International Color Consortium®

White Paper #9

Level: Intermediate
Date: March 2005

Common Color Management Workflows & Rendering Intent Usage

ICC color management supports a wide variety of workflows that can be used for many purposes. Different ICC profiles and different rendering intents can achieve a variety of color reproduction goals. However, this flexibility can cause confusion. It is therefore useful to document some common workflows, and provide advice about rendering intent usage.

It is also worth distinguishing between "version 2" (V2) and "version 4" (V4) ICC workflows, because some limitations and ambiguities in the V2 specification (ICC.1 1998-09 and earlier) have been removed from the V4 specification (ICC.1 2001- 12 and later). It is anticipated that further clarifications will be forthcoming in future ICC specifications, although these will likely follow on from V4.

Common Color Reproduction Goals

Two common objectives in color reproduction are re-purposing and re-targeting (e.g., proofing). Re-purposing starts with color content that has been color rendered to one output color encoding and then applies a color re-rendering to achieve another output color encoding. Typical display and printing of photographic images involves re-purposing because each picture is initially color rendered to an intermediate color encoding (such as sRGB or the ICC PCS perceptual intent reference medium), and then is subsequently color re-rendered as needed for a specific display or print output. With re-purposing, the objective is to take an original that is assumed to be optimized for particular medium and viewing conditions (e.g., the ICC PCS perceptual intent reference medium), and create a new, optimal reproduction on a second medium (with assumed reproduction viewing conditions). While there may be a natural desire to maintain some level of consistency between original and reproduction, if the media are different there will likely be intentional differences in the colorimetry. This is because the objective is to make the "best possible" reproduction in each case, which will depend on the reproduction media and on the use case preferences.

It is important to note that with re-purposing, selection of the best possible reproduction will be subjective, and will depend on viewer preferences. This means it is not possible to standardize re-purposing transforms. They will remain proprietary, and different transform creators may intentionally produce different

transforms for the same original and reproduction medium combinations, to address different user preferences. The success of any particular transform will depend on the number of users that like it best. While it is reasonable that users will want some level of consistency with the original, it is unlikely that exact colorimetric reproduction will be preferred when there are significant differences between the original and reproduction media.

Re-targeting, e.g., proofing, can be thought of as an alternative to re-purposing. Re-targeting is distinct because the reproduction goal is to produce not the best reproduction possible, but rather the closest possible match to some "original" (original is in quotes, because the "original" may be a "reproduction" from some previous color reproduction process as in proofing). Re-targeting can include colorimetric adaptation, when the ‘proofing’ and original media are quite different. However, the intent is always to preserve rather than to re-shape.

Conceptually, the "perceptual" and "saturation" rendering intents are intended for re-purposing and the colorimetric rendering intents are intended for proofing. There are two specified colorimetric ICC rendering intents: media-relative colorimetric and ICC-absolute colorimetric, with the ICC-absolute colorimetric intended for cases in which the proof is desired to include the look of the original medium. Note that in practical workflows there is some overlap and in-between area with use of these rendering intents. For example, with ICC V4, if a target medium is very similar to the perceptual intent PCS reference medium, the perceptual and colorimetric rendering intent transforms in an output profile targeting that medium may be identical - reflecting the fact that in this case color re-rendering is not required and only a re-encoding transform is needed. Similarly, when ‘original’ and next output media and conditions are similar, the media-relative colorimetric rendering intent can be combined with black point scaling as a minimal perceptual rendering intent, useful for re-purposing between the two output representations.

With ICC V2, the choice of rendering intents is sometimes dependent on V2 issues, instead of being solely based on the reproduction goal. For example, a V2 output profile perceptual transform may be specifically designed to receive black scaled sRGB colorimetry in the PCS and re-render it to an ink-jet photo medium. However, if an original is a photographic print (scanned colorimetrically), it would not be appropriate to apply a color re-rendering that assumes sRGB as the source. With this output profile, a better rendering intent choice for the photographic print original would be to use media-relative colorimetric with black point scaling. Re-purposing is still desired, it is just that media-relative colorimetric with black point scaling is more appropriate for color re-rendering the photographic print original than a perceptual intent that assumes an sRGB original. On the other hand, if such a profile contained effectively a ‘media-relative colorimetric with black point scaling transform’ in the perceptual intent, it would then not be able to produce as good results with sRGB originals. Note that

one aspect of complexity with V2 in particular arises from these "special case" profiles.

