

Color Management Systems, A Panel Discussion

Bob Chung, RIT

Color management was the theme of the TAGA/ISCC bridge symposium which was held on Wednesday, May 5, 1999. Bob Chung of RIT chaired the session featuring Tim Kohler, Parker Plaisted, Erwin Widmer, and Jim King as panelists. The following captures highlights of the panel discussion.

The Current State of ICC and Its Direction

Tim Kohler, Canon Information Systems, has been active in color management standards activities at Canon and is a dedicated member of ICC. He just finished his two-year term as the ICC chairman. He spoke about the current state of the International Color Consortium as well as the road map to where the ICC is going.

The ICC is working on the color communication standards for color management. Tim gave an example of the importance of communication standards by telling the story of the radio systems used on the Titanic and the closest ship to the Titanic at the time the Titanic began to sink. The closest ship used a rival radio service and the operators of this service had been instructed not to relay messages from other services. Therefore, the closest ship did not get the message that the Titanic needed help. This breakdown in communication due to proprietary systems had tragic consequences.

The ICC was formed in 1993 with seven members. Currently there are over 70 ICC members. Some ICC members make computer operating systems, some make software applications, some make color measurement devices, and some use color management products. The ICC membership represents diverse business objectives, and they often have conflicting interests. However, the current state of ICC-based color management reflects the hard work and cooperative spirit of these members.

The ICC recommendations have been widely adopted and implemented as evidenced by ColorSync on the Apple Macintosh platform and ICM on the Microsoft Windows platform. Today, we have good success with ICC-based

color management if our devices are calibrated and the profiles and CMM come from the same vendor. But that's not quite the goal of the ICC. The goal of the ICC is a vendor-neutral color management solution.

So far, the ICC has only specified the format of the device profiles that are used to store color matching data. There are some shortcomings with the current ICC specifications in the definition of the Profile Connection Space (PCS) and the Color Management Module (CMM) which cause problems in inter-operability. The PCS works well for printing conditions because the PCS is defined relative to a piece of paper under D50 illumination. When we consider matching colors between two monitors, it doesn't make sense to go from a monitor white point to a printed piece of paper and then back to a monitor white point. The ICC does not specify a chromatic adaptation or color appearance model and this results in problems of inter-operability.

The CMM resides in the operating system. It puts two profiles together, combines that with the image data, and does the actual color transformation. There's no explicit CMM specifications. CMMs can do whatever they want as long as they read in the format and write out the format properly. The ICC is contemplating two types of CMMs. One is a smart CMM and the other is a dumb CMM. Currently, the ICC relies on a dumb CMM which primarily does interpolation on the data in the profiles and doesn't take any other input. The smart CMM will take other information such as the viewing conditions, the white point, the level of illuminance, etc., into consideration in color matching. If the ICC moves toward a smart CMM, then a baseline approach to the CMM specifications, e.g., gamut mapping, interpolation, etc., must be made clear. A user should be able to take an image, attach a profile to it, send it to someone else, and they should be able to output the color image and see exactly what the sender expects them to see. If there's no CMM specifications, then inter-operability is not guaranteed. One of the goals of the ICC is to provide a CMM specification.

Implementing ICC-based Profiling Tools

Parker Plaisted, founder and President of Alcyan LLC, specializes in color science and color management software implementation. The ICC specification really just deals with the file format. It does not address how one prepares the data that is stored in the profile. Parker discussed types of profiles, characterization data, and how rendering intents are handled within ICC profiles.

The ICC defines seven different profile types. Of these seven, the three most commonly used profiles are input, display and output profiles. Input profiles are intended for scanners and digital cameras. Display profiles are intended for monitors. Output profiles are intended for printers or film recorders. Some of these profiles are bi-directional and can be used as source or destination profiles.

