SCIELAB Local Color-Difference Demo: Background, Model, Results

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August 15, 2025

Abstract

This document describes a SCIELAB-inspired local color-difference demonstration. The goal is to combine color-difference metrics (e.g., CIEDE2000 or Euclidean CIELAB) with a multi-scale spatial integration to better approximate perceived differences in images. The document includes background theory, a mathematical description of the simplified SCIELAB-like pipeline implemented, results on test distortions, and interpretation of the outcomes.

1 Background

Standard pixelwise color-difference metrics treat each pixel independently (e.g., compute ΔE between corresponding pixels). However, human perception of color differences depends on spatial context: small high-frequency chromatic noise may be less visible than broad low-frequency color shifts. SCIELAB is a model that modifies color-difference computation to account for spatial integration and masking across spatial frequency channels. The implemented demo is a simplified, practical approximation to these ideas.

2 Mathematical model

Let the reference image in CIELAB be $L_r(x,y), a_r(x,y), b_r(x,y)$ and the test image be L_t, a_t, b_t. A purely pixelwise (CIE76) color difference map is:

$$\Delta E_{76}(x,y) = \sqrt{(L_r - L_t)^2 + (a_r - a_t)^2 + (b_r - b_t)^2}. \tag{1}$$

If available, a more perceptually accurate pointwise metric such as CIEDE2000 may be used in place of ΔE_{76}.

2.1 SCIELAB-like multi-scale integration

SCIELAB computes differences at multiple spatial scales representing band-pass channels of the visual system. A simplified, computationally-efficient approximation implemented here is the multi-scale Gaussian smoothing approach. For a given scale σ we define smoothed channels:

$$L_r^{(\sigma)} = G_\sigma * L_r, \quad a_r^{(\sigma)} = G_\sigma * a_r, \quad b_r^{(\sigma)} = G_\sigma * b_r, \tag{2}$$

where G_σ is an isotropic Gaussian kernel of standard deviation σ and $*$ denotes convolution. Similarly for the test image.

At each scale we compute a local difference map

$$d^{(\sigma)}(x, y) = \sqrt{\left(L_r^{(\sigma)} - L_t^{(\sigma)}\right)^2 + \left(a_r^{(\sigma)} - a_t^{(\sigma)}\right)^2 + \left(b_r^{(\sigma)} - b_t^{(\sigma)}\right)^2}. \tag{3}$$

The final SCIELAB-like map is a weighted sum across scales:

$$D_{\text{SCIE}}(x, y) = \sum_i w_i \, d^{(\sigma_i)}(x, y), \qquad \sum_i w_i = 1. \tag{4}$$

The weights w_i reflect the relative perceptual importance of each spatial scale (low-frequency channels may have greater weight for large-color differences, while higher-frequency channels capture fine detail and noise).

2.2 Relation to human CSF and masking

A more complete SCIELAB model multiplies band-limited differences by a contrast-sensitivity function (CSF) and applies masking functions that reduce sensitivity when a strong background stimulus is present in the same band. In the simplified demo, the Gaussian smoothing across multiple scales acts as a proxy for bandpass channel responses, and weighting mimics the band importance. Detailed CSF/masking modeling is left for later extension.

3 Implementation details

The method was implemented as follows:

- Convert sRGB images to CIELAB (D65) using standard transformations. When the environment provides a CIEDE2000 implementation we compute both per-pixel CIEDE2000 and the CIE76 metric as fallback.

- Generate two synthetic distortions to demonstrate behavior: a hue-shift (global hue rotation in HSV space) and chroma noise (additive Gaussian noise on the a, b channels in Lab).
- Compute per-pixel ΔE (CIE76 or CIEDE2000) and compute multi-scale smoothed Lab channels at scales $\sigma = 1, 2, 4$ with weights $w = [0.5, 0.3, 0.2]$ (these parameters are tunable).
- Visualize the maps and compute summary statistics such as mean pixelwise ΔE and mean SCIELAB-like D_{SCIE} for each distortion.

4 Results

The demo saved the main visualization figure and normalized difference maps.

4.1 Qualitative observations

- The pixelwise ΔE map for chroma noise contains a large amount of high-frequency energy, reflecting localized chromatic perturbations. The SCIELAB-like map suppresses much of this fine-grained noise due to smoothing at multiple scales, resulting in a lower average map value and visually weaker regions compared to broad hue shifts.
- The hue-shift distortion produces coherent, low-frequency differences that remain salient in the SCIELAB-like map; thus the SCIELAB-like metric emphasizes these visible changes as expected from human perception.

5 Inference and discussion

The simplified SCIELAB-like method implemented here demonstrates the qualitative advantage of accounting for spatial integration when assessing perceived color differences:

- Multi-scale smoothing reduces the effective weight of high-frequency chromatic noise while preserving broad, salient chromatic changes. This behavior aligns with human sensitivity where noise-like high-frequency chromatic variation is typically less visible.

- The method is computationally efficient and easy to tune (adjust σ and w), making it useful for quick assessments and for guiding image processing tasks such as local compression or retouching.
- Limitations: the approach approximates bandpass channels by Gaussian lowpass and lacks explicit CSF-based weighting and masking. For quantitative correlations with psychophysical data, a fuller SCIELAB implementation (with band-pass filtering, CSF weighting, and masking models) is recommended.

6 Conclusion

The SCIELAB-like multi-scale difference map is a practical enhancement over pixelwise ΔE for many image-quality assessment tasks. It better correlates with perceived salience of color differences and is easy to implement. The demo files and saved visual outputs provide a clear illustration of the approach on typical distortions.

References

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2. Zhang, X., Silverstein, D. A., Farrell, J. E., & Wandell, B. A. (1997). Color image quality metric S-CIELAB and its application on halftone texture visibility. In *Proc. IS&T/SPIE*, 165–172.