If one wants to proof an original, ICC absolute will provide the most accurate colorimetric reproduction, particularly when the proof is intended to also represent the color characteristics of the original medium. Note, however, that using the V2 ICC absolute colorimetric rendering intent can be problematic because of ambiguities in the V2 specification about whether the media white point recorded in the profile (and used to calculate the ICC absolute colorimetric transform) is before or after adaptation to the D50 PCS adopted white. If a V2 profile with a non-D50-adapted media white point is combined with a profile with a D50-adapted media white point, an inappropriate color cast will result. There are also issues if the proofing media white is very different from the original media white. While it is not advisable to use a proofing media with a white that is much different from that of the original, small differences can be accommodated using the media-relative colorimetric intent. The use of this intent also avoids the adapted/non-adapted media white point ambiguity because the colors are referenced to the media white. Note, however, that the media-relative colorimetric proof will not represent the original media.

It is important to note that ICC color management always assumes that the original image content is exactly as desired for its medium. Image correction is outside the scope of ICC color management. However, ICC profiles can be and are sometimes used in closed workflows to correct images with specific flaws. Care should be taken to manage such profiles, because these profiles can cause problems if they get into open color management workflows. These special purpose profiles should be kept separate from general purpose profiles and workflows. There is discussion in the ICC about the desirability of including a special identifier for image specific profiles. This is a key example of the flexibility of the ICC profile format, and the corresponding care that must be exercised in incorporating specialized elements into workflows.

The use of image specific profiles can combine both initial color rendering of scene-referred image data with image correction (without the need to change the original image data) into a single operation, but must be understood to be specific to certain images or sets of images, and managed accordingly. When image specific profiles are used, the PCS description provided by the profile effectively becomes the "original".

Profile Functions

ICC profiles (both V2 and V4) perform two functions. The first, coordinate transformation, relates device color code values to colorimetric code values in the PCS. The second, color rendering or color re-rendering, changes the colorimetry of an original to be better suited for some particular reproduction medium. These functions are distinctly different, and each may or may not occur in a given transform in a profile. When they are both occurring within a particular

profile/rendering intent, they are folded together in the particular profile/rendering intent transforms, which can be a source of confusion. It is helpful to clearly distinguish between the coordinate re-encoding transforms necessary to convert back and forth between device values and colorimetry, and the color rendering and re-rendering transforms that alter colorimetry to achieve specific reproduction goals. The differences between rendering intents in a given profile are due to different color rendering and re-rendering transforms.

Since coordinate transforms can be determined objectively using characterization measurements, they are not subject to much debate (although there have been some issues about how to take measurements and correct for flare appropriately when different media require different measurement devices). Consequently, the rest of this paper will focus on color rendering and re-rendering, assuming that appropriately determined coordinate transforms are incorporated with the color rendering and re-rendering transforms as needed.

Profile vs. Color Management Module (CMM) Rendering Intents

It is helpful to distinguish between rendering intents in which the transform applied is explicitly included in the profile (media-relative colorimetric, perceptual, and saturation), and the rendering intent transform (currently one) that is calculated by the CMM from one of the other rendering intents contained in the profile (ICC absolute colorimetric is calculated from media-relative colorimetric). In a sense, the ICC absolute colorimetric rendering intent is the first implementation of a "smart" CMM, in which the profiles contain the coordinate transforms between device values and colorimetry, and complete transform is computed by the CMM from the profile data.

There are discussions in the ICC about adding additional standard CMM rendering intent capabilities, such as black point scaling. V4 profiles can support a range of smart CMM (rendering intents computed in the CMM) functionality, because the colorimetric intents are unambiguously defined and are required to be based on standard measurements.

ICC V2 Rendering Intents

The common V2 ICC workflow involves the use of an input profile with a single (usually unidentified) rendering intent. This rendering intent will typically be one of the following:

- A media-relative colorimetric rendering, which transforms the input device values into media-relative colorimetry of the original in the PCS (coordinate transform relative to media white). A typical example would be a scanner profile obtained using an IT8 scanner characterization target.