A profile contains characterization data for a particular device. Data can be stored in a profile using a matrix model or look-up-table (LUT) model. The matrix model contains linearization curves and a matrix of CIE XYZ values which follows the linear mixing rules. The advantage of the matrix model is that it's computationally simple. But the assumption is that the device has to conform to linear mixing rules. So, if we violate the linear mixing assumption, we can't obtain good results. The matrix model is appropriate and frequently used for monitor profiles. Look-up tables define the relationship between data sets, e.g., CIELAB-to-CMYK, with more flexibility. But the math is much more complex. A typical profile of an output device contains a number of tags and LUTs. The ICC provides no description as to how to determine the data that is stored in these LUTs. So it's left up to the profiling software vendors to decide what they want to do.

Profile construction needs to address gamut mapping and chromatic adaptation. Different software vendors take different approaches in profile construction and treat them as trade secrets. Chromatic adaptation models are needed to account for differences in the white point of the media. Currently, the PCS specifies D50 as the illuminant. This works well for the graphic arts industry. However, if we work with a monitor that has a white point of D65, then we have to apply a chromatic adaptation model to the data in order to communicate color through the PCS. So, a good chromatic adaptation model is important in profile construction.

The ICC specifies four rendering intents within the profile format, i.e., perceptual, relative colorimetric, saturation, and absolute colorimetric. Yet, the ICC allows vendors to not support all four intents. So, when we choose different rendering intents we may get the same result. In addition, the absolute colorimetric intent is CMM-dependent because the CMM takes the relative colorimetric information and uses the white point tag to calculate the absolute colorimetric rendering. If you are working with a matrix model, there is a limitation on what rendering intents can be supported. The look up table-based model can support all four. For a printer profile, you'll probably see all four rendering intents are supported from CIELAB to CMYK (or in B-to-A direction). But going in the reverse direction of CMYK to CIELAB (or A-to-B direction), you may see that only the relative colorimetric rendering intent is supported.

There is a set of required tags that all ICC compliant profiles must have. The ICC has also defined some optional tags, e.g., black point tag. The ICC allows private tags which are different from optional tags. Companies must register a signature for a private tag, but they don't disclose what's in it. The optional tags and private tags in profiles are both a blessing and a curse. The blessing is that these tags allow the profiles to be tailored to different industry applications. The curse is that these tags allow third-party software vendors to build ICC profiles

that will produce different results from each other for the same device and the same CMM.

Performance Evaluation of ICC-based CMS

Erwin Widmer is a research project leader at EMPA in Switzerland. He discussed the performance evaluation of ICC based color management systems. There are many aspects of the color management performance which can be tested. One can test the performance of an input profile from source to PCS; or an output profile from PCS to the destination; or the overall reproduction quality of a color management system. One can also test the performance of a CMM.

When testing the overall reproduction quality of a color management system, standard test images, both synthetic and pictorial, should be used. ISO 12640/12641/12642 Graphic Technology, including the IT8.7/3, are good test images to use. We may evaluate the printed results visually or by means of instrumentation. Judgment of pleasingness of pictorial images can be subjective. Color matching, e.g., between proofs and press sheets, can be assessed quantitatively with the use of ΔE values. Erwin cautioned that there are random fluctuations in the imaging devices which would contribute errors the CMS testing. Errors might come from mapping non-reproducible colors to an output device. Therefore, if we don't get good results, don't jump into the conclusion that ICC doesn't work. By using more consistent imaging devices for CMS testing, we tend to get improved results. Erwin also cautioned that not to take average of ΔE values. Instead, prepare data in ΔL , Δa , or Δb terms, and just the last step to calculate the ΔE value. If we want to test a CMM, it's more accurate to use a software, like the DuPont Color Scientist, to perform the computation than going through the digital imaging workflow. You can enter in some values, change the CMM by clicking on a button, and you've got the output values. So, it's very straightforward and easy to do.

Erwin mentioned two research papers, published in the TAGA Proceedings, regarding the performance evaluation of ICC-based color management. In 1996, EMPA studied the performance of output profiles, particularly its gamut mapping, by first calculating some theoretical output values according to an ideal gamut mapping model, and then compare these values to the actual output. They also compared the performance of four profiling tools to that of a high-end legacy system. The conclusion was that a non-professional is able to do prints with color management which are the same or even better quality as a professional without color management. In 1998, Bob Chung and his collaborator published a TAGA paper regarding the comparison between proofs and press sheet. They compared an ICC-based color management and a legacy system using both film-based proofs and digital proofs. They found that ICC-base proofing does not perform better than a well-calibrated film-based legacy

system. One of the ICC CMS weaknesses was that the black component was not preserved in the CMYK-to-CMYK gamut mapping.

