International Color Consortium®

White Paper #7

Level: Introductory
Revised June 2021

# The role of ICC profiles in a colour reproduction system

## *1.0 Introduction*

Colour reproduction can be a complex process. There are many different colour reproduction industries, often utilising different media from one to another, although within some industries there may well be multiple media used. These different industries will often have differing reproduction requirements, even for the same image, depending on the reproduction process itself, and the stage in the workflow at which the reproduction is made. For example an image on a computer display may be required to accurately match the colour of the original image, or be a pleasing (idealised) reproduction of that image, or be a colour match to a printed reproduction of the original (soft-proofing), which in turn may be a colour accurate, or a pleasing rendition, of the original. One of the most important decisions which needs to be made by a user is which sort of reproduction is required at each stage of a workflow where a digital image is rendered in some form.

This paper introduces some of the issues in colour reproduction and discusses how ICC profiles may be used in achieving successful reproductions.

## *2.0 ICC profiles – what are they and how are they used?*

Each ICC input (or source) profile provides a number of colour transformations (in the form of look-up tables, matrices, and/or parametric curves) that define the colour expected from the encoded data of the digital image, in an open format. In other words, the profile defines the colour to be expected with any set of image values – which are often device values, but may be in some standard colour image encoding (such as sRGB). The colour space used by ICC profiles is the internationally accepted CIE system for defining colour matches, and so using this it is possible to ensure that colours from input will match those on output (assuming the output has an adequate colour gamut), for the viewing conditions for which the colour is defined. The conditions selected by ICC are those defined in international standards for viewing and the resultant colour space is known as the Profile Connection Space (PCS). The fact that the format is public means that any ICC compliant system should be able to use these profiles to interpret the colour intended for that digital image. In conjunction with the correct display and/or output (destination) profiles, which also contain a number of transformations, various reproduction options can be achieved.

The reason that a profile contains multiple transformations is to allow the user to select the one appropriate for the purpose. The various rendering intents that these transformations provide are intended to be applicable to different reproduction goals. The choice can have a significant effect on the colour reproduction achieved so the selection of the appropriate transform is an important decision for the user.

The basic way in which ICC profiles are typically used to achieve colour reproduction is by combining a source profile with a destination profile to enable input device data to be transformed to that required to give the required colour on output. Selection of the appropriate transforms, by selection of the rendering intent, enables the desired reproduction to be achieved. The combining of the profiles is performed by a CMM, which can be provided at various places in the workflow (such as the image editing software, raster image processor or printer driver, among others). In some reproduction procedures there may be more than two profiles used (such as simulating a print on a display), or even special cases where only one is used that has been constructed by combining a source and destination profile (DeviceLink profiles). However, these are natural extensions of the basic procedure described here and greater detail will be found in the ICC workflow guidelines.

## *3.0 ICC profiles as part of a colour reproduction system*

Simply using a CMM that only supports the basic ICC architecture to calculate and apply the transformation from input device space to output device space does not necessarily provide a colour reproduction system that suits all needs. So long as the application providing the CMM allows the selection of the appropriate rendering intents at the time the appropriate profiles are combined, there are many market sectors where it is perfectly adequate – particularly where input devices are 'smart'. However, there are other markets where it may not be. In such situations additional functionality needs to be provided by the colour management vendor.

### 3.1 Image editing

One issue is that many captured images are not ideal. They frequently exhibit colour casts, limited dynamic range, or poor tonal rendition, which may not be obvious on some media but will be when reproduced on others. Such 'errors' need correcting during the process of reproduction. Algorithms for automatically optimising digital images have been developed, and are a part of many image capture, colour management or editing applications. In fact they may often be applied without the user knowing. However, because of the subjective nature of colour reproduction such automatic algorithms may not suit every user, or every image. Thus, for high quality imaging, unless the user is confident in the quality of captured images, every image should be assessed and corrected as necessary. Such corrections require a subjective assessment of the image, which means that it has to be rendered in some form to judge its quality. For many users a well calibrated video display is adequate for this purpose, though for some high quality applications the image is first rendered in its final form, which implies some sort of iterative correction process.

Each ICC profile is defined for a specific combination of device and media (as appropriate) and as such, when used appropriately, should enable faithful reproduction of the colorimetry of the encoded image. Although the perceptual and saturation rendering intents include optimisations for media and viewing condition differences, device profiles – which are determined independently of any images - do not apply image specific optimisations. Where precision is of the utmost importance colour management software can be designed to update device profiles to also include image corrections, but because of the subjective nature of this correction it is usually sensible, in the view of many experts, to keep the characterisation and image enhancement algorithms conceptually separate. Alternatively, the algorithms for image correction, if automated, can be applied at the same time as the media transform specified by the device profile – and as "smart" CMMs (which add functionality by interpreting both profile and image information in calculating the reproduction transformation) are developed such procedures are very likely.

