Definition & Use of the ISO 12640-3 Reference Color Gamut

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Abstract

While a number of color encodings are specified for imaging applications, neither the group developing the ISO 12640-3 CIELAB standard color image data, nor the ICC, found a suitable existing specification for a large gamut reflection print reference medium. Such a specification was needed as a color rendering target for the creation of the CIELAB standard images. Thus, the ISO working group started to develop the reference color gamut specified in the Draft International Standard ISO 12640-3. The ICC, in order to improve the interoperability issue encountered with ICC v2 profiles when using the perceptual rendering intents, adopted this reference color gamut for the perceptual reference medium for ICC v4 profiles. This paper describes the developmental requirements; the details of the specification of the reference color gamut as well as how to use it in the context of the ISO as well as in the context of ICC. It provides a more in-depth discussion than the ISO draft or the amendment to the ICC specification.

Introduction

Color reproduction of natural images by printing or photography rarely requires that colors be reproduced with colorimetric accuracy. While this may be partially attributable to differences in viewing conditions requiring colorimetric changes to maintain color appearance, the major reason is usually that the gamut of colors captured is different from the gamut of colors that produces the most pleasing reproduction on any particular reproduction medium. The differences in these gamuts are rarely just that one is simply larger or smaller than the other. Often the gamut boundaries of the capture and reproduction have a quite different shape. Even when the captured colors fall entirely within the gamut of the reproduction medium, changes in the relationships of the colors to each other may produce a more pleasing result.

To achieve satisfactory color reproduction, color rendering or re-rendering are typically employed. As defined in ISO 22028-1 [1], color rendering and re-rendering include preferential changes, in addition to correction for color appearance effects, to produce pleasing reproductions. A key point is *the reproduction colors that will be most pleasing depend on the characteristics of the reproduction medium.* It is therefore necessary to have a reference medium description, including a reference color gamut, as the target for optimizing color rendering, and for interpreting the source image for color re-rendering purposes.

Historically, when few capture methods existed and reproduction options were more limited, color rendering and re-rendering were achieved on a 'device to device' basis, usually empirically. In film photography the color rendering is defined primarily by the characteristics of the transparency film or negative film/paper combination provided by the manufacturer. In printing the scanners used for image capture provided facilities for the user to adjust the re-rendering to optimize the colors for a relatively limited range of mass production printing conditions. In motion picture production, the color rendering is still largely defined by negative and print film characteristics, although control of the intended result is now often achieved through digital manipulation of negative scans, as opposed to the traditional "color timing" of the exposure when printing.

However, the development of digital photography and low cost computers, together with the evolution of low cost scanners and printers has led to an environment in which direct development of device to device transformations is often impractical. Techniques have evolved where the digital data obtained from a capture device, and required by an output device, are each defined colorimetrically by a mathematical model. Color reproduction is achieved through one of two paths: The first (and most common) approach is for the capture device to create an image file, which is color rendered for some reference medium and viewing conditions, and encoded using a standard color image encoding (like sRGB). Then, the receiving device interprets the encoded data and performs color re-rendering to produce a pleasing reproduction on the actual reproduction medium. The advantages of this approach are that the color rendering and re-rendering to and from the exchange encoding can be tuned for each device, and is provided by the devices - no external color management is required. In the case of scene capture, this approach also communicates an intended color rendering of the scene on the encoding reference medium, which can be useful as there may be various scene color renderings, depending on the artistic intent. The disadvantages of this approach are that the number of exchange color encodings must be kept small to keep device support of each from becoming an undue burden, and that the best results will be obtained when the exchange encoding reference medium is reasonably similar to the intended reproduction medium.

The second approach is to use color profiles, which are assigned to the source image for interpretation of the image data, and color profiles describing the output condition for converting the desired output colorimetry into output device values. The desired output colorimetry can be obtained in several ways:

1. A facsimile reproduction of the image described by the source file is desired, in which case the color management system attempts to create a matching reproduction. In this situation an aware user will select a reproduction medium that minimizes the need for gamut mapping.
2. The user manually and iteratively edits the image file (as necessary) to produce the desired reproduction, viewing the results of the edits on the intended reproduction medium, or on some proofing or preview medium that has been deemed satisfactory for this use. (Although this approach can be achieved empirically without use of profiles, it is common to

use them for interpretation of the source values, and encoding of the desired reproduction colorimetry as destination device values.)

