A Case for a Linear Difference Metric

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XYZ Color Science
1920 – Definition of Luminance

y - Color Matching Function

Relative Response

Wavelength - nm.

400 450 500 550 600 650 700

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1930 – CIE 1931 xyz

A graph showing the relative response of the CIE 1931 xyY color space as a function of wavelength (nm). The graph includes curves for x, y, and z components.
1940 MacAdam Ellipses
1976 Color Space Battle

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Working Color Gamut
Color Measurement
Camera – Spectrum Locus
Spectrometer vs Camera

- Spectrometer
  - Calibration Target
  - Known Illumination
  - Computed Sample Spectral Reflectance
  - Known xyz Color Matching Functions
  - Defined Color Space
  - Single Point Measurement

- Camera
  - Filter – CCD Combination – No Target
  - Unknown Illumination
  - Unknown Sample Spectral Reflectance
  - Unknown Color Matching Functions
  - Unknown Color space
  - Produces an Image
Gamut Comparison

![Gamut Comparison Diagram]

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A Linear Color Difference Metric

- Primaries – sRGB
- Guth Opponent Ideas
- Test with MacAdam Ellipse Data
- Minimize Unknown Coefficients
- Test Against
  - CIE 1976 Luv
  - CIE 1976 Lab
  - CIE DE 2000
QTD Vectors

- \( T = R - G \)
- \( D = 0.5 \times (R + G) - B \)
- \( A = 0.2127 \times R + 0.7152 \times R + 0.0722 \times B \)
- \( Q = A + K1 \times (Red + Green + Yellow + Blue) \)
- Rewritten
- \( Q = A + K1 \times (|T| + |D|) \)
T – D Diagram and Hue Angle
Determine K1
Q, P and Color Difference

- \( Q = A + 0.125 \times (|T| + |D|) \)
- \( P = K2 \times \ln \left( \frac{Q}{Q_0} \right) \)
- \( \Delta P = P_2 - P_1 \)
MacAdam Warped Space  QTD Color Space
Eccentricity of Macadam Ellipses  

JND for MacAdam Ellipses
QTD Color Difference Model

- $T = R - G$
- $D = 0.5 \times (R+G) - B$
- $A = 0.2127 \times R + 0.7252 \times G + 0.0722 + G$
- $Q = A + 0.125 \times (|T| + |D|)$
- $P = 65.5 \times \ln\left(\frac{Q}{Q_0}\right)$
- $\Delta P = \frac{(65.5 \times (\Delta A^2 + \Delta T^2 + \Delta D^2)^0.5)}{Q}$
QTD - DE2000 Comparison

- **QTD**
  - 5 equations
  - Eccentricity – 1.95
  - Saturation
  - Agrees with 1976 ΔE
  - All linear calculation
  - 2 constants for definition
  - T-D axes align with unique hues
  - Hue correlates to Munsell

- **DE2000**
  - 22 equations
  - Eccentricity – 2.9
  - No saturation support
  - ΔE factor of 2 low
  - Nonlinear Calculation
  - Many constants
  - a-b axes do not align with unique hues
  - Hue correlates to Munsell

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Conclusions

- The sRGB primaries can produce a nearly uniform color space

- QTD has
  - Color wheel T-D plot
  - T-D axes align with unique hues
  - Predicts brightness
  - Predicts ΔE better than the CIE Metrics

- CIE DE2000 fails to predict ΔE for MacAdam data

- What is a JND?