

# Using the ICC V4 Reference Medium Gamut in a real-world color workflow

Randall Guay, Mark Shaw; Hewlett-Packard Company; Boise, Idaho, USA

## Abstract

The ICC V4 Perceptual Reference Medium Gamut (PRMG) has been proposed as a “fuzzy” rendering target that vendors can use to achieve consistent color reproduction in multi-vendor workflows. By defining a device independent “device referenced” rendering target, vendors are able to improve the inter-operability of ICC profiles. This paper describes an implementation of the ICC V4 workflow in which the color preferencing can be applied on the host, and discusses how to work around some problems in using such a workflow.

## Introduction

The goal of color management, and that of the ICC<sup>i</sup>, is to provide the customer with a consistent print experience regardless of the marking technology that one uses. However, problems with interoperability of early ICC profiles arose due to the fact that different vendors design their ICC workflows in different fashions. This is especially true when it comes to aspects like gamut mapping, color preferencing, and black point compensation, where the algorithms represent the “look and feel” of a company’s brand identity.

As a remedy, the ICC V4 Perceptual Reference Medium Gamut<sup>ii</sup> (PRMG) has been proposed as a target rendering gamut. When building the perceptual intent of a ICC V4 profile, rather than mapping the entire Lab (or XYZ) PCS volume to the device gamut, a vendor may assume that an “output device” shaped volume (the V4 PRMG) defines the gamut of colors to map to/from. Each vendor would assume a source was to be rendered into the PRMG gamut, and the destination rendered from that gamut, thus giving more consistent results between vendors in an open color workflow. In this paper we discuss the use of the PRMG in an open color workflow. In order to maximize the portability of the workflow we have investigated potential implications of rendering the source document content to the PRMG and using it as the intermediate working space for document workflows.

## Description of the Color Workflow

In this experiment, a two-step color workflow similar to that of the ICC was used, as shown in Figure 1. First the source color gamut is mapped using a 3D Color Look-Up Table (CLUT) to an Intermediate Working Space (IWS) that is truncated to 8bpp. The IWS colors are then mapped through a second 3D CLUT and a Tone Reproduction Curve (TRC) to the device’s native color space. In our experiments the device space was CMYK. As with the ICC, this workflow allows the source and destination transformations to be independently specified and any color preferencing to be done in the source transform on an object by object basis going to the IWS. Example input color gamuts include sRGB, AdobeRGB,

SWOP, and Euroscale, etc. Different media types such as Plain Paper, Photo Paper, were used for the destination gamuts.

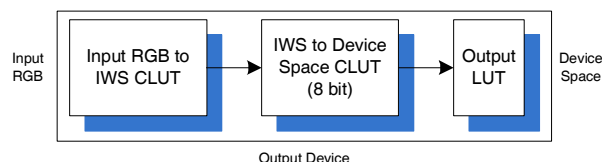


Figure 1. Simplified diagram of existing color workflow

In order to minimize document processing times, color transforms are commonly implemented through hardware assisted ASICs. Depending on the output device’s memory constraints and hardware resources, the IWS is commonly of limited bit depth (such as 8bpp). This is due to the significant cost of increasing resources within an embedded system. To accommodate the use of the V4 PRMG within the IWS, the IWS encoding was defined using a wide-gamut colorimetric RGB gamut. This type of encoding has a number of benefits, the biggest being that, if the primaries of the encoding are chosen carefully, the nodal efficiency (number of useful nodes within a CLUT) is higher than its equivalent table encoded in CIELab.

## Gamut Mapping

In document workflows, knowledge of the source gamut surface is an important consideration. Many users expect saturated colors in the document to be mapped to saturated device colors in the reproduction, even at the loss of colorimetric accuracy. The fact that the gamut boundary of the source color gamut within the IWS was undefined presented a significant problem in traditional ICC workflows. When a vendor created the B2A0 tag of an output device profile, they would have no knowledge of the assumptions that were made when the A2B0 tag of the input profile was made. Sub-optimal color rendering of surface colors would ensue due to the lack of knowledge of gamut surface colors.

## Color Extrapolation

With the PRMG in an ICC V4 document workflow, one solution is to expand the gamut of the source color gamut to the gamut surface of the PRMG in the A2B0 tag, and then compress the gamut surface of the PRMG to that of the device gamut in the B2A0 tag. This simplifying assumption is not as simple as it sounds when using the PRMG as the reference gamut. The surface entries in the source gamut no longer map to the surface of the IWS; they map to the surface points of the PRMG encoded within the IWS. Furthermore, the values which map to the PRMG surface must fit within the chosen color encoding scheme in order to prevent clipping of the PRMG gamut. As can be seen in Figure 2,

the colorimetric values of the PRMG transformed into the IWS do not extend to the surfaces of the IWS encoding, but rather the PRMG forms a sub-volume within the IWS. The dotted lines in Figure 2 represent the boundaries of the IWS encoding.