3. The color management system applies 'run-time' processing to the image in an attempt to color render or re-render it to produce a preferred reproduction for the selected medium. The application of the processing may be automatic or user guided, but cannot happen until the reproduction medium is selected. (The profiles have the same function as with method 2.)
4. The color profiles may contain pre-determined color rendering or re-rendering transformations to and from a profile connection space (PCS) reference medium. In this case the color profiles are performing a similar type of color processing that is performed by devices in going to and from a standard color image encoding (the first path).

The advantages of using the standard color image encoding path are simplicity (assuming the number of standard color encodings is very limited and those in use are widely supported), and that there is no need for a color management system. The advantages of the color profile approach are increased flexibility - color profiles can support all four options described above simultaneously - and the ability to support a virtually unlimited number of color encodings. ICC color profiles [2] are the implementation of the color profile approach.

However, in the early development of ICC color management, the need for color rendering and re-rendering, and the dependence of preferred reproduction on the reproduction medium, were not widely understood. Therefore, the ICC specifications published before 2001 did not clearly describe a standard perceptual intent reference medium. Profile creators were free to choose their own reference medium (and some did), but there was no assurance of interoperability between profile perceptual intent transforms. Consequently, the most common application of ICC version 2 profiles was accomplished using methods 1 and 2 as described above.

With ICC version 4, a standard perceptual intent reference medium dynamic range and viewing conditions were defined, but it took somewhat longer to achieve consensus on a perceptual intent reference medium color gamut. It was the development of ISO 12640-3 and the approval of the ICC perceptual intent reference medium gamut proposal in 2005 that have now provided a complete description of the ICC perceptual intent reference medium. The procedures for determining perceptual color rendering and re-rendering transforms cannot be defined by the ICC as the ‘rules’ for this process are not (and possibly never can be) sufficiently well-defined nor universally accepted for all images and media. Thus, the color rendering and re-rendering are assumed by the ICC to be defined by the vendor of the software that generates profiles. In some cases these transforms are manually tweaked by profile creators or users to improve the results.

One necessity for a reference gamut comes from the desire to improve the interoperability of ICC profiles. Another one comes from the desire to provide digital images that can be used for the evaluation and optimization of color reproduction algorithms and systems. It is essential that the color encoding and gamut boundary for those images is well defined. While many people and entities use their own images for such applications, it is convenient to have a standard set of images that are readily obtainable by anyone. ISO defined such a set in 1993 [3] – these were defined to be in CMYK with the reference medium assumed to be that obtained by ‘traditional’ mass production printing. This format suited most of the color reproduction procedures in common use at that time. However, the separation of the color reproduction transformations into source and destination by the ICC, and the increasing use of sRGB as a standard encoding, required that alternative color formats be specified, and in 2001 a second set of images was defined [4]. These images were defined in two formats, 16-bit XYZ (with respect to illuminant D65) and 8-bit sRGB as defined by IEC 61966-2-1 [5]. However, the reference color gamut for these images is defined to be that of the sRGB reference display. The committee developing these images decided that an additional set of images, encoded as 16-bit CIELAB color space data (with respect to illuminant D50), would be helpful, particularly for evaluation of profile based systems. The committee wanted these to have a larger reference medium color gamut than sRGB, so that it would include the majority of reflection colors that may be encountered in practice – this was initially agreed to be the gamut of real world colors surface colors. The result of this work, ISO 12640-3 [6], contains CIELAB standard color image data - images that have been color rendered to the gamut specified in that document and what is now also the ICC v4 perceptual intent reference medium (PRM) gamut. These images and test charts are useful for evaluating color re-rendering from the PRM to various printer/media combinations.

Development of the Reference Color Gamut

When this work began, the best-known definition of the gamut of real world surface colors was that published by Pointer [7] in 1980. Many of those involved with the development of the reference gamut defined in this paper suspected that this may have been superseded by newer devices, and an investigation was carried out to assess the gamut of surface colors currently available in order to develop a reference gamut. The dependence of the optimal color reproduction on the output medium characteristics was also becoming more widely recognized, resulting in increased focus on color print media.

