U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Color Rendition Metrics
An Overview of Ongoing Work

Lightfair 2014

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The Premise

- CRI – Despite all the talk, it's still here and being widely used
- CQS – After showing great promise, it has been lurking for years, but has never gained widespread acceptance
- CIE – One committee turned into two; progress is being made, but official standards are still at least a year away
- IES – Formed a small group last year to propose a solution within a year

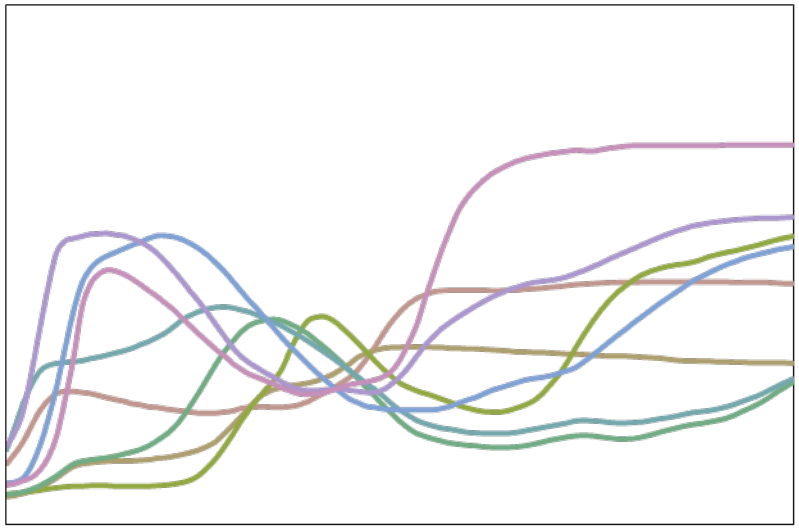
The Problem

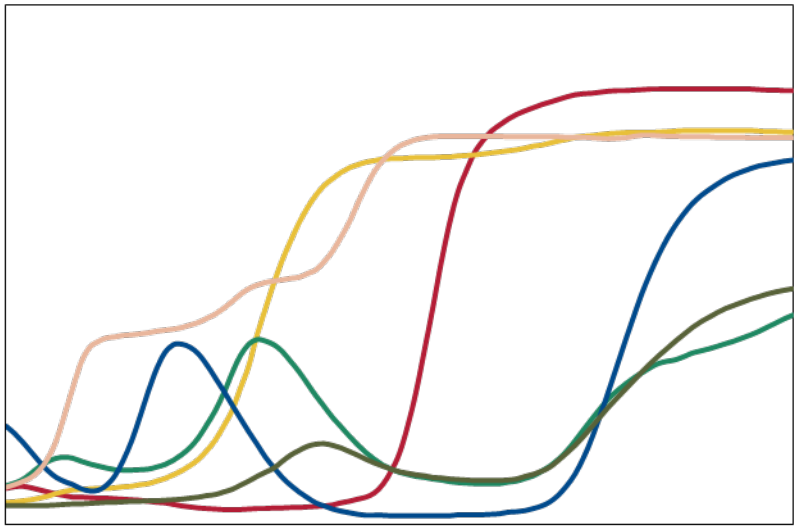
- Humans experience color subjectively
- Metrics attempt to characterize color mathematically (and may attempt to characterize the subjective experience)
  - They tend to be imperfect, but are still generally useful
- There is more than one way to make an accurate color rendering metric
  - Metrics capturing fidelity
  - Metrics capturing preference
  - Metrics capturing saturation

Color Rendering Index (CRI, R_a): Basic Info

- Developed 1948-1973
- It's a fidelity metric
  - Reference is blackbody radiation (< 5000 K) or a mathematical representation of daylight (> 5000 K) at same CCT as test illuminant
- Compares chromaticity of eight (pastel) test color samples under test illuminant to reference illuminant (easy to "game")
  - R_a (using 8 samples) is part of a larger system that includes 14 (now 15) total samples
- Averages (and scales) differences of each sample to result in single number (often misunderstood)
  - Maximum score of 100 if all samples match exactly
  - Scaled so that a halophosphate fluorescent lamp had a score of 50
- Applicable to sources near blackbody locus
- Does not predict appearance of specific objects (like all metrics)
- Uses the Von Kries chromatic adaptation transformation (outdated)
- Uses CIE 1964 UCS (outdated)

CRI: The methods behind the metric





Approximation of Color Samples for CRI R_a (3000 K Blackbody Radiation)

