Status of CIE Color Appearance Models

AIC Color 01 Rochester

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• Overview of Color Appearance Models
  • History of CIECAM97s
  • Ongoing CIE TC Activities
  • Future Directions
What is a Color Appearance Model?

• Color appearance models extend basic colorimetry (XYZ) to predict the appearance of stimuli (e.g., Lightness, Chroma, Hue) in a variety of viewing conditions.

• They account for changes in visual response due to changes in viewing environment.

• These models are a tool.
What Does a Color Appearance Model Enable?

- Mapping from Measurements to Words (Physics to Perception)
- Prediction of Color Matches (or Changes) across Changes in Viewing Conditions
Appearance Correlates

- Brightness, Lightness
- Colorfulness, Chroma, Saturation
- Hue
Color Appearance Phenomena

If two stimuli do not match in color appearance when \((XYZ)_1 = (XYZ)_2\), then some aspect of the viewing conditions differs.

Various color-appearance phenomena describe relationships between changes in viewing conditions and changes in appearance.

(Stevens Effect, Hunt Effect, Simultaneous Contrast, Surround, Color Constancy, Memory Color, Discounting-the-Illuminant, Adaptation, etc.)
Josef Albers: Simultaneous Contrast
Chromatic Adaptation
Discounting-the-Illuminant
Putting it All Together

Components of a Color Appearance Model

(1) Chromatic Adaptation Transform
(2) Uniform Color Space
(3) Appearance Correlates
History of Color Appearance Models

1970's: CIELAB and CIELUV

Early 1980's: Initial Hunt and Nayatani Color Appearance Models

Late 1980's: Revisions of Hunt and Nayatani Models

Early 1990's: Model Testing, Further Revisions, New Models (e.g., RLAB, LLAB)

Late 1990's: Convergence ... CIECAM97s

Early 2000's: Widespread focused testing and refinement
CIECAM97s

- **CIE 1997 Interim Color Appearance Model (simple version)**
  - An internationally agreed upon model that incorporates the best features of previously published models
  - Current state-of-the-art, but undergoing refinement as expected (CIE TC8-01)

- **CIELAB** is a simpler example of a color space that describes appearance.
Where's CIECAM97c?

CIE 1997 Interim Color Appearance Model (comprehensive version)

- To be a fully comprehensive extension of CIECAM97s.
- No Apparent Demand
- Thus, Never Formulated
Work of CIE TC1-34

• CIE TC1-34, Testing Colour Appearance Models
• CIE Experts Symposium, Vienna, 1996
• Four Models Considered
• Kyoto, 1997
• CIECAM97s Born
• As good as the best in each situation.

Note: Authors of no less than 8 models served on the committee!!
The Formulation of CIECAM97s

- Use Good Parts from Existing Models
- Create a Consistently High-Performing Model
- Find a Single Model with Committee Consensus
- Simple and Comprehensive Versions
- Bradford CAT & Hunt Color Space
Expectations for CIECAM97s

• Perform as Well as Best Model in All Circumstances

• Evolution, Not Revolution

• Interim, Continuous Improvement

• Basis for Comprehensive Model
CIECAM97s Chromatic Adaptation Transform

- Based on the Bradford CAT
  - An Extension of Bartleson
  - Incomplete Adaptation & Discounting Added
- von Kries on R & G
- Nonlinearity on B
- Unique XYZ-to-RGB Transform
CIECAM97s Color Space

- Based on Structure within Hunt Model
- Enhancements Based on Various Tests, etc.
- Hyperbolic Nonlinearity
- Color Difference Signals
- Appearance Correlates
Appearance Correlates

- Brightness, Lightness
- Colorfulness, Chroma, Saturation
- Hue

- Built Up to Fit Experimental Data
- Need 5 of 6 to Fully Describe Appearance
Hue

- The degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow.

\[ h = \tan^{-1}\left(\frac{b}{a}\right) \]

<table>
<thead>
<tr>
<th>Color</th>
<th>H</th>
<th>e</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>20.14</td>
<td>0.8</td>
<td>0 or 400</td>
</tr>
<tr>
<td>Yellow</td>
<td>90.00</td>
<td>0.7</td>
<td>100</td>
</tr>
<tr>
<td>Green</td>
<td>164.25</td>
<td>1.0</td>
<td>200</td>
</tr>
<tr>
<td>Blue</td>
<td>237.53</td>
<td>1.2</td>
<td>300</td>
</tr>
</tbody>
</table>
Lightness