The ISO 12640-3 reference color gamut was derived from three different color gamuts developed quite independently, but for similar reasons. The first was developed within ISO TC 130 in order to provide an estimate of the gamut of surface colors for the purposes of ISO 12640-3 as stated above. The second was developed by Hewlett-Packard as the gamut of colors reproducible by one of a broad variety of color printers, and this was offered to the International Color Consortium (ICC) as a reference color gamut for perceptual rendering intents. It was also offered to those developing ISO 12640-3 for consideration. During the development of this reference color gamut another useful gamut was brought to the attention of the committee. This is a gamut, known as PhotoGamutRGB [8], which is based on measurement of the results obtained from silver halide printers, used for producing photographic prints from digital images.

On review it became clear that, although there were some differences, there was also considerable similarity between these gamuts. So, it was agreed that the data from the three sources should be reconciled in order to produce the single reference color gamut described in this paper. This reconciliation is discussed below. However, for information purposes the derivation of each of the gamuts will also be briefly described.

Gamut developed by TC 130 (predecessor of the reference color gamut)

The initial specification for the reference color gamut for ISO 12640-3 was obtained by finding the maximum gamut obtainable with real-world surface colors, according to the published data available to the committee in 1998. The main sources of this data were the Pointer gamut, which was defined after analyzing color data from the following sources:

- 768 colors from the Munsell Limit Color Cascade;
- 310 colors from the Matte Munsell Atlas;
- 1393 colors from ink and paint samples, textiles, colored plastics and papers (measured by Pointer);
- 1618 colors describing flower colors (tabulated by the Royal Horticultural Society).

Altogether, the color coordinates of 4089 colors were available. Pointer combined these color data and published the maximum chroma value at 36 hue angles and 16 lightness levels. However, the Pointer gamut data refers to CIE standard illuminant C, whereas the committee needed the gamut with respect to illuminant D50. The Pointer gamut boundary data was therefore converted to that for D50 using the Bradford chromatic adaptation conversion used in CIECAM97s. The resultant data was then combined with other color data exhibiting high chroma values. In particular the data for 1025 Pantone colors, a series of measurements of printed samples made at the EMPA laboratories in Switzerland, and the colorimetric data from the SOCS data set as published in ISO TR16066 [9] were included.

From these data (XYZ data) the color gamut was calculated as a convex hull and then transformed into the CIELAB color space. Table 1 shows the maximum chroma value for 36 hue angles and 19 lightness levels.

HP's superset of printer gamuts

Hewlett-Packard had undertaken a study of the gamut of colors available from a wide range of printing devices (inkjet printers, laser printers and silver halide printers). A composite gamut produced from this data, as a series of CIELAB L* vs. C^*_{ab} plots defined at 16 hue angles, was presented to the TC 130 committee developing ISO 12640-3. Table 2 shows the gamut boundary data extracted from those plots.

PhotoGamut RGB

This gamut was defined by a group of color imaging experts involved with the reproduction of digital photographs in Germany. It was defined as a means of providing pleasing reproductions of sRGB images when printed using commercial silver halide photographic printers. This is achieved by assigning the PhotoGamutRGB ICC profile to sRGB images prior to printing, thereby color re-rendering the images.

The gamut definition was based on measurement data from a number of silver halide printers and is supposed to be both a superset printer and a fuzzy target for re-rendering. We extracted the data from the PhotoGamutRGB_avg6c.icc profile available on their web page [8] and black point un-scaled it (common practice with ICC version 2 perceptual transforms was to scale the black point to zero) in XYZ, to bring the black point from L*=0 to L*=3.1373 (the ICC version 4 perceptual intent reference medium black point). The gamut is shown in table 3.

