# Gamut Mapping for Small Destination Gamuts

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## ABSTRACT

In this paper we present a new approach to develop gamut mapping algorithms for small destination gamuts in particular newspaper printing. Gamut mapping algorithms have to satisfy the constraints of the destination gamut, preserving as much of the color appearance of the original image as possible. For small destination gamuts it is a special challenge to find a good compromise between conservation of color, lightness, saturation, and local contrast. This work focuses on two main points: One is the control of the local mapping properties in particular continuity and contrast conservation of the mapping. The second is the use of a large set of application relevant test images for the psychovisual tests in contrast to the usually small set of high quality test images.

## 1. INTRODUCTION

In this paper we present a new approach to develop gamut mapping algorithms (GMA) for small destination gamuts in particular newspaper printing. Mapping a given source gamut to a destination gamut – so called gamut mapping – is a key feature in every color reproduction process. Gamut mapping algorithms have to preserve as much as possible of the original color appearance. This is a complex mixture of different aspects such as color saturation, contrast and lightness. A lot of different algorithms were proposed with special emphasis on one or the other aspect (see Morovic[1] for a recent overview). With a few exceptions[2,3,4] gamut mapping research mainly deals with destination gamuts assuming that the majority of source colors lie within the destination gamut. For small destination gamuts it is a special challenge to find a good compromise between conservation of color, saturation, and local contrast. Nonlinear scaling of lightness[5,6] and/or nonlinear chroma compression[3,4] were proposed to allow for good reproduction of midtone colors and at the same time avoiding clipping artifacts for highly saturated colors. Modern algorithms try to optimize lightness and saturation simultaneously. The increasing complexity of the algorithmic design however makes it difficult to assess the output quality only by the traditional method, namely the application of the GMA to a small set of established test images judged by a small number of observers. Recently, in order to improve the comparability, the technical committee of CIE worked out and published corresponding guidelines[7]. The CIE committee hopes for an active participation in applying and further developing these guidelines. We understand our paper as a contribution to this discussion, in particular on its application to small destination gamuts. Two points are of special interest for this work: One is a good control of the local mapping properties, in particular continuity of the mapping and contrast conservation[8]. The second is the use of a large set of application relevant images for the psychovisual tests compared a small set of high quality test images.

## 2. ALGORITHM

The presented new algorithm called 'Smooth Gamut Deformation Algorithm' (SGDA) incorporates two main features of the CARISMA algorithm[2]. The first is to use the same type of hue shift as defined by the hue differences of the primary and secondary colors of the source and destination device. The second feature is the goal to map source cusps to destination cusps. Different from CARISMA the mapping is done with a nonlinear gamut compression. Furthermore the algorithm is designed to map to the full destination gamut, thus allowing also for gamut expansion. CIELAB is used as working color space. With a set of parameters we optimized the algorithm for the specific destination device: 1) the amount of hue shift, 2) the position of the focal point on the gray axis and 3) the shape of the mapping function. The key feature of the algorithm is the mapping of the gamut border: Border colors $S_s$ are mapped in two steps. First a general hue shift is applied, which is constant within a given hue plane. Then colors $S_s$ on the source gamut border are mapped to the destination gamut border $S_d$ within this hue plane by equalizing the normalized areas $A_s$ and $A_d$ bounded by $F_s$ - $W_s$ - $S_s$ and $F_d$ - $W_d$ - $S_d$ respectively (see Figure 1). The bulk colors $X_s$ are mapped to $X_d$ in relation to the border color $S_s$ using a nonlinear compression along straight lines toward a focal point $F_s$. The final optimization of the parameters was made by visual inspection of mapped images and at the same time controlling local mapping features with a UnitDE-Test[8]. CIELAB without white point adaptation was used as working color space. The following nonlinear compression was used:

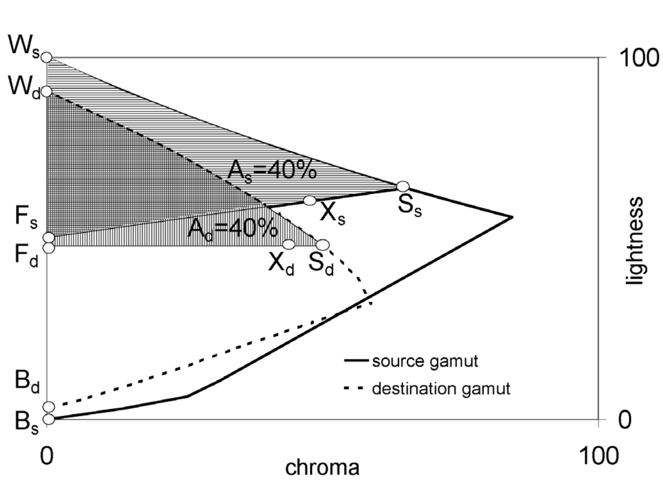


**Figure 1:** Basic mapping scheme of SGDA for surface colors using normalized areas and nonlinear mapping.

$$X_d = p_2 \{ S_d \tanh^{-1}[ S_s/S_d \tanh(X_s/S_s)]\} + (1 - p_2) (X_s S_d/S_s) \quad (1)$$

The parameter $p_2$ allows adapting the degree of nonlinearity. For our study we used $p_2 = 0.75$. For $p_2 = 1$ this function simulates the mapping behavior of photographic paper: Its saturation curve can be approximated with a *tanh*-type function[9].

## 3. EXPERIMENTAL

**Gamut Boundary Description:** The gamut boundary was approximated by a set of gamut surface points connected to a grid of triangles. The description used resembles the "Segment Maxima Gamut Boundary Descriptor"[10]. One main difference is that positions of the grid points are not defined by fixed spherical angles. In this way corners and edges of the gamut boundary, which are usually well defined for media gamuts, can be modeled to a better precision, because grid points can be put exactly on corners and edges. We used a 1440 face grid. For this paper we used sRGB as source and newspaper printing as destination device. In Figure 2 we show the grid of the sRGB gamut compared to newspaper gamut. The newspaper gamut was calculated using color data from the ICC-Profile based on ISO 126473 ("Zeitung_QUIZ_28_02.03V2.icm" from www.ifra.com).

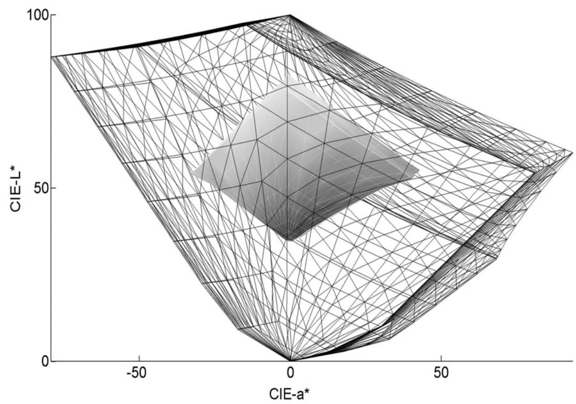


**Figure 2**: Newspaper gamut (solid) compared to sRGB gamut (wire grid). The color space is CIELAB.

**Psychovisual Tests:** As far as applicable, the test procedure was made following the CIE-guidelines. All pair comparisons have been performed on an LCD screen (EIZO cg21). The background of the screen was set to neutral gray. Behind the screen and in the back of the observer dark gray and black paper backgrounds respectively were used. The illuminance of the surrounding in the middle of the switched off monitor was 40 lx and the color temperature of the illumination was 4570K. On the screen no reflexes of the illumination were visible to the observer. After monitor calibration the colors of the mapped images were displayed with the mean deviation of $\Delta E = 3.0$ and the maximum color deviation $\Delta E_{max} = 5.4$.