TCS 01 TCS 02 TCS 03 TCS 04 TCS 05 TCS 06 TCS 07 TCS 08

Color Samples for R_9–R_{14}

TCS 09 TCS 10 TCS 11 TCS 12 TCS 13 TCS 14

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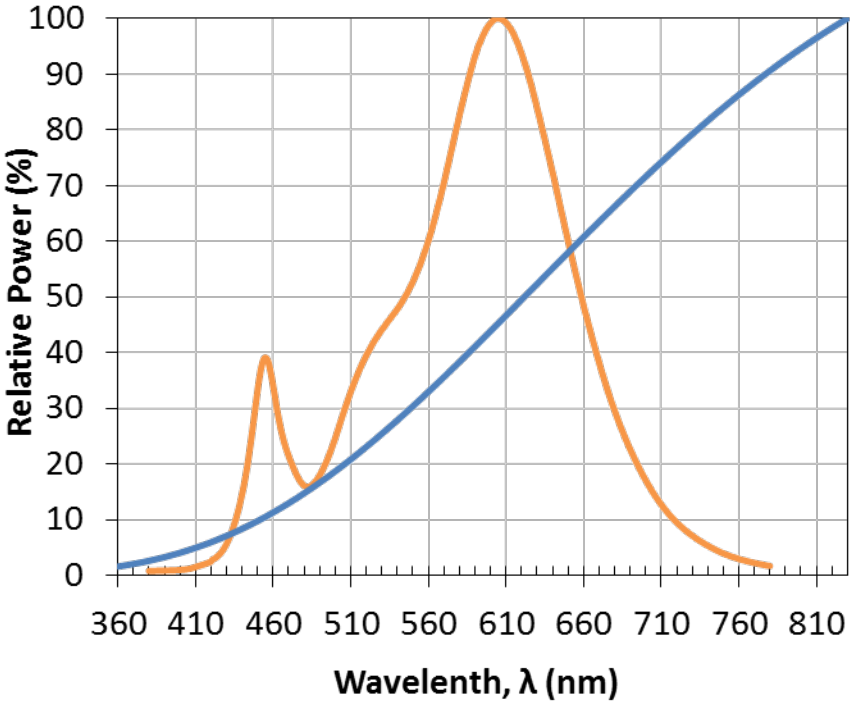
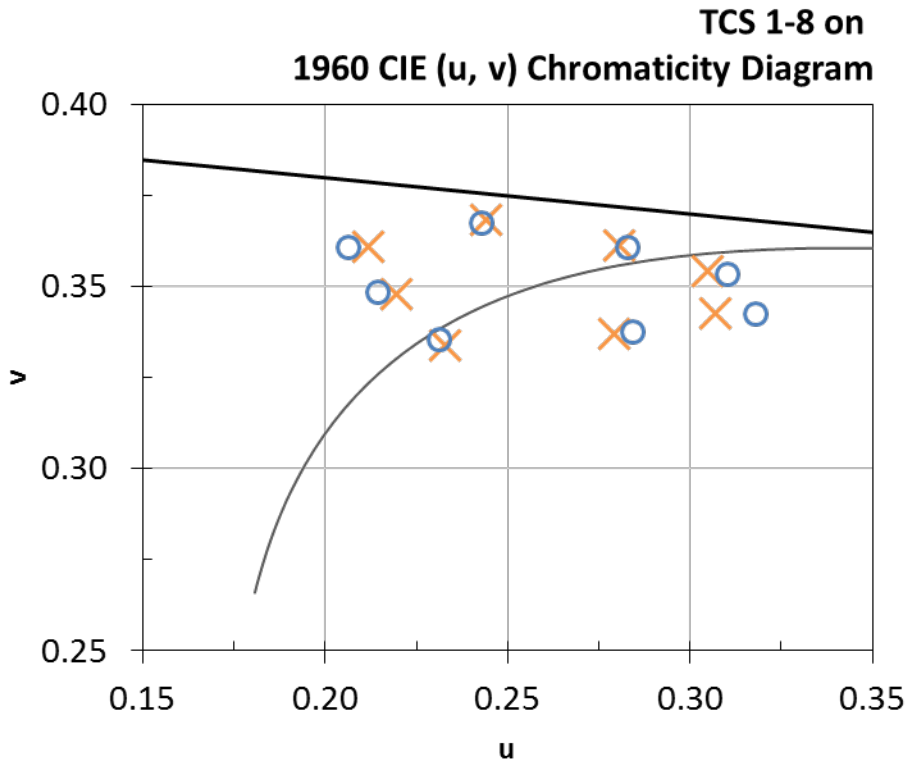
CRI: The methods behind the metric





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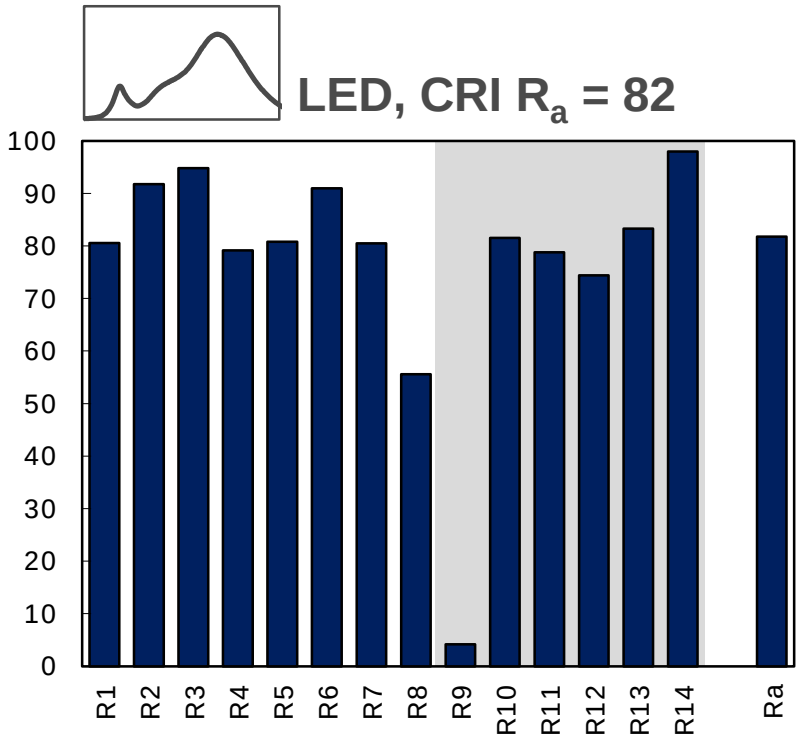
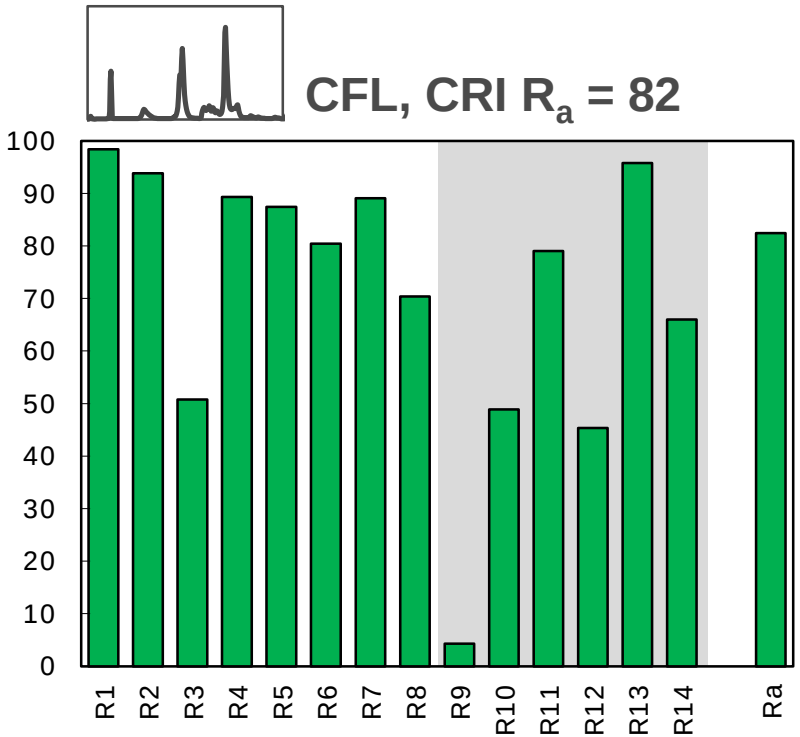
CRI Limitations