The ISO 12640-3 reference color gamut

The reference color gamut defined for ISO 12640-3 should not be assumed to be a specific attempt to precisely define the gamut of real world surface colors. Although it is likely that it does include the majority of such colors (and therefore approximates that gamut) the mixed data sources used to derive it contribute a degree of uncertainty to the data. This is primarily attributable to the measurement procedures used in each of those studies being loosely specified. In particular, if any of the samples in table 1 exhibited fluorescence, the measurement result would be highly dependent on the measurement procedure used. While none of the samples included were known to be highly fluorescent, the uncertain origin of some of them means that this cannot be certain. Thus the reference color gamut should be thought of as a gamut that includes the vast majority of surface colors that may be encountered in reflection print color reproduction. However, there may well be some colored samples that give rise to measurements that fall outside of this gamut, particularly highly fluorescent samples, and so as an estimate of the precise gamut of surface colors it should be considered to be 'fuzzy'.

A number of considerations went into the derivation of the reference color gamut. The first was how to define the white and black points as these are very important components of the gamut. Since it was anticipated that the CIELAB reference images would be widely used for the evaluation of color management systems it seemed sensible to define the white and black to be consistent with those defined as the white and black for the reference medium in ISO 15076-1. These points are specified to have a reflectance factor of 0.89 and 0.0030911, respectively. While it is likely that neither of these represent the highest reflectance white, or lowest reflectance black, obtained in high quality printing systems or obtainable with surface colors, they are likely to be close to these values. Thus, this dynamic range provides a reasonable approximation to the maximum practical gamut. There is no fundamental reason to expect that the highest and lowest reflectance colors occurring in practice will necessarily be neutral. However, if they are not, neither is there any fundamental reason to expect them to have their positive chroma at any particular hue. Since any chroma of the lowest and highest reflectance colors is likely to be small it was decided, for the purposes of ISO 12640-3, that the reference white and black should be assumed to have a chroma of 0.

The second consideration was to decide whether the data should be specified as 'absolute' data (i.e. with respect to the perfect reflecting diffuser) or relative to the media white (the media white is used as the reference white in creating the CIELAB values). The data reported by Hewlett Packard was provided as media relative data. However, inspection of the TC 130 data suggested that this data was somewhat mixed. Since the data was obtained by combining data from various sources obtained over many years the provenance of it, particularly with respect to the reference white, cannot be completely certain. Some of the very high chroma values at L* values of 95 were felt to be most likely relative, whilst some of the high chroma dark colors were felt to be most likely absolute. In principle, it makes little difference to the specification whether the data is specified either way, as it is simple to calculate one from the other – providing the reflectance of the white is specified. As there is no reason that the natural images should have a specified white point it was decided that making the data relative was sensible – but if absolute data is required by any user it can be calculated from the defined reference medium white.

A third consideration was to provide a relatively smooth surface to the three dimensional gamut, yet with distinct cusps at each hue angle. These two criteria were deemed desirable for optimizing color rendering and re-rendering. Taking account of the criteria above, the data from the three gamuts was compared in order to provide a combination of the three that could act as the reference color gamut. In general, the objective was to try to include all the data specified in the three data sets, in other words to provide a superset of three data sets. At the same time it was deemed important to only include colors present in the natural world.

Table 1: Predecessor of the reference gamut developed by TC130: Maximum chroma values C^*_{ab} obtained with surface colors (calculated as a convex hull for illuminant D50 and the 1931 (2°) standard colorimetric observer)

