

# Color matching functions for a perceptually uniform RGB space

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## Abstract

Perceptually relevant color differences have traditionally been evaluated using Euclidian distances ( $\Delta E$ ) in CIE standardized color spaces, such as CIE Lab and CIE Luv. Here we derive RGB color matching functions for a hue constant color space uniform in terms of color differences. We optimize the hue constancy of the RGB color matching functions based on a gamma and brightness independent hue representation.

## I. INTRODUCTION

CIE Lab<sup>1</sup> 1976 [1] is based on the CIE 1931 XYZ color matching functions (CMFs). The non-linear relations for L, a and b values are an attempt to model the non-linear and opponent response of the human visual system, and to derive a color space representation where perceptually relevant color differences can be calculated with a simple metric. In the case of CIE Lab (and also CIE Luv, although we will not discuss it here), color differences are expressed as Euclidian distances ( $\Delta E$ ) between two color coordinates in the three dimensional color space.

As the CIE Lab color space is not perfectly perceptually uniform, i.e. equal Euclidian distances are not necessarily perceptually equal, new difference formulae ( $\Delta E$  CIE94,  $\Delta E$  CIE2000) were proposed based on new results of psychophysical studies. For  $\Delta E$  CIE94 [2], weights were introduced to adjust for the respective influence of lightness, chroma and hue.  $\Delta E$  CIE2000 [3], an improved version of CIE94, contains an additional term representing a hue-chroma interaction. These successive versions of color difference formulae, all based on CIE Lab 1976, give better overall perceptual performance but are also heavier to compute.

CIE Lab  $\Delta E$  or one of the subsequent formulae are also applied to evaluate color differences in color imaging applications. CIE Lab is also used as an image editing color encoding and as a profile connection space (PCS) in ICC color management applications [4].

However, other color encodings that mimic the perceptual response of the human visual system are also often applied in image processing tasks. The well known YCrCb encoding [5], which is a linear transformation of (non-linear) RGB is used in compression to subsample image chrominance, and HSV is used in segmentation tasks. Thus, for many imaging applications, an approximation of a perceptual color space seems to be sufficient for engineering tasks.

In this study, we also take an engineering approach to define a RGB color space that is approximately uniform with respect to hue and to color differences, suitable for imaging applications such as editing. We are optimizing a linear transform from XYZ to RGB color matching functions (CMFs), which can form the basis of a RGB color encoding.

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<sup>1</sup> The correct notation is CIE L\*a\*b\*. We neglect the (\*) in this abstract.

## I. EXPERIMENT

This experiment is an extension of the work done by Finlayson and Süsstrunk [6]. By sampling the surface of a sphere [7], which ensures that the length of the sensors is always equal to one, they tried different combinations of RGB CMFs to find the ones who result in the most hue constant color space. Their optimization was based on hue-constant psychophysical data by Hung and Berns [8]. The optimization criterion was line fitting of hue lines in a logarithmic, opponent color space. The hue definition used here is independent of gamma and brightness [9].

Here, we extend the experiment to the Munsell dataset [10] and introduce a new constraint on the hue uniformity. We calculate the XYZ values for the Munsell reflectances under D65, and apply a linear transform from XYZ to RGB for each combination of RGB CMFs.

Our optimization relies on geometrical considerations: we want a hue constant transform and a uniform space in terms of color differences. The first criterion is hue constancy, estimated by fitting a line through each hue angle. The deviation of each hue line from a straight line gives us a measure of hue uniformity. However, this still does not result in a suitable transform, the hue angles also should be equally distributed. We thus introduce a condition on the uniformity of hue angles.

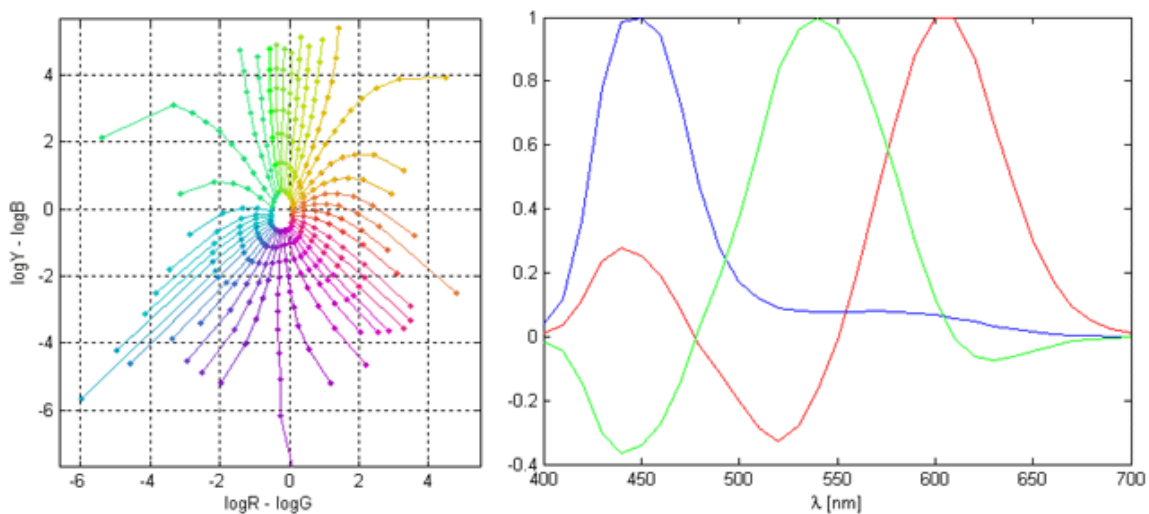


Figure 1. Log Opponent Color representation for a transform optimizing hue angles and corresponding sensors

Figure 1 shows the preliminary result obtained by optimizing for hue constancy and hue angle including transforms located in a  $25^\circ$  cone centered on sRGB coordinates. In the final paper, we will discuss the experiment in more details and present results performed on larger samples sets, with refined optimization criteria, and comparisons with standard color difference calculations.

Our method is flexible and offers many degrees of freedom. The different optimization criteria can be modified to suit the wanted properties of the CMFs.

### III. REFERENCES

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