- Averaging, references and other methodological issues
- Does not convey exact color appearance
  - Very saturated could be the same as very unsaturated
- Does not work as well for very discrete SPDs (i.e., RGB LED)





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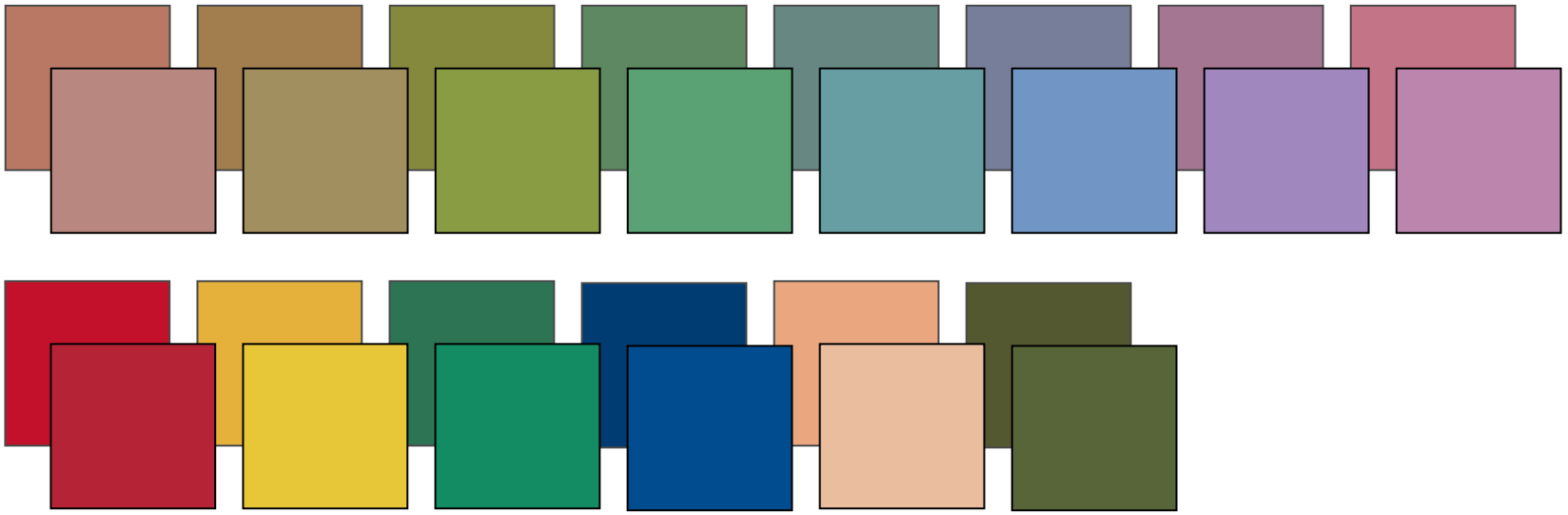
CRI Limitations

2700 K (back) versus 6500 K (front)



Objects will looks different under sources with same CRI at different CCTs

(although chromatic adaptation helps)

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Special Color Rendering Index R_9

- Part of the same system as CRI R_a
  - Same calculation method
- Saturated red
- Red is particularly important for human skin complexion
- Often considered a valuable supplement to CRI R_a

Because color space is skewed at red…
R_9=0+ is Good; R_9=50+ is Very Good; R_9=75+ is Excellent

[Equivalent R_9 CRI = 100 – (100-R_9)/4]

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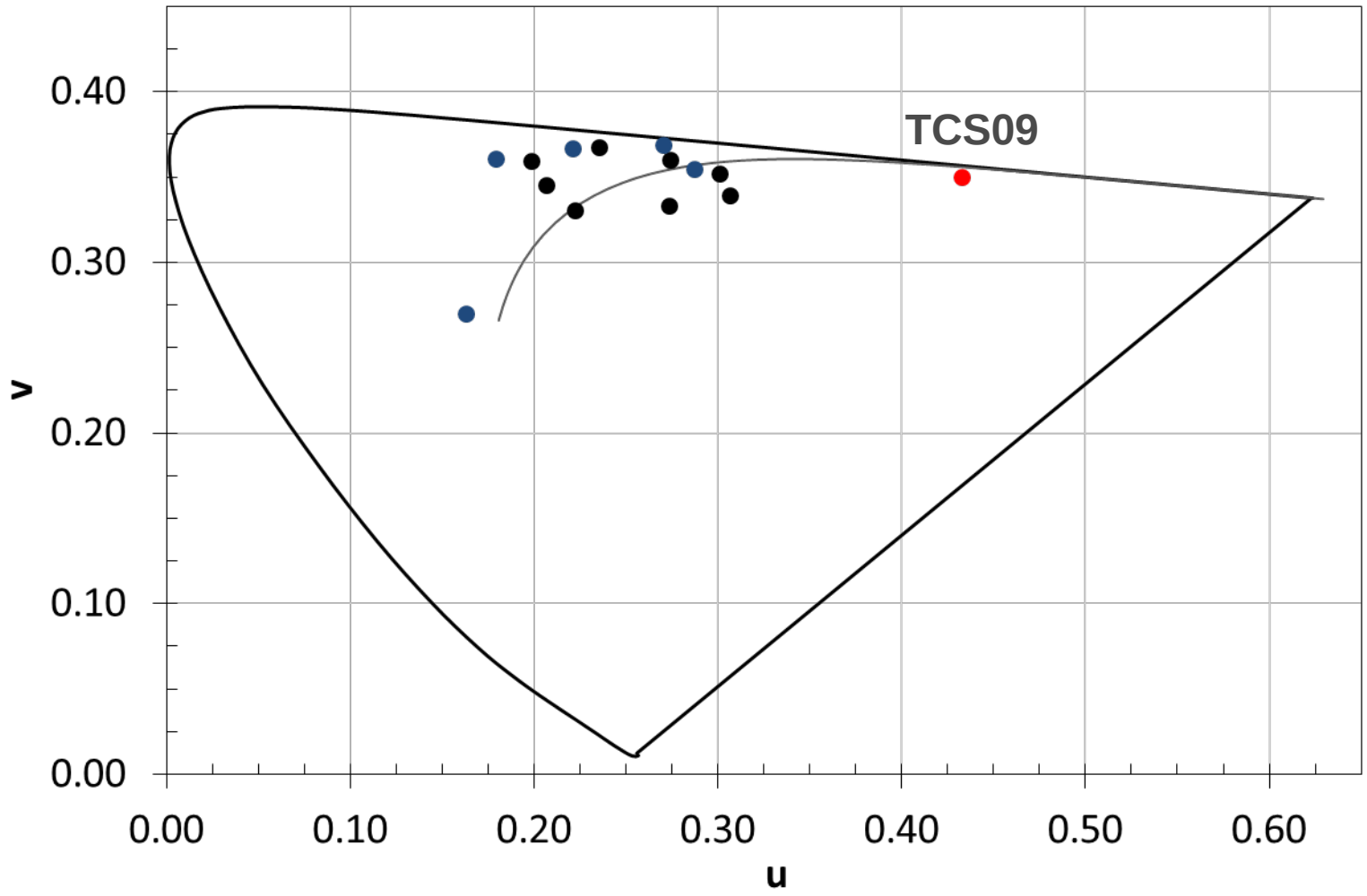
Special Color Rendering Index R_9