h [°]	L*= 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
0	30	42	49	56	63	70	77	80	82	83	84	82	72	60	48	37	26	16	6
10	28	40	48	56	63	70	77	80	82	82	83	82	75	63	51	39	28	16	6
20	25	40	49	57	64	72	79	83	84	84	85	84	79	67	55	42	30	18	6
30	17	34	51	60	68	77	85	88	89	88	89	88	86	74	61	48	34	20	7
40	13	26	39	52	65	78	90	96	97	96	95	93	93	85	71	56	40	24	9
50	11	22	33	43	54	65	75	85	95	99	102	100	98	94	87	69	49	29	11
60	10	19	29	38	48	57	66	74	83	91	98	104	107	105	97	84	59	35	13
70	9	18	26	35	43	52	60	68	75	82	89	96	102	108	113	99	77	44	16
80	8	17	25	33	41	49	56	63	70	77	83	89	95	101	106	112	104	64	20
90	8	16	25	32	40	47	54	61	68	74	79	85	91	96	102	107	112	113	30
100	8	17	25	32	40	47	53	60	66	72	77	83	88	93	98	103	108	96	43
110	9	17	25	33	41	48	54	60	66	72	77	83	88	93	98	99	94	67	25
120	9	18	27	35	43	50	57	63	68	74	80	85	91	97	97	90	77	47	17
130	10	21	30	39	47	55	61	67	73	79	85	91	97	100	91	82	62	37	14
140	12	24	34	43	50	57	63	70	76	82	87	92	93	90	86	78	52	30	11
150	14	28	39	48	54	61	68	75	81	88	93	91	87	83	75	66	45	26	9
160	16	31	44	53	61	68	75	82	87	92	92	89	84	75	68	58	40	23	9
170	17	34	49	60	70	73	76	79	83	88	86	83	78	70	62	53	38	22	8
180	16	33	47	59	67	69	73	77	82	86	83	80	73	67	59	50	36	21	8
190	16	31	43	53	60	63	67	71	75	78	77	75	69	64	56	48	35	21	8
200	16	30	41	48	54	59	63	67	71	72	71	70	65	60	54	47	36	21	8
210	16	29	38	44	51	56	60	64	68	68	68	66	62	57	51	44	35	22	8
220	17	29	37	43	49	55	59	63	66	66	66	65	61	56	50	42	34	23	8
230	18	30	36	42	48	54	60	64	66	66	66	65	61	56	50	42	33	23	9
240	20	31	37	43	49	55	61	67	67	68	68	67	62	56	49	41	33	24	11
250	22	32	38	45	51	57	63	68	70	71	68	63	58	52	45	38	31	24	14
260	25	34	41	48	54	61	66	71	71	70	66	61	55	50	43	37	30	23	17
270	29	38	46	53	61	67	72	73	73	71	66	60	54	49	42	35	29	22	14
280	36	45	53	62	70	76	77	78	78	73	66	60	54	49	42	35	29	22	10
290	45	56	67	77	84	84	83	83	80	75	68	62	56	50	43	36	29	22	8
300	62	78	91	98	94	91	89	85	82	77	71	65	59	52	46	38	30	20	7
310	74	96	97	100	100	98	94	90	86	81	76	70	62	55	48	39	30	18	6
320	53	71	78	85	92	99	101	96	91	85	79	73	66	58	50	41	28	17	6
330	42	58	65	72	79	86	92	95	93	89	85	77	70	60	50	38	27	16	6
340	36	49	57	64	70	77	84	89	89	90	89	83	72	59	48	37	26	15	5
350	32	45	52	59	66	72	79	83	84	86	88	84	71	59	48	37	26	15	5

Table 2: HP's superset of printers gamut: Maximum chroma values C^*_{ab} obtained with printing devices (calculated for illuminant D50 and the 1931 (2°) standard colorimetric observer)

h					L*=				
[°]	10	20	30	40	50	60	70	80	90
0	25	50	68	83	86	81	65	45	20
22.5	20	50	75	82	85	81	60	40	20
45	10	37	68	98	101	102	88	59	30
67.5	8	27	45	60	76	91	105	108	60
90	10	22	37	52	69	82	98	112	123
112.5	10	28	45	60	75	90	103	107	90
135	12	33	55	75	96	101	95	81	45
157.5	15	40	63	84	98	95	80	60	32
180	15	40	62	81	89	85	75	50	25
202.5	19	35	53	69	76	74	66	49	27
225	20	37	50	60	68	70	63	48	27
247.5	20	40	53	62	69	57	45	31	18
270	32	55	68	68	60	50	40	27	15
292.5	55	82	92	80	68	55	42	29	15
315	40	92	103	96	90	70	53	36	18
337.5	33	60	85	97	98	90	71	51	26

