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Defining the gamut of extended colour gamut printing

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Abstract

A gamut boundary test chart can be used to define the gamut of a colour reproduction system as a set of vertices and triangular faces. This makes it possible to analyse characteristics of a reproduction system gamut, such as its volume. A standard chart is currently defined only for RGB and CMYK colour spaces, but the increased adoption of extended colour gamut printing requires a different approach. Here a new test chart is proposed that extends the colour spaces to include extended-gamut printing, with up to seven colorants.

Introduction

It is often important to know the gamut of an output medium, in terms of the range of colours that can be reproduced on it. The main applications are gamut mapping (translating colours from one medium to another medium with a different gamut), visualization (where the gamut is rendered as a polytope in 3D space) and performance analysis (such as comparing different output systems or predicting whether a given colour can be reproduced on a particular system).

The gamut boundary is normally specified as a set of colorimetric coordinates, each of which defines a point on the gamut surface[1]. These coordinates are usually CIELAB, but more perceptually uniform spaces (such as CIECAM16) can also be used. To build the gamut boundary descriptor, the gamut surface can either be sampled in colorimetric coordinates, or in device coordinates which are subsequently mapped to colorimetric coordinates using the device model. A systematic sampling in a CIE space is useful for many purposes, including most gamut mapping algorithms and any method which requires a regular surface grid. On the other hand, sampling in device space and then mapping to colorimetry enables the boundary of the reproduction system to be determined directly from measurement or from characterization data.

The focus of this paper is sampling in device space.

Display gamuts

The gamut of a display is mainly a function of the colorimetry of the primaries, which combine additively to form the white point. The black point of a real display (as opposed to a colour encoding such as sRGB) will have non-zero luminance and will depend on the particular display technology together with incident light falling on the faceplate. In certain cases a printed reproduction will be expected to match an original seen on a display, and the relative gamut sizes will determine whether this is possible.

Printer gamuts

For reflective media, the set of colorant primaries, their secondary overprints, together with the media white and black points, define the eight vertices of a hexahedron.

This may be sufficient for applications where the gamut surface does not require great precision. However, due to the nature of the CIELAB colour space, media gamuts (both print and display) are inevitably concave and so the hexahedron overestimates the gamut volume. A convex hull can readily be determined from a characterization data set, but this will also fail to track the concave gamut shape in CIELAB. For this reason a denser sampling of the gamut surface is needed.

Gamut boundary test chart

A test chart was described[2] in 2000 for RGB and CMYK devices. This defined a two-dimensional target with approximate hue and lightness dimensions: the hue dimension is approximated by the ratio of colorants, while the lightness dimension is approximated by the magnitude of colorant amounts. This forms a grid which can be readily triangulated as a polyhedron, with the top and bottom rows converging to the media white and black points respectively.

Subsequently a refinement of this target was described[3]. The new target increased the sampling density in both hue and lightness, with 36 columns corresponding to different colorant ratios, and 22 rows corresponding to different colorant amounts. This target was initially generated in RGB and converted to CMYK; this approach produced a grid with a more visually uniform spacing and increased granularity compared with the original target. This chart is shown in Figure 1, and the colorant amounts are given in [3].

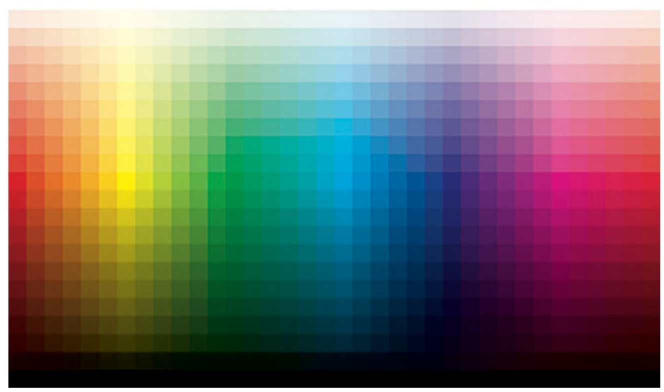

Figure 1. Gamut boundary test chart for RGB and CMYK

This gamut boundary target provides a convenient method of determining the gamut boundary of any RGB or CMYK medium. The coordinates of the chart are converted to CIELAB by one of three methods: a) the chart is output on the device whose gamut is needed, and the subsequent stimuli measured; b) the chart is converted from colorant amounts to CIELAB using the forward device model for the device; or c) the ICC profile for the device is applied to the chart.