An input profile can be embedded in an image, or sent as a separate file. Either way it can be used to define the intended colour as already stated. However, the sender of the file has to be responsible for ensuring that the correct profile is embedded, but equally importantly has the responsibility for ensuring that the image is pleasing. If the image needs correction this should be undertaken prior to sending it, either by directly editing the image or the profile. In the event that this has not been done, and it is the responsibility of the receiver to optimise the image to make it pleasing, this must be made clear when the image is sent. The sender of the file must then be prepared to accept the changes made, or ensure a proofing cycle that will enable corrections to be specified is part of the workflow.

### 3.2 Rendering issues

The choice of rendering intent is an important one, as already discussed. General guidelines as to which rendering intent is appropriate to different types of images, and/or workflow stages, are given elsewhere on the ICC web site. Essentially the selection comes down to whether a colorimetric match is required between input and output, such as for proofing and preview applications (or when the output media has a gamut close to that of the image) or whether the reproduction is to be the most pleasing by compensating for the differences in viewing conditions and gamut between source and destination media.

The different rendering intent transforms in a profile are usually dependent on the profile creation software used to make them. While colorimetric renderings may well be somewhat different - because different vendors can use different targets for profile creation, different measurement devices, and different mathematical models – such differences are usually small. However, the perceptual and saturation intents can vary significantly. With older profiles there was an additional complication concerning ambiguity around the definition of the white and black values in the PCS to which the appropriate image data should be mapped, which could be interpreted differently by different profiling vendors. Thus, when profiles from different vendors were combined the results could be unpredictable and/or low in quality. Although the use of version 4 profiles should avoid this latter issue, it is not intended to ensure that the perceptual and saturation rendering intents provided by different vendors produce the same transformation. This is an area where different profiling vendors will provide solutions most appropriate to the markets they have most experience of, and it is up to the user to select that product which produces the most appropriate tables for their needs. The same vendor may even offer the option of different perceptual renderings to produce different 'looks'.

Differences between profiles will usually be more noticeable where the difference between the source and destination gamut is large. To enable consistency of rendering on the input side, the ICC suggests the Perceptual Reference Medium Gamut as a rendering target for the perceptual rendering intent. If this is used in a rendering workflow, the output profile does not have to make arbitrary choices about how it maps the source gamut to the output medium gamut.

One of the complications in trying to specify perceptual or colorimetric renderings in any objective way is the fact that there is limited agreement between experts as to what constitutes an optimum colour re-rendering, which includes appearance and preference adjustments, and gamut mapping. This is complicated by the fact that such studies are inherently difficult. From the discussion above it will be clear that both media differences and image content affect the perceived quality of the colour re-rendering, and separating these in any study is not easy. If both are included in the study it will generally be necessary to evaluate large numbers of images (maybe several hundred) before coming to a reasonable conclusion as to an optimum algorithm. The ICC sRGB v4 profile, for example, went through exhaustive testing by ICC members before it was adopted as a recommended solution to the perceptual intent transform from sRGB to the Perceptual Reference Medium Gamut.

Even if we assume that the image has been edited to remove any problems – so that the profiles are only expected to optimise the mapping for the media differences – it is still difficult to get agreement on that mapping. Trying to find a single algorithm that will work well for a variety of source and destination media types, and for a range of gamut shapes, complicates that further. All these reasons, together with the fact that other issues (e.g. viewing condition differences and user preferences) are often compensated for in perceptual and saturation renderings, make it very difficult to come to any general recommendation on the way to perform such mappings. In general, users with high quality expectations must choose their colour management software with care, or rely on expertly designed systems provided by companies for specific markets. Such systems may well provide correction routines to enable users to achieve specific rendering of particular colours.

### 3.3 Retention of separation information

One of the problems encountered in many practical colour reproduction procedures is the difficulty of optimising non-colorimetric profiles independently of one another. Although this should be substantially eased by the use of v4 profiles, in which the PCS reference medium to be assumed in perceptual profiles is more precisely defined than previously, the wide differences in gamut and media which may be encountered between input and output, as well as the effect of image content, places a significant difficulty in the path of a vendor or user optimising such profiles. While non-colorimetric renderings in profiles can be, and often are, optimised separately, the reproduction requirements of some high-quality market sectors require that final optimisation can only be done for the pair of profiles to be employed in generating the colour transformation.

Because of this there are certain market sectors, notably in printing and publishing, where users prefer to optimise their profiles and convert to the output space (CMYK, possibly with additional separations) early in the process, or even use proprietary methods for producing the separation data. This introduces an issue for some users where they wish to exchange separation data, but later use profiles to convert to other output device spaces which use the same number of colorants. Because ICC profiles use the CIE colour space as the reference it means that while a colour match should be maintained the relationship between the separation values for each pixel is most likely to change. For many users this is often unimportant for many images (as, for example, they select the GCR they require for their own printing conditions) - but not for files where elements are defined in only one or two separations (such as black only borders and text). For such elements, maintaining the separation composition can often be more important than precisely matching the colour.