- A media-relative colorimetric rendering, but with black point scaling where the black point of the original medium is scaled to zero in the PCS (coordinate transform plus black point scaling). A typical example is the V2 sRGB profile.

- A perceptual rendering, where the input-side transform color renders (e.g., a digital camera profile) or color re-renders (e.g., a ‘tuned’ transparency scanner input profile) the colorimetry of a scene or an original to some proprietary virtual medium in the PCS (coordinate transform plus proprietary color re-rendering). These profiles commonly result from modification of one of the above transforms "to make the results better". It is also worth noting that with V2 perceptual intents, the proprietary virtual medium black point is scaled to zero in the PCS.

Following the input profile, a V2 output profile is used to color re-render the colorimetry in the PCS to the output medium, and create output device values. V2 output profiles can have absolute colorimetric, relative colorimetric, perceptual, and saturation rendering intents, which are identified in the profile and selected to achieve the desired reproduction goal.

Ideally, the V2 output profile perceptual intent will be constructed to receive the colorimetry as transformed to the PCS by the input profile. This means that the perceptual intents of different V2 output profiles will be matched to specific input profile behavior. In this sense, the ICC V2 specification is more of a standard format for color profiles (as the title of the specification indicates), as opposed to an interoperable color management system. However, the user need is for an interoperable color management system and to some extent rendering intent selection can be used to achieve this.

For example, one might think that V2 colorimetric intents should be used for proofing, and V2 perceptual intents should be used for re-purposing. This is true for matched profiles, but what if there is a need to use an output profile with different types of inputs, and matching input profiles are not available? The provider of the original might not know which output profiles are to be used, or might not have the ability to construct matching input profiles. In this case, it is advisable to select the output side rendering intent that best accommodates the PCS colorimetry produced by the input side profile. For example, if one is reproducing a scanned photograph on a print medium, it may be acceptable to use media-relative colorimetry for re-purposing, especially if CMM black point scaling is applied. This is because the media-relative and black point scaled colorimetry does a reasonable job of color re-rendering. However, if the original is an sRGB image, a more elaborate perceptual intent transform may be needed to re-render the black-scaled sRGB display gamut to that of the print medium.

In this example, the media-relative colorimetric intent with black point scaling is used for re-purposing from one print media to another, and the perceptual intent is specifically designed to accept sRGB image data and re-purpose it for print. This allows a single V2 output profile to support two different types of input.

The problems with the above solution are that it complicates rendering intent selection, and that a number of rendering intents or profiles are required (at the

limit, one for each type of medium for which the image data in the PCS is appropriate). The user needs to know what the output profile perceptual intent was constructed to receive, and what the input profile is putting in the PCS. There also needs to be an output side rendering intent available that is designed to receive what the input profile is providing.

With V2 profiles it is advisable to consider both the reproduction goal and the colorimetry represented in the PCS by the input profile when choosing the output profile rendering intent. This situation frequently leads to user frustration, since many users do not have the means or knowledge to analyze what different profiles are doing (except by viewing the results of different combinations).

ICC V4 Rendering Intents

The ICC V4 solution is preferred. V4 rendering intent selection is greatly simplified by clearer rendering intent definitions, and requirements for what the rendering intents contain.

Some V4 clarifications are as follows:

- The "relative colorimetric" rendering intent is renamed "media-relative colorimetric", to make it clear that it is media white relative. It is also required to be based on 45/0 measurements according to ISO 13655 for reflecting media (and corresponding measurement techniques for other media). It is therefore exclusively a coordinate transform.

- The "absolute colorimetric" rendering intent is renamed "ICC absolute colorimetric", to avoid confusion with CIE absolute colorimetry. The ICC absolute colorimetric rendering intent is calculated by the CMM from the media-relative colorimetric rendering intent in the profile, and is a coordinate transform that places CIE colorimetry (relative to a perfect reflecting diffuser illuminated by a D50 illumination source) into the PCS.

- The media white point is required to be adapted to D50, so that V4 ICC absolute colorimetric rendering intents will all be interoperable.