What's Next in Shaping the Color Management Paradigm

Jim King has been with Adobe Systems since 1988. He is one of the people responsible for the vision, architecture, design, prototyping, and ultimate development of new products and new features for existing Adobe products. He indicated that there are many people who have been doing color management for a long time; but not in the open-system context. The ICC provides the architectural framework for the new generation of desktop color management. Many software vendors have implemented and are implementing ICC color management in their key products.

The colors in a single image are best represented in a single colorspace. The set of colors possible on a display device is best represented by a single colorspace. When we work with images and devices, there's a one-to-one correspondence between color spaces and those images and devices. It turns out that it isn't general enough when applied to documents, according to Jim King. For example, if we were to put together a document, we might have line art, text, and sampled images. Different color spaces may be most appropriate to describe the different elements in a document. Documents are typically created as a collection of materials from different sources and it is often best not to convert color data until it is necessary. So we could easily have color values from four or five color spaces in one document.

It is also important to think of documents as compound objects because when it is possible to represent information as either text or graphics as opposed to sampled image data, significant space savings can be achieved. In addition, better results are obtained when scaling and/or rotating text and graphics. Pictorial images are pixel-based. A 300 dpi image may be 48 megabytes in size. Line art, as represented by vector objects, can be much smaller than pixel-based images. In other words, if we drew a line and made it into an image at a particular resolution, we're stuck with that pixel representation. If we scaled it to a larger size it would get the "jaggies." King showed a calendar page with a picture on the top half and the normal grid for a month on the lower half. When the whole calendar page is represented as an image it is over 48 megabytes, but if the bottom half is represented as line art the size is reduced by almost one half.

In PostScript and PDF, line art is represented as vectors in a two dimensional space. The same thing with characters. They use outline fonts which are done as graphics and are only filled-in when put on a screen or output to a film setter. We want to get away from thinking of documents as big hunks of image. They are really composite pages, made of text, image, and graphics materials.

On a different note, Jim King thinks that "We have it backwards." Users don't want to think in terms of colorspaces. They just want to have "colors" like "red." It is a requirement to modify the colors values to reflect the proper colorspace of a display or a printer, but do the users want to be so aware that each device requires the data to be converted to that device's colorspace? Today users are very aware of the need to convert from one colorspace to another using ICC profiles to guide the conversion. Maybe we could hide this complication from the users better.

The part that may be backward is that we think of moving color data from one device to another by converting the values. It might be better to think of moving the devices over the data as a window, only converting temporarily in order to show the data on that device. The data would stay in its own colorspace indefinitely. This might match the users views of having just colors.

When Adobe considered implementing color management in PostScript Level 2, the initial proposal was to have all color data represented in CIEL*a*b*. At that time, about 10 years ago, the user community had very negative feedback from that proposal, King said. The machines were too slow to convert data every time you display it. So instead they implemented a system that was based on allowing each object to be in its own colorspace much like the ICC model. In fact, although not exactly the same as ICC the method, the method employed by both PostScript and PDF is very similar and conversions between the PostScript and PDF profiles to/from the ICC ones is not hard. The output profile inside a PostScript printer is called the color rendering dictionary (CRD). The input profile is called a Color Space Array (CSR). In PDF, Adobe uses the object-by-object color management similar to what is in PostScript but the recent release of Acrobat 4.0 and PDF 1.3 allow the use of ICC profiles as one of the options.

Software vendors need to constantly strive for user-friendly interfaces. In addition, the progress in color management must also come from better computer science, e.g., adopting 16 bits per pixel per channel instead of 8 bits to represent image data, and better color imaging devices with wider gamuts to minimize the gamut compression problem.