.
11. Kang, H., Color Scanner Calibration*, J. Img. Sci. & Tech,* **36**, 162-170, 1992.
12. Li, C., Luo, R., & Hunt, R. W. G., The CAM97s2 Model, *Proceedings of the 7th IS & T/SID Color Imaging Conference*, Scottsdale, 1999.
13. http://www.colour.org/tc8-03/
14. McDowell, D. Reference Printing Conditions: What Are They & Why Are They Important?, *The Prepress Bulletin*, March/April 1999.