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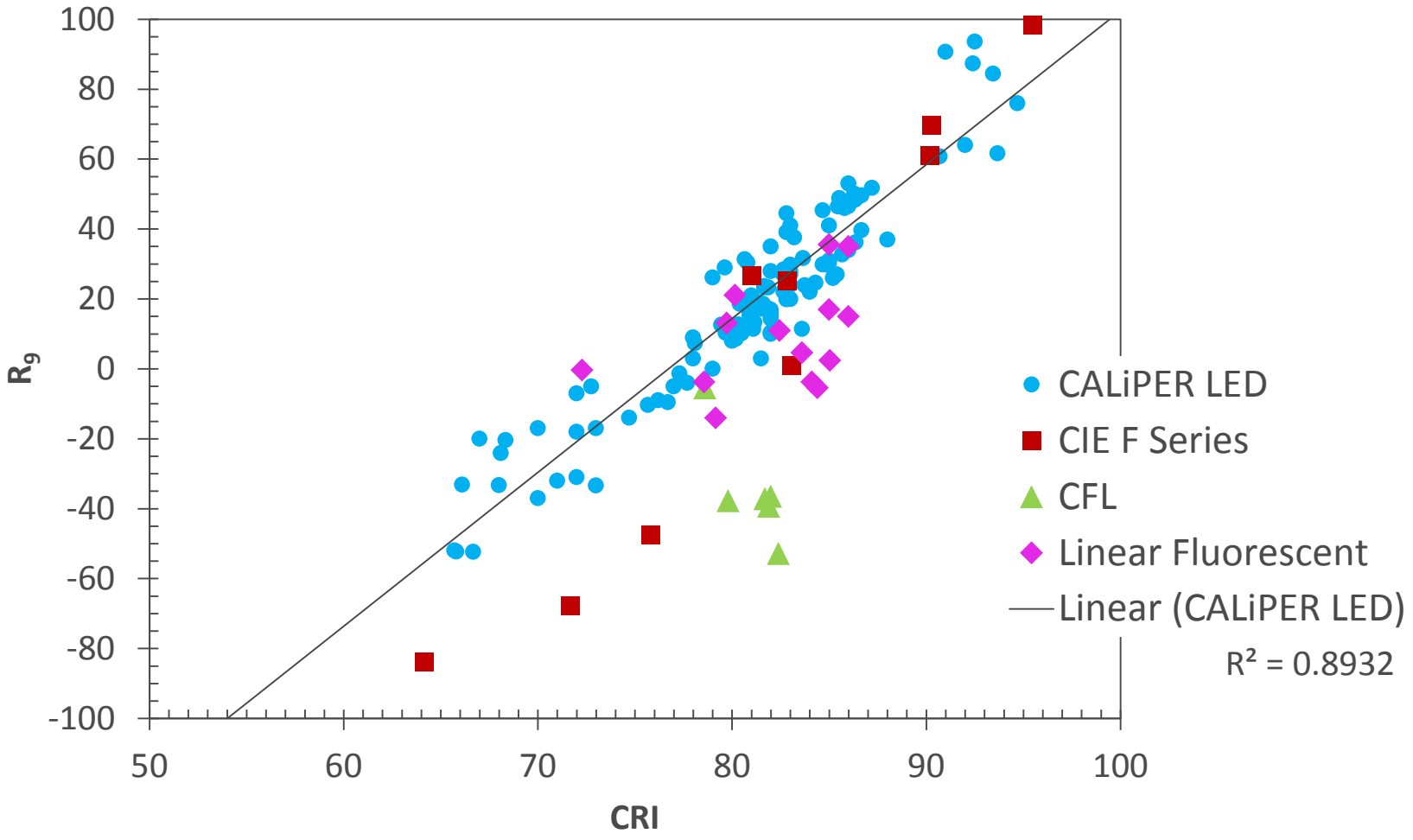
CRI versus R_9