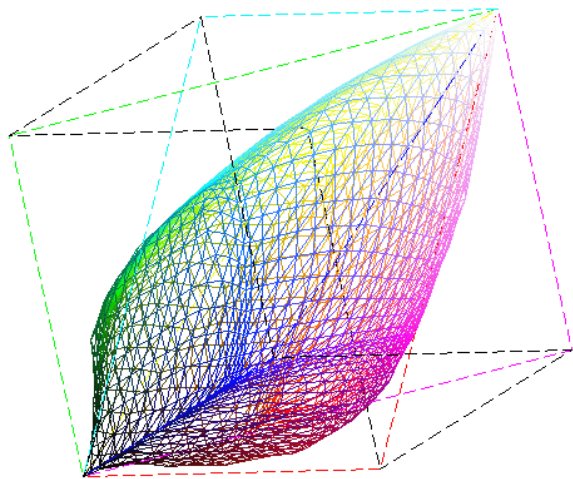


Figure 2. PRMG encoded in the IWS

This is of significant importance. Assume you have a pure source device color, such as fully saturated yellow. In many cases the desired rendering of pure source device yellow would be pure yellow on the destination device. But the encoding for this color, as mapped to the RMG and encoded in the IWS, is not on the surface of the IWS, and is most likely not exactly “on node” when mapping into the destination CLUT. When the point is interpolated through the destination CLUT, it will be impossible to assure pure device yellow. This is illustrated in Figure 3’s left hand side.

This problem has been addressed by Bhachech, et al.<sup>iii</sup> Colors near the gamut boundary can be more accurately reproduced by using Color Extrapolation. Typically, entries in a CLUT ranging from 0 to 255, or 0 to 65535, are defined to map to the range 0.0 to 1.0 in the output device space. By redefining the encoding of the output CLUT to allow for values outside the typical range, extrapolation of the “near surface” nodes to increase the range of the output data can give very good results.<sup>iii</sup>

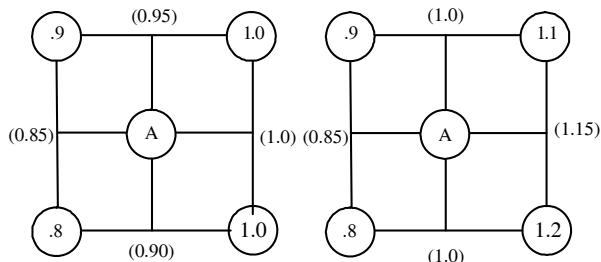


Figure 3 - Interpolation on a rectilinear grid  
 Left - A interpolates to 0.925  
 Right - A interpolates to 1.0

Certain codes can map to negative numbers, and others map to numbers greater than 1.0. In Figure 3, for example, 255 would map to 1.2. The Output TRC is then used to clip the extrapolated

range back to 0.0 to 1.0, and expand the dynamic range of the output device values to 0 to 255.

## Using the Inverse Map

It is possible to directly map from a given source color gamut to the PRMG, and from the PRMG to a destination gamut. But gamut mapping from the source color space directly to the PRMG and back would give a different result, compared with mapping the source color space to the IWS. So we chose to map from the IWS to the PRMG, then back to the IWS. This allows us to compare the two approaches directly. Any difference is due to a failure to invert the transform, not from different choices in gamut mapping. An additional CLUT, mapping from the IWS to the PRMG (as shown in Figure 2) is concatenated with existing Source CLUTs. An inverse CLUT, created using the Color Extrapolation process, maps from the PRMG to the IWS, and is concatenated with destination CLUTs. The inverse CLUT has an interesting shape, as shown in Figure 4. Note that many values exceed the range 0.0 to 1.0.