Table 3: PhotoGamut RGB (defined from measurements of silver halide printing devices - calculated for illuminant D50 and the 1931 (2°) standard colorimetric observer)

h					L*=				
[°]	10	20	30	40	50	60	70	80	90
0	16	41	66	86	81	67	51	31	15
20	18	43	69	90	85	67	50	30	13
40	10	30	55	80	93	77	57	35	15
60	8	20	39	55	73	92	80	50	20
80	6	18	31	47	61	75	90	100	50
100	6	18	30	45	60	73	85	96	75
120	8	20	35	50	67	83	85	65	40
140	10	28	47	67	89	90	70	50	29
160	17	39	62	90	99	85	62	41	20
180	12	30	50	72	90	80	66	40	20
200	11	28	42	60	80	76	60	40	20
220	11	28	41	57	74	69	51	34	18
240	13	30	46	60	66	52	40	26	12
260	19	40	59	67	59	49	36	21	10
280	33	60	77	70	60	59	35	21	10
300	65	103	90	80	69	52	39	24	12
320	25	72	100	96	83	69	50	31	17
340	19	49	76	98	97	81	62	40	20

Such a minimalist approach could mean that the final data set omitted some realizable surface colors – particularly surface colors obtained by transmission. In this context, the decision to use the reference medium black from ISO 15076-1, together with a suspicion that some of the data in the gamut originally defined by TC130 could be absolute measurements, and the requirement for smoothness, meant that some high chroma colors of low lightness, which were specified in table 1, were omitted. The reference color gamut, obtained by empirically combining the gamuts in tables 1, 2 and 3, is defined in table 4 together with the white ($L^* = 100$, $C^*_{ab} = 0$) and black ($L^* = 3.1373$, $C^*_{ab} = 0$).

When implementing a transformation from one three dimensional gamut to another it is often helpful to know the location of primary and secondary colors for the device used to create each of the gamuts. Thus, table 5 provides L^*, C^*_{ab} and h_{ab} values of the nominal primary and secondary colors of the reference color gamut. The positions were determined empirically taking the shape of the reference gamut itself as well as the position of the primary and secondary colors in a wide set of output devices into consideration. It should be noted that, unlike measured values for real device primaries, these values are not intended to represent pure virtual device primaries and there is some latitude in their use.

Table 4: The ISO 12640-3 reference color gamut: Maximum chroma values C^*_{ab} (calculated for illuminant D50 and the 1931 (2°) standard colorimetric observer)

h		L*																			
[°]	3.1373	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	0	11	26	39	52	64	74	83	91	92	91	87	82	75	67	57	47	37	25	13	0
10	0	10	24	38	50	62	73	82	90	92	91	87	82	75	67	58	48	37	26	13	0
20	0	10	23	37	50	62	73	84	93	94	94	90	85	78	70	60	50	39	27	14	0
30	0	9	22	35	48	61	74	86	98	100	101	96	90	83	75	65	54	42	30	15	0
40	0	8	21	34	47	60	73	83	93	97	101	99	97	90	83	73	61	47	34	17	0
50	0	8	20	32	43	55	66	77	88	95	99	101	100	98	92	85	72	56	40	20	0
60	0	7	17	27	37	47	57	67	76	84	91	96	100	102	103	98	90	72	51	26	0
70	0	6	16	25	34	43	52	60	68	76	83	90	96	100	104	107	109	100	74	37	0
80	0	6	15	23	32	40	48	57	64	71	78	85	91	97	103	107	110	113	110	70	0
90	0	6	14	22	30	39	47	55	62	68	75	82	88	95	101	106	112	117	120	123	0
100	0	6	14	22	30	38	46	54	61	68	74	81	88	94	100	106	109	112	112	92	0
110	0	6	14	22	31	39	47	55	63	69	76	83	89	96	100	103	106	107	102	75	0
120	0	6	15	24	32	41	49	58	66	73	80	87	93	98	101	102	99	91	73	50	0
130	0	6	16	25	35	44	54	63	72	80	87	93	97	101	99	94	86	73	56	34	0
140	0	7	18	28	38	48	57	67	77	86	95	98	101	97	93	85	75	61	44	26	0
150	0	7	19	30	40	51	62	72	83	92	97	99	96	91	85	76	66	52	37	22	0
160	0	7	20	32	44	56	68	80	92	96	99	97	92	87	79	70	59	46	33	19	0
170	0	8	20	32	43	53	64	75	85	91	96	93	89	82	75	65	55	42	30	17	0
180	0	8	20	31	41	52	62	72	81	87	92	90	86	79	71	61	52	40	28	15	0
190	0	8	20	30	40	50	60	68	76	82	87	85	82	76	69	60	50	39	27	14	0
200	0	8	20	30	38	47	56	63	70	76	82	81	77	72	66	58	49	38	27	14	0
210	0	8	20	29	37	46	53	60	66	73	79	80	75	70	64	57	49	38	27	14	0
220	0	8	20	29	37	45	52	59	65	71	76	75	72	68	63	56	48	38	27	14	0
230	0	9	20	29	38	46	53	59	65	70	75	73	71	66	61	54	46	36	26	13	0
240	0	10	22	31	40	48	55	61	67	71	74	70	66	61	56	49	41	32	23	12	0
250	0	11	24	34	43	51	59	65	70	73	71	68	63	58	52	45	38	30	21	11	0
260	0	14	27	38	48	57	64	69	73	73	70	66	61	56	50	43	35	28	20	10	0
270	0	17	32	45	55	65	70	75	75	73	70	66	61	55	49	42	34	27	19	10	0
280	0	21	42	55	68	75	81	80	79	76	72	67	61	55	49	41	34	26	18	9	0
290	0	26	52	68	83	86	89	87	84	80	75	69	63	57	50	42	35	27	18	10	0
300	0	25	69	82	95	94	93	91	88	85	79	73	66	59	52	44	36	28	19	10	0
310	0	21	51	74	91	97	100	98	95	90	84	77	70	63	55	47	39	30	20	10	0
320	0	18	41	62	79	91	102	101	98	95	89	83	76	68	60	51	42	32	22	11	0
330	0	16	35	53	71	82	91	100	104	102	98	91	84	76	67	57	47	36	24	12	0
340	0	14	31	46	61	73	83	92	101	103	99	95	89	80	71	61	50	38	26	13	0
350	0	12	28	42	55	68	77	86	94	96	93	90	85	77	68	58	48	37	25	13	0

