



Quantitative Testing of Color Appearance Models Using the Munsell Renotation Data

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Outline

- ◆ Introduction
- ◆ Munsell Renotation Data
- ◆ Color Appearance Models
- ◆ Color Appearance Metrics
- ◆ Color Appearance Model Performance
- ◆ Applications
- ◆ Conclusion



Testing Appearance Models

- ◆ Why evaluate models?
 - There are so many!
- ◆ Do we need one model?
 - Color management demands this
- ◆ This work is the first application of Munsell data to this set of color appearance models



Munsell Renotation Data

- ◆ Chromaticities used are as published by Newhall, *et al*, JOSA 1943
- ◆ Extracted real colors from data provided by D. Rich and R. Berns
- ◆ Illuminant C tristimulus values are input data for all models



Model Evaluation

- ◆ Models were evaluated only for lightness, chroma, and hue attributes
- ◆ All metrics are based on these three appearance attributes
- ◆ Metrics focus on the particular property of the Munsell Renotation Data, whereby appearance attributes are constant *along each dimension*.



Appearance Models Used Here

- ◆ CIELAB (CIE, 1976)
- ◆ RLAB (Fairchild, 1994)
- ◆ Hunt94 (Hunt, 1994)
- ◆ Nay95 (Nayatani, *et al*, 1995)



Appearance Models Used Here

- ◆ LLAB (Luo, *et al*, 1996)
- ◆ CIECAM97s (CIE TC1-34, 1997)
- ◆ ZLAB (Fairchild, 1997)
- ◆ IPT (Ebner, *et al*, 1998)

Excel and IDL code can be found at:

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



Appearance Models Conditions

- ◆ Recommended Munsell viewing conditions
- ◆ CIE Illuminant C, 1931 2° observer
- ◆ Where applicable, fully discount illuminant
- ◆ Absolute white luminance = 400 cd/m^2
- ◆ Correlated color temperature = 6774°K



Goals and Expectations

- ◆ Goal here is to evaluate the uniformity of these models with respect to the constant hue, chroma, and lightness properties of the Munsell Renotation Data
- ◆ We expect CIELAB and RLAB to perform very well



Appearance Model Metrics

- ◆ Chroma Circularity
- ◆ Chroma Linearity
- ◆ Hue Linearity
- ◆ Hue Spacing
- ◆ Lightness Linearity



Chroma Circularity Description

Input data are
circles of constant
Munsell chroma





Chroma Circularity Description

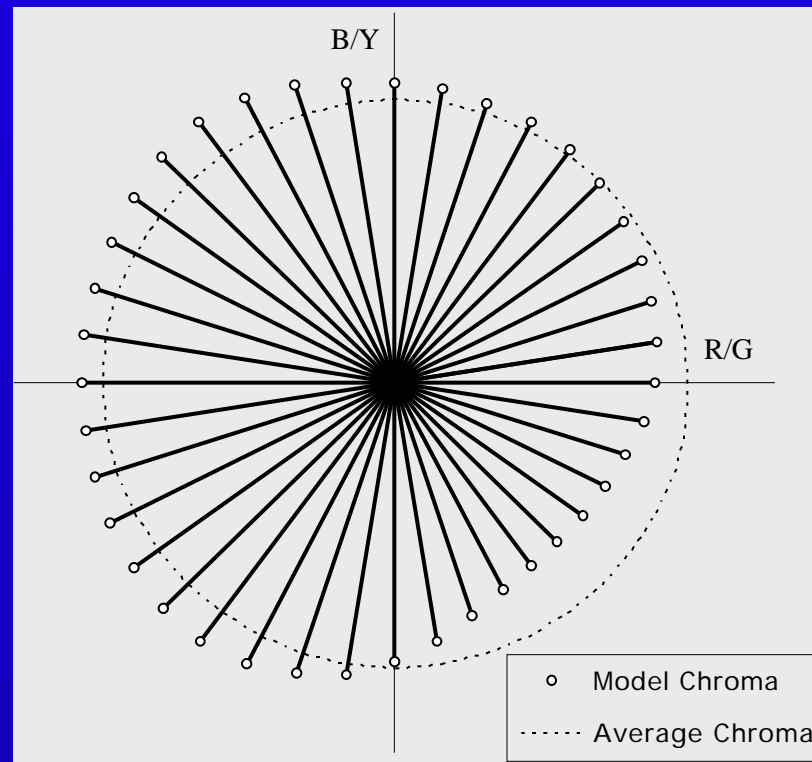
Chromas for each model are normalized to that model's chroma at value=5, chroma=6:

$$C_{\text{normalized}} = \frac{C_{\text{model}}}{C_{\text{model},6}} C_{\text{Munsell},6}$$