• The brightness of a stimulus relative to the brightness of a stimulus that appears white under similar viewing situations.

\[ J = 100 \left( \frac{A}{A_W} \right)^{cz} \]
Brightness

- The perceived quantity of light emanating from a stimulus.

\[ Q = \left( \frac{124}{c} \right) \left( \frac{J}{100} \right)^{0.6} \left( Aw + 3 \right)^{0.9} \]
Saturation

• The colorfulness of a stimulus relative to its own brightness.

\[ s = \frac{50(a^2 + b^2)^{1/2} \cdot 100e(10/13)N_c N_{cb}}{R'_a + G'_a + (21/20)B'_a} \]
Chroma

- The colorfulness of a stimulus relative to the brightness of a stimulus that appears white under similar viewing conditions.

\[ C = 2.44s^{0.69}(J/100)^{0.67}(1.64 - 0.29^n) \]
Colorfulness

- The perceived quantity of hue content (difference from gray) in a stimulus.

- Colorfulness increases with luminance.

\[ M = C F_L^{0.15} \]
Active CIE Committees Related to Color Appearance

TC1-27, Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons

TC1-52, Chromatic Adaptation Transforms

TC8-01, Colour Appearance Modeling for Colour Management Applications

R1-24, Colour Appearance Models
CIE TC1-27, Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons

Chair: Paula Alessi, USA

Performing Visual Experiments to Assess the Performance of Various Models in these Applications

Final Report Expected Soon

(CIECAM97s Performs Reasonably Well)
CIE TC1-52, Chromatic Adaptation Transforms

Chair: M. Ronnier Luo, UK

Formulation of a CIE Chromatic Adaptation Transform

Unable to Reach Consensus

(Several Models Perform Equally Well)
Chair: Nathan Moroney, USA

Creating Implementation Guidelines
Revising/Improving CIECAM97s

Hard at Work, Revised Model Soon?
(Several Revisions Agreed Upon)
CIE R1-24, Colour Appearance Models

Reporter: Mark D. Fairchild, USA

Track and Report Activities to Div. 1

Make Recommendations for New TCs

Will Suggest TC8-01 Model be Endorsed by Div. 1

(Reporting to You Today!!)
Revision of CIECAM97s (TC8-01)


- A Summary of Proposed Revisions
- Several Corrections to Formulation
- A Few Enhancements Proposed
- Additional Suggestions Have Been Made to TC8-01
Some Potential Changes

1. Linearize Chromatic Adaptation Transform
2. Fix Anomalous Surround Compensation
3. Fix Lightness Scale for Perfect Black
4. Reduce Chroma-Scale Expansion for Low-Chroma Stimuli
5. Make Surround Compensation Continuously Variable

Maybe More...
Corrections

• Fix Anomalous Surround Compensation
• Fix Lightness Scale for Perfect Black

These have been discussed, used, and well-agreed upon. (e.g., Li et al. CR&A (2000).)
Linearized Chromatic Adaptation Transform

• Linear CATs have been shown to perform as well as the nonlinear CAT in CIECAM97s

• Optimal Linear CATs can be derived by adjusting the XYZ-to-RGB Transform

• Several Researchers have come to similar conclusions (Li & Luo, Susstrunk & Finlayson, Fairchild)

• A Linear CAT Facilitates Model Inversion

• One Will be Included (which one???)
Chroma-Scale Expansion

• Several Researchers Have Suggested that the CIECAM97s Chroma Scale is Expanded for Low-Chroma Colors (Newman et al., Moroney, Wyble & Fairchild)

• The Chroma Scale can be Easily Manipulated to More Closely Match Munsell Data and Reduce Image Processing Artifacts

• Inclusion of this Change is Still Being Discussed
Continuously-Variable Surround

• The Effect of Surround is Very Viewing Condition and Task Dependent
• It is Difficult to Quantify Predictively
• Continuously Variable Compensation Allows Fine Tuning
• Likely to be Included in Revision
Ongoing Work

• TC8-01 Considering These and Other Suggested Revisions
• Meeting this Saturday
• Goal to Formulate Draft Revision this Autumn
• CIE Div. 1 Endorsement?
Perhaps CIECAM01s, or CIECAM02s, has been conceived, but not yet born.

CIE TC8-01 is making solid progress.

Further improvements beyond those will certainly be possible.

www.colour.org/tc8-01

www.cis.rit.edu/fairchild/CAM.html