Color Gamut Mapping along Electrostatic Field Lines

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Abstract

Most gamut mapping methods project out-of-gamut colors onto the in-gamut colors using a device independent color space (such as CIELAB) with constraints on hue and lightness. Results depend significantly on the shape of the gamut. Especially in the case of concave gamuts, continuous transitions between colors while preserving chroma and lightness are hard to obtain.

We propose a gamut mapping method based on a physical model: the trajectory of a charged particle along electrostatic field lines induced by charges placed on the surface of the gamut. Since an electrostatic field is free of divergence, every out-of-gamut color is uniquely mapped onto a gamut surface point. The distribution of the charges on the surface can be used to influence the mapping.

In Océ's new Color Production System (CPS 700), colors are formed by adhesively collecting seven different toners. Consequently, mixed colors consist of toner particles beside each other and not on top of each other, giving the color gamut a concave shape. Our method yields smoother transitions between colors than any other method we have tried.

The paper will discuss the need for continuous gamut mappings, the field line method and its benefits for transitions between monocolors in the CPS 700.

Introduction

Color output devices can output a limited range of colors. This range consists of the primary colors of the device and combinations of these primaries. This is the so-called gamut of the output device. Colors outside this gamut cannot be reproduced. The usual workaround is to replace non-reproducible colors by reproducible ones in a process called gamut mapping. Various methods have been proposed[1] that belong to one of two classes: compression and projection (clipping) methods. The methods of the last class seem to give the most satisfying results.[2]

The projection methods are usually based on a projection in CIELAB space and perceptually compared to obtain an optimal "appearance match" for a set of images.[3] Innovations include algorithms that use curved lines along which the colors are mapped to the surface of the gamut.[2]

The gamut of an actual apparatus may not be as regular as often assumed in the specification of the algorithm. As a result, non-reproducible colors correspond individually to acceptable gamut colors, but a continuous series of colors along a line in color space does not necessarily correspond to a continuous series on the gamut boundary. In this paper we put forward a method that is especially suitable to ensure the continuity in the gamut mapping process.

Color Theory

Although, from a physical point of view, color can be completely described by the reflection of light at various wavelengths, the sensitivity of the human eye makes the perception of color a complex multidimensional subject. In the perception of color, gloss, spatial variation, etc. play an important role, but in this paper, we will only consider the diffusely reflected light of a homogeneous area that can be represented in the three-dimensional CIELAB space. In these coordinates, the perceived difference between two colors (L_1^*, a_1^*, b_1^*) and (L_2^*, a_2^*, b_2^*) is given by the usual measure for distance, delta E:

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \qquad (1)$$

Color Discretization

When calculating a mapping, colors are discretized. The step size in different directions is taken small enough to avoid visible transitions between two adjacent colors and sufficiently large to have a reasonable calculation time. Actions on color data may on the one hand increase the distance of originally adjacent colors or on the other hand make originally different colors identical. Both effects lead to banding on the hardcopy and is therefore to be avoided.

ΔE Gamut Mapping

The first idea to map an out-of-gamut color to the gamut is to use the closest gamut color available. This is called 'ΔE gamut mapping'. A disadvantage of this method is that many colors reduce to a single gamut color, flattening out all details of images with many out-of-gamut colors. For this reason the various methods mentioned in the introduction are proposed.

In figure 1 we show the effect of the ΔE gamut mapping algorithm on a two-dimensional scale. The gamut is reduced to a Lightness – Chroma area at a certain hue, with a boundary that is realistic for hardcopy print processes like the Océ CPS700. A series of colors outside of the indicated gamut is mapped to this boundary according to the arrows. Three types of color points can be discerned:

Type (A) color points with neighbor points that have a similar distance after mapping,

Type (B) color points with neighbor points that have a much smaller distance after mapping, and

Type (C) color points with neighbor points that have a much larger distance after mapping.

As can be seen, the irregularities in the shape of the gamut lead to the occurrence of all three types of color points. In an image with gradually changing colors the occurrence of type (B) and (C) points leads to banding.

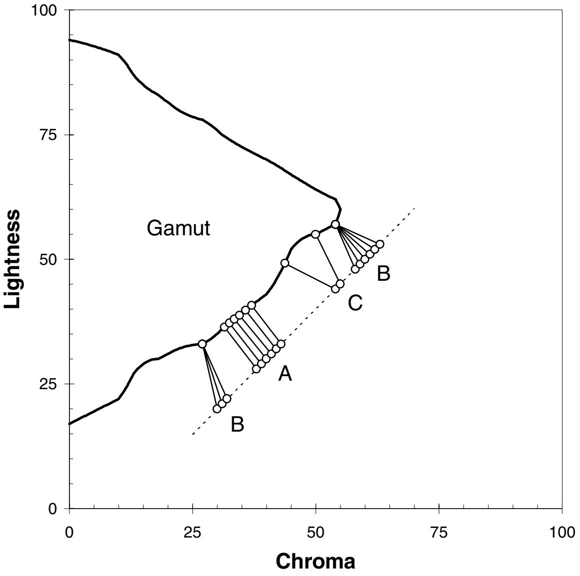

Figure 1. Minimal Delta E

Gamut Mapping using Electrostatic Fields

We propose a method that is based on a physical model: a charge in an electric field. An electric field of a set of fixed (static) point charges has the property that it is free of divergence outside the region of charges. This means that field lines never cross and never disappear before the lines reach a charge that generates the field. This property is extremely useful for the mapping of out-of-gamut colors.