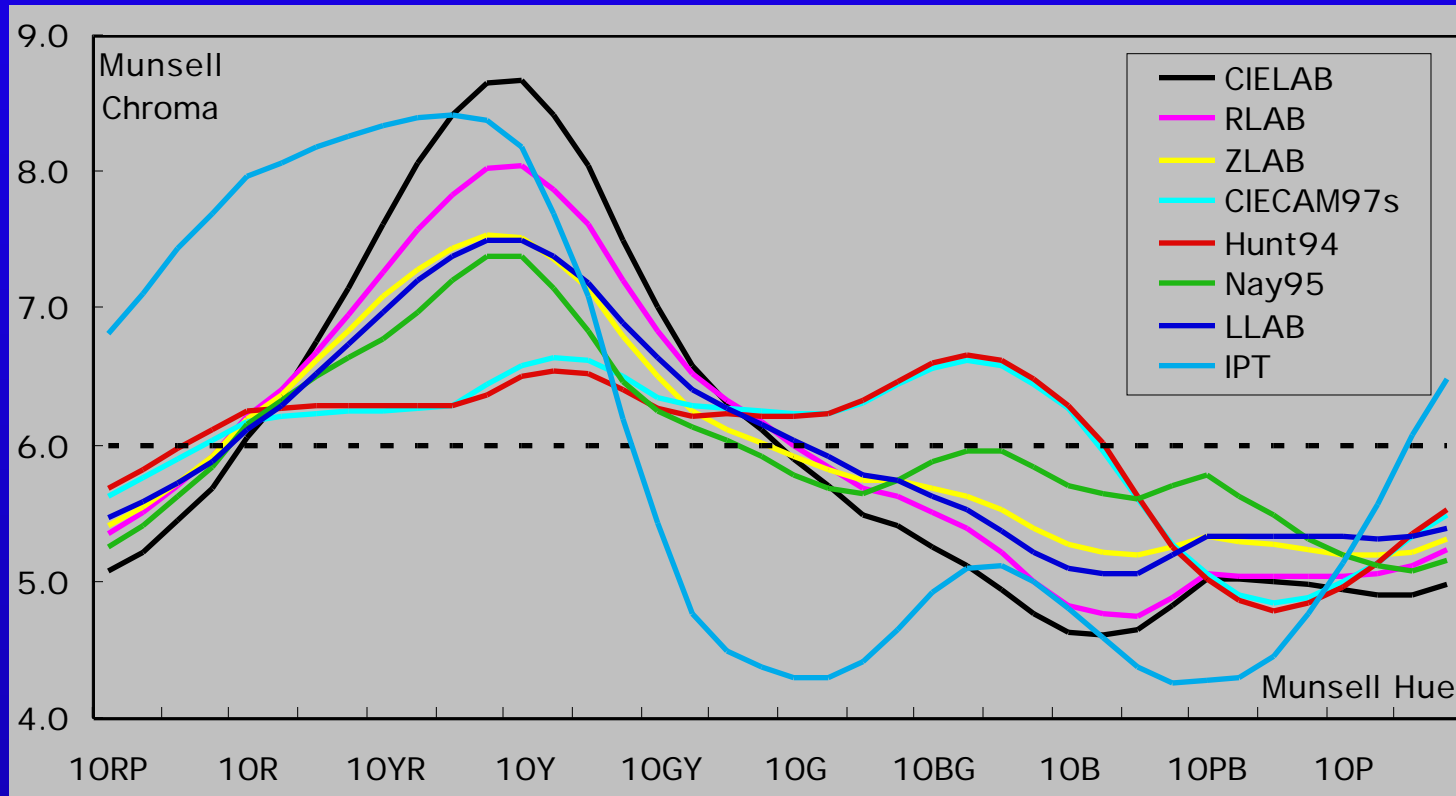
Chroma Circularity Description

Normalized Model Chroma vs Munsell Hue



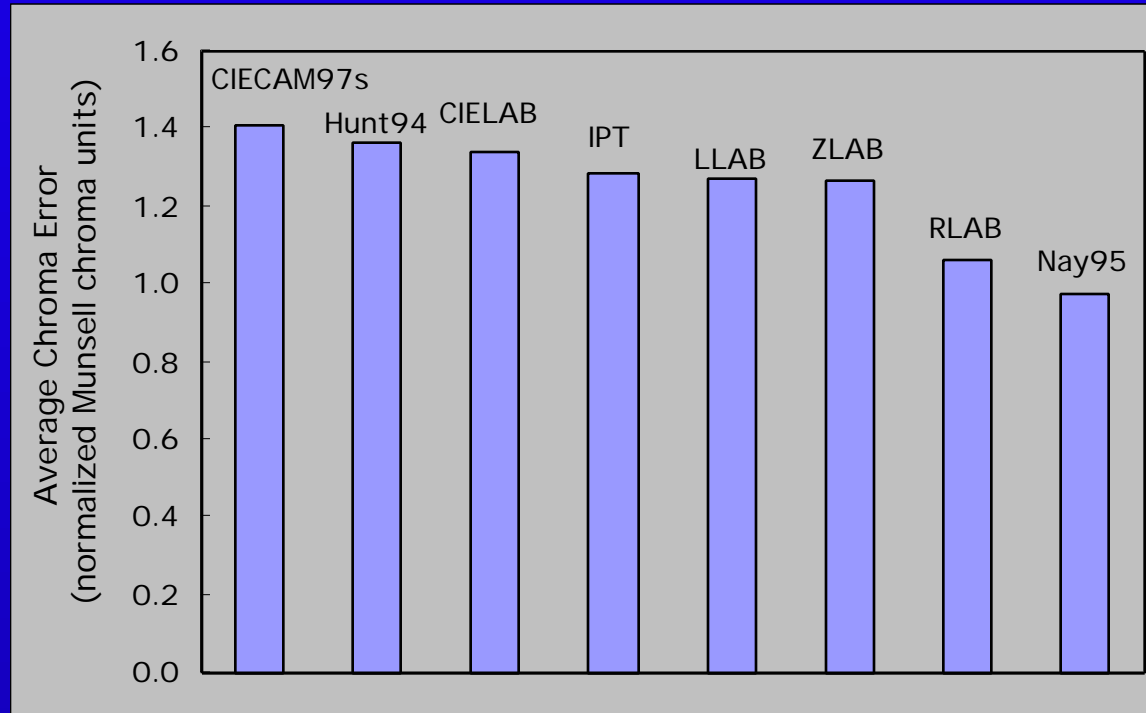


Chroma Circularity Results





Chroma Circularity Summary

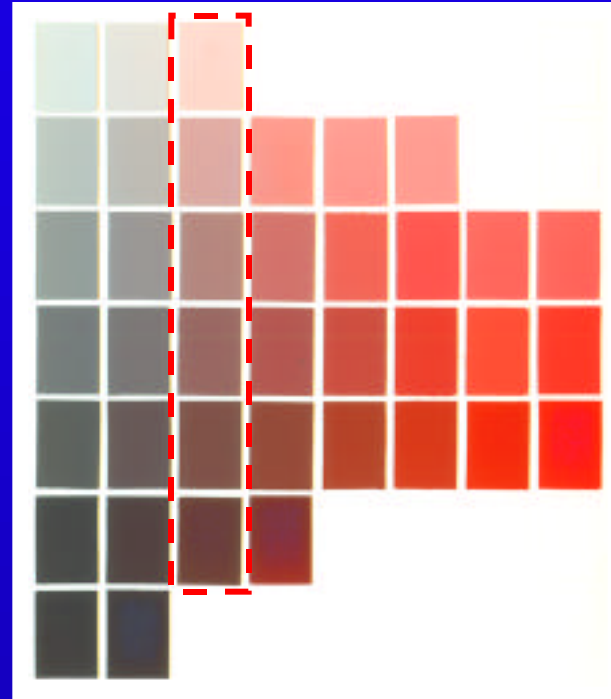


RMS difference between Munsell and normalized model chroma for four Munsell value/chroma combinations.



Chroma Linearity Description

Input data are
lines of constant
Munsell chroma
and hue





Chroma Linearity Description

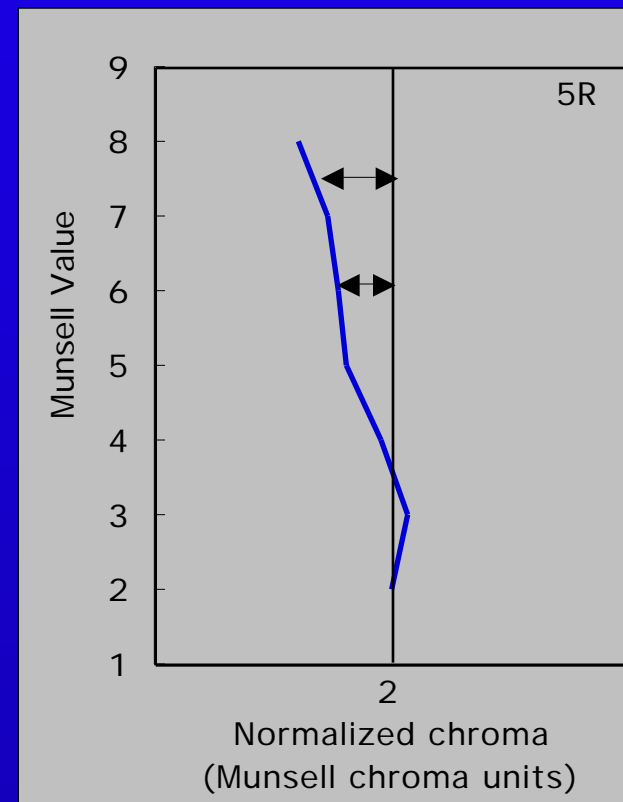
- ◆ Chromas for each model are normalized to that model's chroma at value=5, chroma=6
- ◆ RMS difference between normalized chromas and their normalized averages