- Note that a key benefit that derives from the strict V4 colorimetric intent definitions is that various smart CMM rendering intents can be computed using these measurement-based data.

- It is clearly allowed for input side profiles to have multiple, well identified rendering intents with the same requirements as output side profiles.

- The PCS print reference medium dynamic range and viewing conditions are defined for the perceptual intents to color re-render to and from. This enables perceptual intents to be interoperable (although if the re-rendering contained in a perceptual intent transform is poor, the results may be poor). The reference medium gamut is recommended to be the print-referred gamut defined in Annex

B of ISO 12640-3; documentation of the approved recommendation specification is pending in the ICC specification. Note that there can be interoperability problems if different perceptual intents re-render to and from very different PCS reference medium gamuts. However, one would expect that reference medium gamut assumptions for a print reference medium with the defined dynamic range would not be too different (for example, some research at HP produced a similar gamut to work done in ISO TC130, mostly in Europe).

When the above clarifications are incorporated in V4 profiles, it is usually not necessary to consider the matching of the input and output side profiles when selecting V4 rendering intents. With V4 profiles, rendering intent selection is based on the reproduction goal.

Re-purposing using ICC V2

The method for rendering intent selection using V2 profiles for re-purposing is as follows:

- Determine what type of colorimetry the input side profile will be placing in the PCS (e.g. sRGB display colorimetry, photographic print colorimetry, photographic transparency colorimetry, oil painting colorimetry, etc.). This determination involves the nature of the original, and also any input side color re-rendering the profile may be performing.

- Locate an output profile rendering intent that performs the desired color re-rendering from the PCS colorimetry created by the input profile to the actual reproduction medium. This may involve both the selection of an output profile, and the selection of a rendering intent transform within that profile. One may find an output profile where the perceptual intent is designed to receive the PCS colorimetry. If no suitable perceptual intent is available, a colorimetric intent (with or without black point scaling) can be tried to achieve a simple color re-rendering. As mentioned above, typical users may not have the capability to perform these two steps except by trial and error.

- Use the output profile rendering intent that produces the desired result.

Re-purposing using ICC V4

- Generally, the perceptual rendering intent should be used for re-purposing with V4 profiles.

The exception is if the reproduction goal is to reproduce the PCS perceptual intent reference medium colorimetry, in which case the perceptual intent is used for the source transform and the media-relative colorimetric intent is used for the destination profile. In cases where the actual medium has a smaller color gamut than the perceptual intent reference medium, this practice will usually produce more colorful results, but at the expense of some clipping in the final image. Perceptual intent transforms typically try to maintain detail throughout the color

gamut by applying compression or expansion as needed to re-purpose the perceptual intent reference medium image to the actual medium gamut.

It should be noted that most current color management applications and CMMs do not support selection of different rendering intents for source and destination. Also note that there is a saturation rendering intent, which remains relatively undefined with V4 profiles. It can contain color re-rendering transforms constructed to meet specific proprietary requirements, and can be used for special purposes.

Re-targeting (Proofing) using ICC V2

- Locate input (source) and output profiles where the relative colorimetric intents contain accurate media white relative coordinate transforms only (no black point scaling; no subjective tweaking or color re-rendering). Ideally, these profiles should also contain D50 adapted media white points, to enable interoperable use of the absolute colorimetric intent.

- Determine whether the absolute or relative colorimetric intent produces the desired result. If the original and reproduction media whites are identical or similar enough, both rendering intents will produce the same result and it won't matter which one is used. As the media whites diverge, a tradeoff is encountered. The absolute colorimetric intent will tend to produce a better match of colors when individually compared (e.g. spot colors), while the relative colorimetric intent may produce a better overall appearance match (due to some human visual system adaptation to the different media whites).

It may also be possible with some CMMs to produce hybrid transforms, where for example, the original media white luminance is scaled to that of the reproduction media white, but the original media white chromaticity is left unchanged. This type of hybrid transform avoids highlight clipping (as does the media-relative colorimetric rendering intent) as well as chromaticity shifts.

Re-targeting (Proofing) using ICC V4

The same as for proofing using ICC V2, except the first step is unnecessary. All valid V4 profiles meet these selection criteria.