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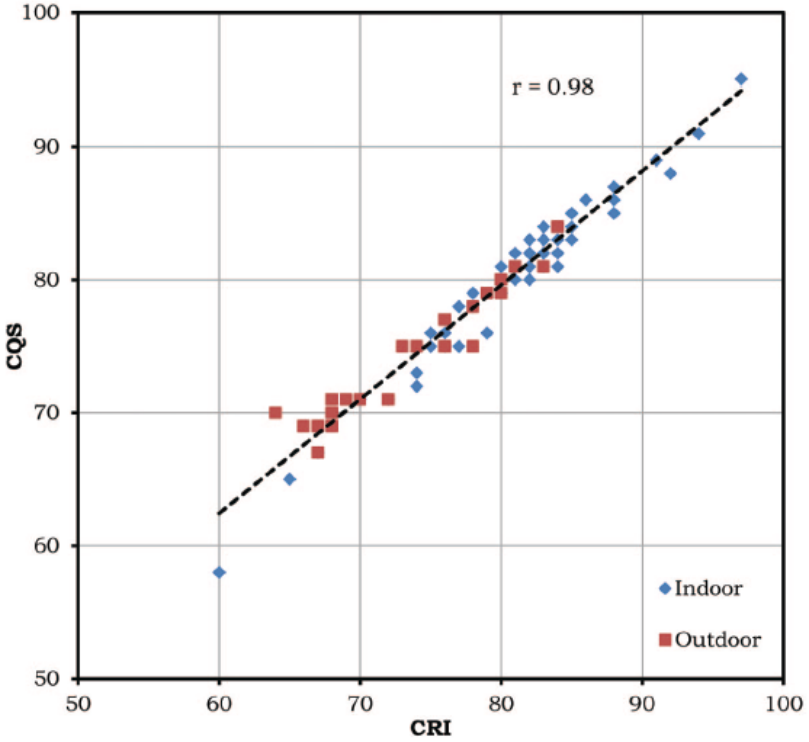
CIE TC 1-69: Color Rendition by White Light Sources

- Followed CIE TC 1-62 (which followed TC1-33 and others), *Color Rendering of White LED Light Sources*
  - Recommended a new color rendering metric, applicable to all types of light sources, to supplement CRI (concurrent use intended, at least at first)
- Formed 2006
- Intent was to develop a single number metric with similar scaling to CRI
- Large number of constituents (40+), with international representation
- Involved experimental work by many involved parties
- Ultimately, agreement was not reached (unanimous agreement required by CIE procedures)
  - What type of metric is the single best?

Color Quality Scale (CQS)

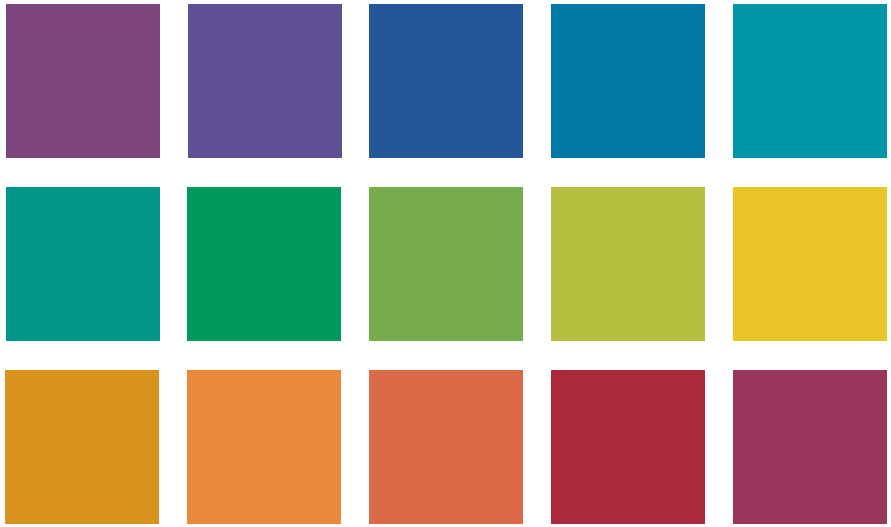
- Developed (in part) for TC 1-69
  - Has gone through several iterations
- 15 Munsell samples with moderate saturation
- Improved “math” (e.g., color space, chromatic adaptation transformation)
- Similar scale to CRI (i.e., maximum of 100)
- Three components: Q_a, Q_f, Q_g
- Q_a, the main metric, penalizes reductions in chroma, but allows minor increases in chroma
  - Attempt to characterize subjective color experience

Color Quality Scale (CQS)



[Wei and Houser, Leukos, 2012]

Color Samples



CIE TC1-90 and TC1-91

- TC1-90 is focused on a new color fidelity metric
  - Now considering CRI2014/CRI2012
  - Physical samples created and experiments being conducted at several labs
  - Goal is to have a new metric by the end of this year
- TC1-91 is considering only non-fidelity metrics
  - CQS, FCI, GAI, MCRI, PS
  - Visual experiments will be conducted
  - Will not necessarily pick one measure
  - Goal is to finish the work in one year
- Recommendations will be combined and given to a new committee that will make them into an official CIE standard