Chroma Linearity Results

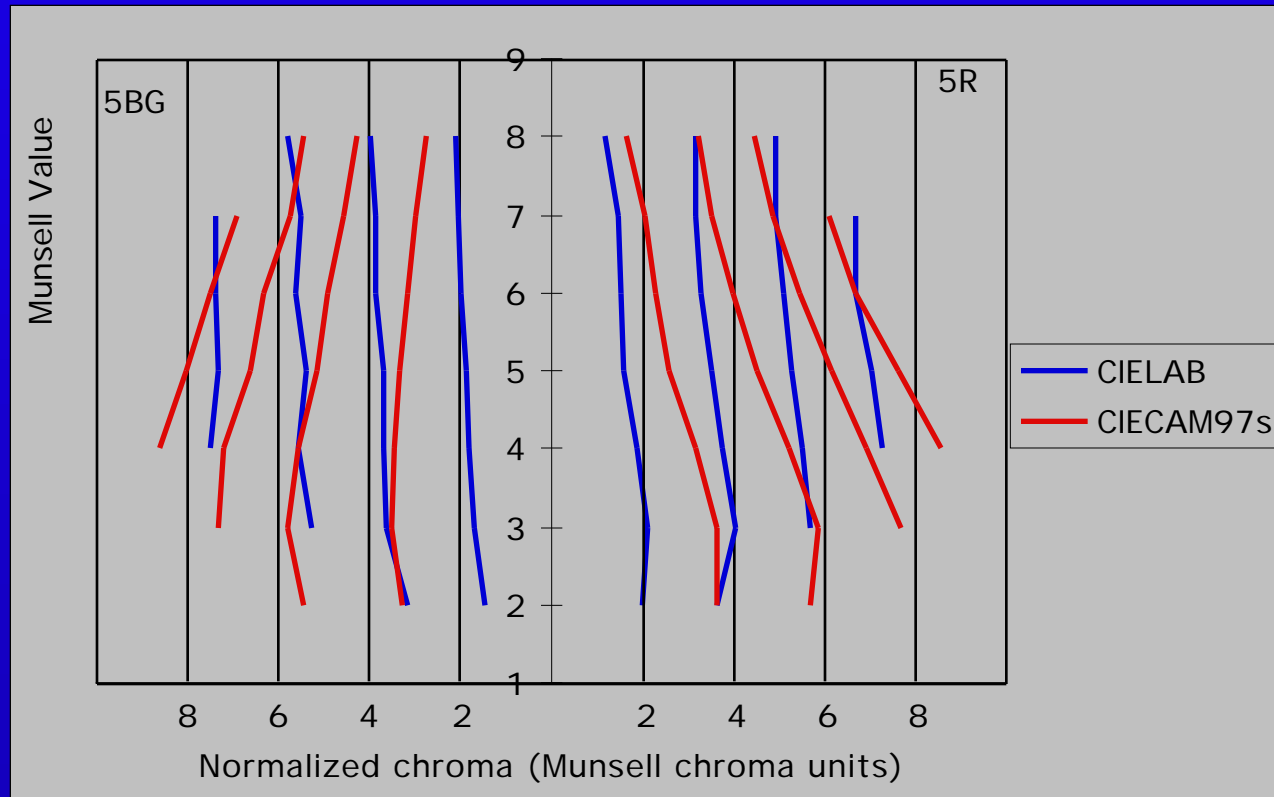
$$C_{\text{normalized},2} = \frac{C_{\text{model},2}}{C_{\text{model},6}} C_{\text{Munsell},6}$$

CIELAB chroma lines for
Munsell chroma=2,
hue=5R (red)