Coordinated work between CIE TC8-13, ISO TC 130 WG14 and ICC, which included extensive testing of different methods, led to the chart in Figure 1 being recommended for the purpose of defining output media (print and display) gamuts in CIE 246[4], and for printer colour gamuts in ISO 18621-11[5].

Face/vertex boundary description

The regular layout of the chart gives rise to an ordered triangulation. The chart is read row-wise, and each row in the face list represents the indices of three vertices that form one of the triangles on the surface. A list of triangular faces has been provided for the chart. When the vertices are mapped into CIELAB space by one of the methods described above, the same face list can be applied since the vertices retain the same positions in relation to each other. In colorant space, the face list spans the entire surface of the gamut polytope, with no overlaps or gaps. After mapping into CIELAB this condition is not always fully met and there may be a small number of incorrectly-oriented faces, but procedures for handling the possible errors have been described[5].

The gamut defined by the set of CIELAB vertices and the corresponding face list can then be used for the principal applications of gamut mapping and performance analysis. A gamut mapping algorithm (GMA) typically locates the intersection between the gamut surface and a line subtending from the point to be mapped to the neutral axis of the gamut6. Many GMAs in effect require the gamut surface to be defined at a series of planes of lightness and chroma at different hue angles, so that the gamut boundary is represented by a line connecting vertices in 2D space and the intersection is found between this line and the mapping direction. If the gamut boundary is represented by an arbitrary triangulation in 3D space, the corresponding intersection is between the mapping line and a triangle in 3D space[7].

Device gamut and usable gamut

It is necessary to distinguish between the device gamut and the usable gamut The device gamut is obtained when the full range of colorant values are sampled and measured. In practice, workflow components usually limit the maximum total amount of ink that can be deposited in one location, to avoid excessive ink consumption and problems with drying. This total ink limit is expressed in the device ICC profile, where for example a pure black in the source image is mapped to ink amounts that are less than 100% of all four colorants.

Gamut volume

Gamut analysis requires the volume of the gamut polytope, which is determined by adding a point at the centre of the gamut such that each surface triangle becomes a tetrahedron; the volume of each tetrahedron is calculated and then the volumes summed to provide the gamut volume[4]. Performance metrics such as Gamut Comparison Index can then be applied.[8]

Having a well-defined procedure to determine the gamut surface of a given device makes it possible for different users to obtain the same gamut from the same data, and also provides a basis for objective comparison between different media gamuts.

Some challenges in gamut definition

The face/vertex encoding combined with the procedure for obtaining gamut surface vertices adopted in CIE246 and in ISO 18621-11 provide a robust and reproducible method of specifying the colour gamut of an output device. However, two particular cases are not addressed by these documents: HDR displays and n-colour printing.

HDR displays

CIE TC8-13 excluded HDR display gamuts from consideration, owing to the problem of defining the state of adaptation. As discussed above, gamuts are usually represented in CIELAB coordinates, where the reference white used in calculating L*, a* and b* coordinates corresponds to the XYZ colorimetry of the adopted white point. For reflective media, this means the XYZ values of a perfect reflecting diffuser under the chosen viewing illuminant, which constrains the L* of the white to a maximum of around 95 for highly reflective substrates. Optionally a reflective gamut can be expressed in media-relative CIELAB, whereby the XYZ values are first scaled so that the media white point is equal to the illuminant. For displays, the XYZ colorimetry of the display peak white is taken as the adopted white point, leading to an L* range with an upper bound of 100. This is already media-relative, so no further scaling is needed.

We can also note that due to the linearly additive nature of self-luminous systems, the XYZ colorimetry of a display gamut can readily be estimated from measurement of the primaries and the display model.