When we place (negatively charged) point charges with charge Q_i on every boundary point i of the gamut, an electrostatic field E arises outside the gamut. The electric field at a certain point (L^*, a^*, b^*) is calculated as follows:

$$\vec{E}(L^*, a^*, b^*) = \sum_{i=0}^{\text{total charges}} \frac{Q_i}{\left\|\vec{r}_i\right\|^2}\,\vec{r}_i \qquad (2)$$

where r_i points from point (L^*, a^*, b^*) to charge i at (L_i^*, a_i^*, b_i^*) and has length

$$\left\|\vec{r}_i\right\| = \sqrt{(L_i^* - L^*)^2 + (a_i^* - a^*)^2 + (b_i^* - b^*)^2} \qquad (3)$$

In every color point outside the gamut, the electric field points in the direction of the boundary of the gamut. A charged particle would move along this electric field towards the gamut. Following this particle we obtain a trajectory ending on the gamut boundary. All colors on a trajectory are mapped to the same gamut boundary color.

In figure 2 we show the same two-dimensional gamut as in figure 1 with the same series of colors that is mapped. The type B) color points are spread further apart and the type C) color points come closer to each other. For both types of points the mapped colors never coincide, except when the distance between two colors reaches the level of discretization of the gamut boundary.

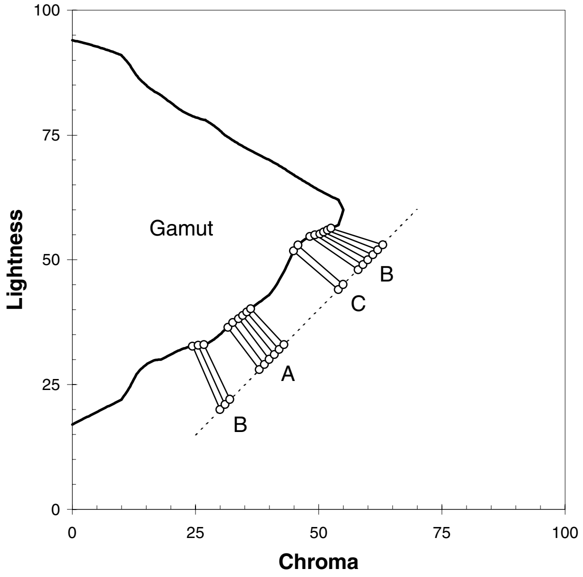

Figure 2. Electrostatic Field Lines

In a three-dimensional color space, the same principle applies for two primaries with different hue. The distribution of charge on the gamut boundary can simply be done by placing one unit charge on every boundary point or more complex by adding extra charge to preferred color points, e.g. the primary colors. The boundary of the gamut is found by checking whether the neighboring colors also belong to the gamut or not. When the gamut is a set of discrete points in CIELAB space, one could define the boundary points as those points that miss either one of its six or one of its 26 neighbors. The speed of the algorithm will increase linearly with the number of charges.

CPS 700

The new color technology of Océ is based on the successful CopyPress technology which results in a monolayer of toner that is brought onto the paper. Color mixing is accomplished by placing the seven primary conductive, magnetic toners next to each other instead of on top of each other. As a result, the hardcopy feels more like offset than the traditional color copy output.

The gamut for this printing process is influenced by the color of the primary toners, the way color mixing is done and restrictions on the maximum amount of toner that can be developed. This shape of this gamut is irregular and has some cusps. To map the colors neatly on the boundary we have used the algorithm described above. The results were compared to other methods, such as the ΔE algorithm, a ΔE_{cmc} algorithm, a standard constant hue algorithm, the curved line algorithm[2] and a number of projection methods. We have not found another method that is equally successful.

As test material we used both photographic originals and specially designed bitmaps. On the first type of originals the most conspicuous finding was that the saturation of the hardcopy was higher than we were used to. In fact, loss of saturation occurs with many gamut mapping algorithms.

The specially designed bitmaps were used to check banding for many out-of-gamut wedges. In all cases banding was found to be minimal for the field line gamut mapping algorithm.

Conclusion

We have developed a new method for gamut mapping that explicitly takes into account the irregularities in the shape of a gamut that may follow from print process limitations. This avoids the risk of banding for gradually changing out-of-gamut colors. The method enables the incorporation of preference elements like extra accentuation of the primary colors.

References

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Biography

Maarten van Gestel received his Masters Degree in Physics from the Eindhoven University of Technology, the Netherlands, in 1999. Since then, he has been working at Océ's Research and Development laboratory in the field of image processing. His work for the CPS 700 focused on the development and implementation of this new gamut map algorithm. Currently, he is working on image processing algorithms for color scanners.