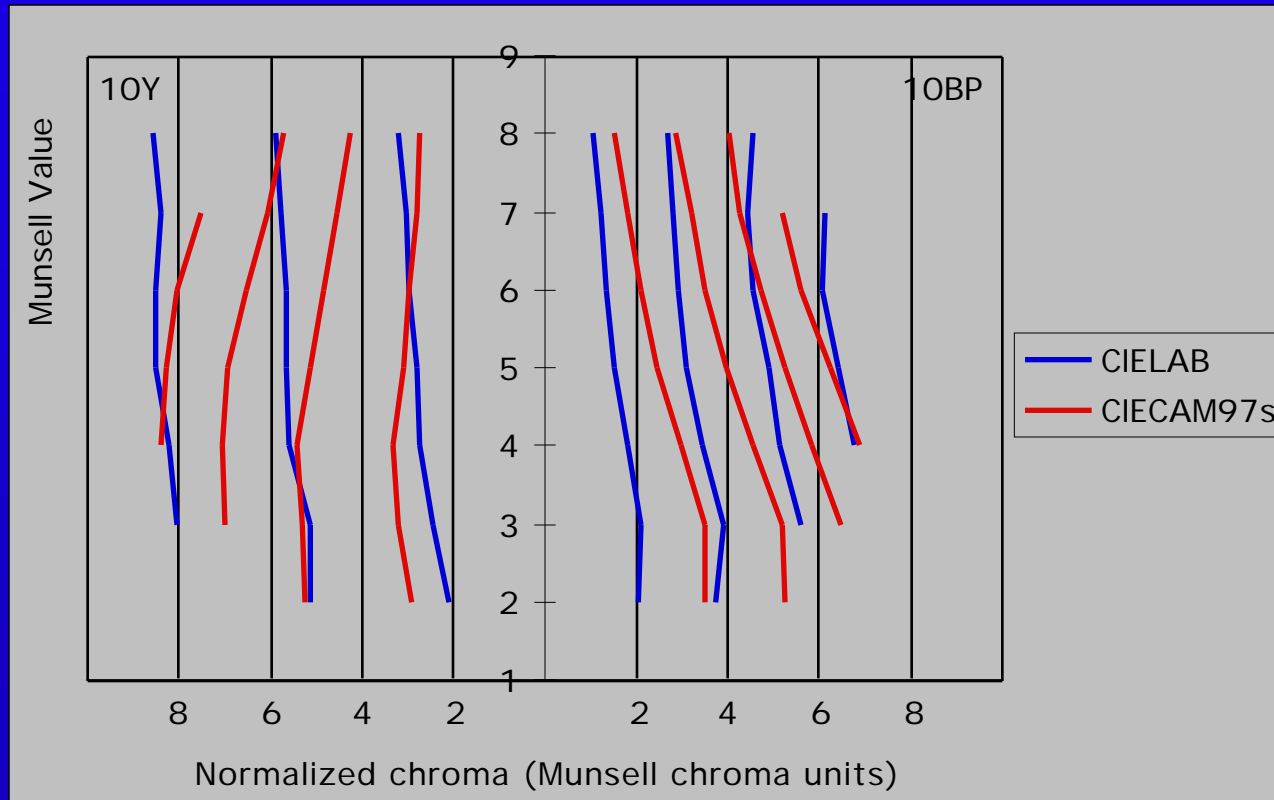
Chroma Linearity Results



Constant chroma lines for red/green slice of Munsell space



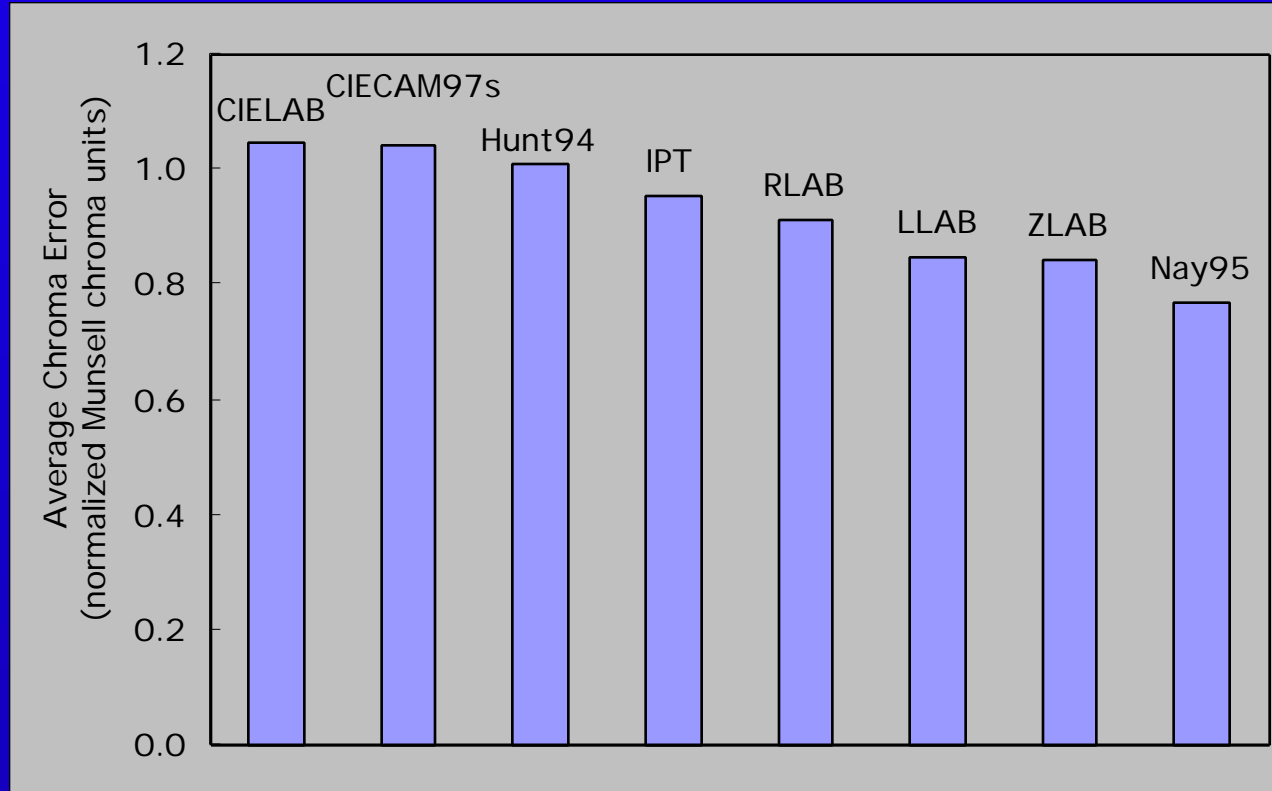
Chroma Linearity Results



Constant chroma lines for blue/yellow slice of Munsell space



Chroma Linearity Summary

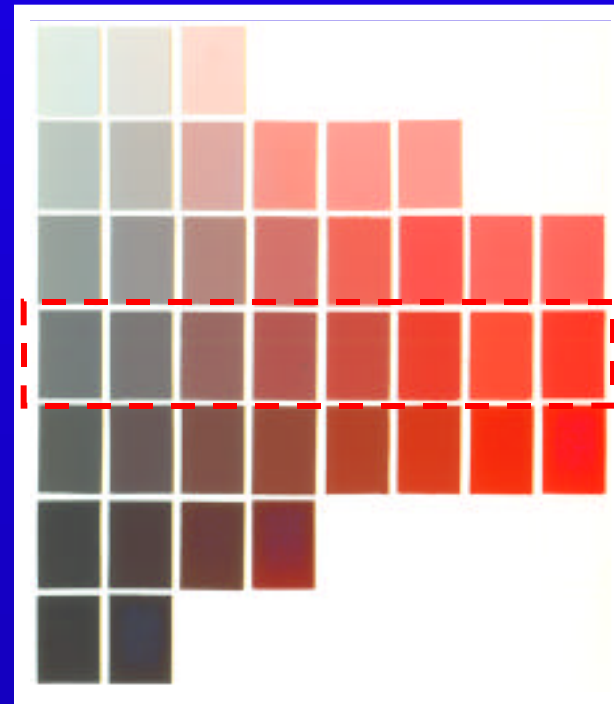


Chroma error from average normalized chroma



Hue Linearity Description

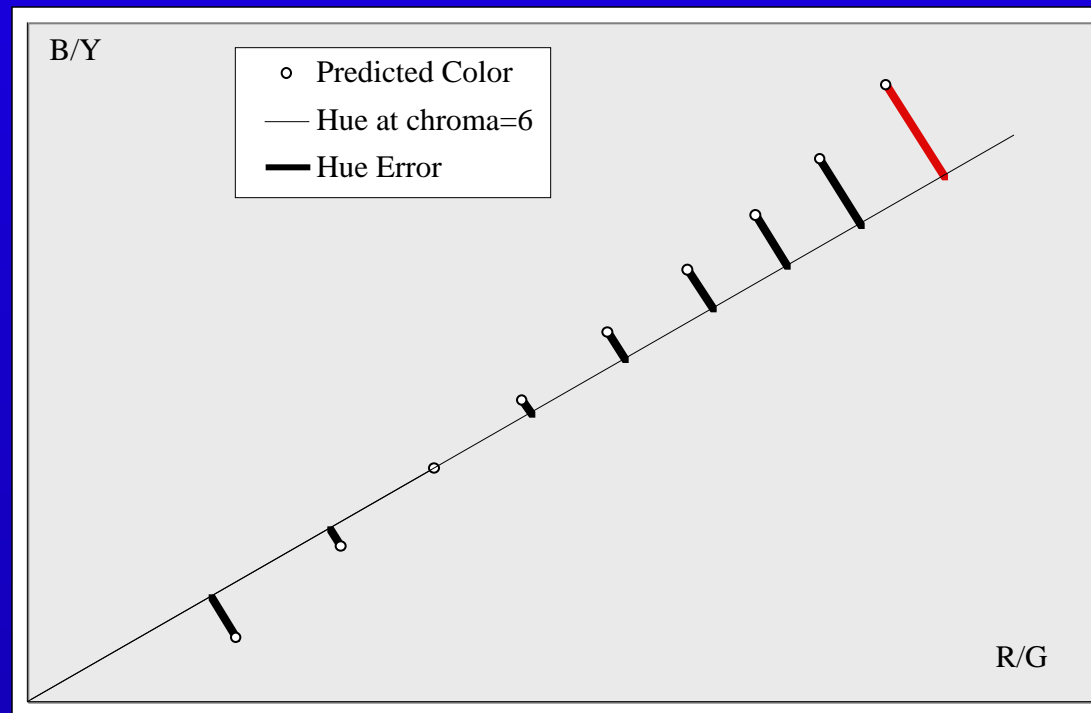
Input data are
lines of constant
Munsell hue and
value