For the psychovisual test two sets of test images were used: a first, traditional test set of 5 ISO test images and the SKI image recommended by the CIE guidelines (see Figure 3) and a second, large set of 250 images from a newspaper agency[11]. The average amount of out of gamut colors was 72% and 74% for the first and second test set, respectively. This is much more than in applications with larger destination gamut such as photographic printing (27%, 31%) and inkjet printing (21%, 29%). The original image and two mappings thereof were shown simultaneously on the screen, the original at the top border in the middle of the screen and the two mappings of a pair side by side in the middle of the screen. All images had a constant height of 10.5 cm. The observing person had to select the mapped image which he or she judged to be the better representation of the original image. If both mappings were judged to have equal quality, the original image had to be selected. The observers were members of the staff of our institute. They were instructed and trained for tests doing a test with 3 different GMAs applied to 5 images. Every observer had passed the "Ishihara test" and the "Farnsworth-Munsell Hue test"[12] with at least average discrimination. Each pair of different mappings was shown equally often with exchanged positions to eliminate preference effects of left or right position. The results of the judgment of identical pairs were used only to assess the consistency and were eliminated when computing the z-score matrix and the accuracy scores. All pairs were presented in random order.


**Figure 3**, Images of first test set

**4. RESULTS AND DISCUSSION**

The following algorithms were compared: SGCK and HPMinDE both recommended as reference algorithms by the CIE guidelines[7], the newly presented algorithm SGDA and a three dimensional implementation of the Schläpfer algorithm[3,8] (SCHLP). The combined results of the two test sets are shown in Figure 4. It summarizes the judgments of 14 persons having compared 1008 pairs using the first test set and 17 persons having compared 6000 pairs using the second test set. The accuracy scores shown, were calculated from the z-score matrix as described by Morovic[13]. Overall SGDA performs best, and HPMinDE worst. An interesting result is the differences between the two test sets, in particular of SGCK and SCHLP. One cause could be that a small test set is not representative enough. Another possible explanation could be that the generally higher noise of news agency prints compared to high quality test images favor algorithms with a smooth local mapping behavior. In a previous study[8] it was shown that SGDA and SCHLP show uncritical behavior concerning discontinuities and contrast loss, whereas SGCK showed discontinuous behavior and HPMinDE showed pronounced contrast loss. Even if in the design of SGDA the local mapping behavior is added as an additional explicit constraint in addition to lightness, saturation and contrast

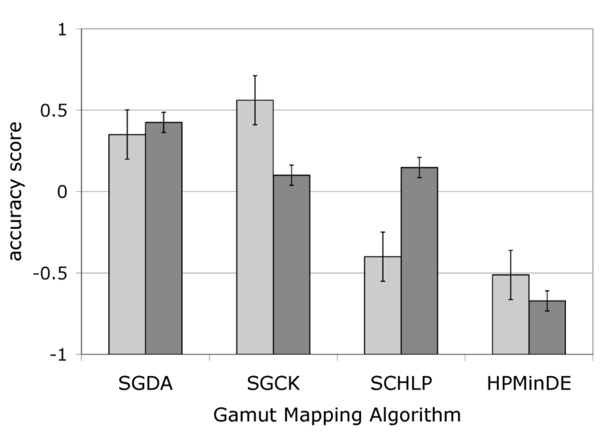


**Figure 4:** Psychovisual tests: Results using 6 test images (left bar) and a set of 250 newspaper agency images (right bar), both shown with error

conservation, it yields good results for the newspaper printing application. In contrast to several gamut mapping studies, suggesting that clipping is to be preferred over compression[5,14,15,16] the above results confirm that for small destination gamuts this does not hold. This is in agreement with other GMAs proposed for newspaper printing[2,3,4].

## 5. CONCLUSIONS

The presented results show that special attention to the local mapping behavior in gamut mapping designs need not to be at the expense of other psychovisual goals and yield good results for the newspaper printing application. The CIE-Guidelines turned out to be helpful for the test setup even if some improvements could be made in order to cover also specialized applications such as newspaper printing. The presented results also call for an extended discussion on the size of test sets. The presented results do not give a definitive solution to the gamut mapping to small gamuts, they rather are a starting point to motivate further research work. In particular the potential improvements through image dependent gamut mapping and spatial dependent mappings are not explored here.

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