A method for Gamut Compression towards L=50

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1 Introduction

A method presents the process of compressing an image's RGB gamut into a CMYK gamut using a mathematical approach based on LAB and LCH color spaces. The purpose is to ensure that all colors within the original RGB gamut fit within the CMYK gamut, which is typically smaller. In addition to clipping out-of-gamut colors, the code applies a proportional compression of all colors towards the CMYK boundary while keeping the overall color characteristics of the image intact.

2 Methodology

The workflow of the process can be divided into the following steps:

- Convert the image from RGB to the LAB color space.
- Calculate the LCH (Lightness, Chroma, Hue) values for both the RGB image and the CMYK gamut.
- Compute the convex hull for both the RGB and CMYK gamuts.
- Compress both in-gamut and out-of-gamut colors towards the CMYK boundary along the lightness axis towards $L^* = 50$.
- Visualize the convex hulls and compute the Delta E 2000 between the original and compressed images.

2.1 Color Space Conversion: LAB to LCH

The LAB color space is perceptually uniform, meaning that changes in LAB values correspond to consistent changes in human perception. The conversion from LAB to LCH is performed using the following equations:

$$C = \sqrt{a^2 + b^2} \tag{1}$$

$$H = \text{atan2}(b, a) \tag{2}$$

$$H = H \times \frac{180}{\pi} \quad \text{(convert to degrees)} \tag{3}$$

$$\text{if } H < 0, H = H + 360 \tag{4}$$

Where:

- L is the lightness component.
- a and b are the chromaticity components.
- C is the chroma.
- H is the hue angle (in degrees).

The inverse conversion from LCH back to LAB is defined by:

$$a = C \times \cos(H \times \frac{\pi}{180}) \tag{5}$$

$$b = C \times \sin(H \times \frac{\pi}{180}) \tag{6}$$

2.2 Convex Hull Computation

The convex hull is computed in the L-C (Lightness-Chroma) plane for both the original RGB gamut and the CMYK gamut. This convex hull represents the outer boundary of each color space. Any color in the RGB space that falls outside the CMYK convex hull is considered out-of-gamut and is compressed.

The convex hull computation is done using the `scipy.spatial.ConvexHull` function, which returns the vertices defining the outer boundary of the given set of points in the L-C plane.

2.3 Gamut Compression

Out-of-gamut colors are moved to the nearest point on the CMYK gamut boundary. The compression process also affects in-gamut colors proportionally, moving them towards the point $L^* = 50$. The compression is controlled by a factor f (usually between 0 and 1), which dictates how aggressively colors are compressed.

For any point (L, C) in the RGB gamut, the compression is given by:

$$L_{\text{compressed}} = L + f \times (L_{\text{nearest}} - L + (50 - L)) \tag{7}$$

$$C_{\text{compressed}} = \min(C + f \times (C_{\text{nearest}} - C), C_{\text{nearest}}) \tag{8}$$

Where L_{nearest} and C_{nearest} are the lightness and chroma values of the nearest point on the CMYK boundary.

2.4 Delta E 2000 Calculation

The Delta E 2000 (ΔE_{2000}) is a metric used to quantify the perceptual difference between two colors in the LAB color space. The formula for ΔE_{2000} is complex and takes into account several correction terms to adjust for the non-uniformity of the LAB space. The `skimage.color.deltaE_ciede2000` function is used to compute ΔE_{2000} between the original and compressed LAB images.

The final Delta E value is the average over all pixels in the image, defined as:

$$\Delta E_{2000} = \frac{1}{n} \sum_{i=1}^{n} \Delta E_i \tag{9}$$

Where:

- n is the total number of pixels.
- ΔE_i is the color difference for pixel i.

3 Observations

The following are observations from the code's output: The convex hull of the compressed RGB gamut is fully contained within the CMYK gamut. No points lie outside the CMYK boundary after compression. The compression ensures that all colors, both in-gamut and out-of-gamut, are moved towards $L^* = 50$, preserving overall lightness while reducing chroma for out-of-gamut colors. The average Delta E 2000 between the original and compressed images was calculated as **6.1366**, indicating a moderate color difference. This value shows the perceptual color difference between the two images after compression. The factor f controls the compression intensity. A higher factor results in stronger compression towards $L^* = 50$, while a lower factor retains more of the original color characteristics.