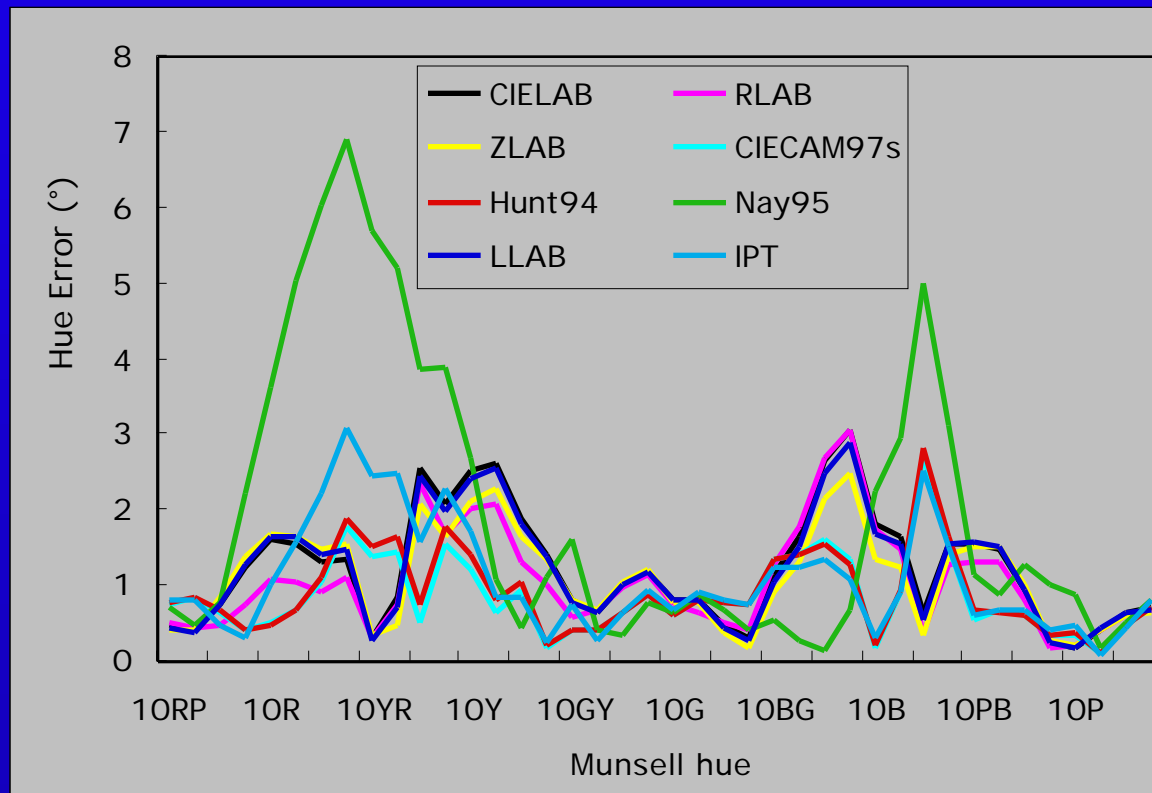
Hue Linearity Description

- ◆ Report RMS and max difference between predicted hue and hue at Munsell chroma=6





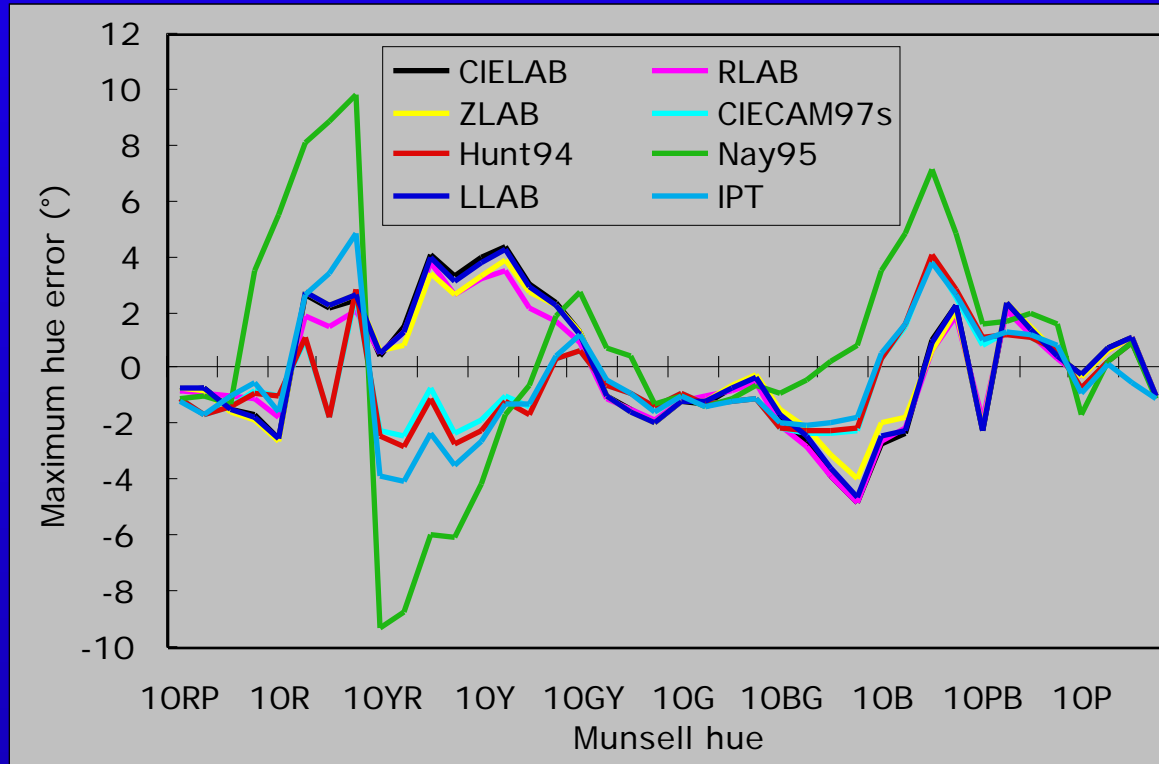
Hue Linearity Results



RMS difference from hue at chroma=6.



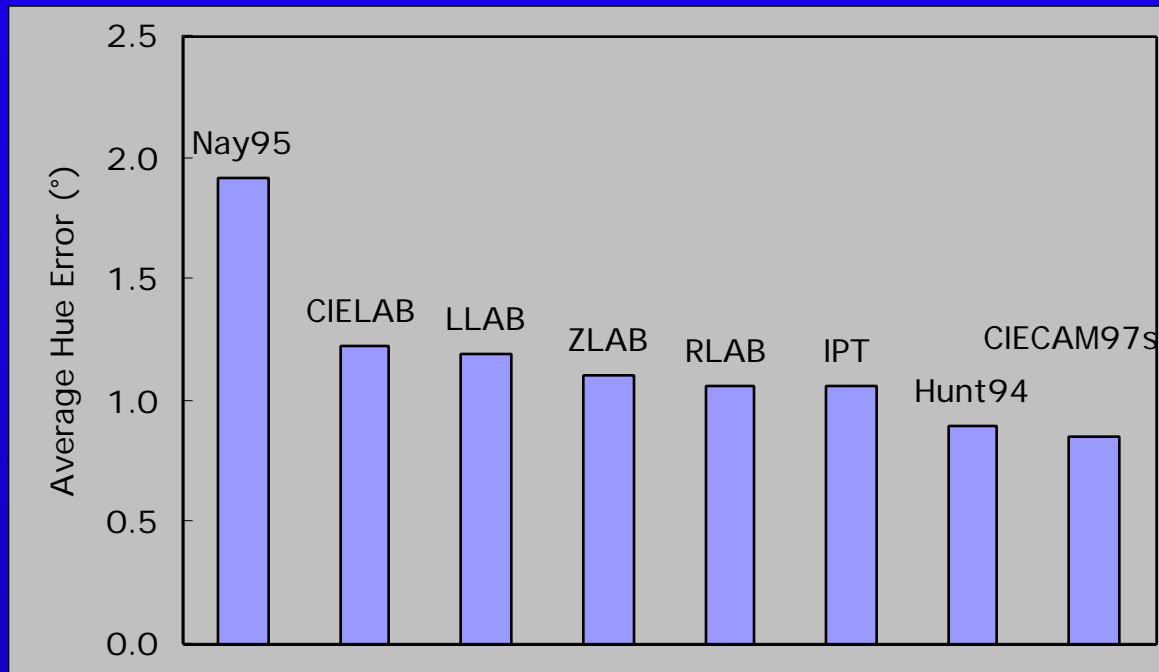
Hue Linearity Results



Maximum difference from hue at chroma=6.



