

Reconstruction-based color-enhancement algorithm for dichromats

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Goal

Original Transformed

Trichromat

Dichromat

Transform images so the dichromat can access more information

Previous Literature

Hue Rotation
(e.g., Huang et al., 2007, Ching & Sabudin, 2010)

Confusion Lines
(e.g., Milic, 2015; Tsekouras, 2021)

(Many more: Huang et al., 2007; Zhu et al., 2019; Tsekouras et al., 2021; Flatla et al., 2013, etc.)

General Idea

Trichromat Deuteranopic simulation

Find a transformation that redistributes info from missing cone plane

Tradeoff

Enhance information: Original Transformed

Preserve similarity: Original Transformed

Want to find an optimal tradeoff between these two extremes

Optimization

Image transformation

Find a transformation that minimizes our loss function

$\text{argmin}_{T_\theta} (\text{Loss})$

$$\text{Loss}(T_\theta(I)) = (1 - \lambda) \cdot \text{DistortionScore}(T_\theta(I)) + \lambda \cdot (-\text{InfoScore}(T_\theta(I)))$$

Class of Transformations $T_\theta(I)$

$$\begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{bmatrix} \cdot \begin{bmatrix} R_{11} & R_{12} & \dots & R_{N-1} & R_N \\ G_{11} & G_{12} & \dots & G_{N-1} & G_N \\ B_{11} & B_{12} & \dots & B_{N-1} & B_N \end{bmatrix} = \begin{bmatrix} R'_{11} & R'_{12} & \dots & R'_{N-1} & R'_N \\ G'_{11} & G'_{12} & \dots & G'_{N-1} & G'_N \\ B'_{11} & B'_{12} & \dots & B'_{N-1} & B'_N \end{bmatrix}$$

T_θ Global linear transformation

I RGB contrast image

$T_\theta(I)$ Transformed RGB contrast image

$\theta = [t_{11} \ t_{12} \ t_{13} \ t_{21} \ t_{22} \ t_{23} \ t_{31} \ t_{32} \ t_{33}]^\top \quad T_\theta^* = \text{arg min}_{T_\theta} \{ \text{Loss}(T_\theta(I)) \}$

Linear color transformation on the RGB contrast image

DistortionScore

Distortion is computed as the CIELAB 2000 difference metric, averaged over all the pixels

ΔE_{00} Compares colors in CIELAB space while weighting lightness, chroma, and hue differences to better match perceived color differences.

$$\frac{1}{N} \sum_{i=1}^N \left(\Delta E_{00}(\text{LAB}_i^{\text{original}}, \text{LAB}_i^{\text{transformed}}) \right)^2$$

More distortion

DistortionScore = 0

DistortionScore = 0.05

DistortionScore = 0.15

InfoScore

Information was quantified by how well the original image could be reconstructed from the projection of the transformed image onto dichromat color space

Original Transformations

Regression reconstruction

Reconstruction quality was measured using CIELAB 2000

InfoScore

$$-\frac{1}{N} \sum_{i=1}^N \left(\Delta E_{00}(\text{LAB}_i^{\text{original}}, \text{LAB}_i^{\text{reconstructed}}) \right)^2$$

“How well can we reconstruct this ...”

“... from each of these”

Results: Examples

Prioritizing minimizing distortion

Prioritizing maximizing information

Future Directions

Improving Each of the 3 Components

- T_θ : Allow transformations to vary across space
- Distortion: Use color discrimination thresholds to better define distortion (Hong et al. 2025)
- InfoScore: More sophisticated reconstruction algorithm (e.g., NN denoiser reconstruction)

Evaluation Metrics

- “Which looks better?”
- “Which transformation allows dichromats to read the graph correctly?”
- “Which transformation improves visual search?”