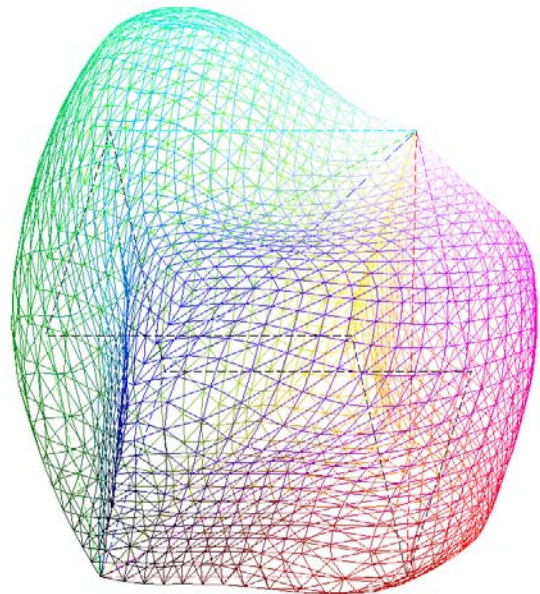


Figure 4. Inverse IWS Map with Color Extrapolation

## Hue Mapping

In the ICC V4 PRMG, values along hue angle 90 are considered pure yellow. Most users prefer that yellow come through pure, even if colorimetrically they should have a small amount of cyan or magenta. The extrapolation can get very close, but even using this extrapolation method, yellow is not quite rendered pure.

In order to solve this problem, for colors along the white – to – saturated – yellow vertex, a final adjustment to the CLUT nodes must be made so these values come out pure yellow. The source yellow vertex nodes are processed through the tables, and generate output values based on the inverse and destination CLUTS. The differences between the actual output and the desired output are calculated, and these values are subtracted from the adjacent nodes in the destination CLUT. The resulting nodes then generate the

exact value for the specified color. Colors near the vertex are rendered slightly less optimally.

### Comparison with Existing Method

When using an 8 bit data path, maintaining as many gray levels as possible becomes especially important. This is a concern even when mapping through the existing IWS. The effective number of gray levels was determined by generating a gray ramp, running the image through the lookup table processing, and determining how many distinct gray levels, as measured by L\*, are present in the resultant CMYK image. The ramp image is quite simple:



Figure 5. Ramp image used to analyze number of gray levels

This image is 1024x180 pixels in sRGB, with 256 levels of gray. Using the existing pipeline, 204 levels of gray are available. This is inherent whenever mapping quantized data from one gamma to another. Mapping into and back out of the RMG gives 197 levels. This is somewhat fewer, but quite comparable. This number of gray levels is sufficient in most instances to exceed the capabilities of the destination device.

The differences between using the IWS and using the PRMG were evaluated. Images analyzed include Biztest and Sunflowers. The images were taken through to the CMYK values using both methods, then the CMYK data was converted to Lab, and the differences taken. The images are shown below.



Figure 6. Original images : Biztest (Left), Sunflowers (Right)

### Results

The two sample images had some small differences in DeltatE94. The results are shown in Table 1.

	Ramp	Biztest	Sunflowers
Mean	0.35	0.49	0.90
Std Dev	0.39	0.62	0.65
Max	1.47	9.05	7.21

Table 1. Statistical differences between IWS and PRMG on selected images

### Conclusion

We have shown how to adapt an existing color workflow to one that conforms to the PRMG. There is an existing preferred gamut mapping from a source gamut to the IWS. The IWS is then gamut mapped to the PRMG. An inverse table is created from the IWS to PRMG map. This table "undoes" the forward map, and preserves the preferred mapping from the IWS to the device gamut. A check is made to verify that the inverse map exactly preserves pure yellow for entries along the CIELCh 90 degree hue plane. The existing Source CLUTs are concatenated with the forward map, and the inverse map is concatenated with the destination CLUTs. Backward compatibility is maintained, and compatibility with other vendors is enhanced. The workflow in Figure 7 appears identical to that of Figure 1, but with the concatenated tables replacing the existing tables:

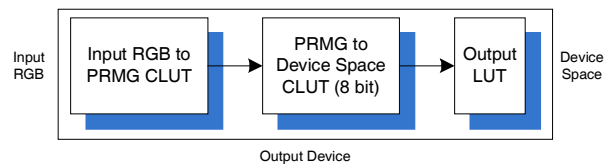


Figure 7. Color workflow using PRMG exchange space

Having two table lookups connected by an 8 bit pipeline has the potential to cause problems with loss of color levels. While approximately 200 levels are adequate for many applications, others may require additional gray levels. This could be accomplished either by increasing the bit depth of the color pipeline, or by spatially dithering the output data to increase the number of apparent gray levels.

### References

- [i] International Color Consortium, [www.color.org](http://www.color.org)
- [ii] Definition & Use of the ISO 12640-3 Reference Color Gamut, Jack Holm and Ingeborg Tastl, Hewlett-Packard Company (USA); and Tony Johnson, London College of Communication (UK), Fourteenth Color Imaging Conference, 2006
- [iii] Improved Color Table Inversion Near The Gamut Boundary, Miheer Bhachech, Mark Shaw, and Jeffrey DiCarlo, Hewlett-Packard Co. (USA), Fourteenth Color Imaging Conference, 2006