Hue Linearity Summary



Hue error at Munsell value=5



Hue Spacing Description

Input data are
circles of constant
Munsell chroma



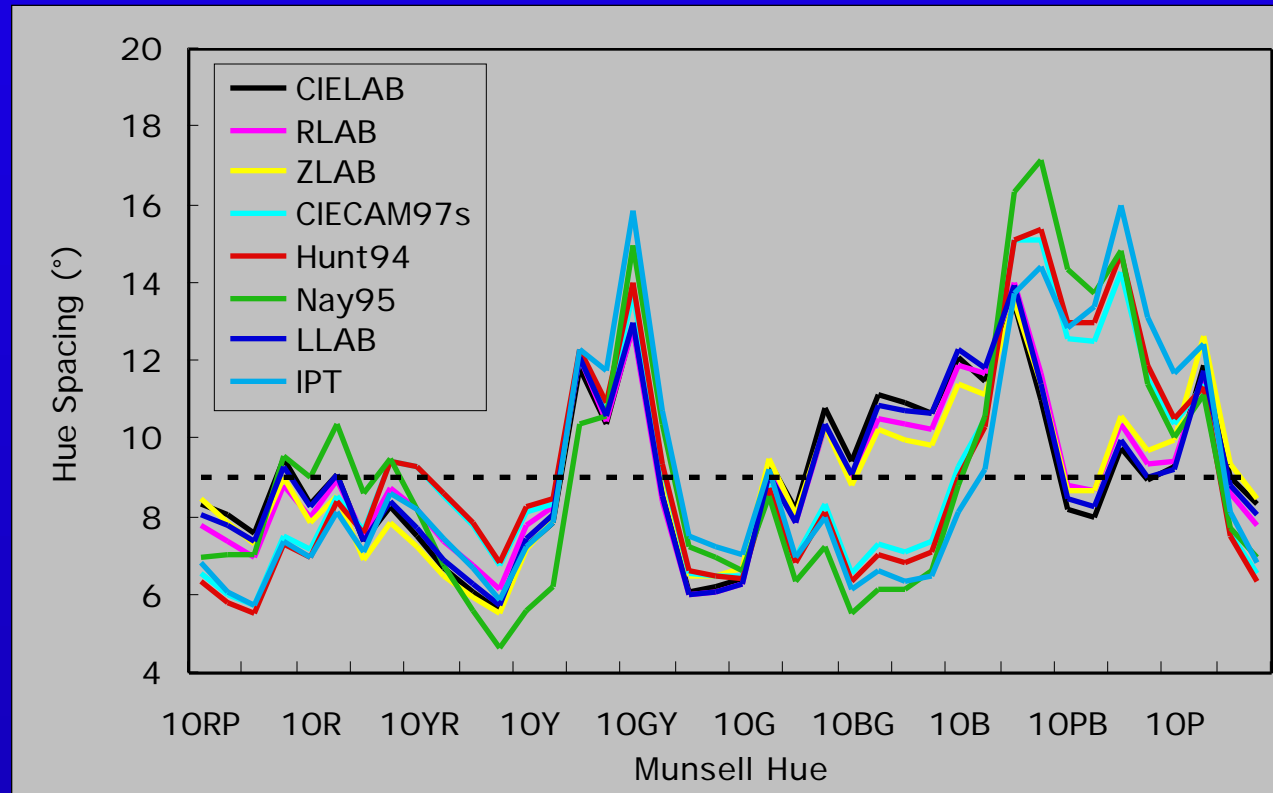


Hue Spacing Description

- ◆ Reported as RMS difference between predicted hue and ideal spacing
- ◆ Ideal hue spacing is $360^\circ/40 \text{ hues} = 9^\circ$



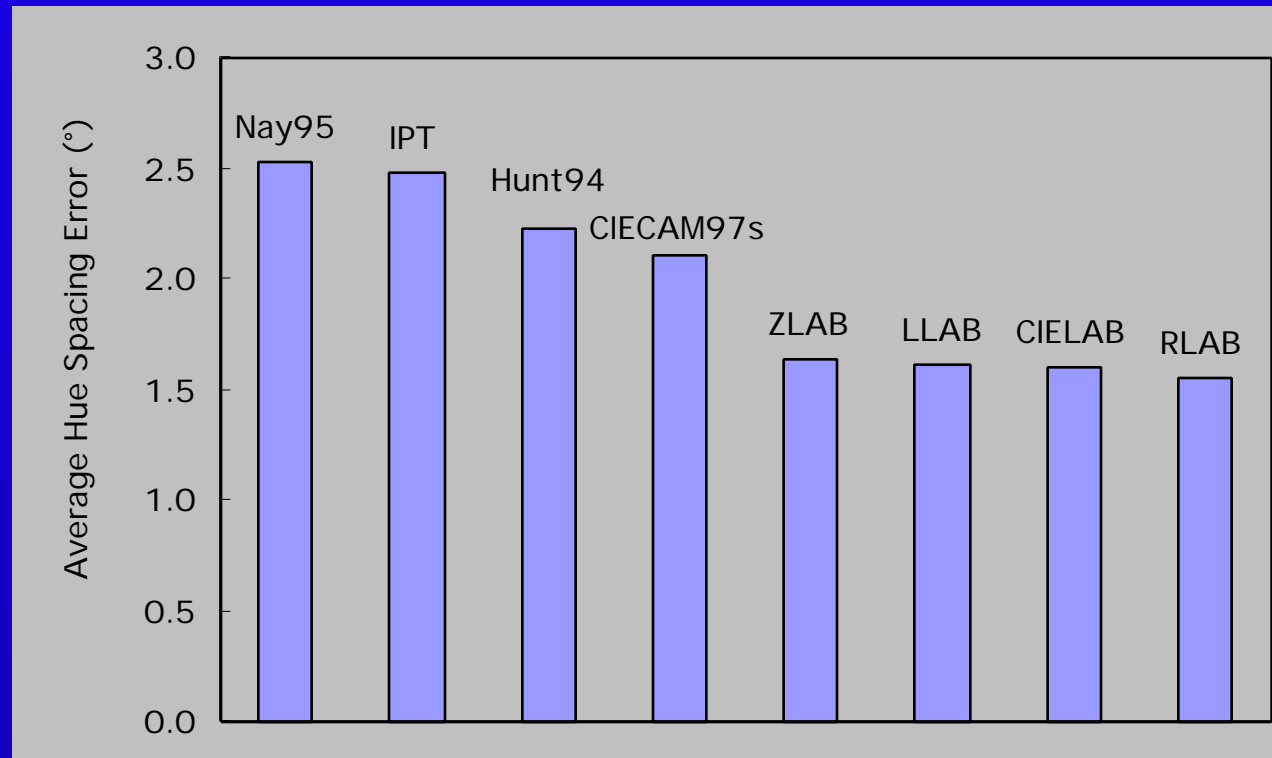
Hue Spacing Results



Distance between hue lines at Munsell value=5, chroma=6



Hue Spacing Summary



Average hue spacing error at Munsell value=5, chroma=6

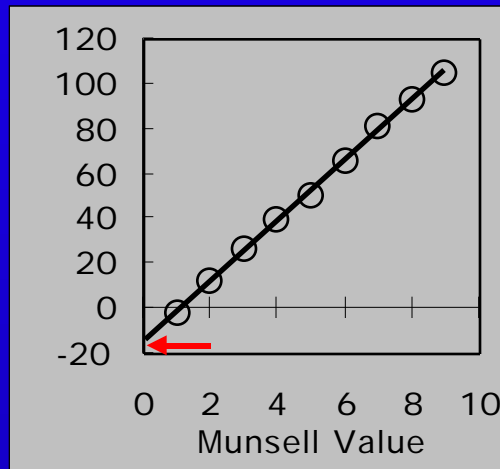


Lightness Linearity Description

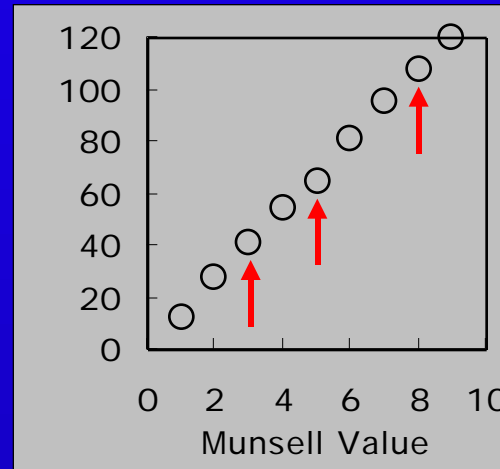
- ◆ Input data are Munsell value scale (neutrals)
- ◆ Plotted as lightness vs Munsell Value
- ◆ Linearity reported as distance between translated, normalized data and Munsell value