With HDR displays, the peak white has a much greater luminance than a standard dynamic range (SDR) display. The full luminance range is only used for small spatial areas and for limited time periods; and in a sequence of frames such as a video the adapted luminance level is likely to be content-dependent and vary during the sequence. One option would be to assume an observer adaptation to the diffuse white luminance (also referred to as graphics white or reference white), which is often fixed at 203 cd/m^2. If this is taken as the reference white in calculating CIELAB, the HDR gamut would be represented as being identical to an SDR display having the same primaries, which would not correspond to the visual impression of the gamut, and would not support comparison between the gamuts between two different displays. Moreover, the L* function which scales from luminance to lightness using a cube root function does not predict just-noticeable differences well at higher luminances [9], and there are alternatives with better performance [10]. This implies that a colour space other than CIELAB would be necessary if the goal is to have a good visual representation of the gamut. From the above it can be seen that more work is needed in order to recommend a gamut definition method for HDR displays.

n-colour printing

Printing with more than the conventional four process primaries cyan, magenta, yellow and black is referred to as *n*-colour printing, where *n* can be any integer depending on the requirements of the reproduction, which may include specific spot colour inks or inks which extend the gamut generally. This paper focuses primarily on extended-gamut ink sets with up to three additional colorants.

Spectral gamuts

A further case not considered in CIE246 and ISO 18621-11 is spectral gamut definition. Again for self-luminous displays the gamut surface can readily be determined using the principle of additivity from the spectral emission of the primaries and the electro-optical transfer function, while for reflective media the task is more complex.

Extended colour gamut

Although CMYK four-colour process printing is well established, for some applications the gamut is insufficient and additional colorants are used to extend it. Any reasonably high-chroma colorant with a hue angle different from cyan, magenta or yellow will tend to increase the total gamut volume, but a particularly common usage consists of three colorants whose hue angles are intermediate to the cyan, magenta and yellow primaries. The additional colorants are often orange, green and violet, leading to a seven-colour ink set denoted CMYKOGV, which forms the basis of Extended Colour Gamut (ECG) printing. Recommended aim values for OGV colorants are given in ISO 21328[11], and are shown in Table 1.

Table 1. OGV colorant aim values (ISO 21328)

Ink	L*	a*	b*	C*	hab
Orange	70	56	80	98	55
Green	66	-73	1	73	181
Violet	24	46	-55	71	307

Figure 2 shows a projection in CIELAB a*/b* coordinates of a colour gamut formed from CMYOGV primaries. In a given press run, one, two or all three of the OGV set may be used, depending on the job requirements.

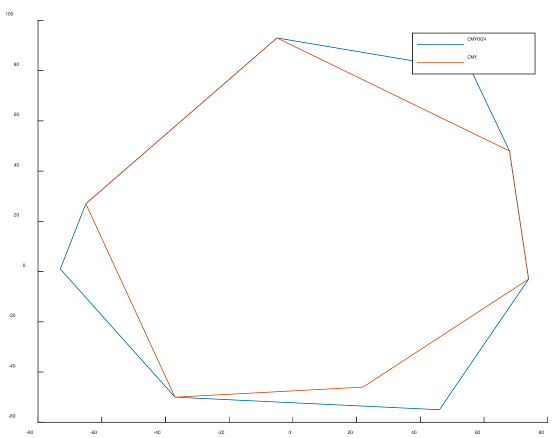

Figure 2. Simplified projected gamut of ECG printing using ISO 21328 primaries

A test chart for ECG

There is now a need for a gamut determination procedure for CMYKOGV that shares the advantages of simplicity and consistency of that described in CIE 246 and ISO 18621-11, which requires a suitable test chart

Here we propose a chart which simply replaces the C, M and Y colorant amounts in intermediate hue angles to accommodate the OGV inks. So for example, in the chart column where cyan and yellow amounts are equal, both are replaced by the same amount of green; in columns between green and cyan, yellow is replaced by the same amount of green; and in columns between green and yellow, cyan is similarly replaced by green.

For cases where only a sub-set of OGV is used, only the relevant columns of the chart are replaced, since in other colorants the gamut remains the same as in the CMYK gamut.

The advantage envisaged for this method is that once the modified chart has been prepared the CIELAB coordinates are obtained by the same method as for the CMYK gamut, and the face list provided for the CIE[4] method is then also identical to that for the CMYKOGV gamut. Hence there is no change in the procedure for obtaining the gamut, apart from the use of the modified gamut test chart.