Table 5: L*, C^*_{ab} and h_{ab} values of the nominal primary & secondary colors for the ISO 12640-3 reference color gamut

	Red	Yellow	Green	Cyan	Blue	Magenta
L*	41	95	60	50	21	42
C*	98	123	100	76	95	102
h	29	90	140	220	300	340

Use of the ISO 12640-3 reference gamut

As previously discussed, the reference color gamut was used to define the gamut for the digital images provided in ISO 12640-3. These images can be useful in the evaluation of color management systems and output devices. The reference color gamut has also been specified by ICC as the reference medium gamut for perceptual rendering intent transforms.

In the context of ICC color management the use of the reference gamut should be clear. The transformation defining the perceptual rendering intent of a profile should be developed with respect to the device gamut and the reference gamut. When perceptual rendering transforms from each of the source and destination profiles are combined together, prior to the physical conversion of an image for output, the use of the reference gamut as the common 'interface' will provide a more robust interoperability and therefore more reliable reproduction quality than would otherwise be the case.

Various methods have been proposed for the color rendering, re-rendering and gamut mapping of images, see for example references [10-17]. While some of these have found widespread acceptance in certain situations (for example several chromatic adaptation transforms and XYZ scaling of the black and white points followed by colorimetric reproduction), a wholly universal algorithm is proving somewhat elusive, which is perhaps not surprising. The complexity of the work means that most algorithms are developed for, and evaluated using a relatively small number of media combinations, and a limited number of images. Such algorithms often prove to have issues when used for other media or images, but there are common features defined in many of them that require knowledge of certain gamut boundary properties. Care has been taken to ensure that these properties are clearly defined in the reference gamut specification. It is the responsibility of profile generation software vendors to perform a re-rendering from the device gamut to the reference medium gamut and provide that transform to the user via the perceptual rendering intents of profiles. It should be obvious that transforms going to and from the reference medium gamut have to be different from transforms that were put into perceptual rendering intents of ICC v2 profiles, where a transformation was performed from an "open" CIELAB/XYZ space towards a device gamut. Applying a perceptual transform to the PCS and looking at the resulting CIELAB values can reveal whether a profile builder has used the reference gamut or not. There is also an optional tag in ICC profiles to explicitly indicate whether the perceptual reference medium gamut has been used. It is however more time consuming and to a certain degree subjective to judge whether the profile builder has done a good job or not. The use of a broad range of "natural images" as well as test charts will ultimately reveal the quality.