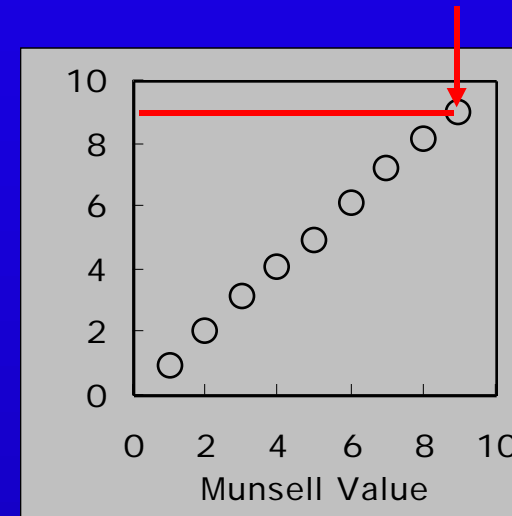
Lightness Linearity Description



Raw Lightness



Translated Raw Lightness

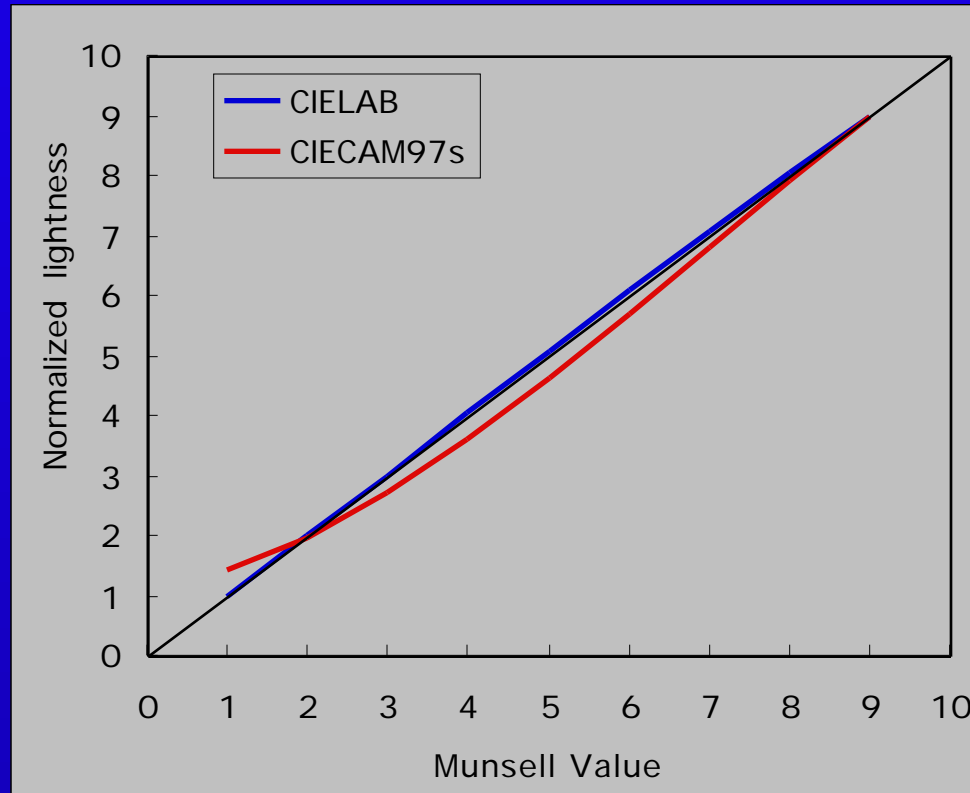


Normalized Lightness

Lightness translation and normalization.



