Working Toward a Color Space
Built on DE2000

John “the Math Guy” Seymour
Applied Mathematician
& Color Scientist
QuadTech

tagaatc.printing.org

Problem to be Solved
To make a ramp that looks linear

Why is this a problem?

Is one of these halfway between white and black?

Why is this a problem?

Isn’t 50% reflectance halfway?

Why is this a problem?

- Human eye is nonlinear
- Very sensitive at low reflectance
- Not very sensitive at high reflectance
- Much effort has been put into “the formula”

History Lesson – Munsell Color Space

Albert Munsell
1858 - 1918
History Lesson – Munsell Color Space

Munsell mixed paints to achieve perceptual linearity

The “1931 Standard Observer”

Tristimulus Values: X, Y, and Z

Chromaticity Diagram

Chromaticity space is NOT perceptually linear!
People Involved in Standard

Improvement to Industrial Colour Difference Evaluation

\[
\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}
\]
\[ \Delta E_{CMC}(L^* : C^* : H^*) = \sqrt{\left( \frac{\Delta L^*}{L_0} \right)^2 + \left( \frac{\Delta a^*}{a_0} \right)^2 + \left( \frac{\Delta b^*}{b_0} \right)^2} \]

McLaren-Style Corrections

- \( \Delta E_{CIE} \) – McDonald (1979)
- \( \Delta E_{CMC} \) – McDonald, Clark, and Rigg (1986)
- \( \Delta E_{BFDO} \) – Luo and Rigg (1987)
- \( \Delta E_{94} \) – CIE (1994)
- \( \Delta E_{100} \) – Kim (1997)
- \( \Delta E_{00} \) – CIE (2000)

**\( \Delta E_{00} \) Formula**

\[
\Delta E_{00} = \left[ \frac{\Delta L^*}{L_0} \right]^2 + \left[ \frac{\Delta a^*}{a_0} \right]^2 + \left[ \frac{\Delta b^*}{b_0} \right]^2 + \frac{\Delta C^*}{C_0} \left( \frac{\Delta H^*}{H_0} \right) \]
Parsimony

... even if you have 11,000 data points, you should be very careful about using eleven parameters in your regression.

http://johnthemathguy.blogspot.com/2012/07/when-regression-goes-bad.html

Uniform Color Space vs. Color Difference Formula

- The space itself is linear
- You can use Euclidean distance formula
- No corrections based on color
Uniform Color Spaces (Proposed)

- Labmg (Colli, Gremmo, and Moniga, 1989)
- ATD (Guth, 1994)
- DCT-95 (Rohner and Rich, 1995)
- LLAB (Luo, Lo, and Kuo, 1995)
- ??? (Tremeau and Laget, 1995)
- CIECAM97 (CIE standard, 1997)
- RLAB (Fairchild, 1998)
- IPT (Einse and Fairchild, 1998)
- L''a''b'' (Thomsen, 1999)
- DIN99 (DIN standard 6176, 2000)
- CIECAM02 (CIE standard, 2002)
- QTD (Granger, 2008)
- L''a''b'' (Berns, 2008)
- LAB2000 (Lissner and Urban, 2010)

Problem to be Solved

Right now, I’m just looking at $L^*$

Parsimony for $L^*$?

Parsimony for $L_{mg}^2$?

Parsimony for $\Delta L$

<table>
<thead>
<tr>
<th>Color Difference Equation</th>
<th># of parameters for $\Delta L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta E_{	ext{CIE}}$</td>
<td>3</td>
</tr>
<tr>
<td>$\Delta E_{\text{CIE}}$</td>
<td>6</td>
</tr>
<tr>
<td>$\Delta E_{\text{CIE}}$</td>
<td>3</td>
</tr>
<tr>
<td>$\Delta E_{\text{CIE}}$</td>
<td>6</td>
</tr>
<tr>
<td>Uniform Color Space</td>
<td></td>
</tr>
<tr>
<td>LABmg</td>
<td>7</td>
</tr>
<tr>
<td>$L''^* (\text{Rohner and Rich})$</td>
<td>5</td>
</tr>
<tr>
<td>$\Delta E_{\text{CIE}} (\text{DIN 99})$</td>
<td>5</td>
</tr>
</tbody>
</table>

Building $L_{00}$

$(0, 0, 0)$

$(1.734, 0, 0)$

$(3.442, 0, 0)$

$(5.124, 0, 0)$
The only thing worthwhile in this whole presentation

This general formula is nothing new!

- Delboeuf Equation (1872)
  \[ D = 10 - 6.1723 \log_{10} (40.7h + 1) \]

- Richter's equation (1953)
  \[ V = 6.1723 \log_{10} (40.7Y + 1) \]
**Progress so far**

- $L_{00}$ – Looks good
- $a_{00}, b_{00}$ – same approach doesn’t help much

---

*Stay tuned…*

John “the Math Guy” Seymour  
Applied Mathematician  
& Color Scientist  
QuadTech  
http://johnthemathguy.blogspot.com/