Gamut Clipping Techniques: SCLIP, CCLIP, and LCLIP

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1 Introduction

Gamut clipping is a crucial process in color management that ensures the colors of an image fit within the gamut of the target color space, such as AdobeRGB. When converting images from one color space to another, some colors may fall outside the target gamut. Gamut clipping techniques are employed to map these out-of-gamut (OOG) colors to the closest possible colors within the target gamut while minimizing color distortions. In this document, we will explore three specific gamut clipping techniques: SCLIP (Spherical CLIP), CCLIP (Chroma CLIP), and LCLIP (Lightness CLIP).

2 Mathematical Background

2.1 SCLIP (Spherical CLIP)

The SCLIP technique involves mapping out-of-gamut colors towards a reference lightness level (usually $L^* = 50$) in the CIELAB color space. The process can be summarized as follows:

- Compute the direction vector from the out-of-gamut color C_{OOG} to the reference lightness level $L^* = 50$.
- Scale the direction vector to move the color towards the gamut boundary along this direction.
- The final clipped color C_{clip} is obtained by subtracting the scaled vector from the original color.

Mathematically, this is expressed as:

$$\vec{d} = C_{\text{OOG}} - [50, 0, 0]^T$$

$$\vec{d}_{\text{scaled}} = \frac{\vec{d}}{\|\vec{d}\|}$$

$$C_{\text{clip}} = C_{\text{OOG}} - \lambda \vec{d}_{\text{scaled}}$$

where λ is the distance to the gamut boundary along $\vec{d}_{\text{scaled}}$.

2.2 CCLIP (Chroma CLIP)

The CCLIP technique focuses on reducing the chroma of out-of-gamut colors while maintaining their hue and lightness. The process is straightforward:

- For an out-of-gamut color $C_{\text{OOG}} = (L^*, a^*, b^*)$, compute the chroma C^*.
- Reduce the chroma by a fixed percentage (e.g., 5%) until the color falls within the target gamut.

Mathematically, this can be expressed as:

$$C_{\text{clip}} = (L^*, 0.95a^*, 0.95b^*)$$

2.3 LCLIP (Lightness CLIP)

The LCLIP technique involves reducing the lightness L^* of out-of-gamut colors to bring them within the target gamut:

- For an out-of-gamut color $C_{\text{OOG}} = (L^*, a^*, b^*)$, reduce the lightness by a fixed amount (e.g., 10 units) until the color is within the target gamut.

This can be expressed as:

$$C_{\text{clip}} = (\max(L^* - 10, 0), a^*, b^*)$$

3 Implementation

The above techniques were implemented using Python, with the skimage and PIL libraries handling color conversions and ICC profile management. The following steps outline the process:

- The input image is converted from the sRGB color space to the CIELAB color space.
- The Gamut Boundary Descriptor (GBD) for the AdobeRGB color space is generated using the ICC profile.
- Each pixel in the image is checked against the GBD. If the color is out of gamut, it is mapped using SCLIP, CCLIP, or LCLIP.
- The mapped image is then converted back to the RGB color space for comparison.

4 Results

4.1 Effect on image quality

- **SCLIP (Spherical CLIP)** technique tends to preserve the overall color balance by clipping colors based on their spherical distance from a reference point. This method often results in minimal color shifts, as evident in the image, where the colors are slightly adjusted but still maintain the original scene's natural look.
- **CCLIP (Chroma CLIP)** method focuses on reducing chroma, resulting in an image with less saturation. The colors in this image appear more muted compared to the original, indicating a loss of color intensity, especially in highly saturated areas.
- **LCLIP (Lightness CLIP)** method reduces the lightness of out-of-gamut colors. This image has darker tones, with a noticeable reduction in brightness, particularly in the highlights and midtones. This method is effective for managing brightness but can result in a less vibrant image.

4.2 Effect on gamuts

- The SCLIP gamut plot shows that the spherical clipping approach has maintained much of the original chroma and lightness distribution. The plot indicates that SCLIP primarily clips colors based on their distance from a reference lightness level (often 50), preserving the color balance.
- The CCLIP gamut plot reveals a significant reduction in chroma across the board. The clipping process has reduced the saturation of colors, resulting in a more constrained gamut with lower chroma values. This explains the muted appearance of the CCLIP image.
- The LCLIP gamut plot shows a reduction in the lightness of colors, with the plot shifted towards lower lightness values. This corresponds to the darker tones observed in the LCLIP image, where bright areas are clipped to fit within the target gamut's lightness constraints.

5 Conclusion

SCLIP is effective for general color preservation, maintaining a balance between lightness and chroma while ensuring colors fit within the target gamut. CCLIP focuses on reducing color saturation, which can be useful for preventing oversaturation but at the cost of vibrancy. LCLIP effectively manages brightness, making it suitable for scenarios where maintaining highlight details is crucial, but it can result in a darker overall image.