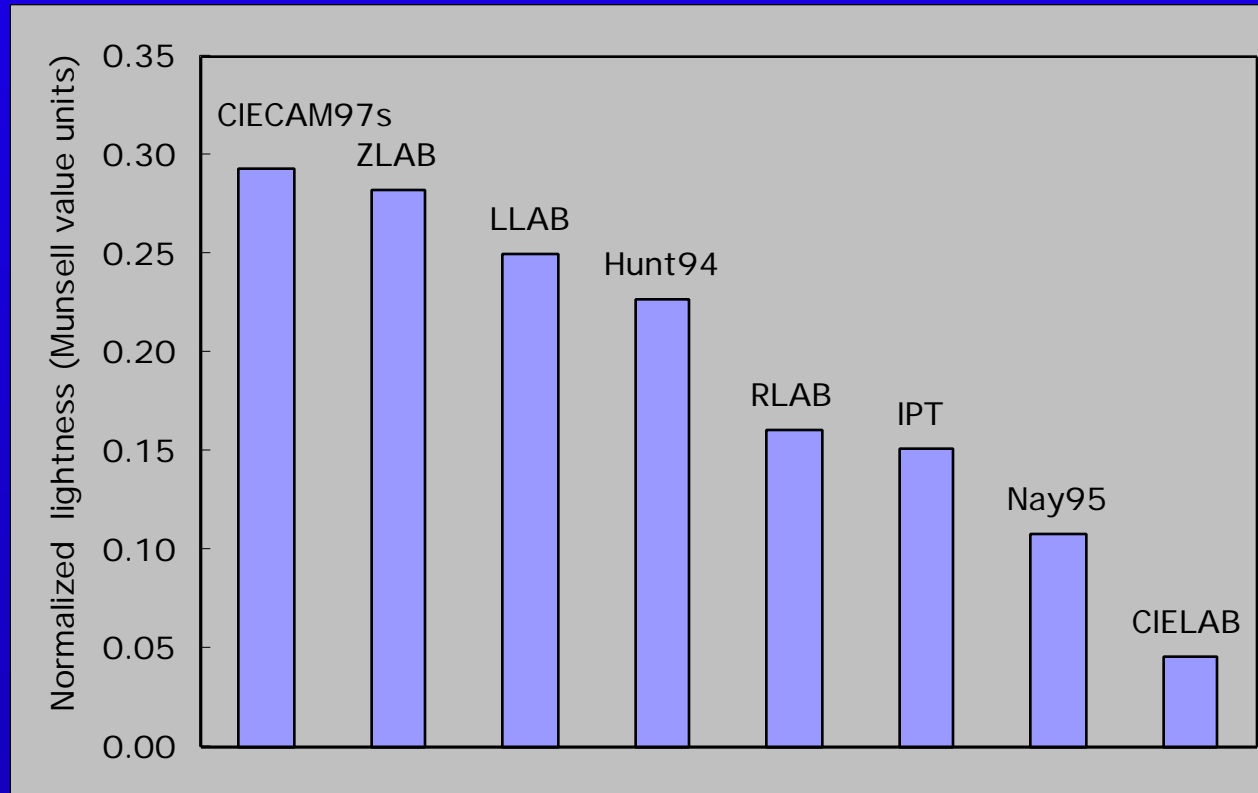
Lightness Linearity Results



Normalized lightness for CIELAB and CIECAM97s



Lightness Linearity Summary



Average difference between normalized lightness and Munsell value

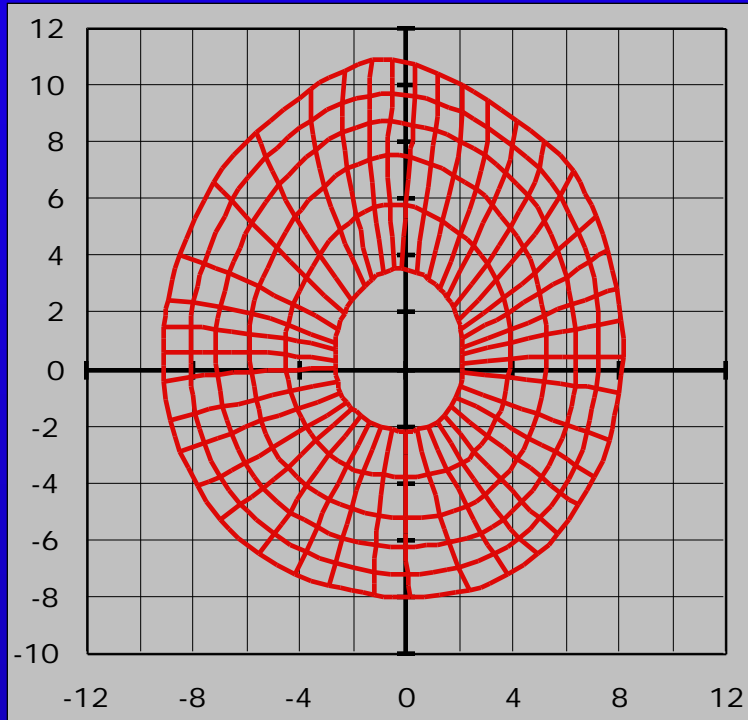


Model Performance Summary

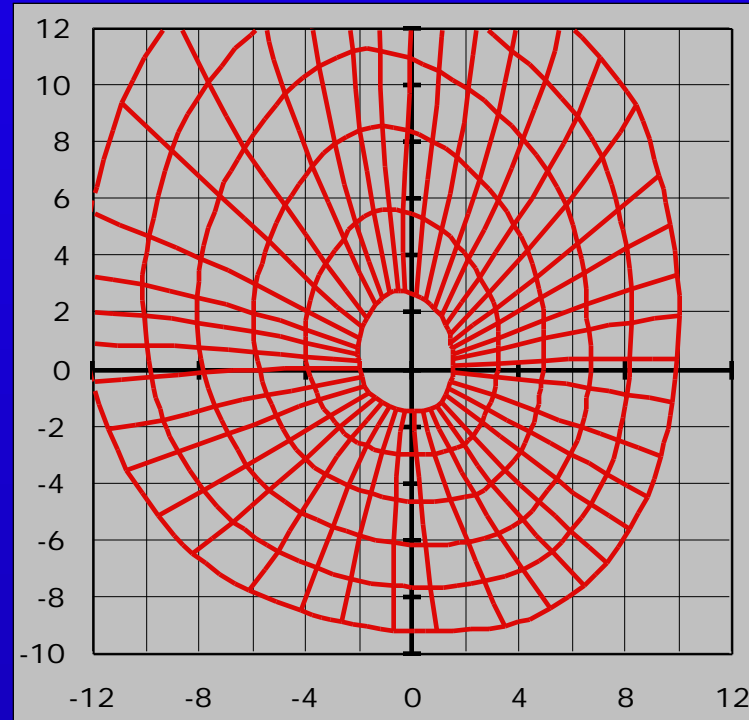
- ◆ Models excel at different metrics
- ◆ Currently no appropriate method to quantitatively rank model performance
 - It would be too deceptive
 - In many ways, it would be incorrect
- ◆ If a statistical comparison can be devised which uses all the metrics described here, it will appear in future work



The Old Way



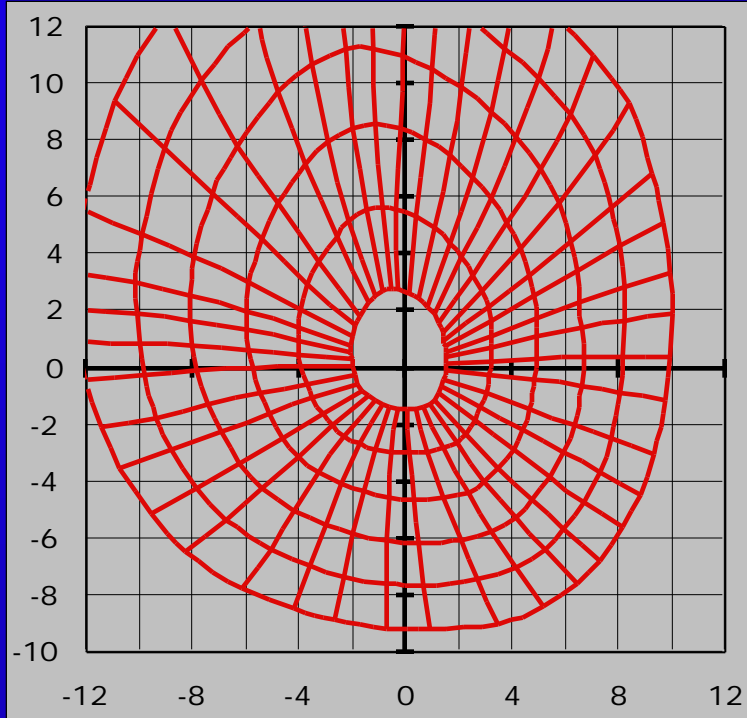
My Model



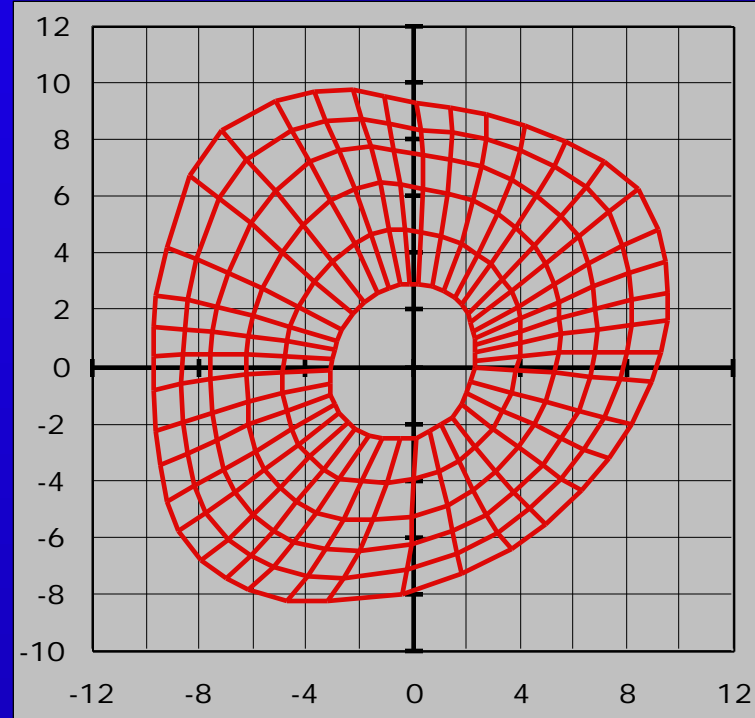
CIELAB



The past and the future?



The Old: CIELAB



The New: CIECAM97s



Possible Applications

- ◆ Model designers can clearly see shortfalls
- ◆ These techniques can be used to help select a model for a specific purpose
- ◆ Can we do another correction of Munsell space?



Conclusions

- ◆ Eight modern color appearance models
- ◆ Evaluation using the Munsell Renotation data as visually-uniform input colors
- ◆ Models evaluated for constant lightness, chroma, and hue response
- ◆ Comparisons were made for model *uniformity* with respect to the Munsell Renotation Data



Conclusions

- ◆ No clear winners or losers, but rather clear distinctions between predictive abilities of the various models for various metrics
- ◆ No claim is being made as to the ability to compare these results to other color appearance model studies
 - Cross-media reproduction
 - Color difference comparisons