Increasingly this will change for many users where the final output profile will be used in proofing simulations, but without conversion of the data until it is finally output. This will necessitate exchange of both input and output profiles, but file formats should be extended to permit this, as PDF/X already has. However, that will not suit every workflow and there will still be a requirement in many workflows to convert separation data. In such situations it is important for some users to be able to retain a good approximation to the K to CMY ratios. Such algorithms are not particularly complex and are provided by a number of software vendors – however, there has been no agreement within ICC on any particular method. ICC are considering methods for specifying CMYK to CMYK conversions, but given the lack of definition as to exactly what trade-off between maintaining separation and colour accuracy is required, beyond the obvious requirements, it is not going to be easy to get agreement. Many users employ software that provides the functionality required for their particular needs, and use it to provide DeviceLink profiles. Others use 'smart' CMMs that offer this functionality.

ICC DeviceLink profiles provide a means to encapsulate a transform from one set of device values to another in a standard format. However, while DeviceLink profiles could be considered to maximise predictability while minimising flexibility, they only provide one transformation intended for a specific pair of devices. 'Smart' CMM functionality has the potential to offer the most flexibility, and therefore the least predictability. Typical ICC colour management using two profiles is somewhere in between, because of the fixed transforms but different rendering intent options.

### 3.4 Device calibration

In order for any colour reproduction system to produce satisfactory results it is necessary that all the devices in the system are behaving as they were when the colour transformations employed in the system were established. This is the case for both proprietary and ICC based systems. In the ICC context it means that a profile is only valid for the state of the device, and the media used, at the time it was made. However, many devices are not inherently stable. So, in order to reduce the need to make a new profile every time a device changes some mechanism for bringing the device back to the state it was in when a profile was made is highly desirable. However, the mechanism used for correction will vary with the device – sometimes physical changes are made to the device itself, at other times changes are implemented in the control software. Sometimes calibration requires measurement of control elements, and input of the resultant data, by the user, at other times it is an automatic procedure.

Whatever procedure is involved it must be the responsibility of the user to ensure that any devices used by them are maintained at a level consistent enough to ensure the profiles for those devices remain valid, and if a device deviates beyond the levels which allow satisfactory use of existing profiles a new profile will need to be produced.

Because of the wide range of calibration procedures which may be encountered, and the differing deviations which may be acceptable to any market sector, ICC cannot make any definitive recommendations concerning calibration. A profile can optionally contain tags that provide calibration data pertaining to the status of the device at the time the profile was made. However, even if these tags are filled, and used by any colour management software to compare with data measured at the time of the calibration, it is the responsibility of the software vendor, or user, to provide the acceptable tolerances beyond which correction needs to be undertaken. However, once this is done the tag information can be used by the colour management software to initiate the necessary correction procedures. Of course, to ensure good quality reproduction, it must be the responsibility of the user to ensure that they can properly calibrate the devices used – where it is not satisfactorily achieved automatically - either directly, or within the colour management software where that functionality is provided.

### 3.5 Measurement procedures

The CIE system of colour measurement has a number of variants. In order to avoid ambiguity it is necessary for any colour reproduction system defined with reference to it to be precise about the measurement conditions to be used. This has been achieved by ICC by requiring that measurement of reflecting and transmitting media be consistent with ISO 13655. The requirements this imposes, together with recommendations for the measurement of displays, are summarised in another white paper on this web site.

However, although by far the majority of users will want to follow these recommendations, the ICC profile also contains a number of optional tags that enable users to specify alternate measurement conditions, observers and viewing conditions, and a required tag to define the chromatic adaptation needed when predicting equivalent colour for adaptation to illumination of a different chromaticity to that of D50. Since in most cases there is no well defined colour conversion between the various conditions specified (except where the tags are used to define the parameters needed by the still evolving CIE colour appearance models) ICC cannot recommend how these are used, but for market sectors where alternative conditions are important they can be utilised by the profile creation software and CMMs using these profiles to provide the desired functionality.  Similarly, characterisation data (both spectral and tristimulus, if desired) can be included in the profile to enable colour management software to utilise it where appropriate.

### 3.6 Summary

As should be clear from the above discussion, colour transformations of considerable complexity can be defined by using ICC profiles.  These can be used to define the transformation at each stage in the colour reproduction system where a colour conversion is required.  While 'basic' profiles will be adequate for many applications, they can be edited to provide particular requirements as necessary.  In some market sectors there may be requirements that go beyond the functionality offered by the basic profile approach – such as CMYK to CMYK conversions that retain the K.  Vendors of colour management software serving these markets usually provide this functionality – and some allow the colour conversions to be defined as DeviceLink profiles to enable such transforms to be applied elsewhere by software that does not support it, or does not achieve it in a manner that is preferred.

For certain market sectors, where additional information can be utilised by the colour management software, various optional tags can be filled with the information necessary to provide additional functionality.  It would be impractical for ICC to define what is mandatory in such cases, as for many markets keeping the profile size to a minimum is of utmost importance.  However, in industry sectors where such optional information would be useful, 'standards' groups serving those market sectors should be encouraged by their users to get agreement among vendors in that sector as to what should be mandated for those applications.

Many captured digital images have characteristics that would not be acceptable if reproduced colorimetrically on a particular media which is different to that assumed in creating the original image.  In order to achieve satisfactory reproduction such images need to be colour re-rendered.  Perceptual intent transforms are intended to achieve this automatically – however users need to ensure that such transforms are satisfactory for their needs and apply further editing as necessary.