The procedure for determining a gamut according to this method is therefore the same as described in CIE3 and ISO 18621-11. If using the device ICC profile, the steps are:

1. The ICC profile for the device is assigned to the test image.
2. The image is converted to CIELAB with the device profile as source, using the ICC-Absolute Colorimetric rendering intent.
3. The CIELAB values are extracted from the image to form the vertex list

The CIELAB values in the vertex list represent the gamut boundary. It can then be used in conjunction with the face list for gamut mapping, visualization or gamut analysis. Figure 4 shows an example visualization of a five-colour CMYKG print. This was generated from a characterization data set consisting of measurements of a test chart printed in CMYK plus Green (CIELAB L*, a*, b* coordinates [63.63 -72.63 35.04]), by first making a 5CLR ICC profile and then applying the profile to the chart in Figure 3 to convert to CIELAB coordinates for the gamut boundary.

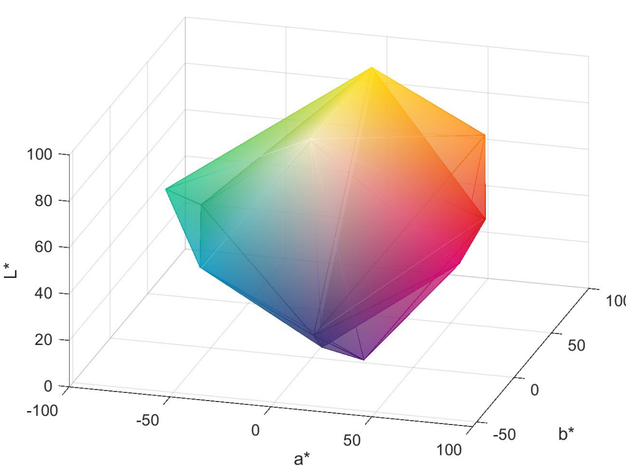

Figure 3. Simplified comparison of ECG gamut with CMYK. Inner figure: FOGRA39 (offset on white coated paper) CMYK primaries and secondaries; outer figure: FOGRA39 with additional ECG colorants

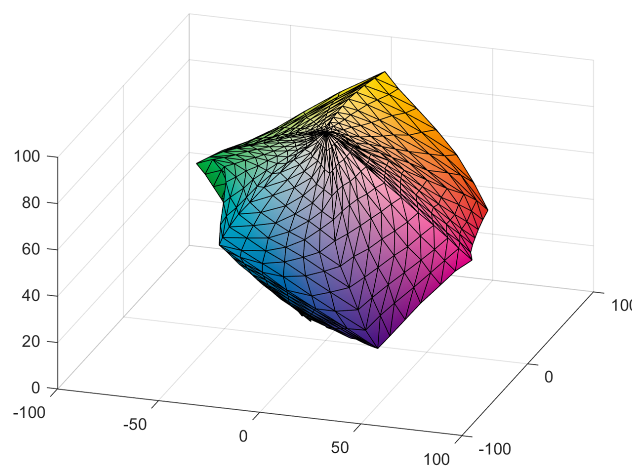

Figure 4. Visualization of the gamut of a five-colour process, using the CMYKG version of the proposed test chart

Beyond the ECG gamut

The ECG system incorporates a single primary colorant at hue angles that lie between those for each pair of cyan, magenta and yellow. The 7-colour chart is not limited to the ECG ink set and can accommodate any colorant in the green, orange and violet segments – for example, a red may be used in place of orange, or a blue in place of violet.

In principle it is possible to extend the colour gamut beyond that of the 7-colour ECG system by adding further high-chroma colorants at additional hue angles (although the actual increase in gamut volume is likely to be small). Depending on the particular colorants there will be a number of options for extending the gamut boundary chart:

- For a white ink that is brighter than the unprinted substrate, it replaces the top (white) row of the target at 100%.
- For a black ink that is darker than the normal black, it replaces normal black in all rows.
- For a second or subsequent ink that lies in one of the orange, green or violet segments, an additional 12 columns can be added to the chart centred on the additional ink, and using the same numerical ratios as described above, generate the intermediate colorant ratios between the additional ink and those adjacent.

Conclusions

A method of adding Extended Colour Gamut colorants to an existing gamut boundary test chart has been described. Charts produced by this method can be efficiently used in the generation of a gamut boundary description consisting of a vertex list and face list, using the same face list as in the standard gamut analysis procedure in ISO 18621-11.

Methods of extending the chart beyond the seven-colour ECG set have been described, making it possible to support any number of inks used in the printing process.

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