Summary & Conclusion

This work was initiated by two requirements, the first was the need for standardized CIELAB test images color rendered to a well defined reference gamut, and the second was the desire to improve the interoperability between perceptual rendering intent transforms of ICC profiles. Details on the ICC use can be found in the perceptual intent reference medium amendment available on the ICC web page [18]. For both requirements the precise form and shape of the reference color gamut is less of an issue than the fact of just having one. For ICC purposes care was taken to include the vast majority of colors that can be reproduced on today’s printing devices. It is possible that some colors might be outside of the gamut, but this doesn’t matter as long as the reference medium gamut is used to re-render to and from. Keeping the complexity of the re-rendering algorithms in mind the reader should also be aware that it is a fuzzy target. The perceptual intent re-rendering should aim for the reference medium gamut as the assumption will be made that the "other profile" will do the same, but it is not a requirement to precisely hit, or clip at the boundary.

References

[1] ISO 22028-1:2004, Photography and graphic technology -- Extended colour encodings for digital image storage, manipulation and interchange -- Part 1: Architecture and requirements

[2] ISO 15076-1:2005, Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2004-10

[3] ISO 12640-1:1996, Graphic Technology - Prepress digital data exchange – Part1: CMYK standard colour image data (CMYK/SCID)

[4] ISO12640-2:2003, Graphic Technology - Prepress digital data exchange - Part 2: XYZ/sRGB encoded image data (XYZ/SCID)

[5] IEC 61966-2-1:1999, Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB

[6] ISO/DIS 12640-3, Graphic technology -- Prepress digital data exchange -- Part 3: CIELAB standard colour image data (CIELAB/SCID)

[7] M.R. Pointer, "The gamut of real surface colors," Col. Res & Appl., 5, p. 145-155 (1980)

[8] www.photogamut.org/E_Index.html

[9] ISO/TR 16606:2002, Graphic Technology — Standard object colour spectra database for colour reproduction evaluation (SOCS)

[10] J. Holm, "A Strategy for Pictorial Digital Image Processing (PDIP)," Proc., IS&T/SID 4th CIC, p. 194-201 (1996)

[11] J. Morovic and M. R. Luo, "Gamut mapping algorithms based on psychophysical experiment," Proc. IS&T/SID 5th CIC, p. 44-49 (1997)

[12] B. H. Kang and M.S. Cho, "Gamut compression analysis based on observer experimental data," Proc. IS&T/SID 7th CIC, p. 295-300 (1999)

[13] R. Balasubramanian, R. deQueiroz, R. Eschbach and W. Wu. "Gamut mapping to preserve spatial luminance variations," Proc. IS&T/SID 8th CIC, p. 122-128 (2000)

[14] P.J. Green and M.R. Luo "Developing the CARISMA gamut mapping model," J. Imaging Sci. and Technol., 46, p. 33-43 (2002)

[15] J. Morovic, "Colour Gamut Mapping," in Colour Engineering (edited by P Green and L MacDonald, J Wiley & Sons Ltd. 2002) p. 297-317

[16] Kok-Wei Koh, I. Tastl, M. Nielsen, D. Berfanger, H. Zeng, and J. Holm, "Issues encountered in Creating a Version 4 ICC sRGB Profile," Proc. IS&T/SID 11th CIC, p. 232-237 (2003)

[17] J. Holm, " Some Considerations in the Development of Color Rendering and Gamut Mapping Algorithms," Proceedings SPIE 5678, p. 137-143 (2005)

[18] http://www.color.org/ICCSpecRevision_22_02_05_PRMG.pdf

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Tony Johnson is Professor of Colour Imaging at the London College of Communication, a post he has held since 1998. His experience of Graphic Arts colour reproduction spans over 30 years. Following a decade with the UK Printing Industry Research Association he then spent 12 years as Research Manager at Crosfield Electronics, a UK company specializing in electronic colour reproduction equipment for the Graphic Arts industry, during the 1980s and 1990s. During all that time he was heavily involved in the development of International Standards, as a member of the ISO TC130 committee, and in 2000 he also became Technical Secretary of ICC until his retirement at the end of 2004.