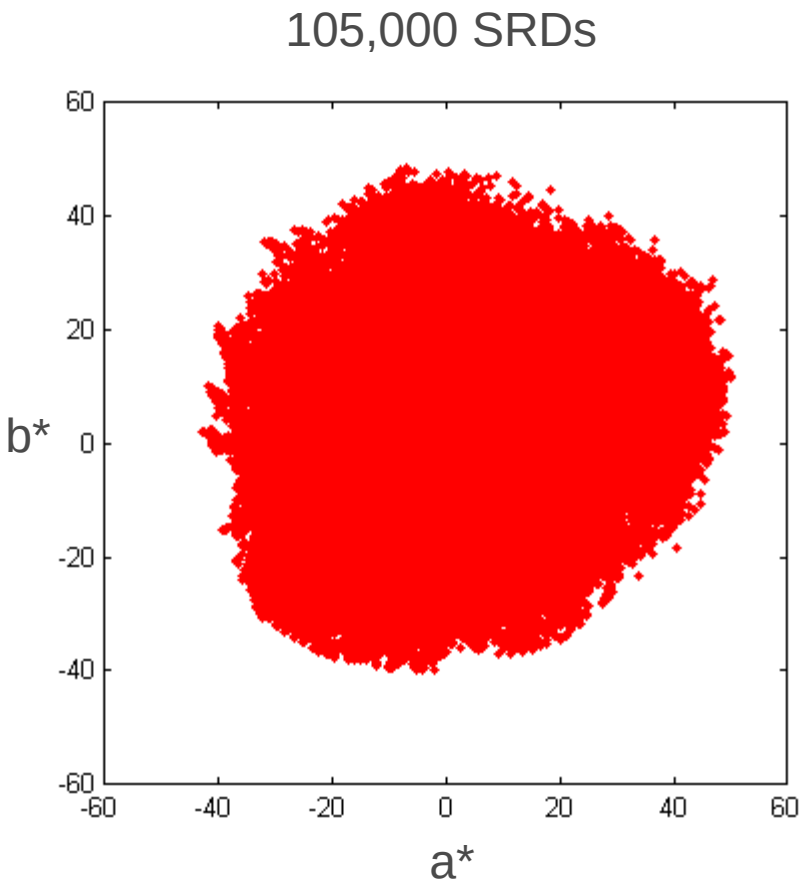
IES Color Metrics Task Group

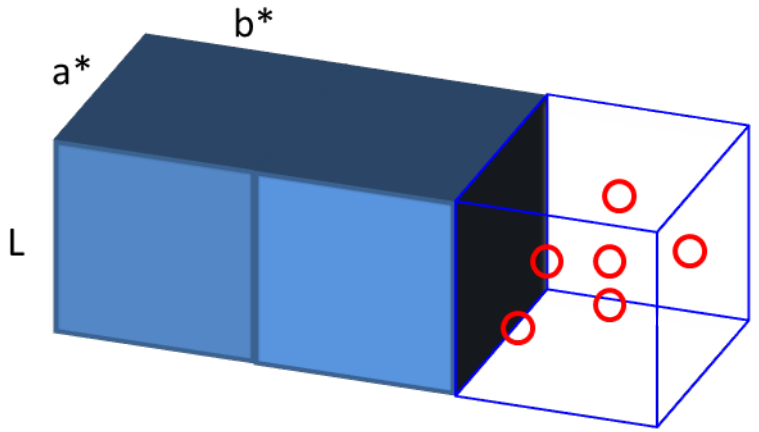
- Formed June 2013
- Current Group Members:
  - Michael Royer (PNNL), Kevin Houser and Tommy Wei (Penn State), Yoshi Ohno (NIST), Randy Burkett (RBLDI), Aurelien David (Soraa), Kees Teunissen (Philips), Paul Fini (Cree)
- Timeline: 1 year
- Goal: To develop a bundle of metrics and/or tools that provides better information for consumers, manufacturers, and specifiers related to the color rendering of light sources used for general interior lighting applications. The metric(s) will not be proposed as a direct replacement for CRI, but rather as an alternative that provides multilevel information to meet the needs of different user groups. The result will be presented as a Technical Memorandum.

IES Color Metrics Task Group – Key Ideas

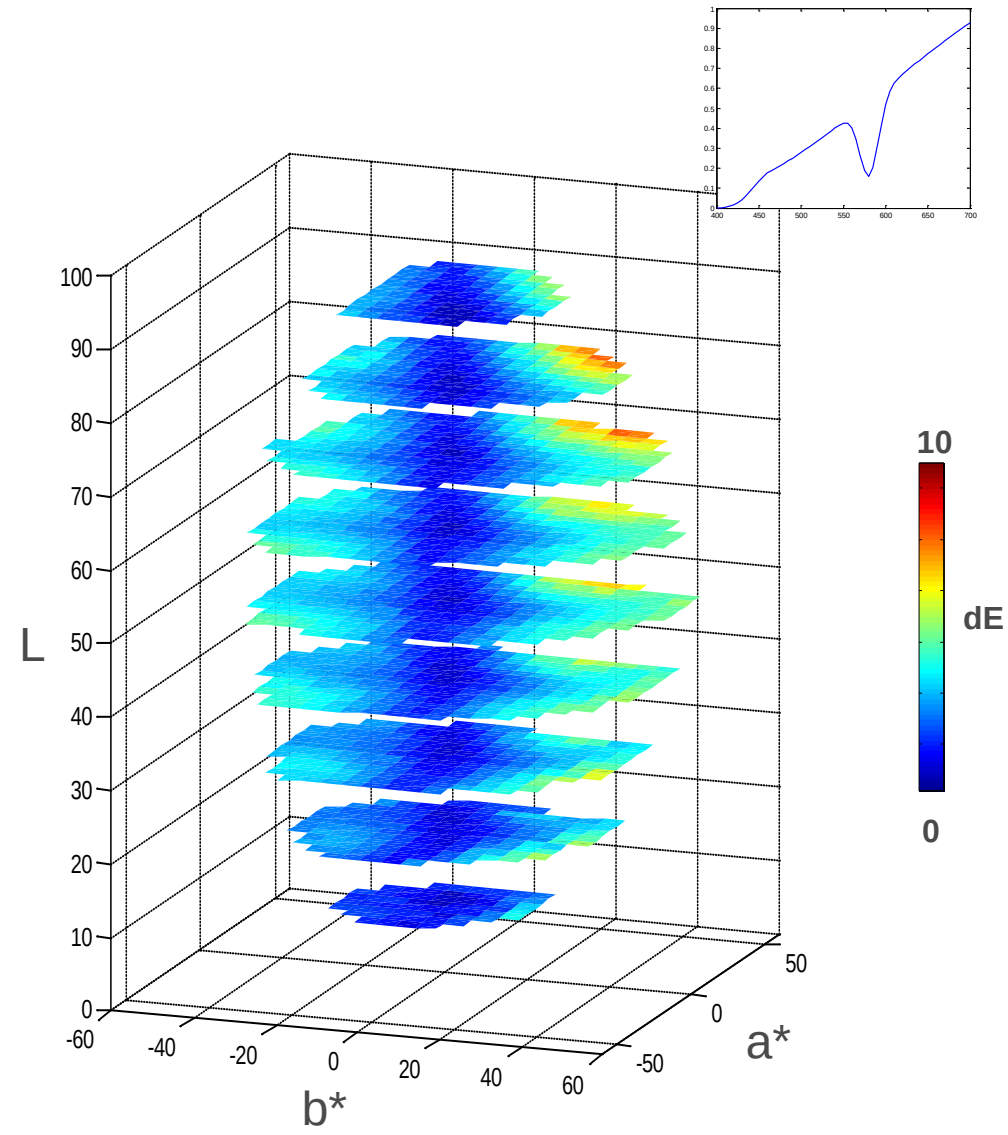
- Statistical/mathematical evaluation only
  - Users must decide preference based on numerical information
  - Metrics as objective/statistical as possible
- Underlying math similar to CQS, with some minor updates
- New set of reflectance samples
  - Real objects: flowers, paints, prints, skin tones, etc.
  - Down-selected to less than 500 samples from library of 105,000 samples
  - Accuracy is maintained within tight tolerances and verified with library of more than 500 real SPDs and 20,000 synthetic SPDs
  - Even sampling throughout color solid (each sample is a unique color)

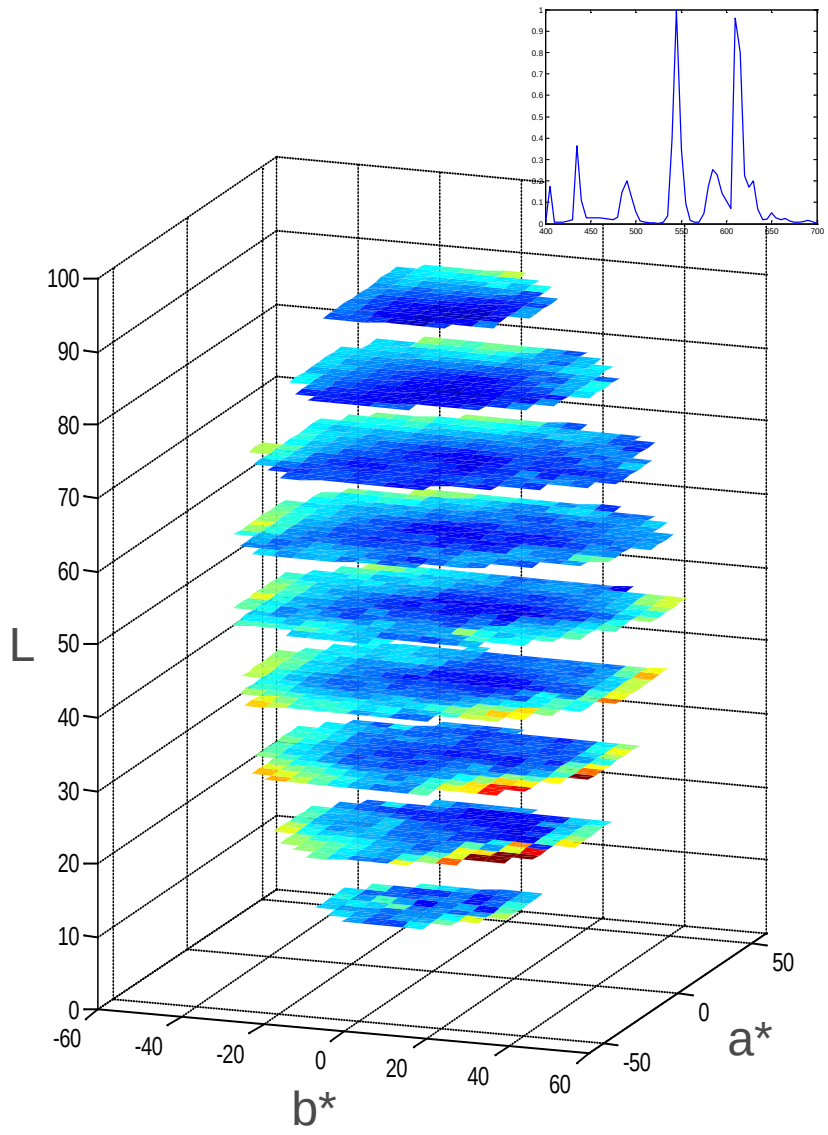
Color Samples Comparison





Calculating Error – Three Dimensions

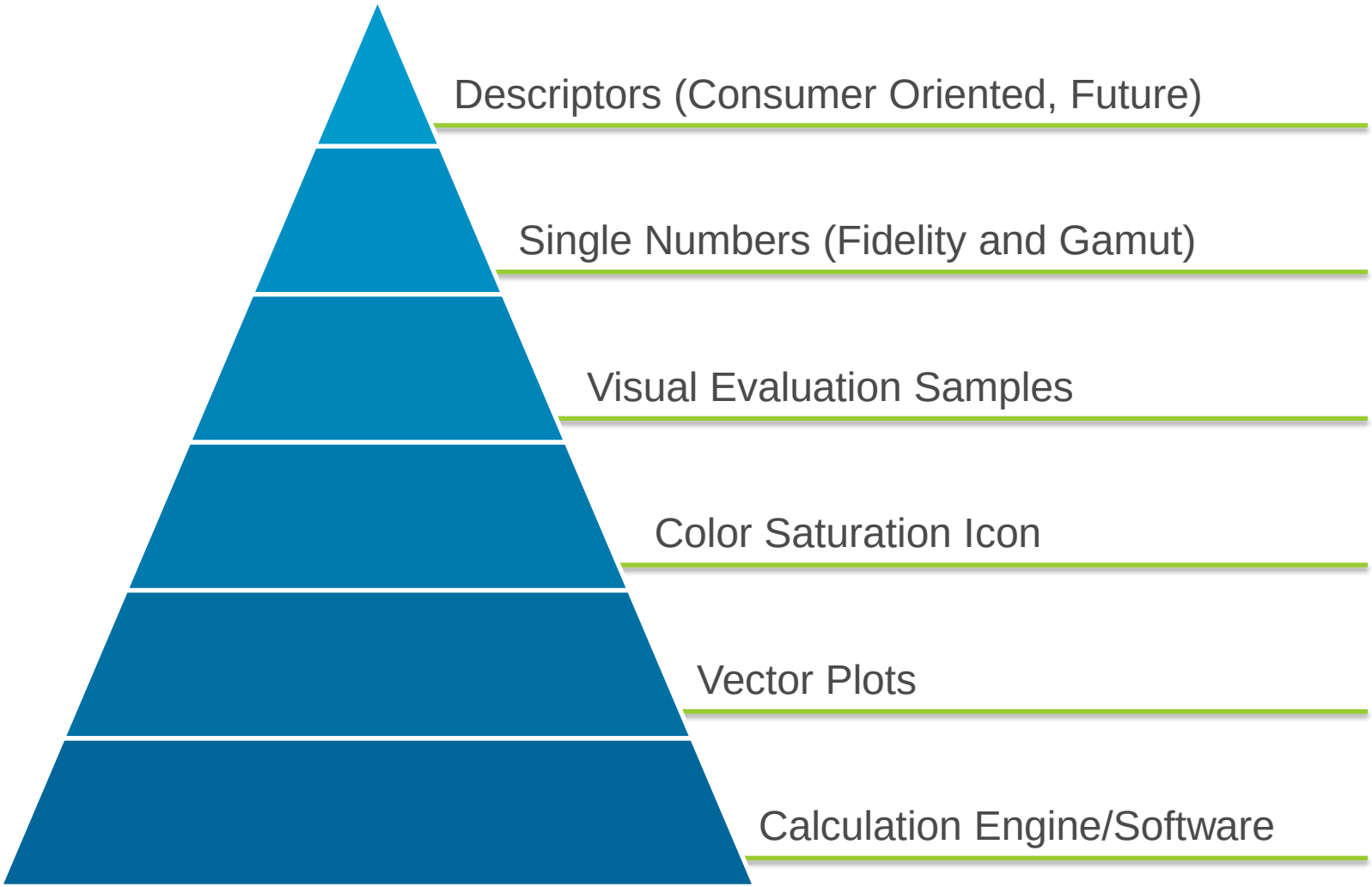




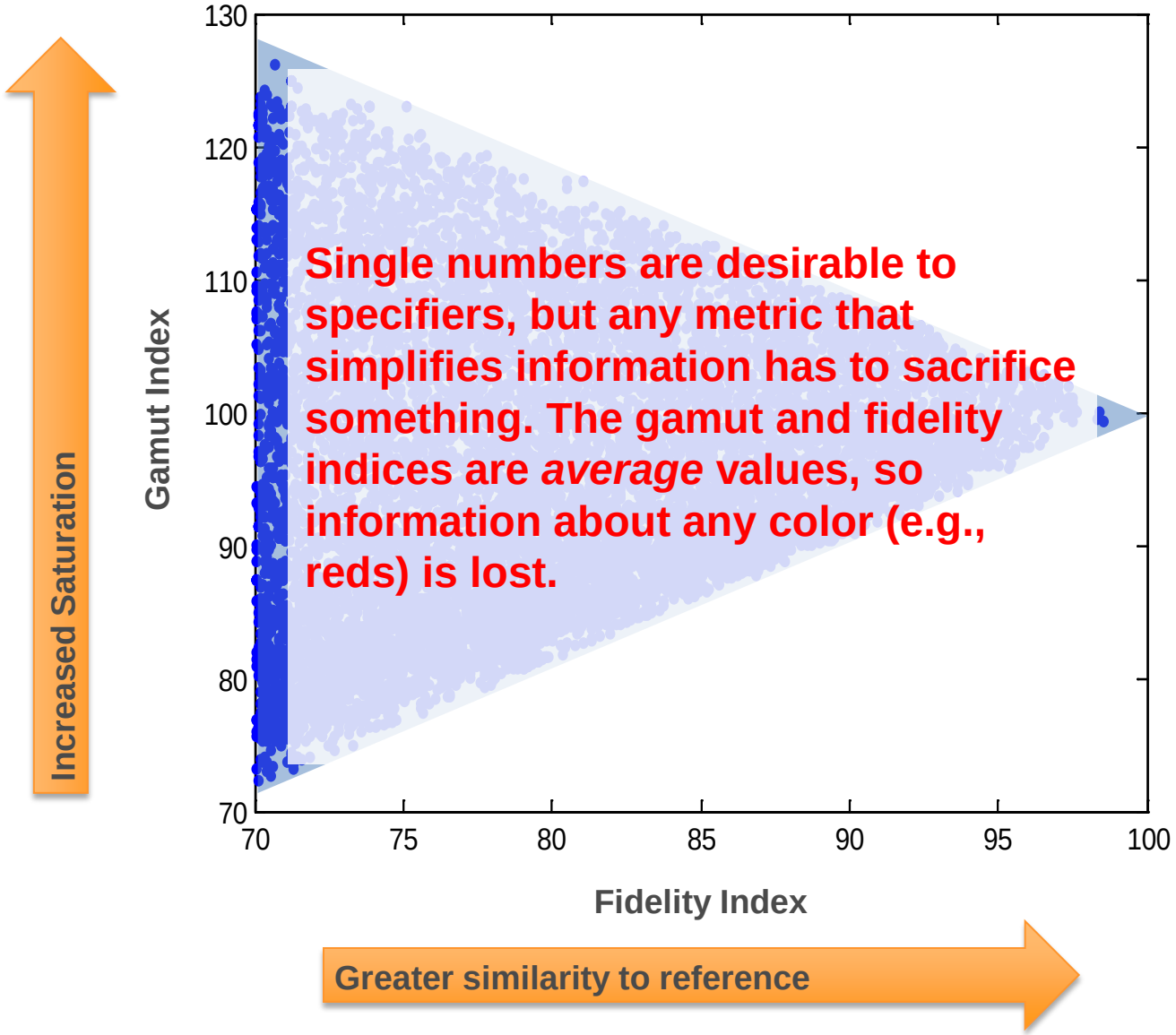
IES Color Metrics Task Group – Outcome Measures

- A calculation engine with accompanying software
- Vector plots showing the shifts of individual reflectance samples
- A color saturation icon, based on average shifts within different hue angles
- A set of 15 samples for visual display in the software
- Fidelity and gamut area metrics, with accompanying two-axis plot
- Consumer-oriented classification scheme for regions of the Fidelity-Gamut plot (Future)

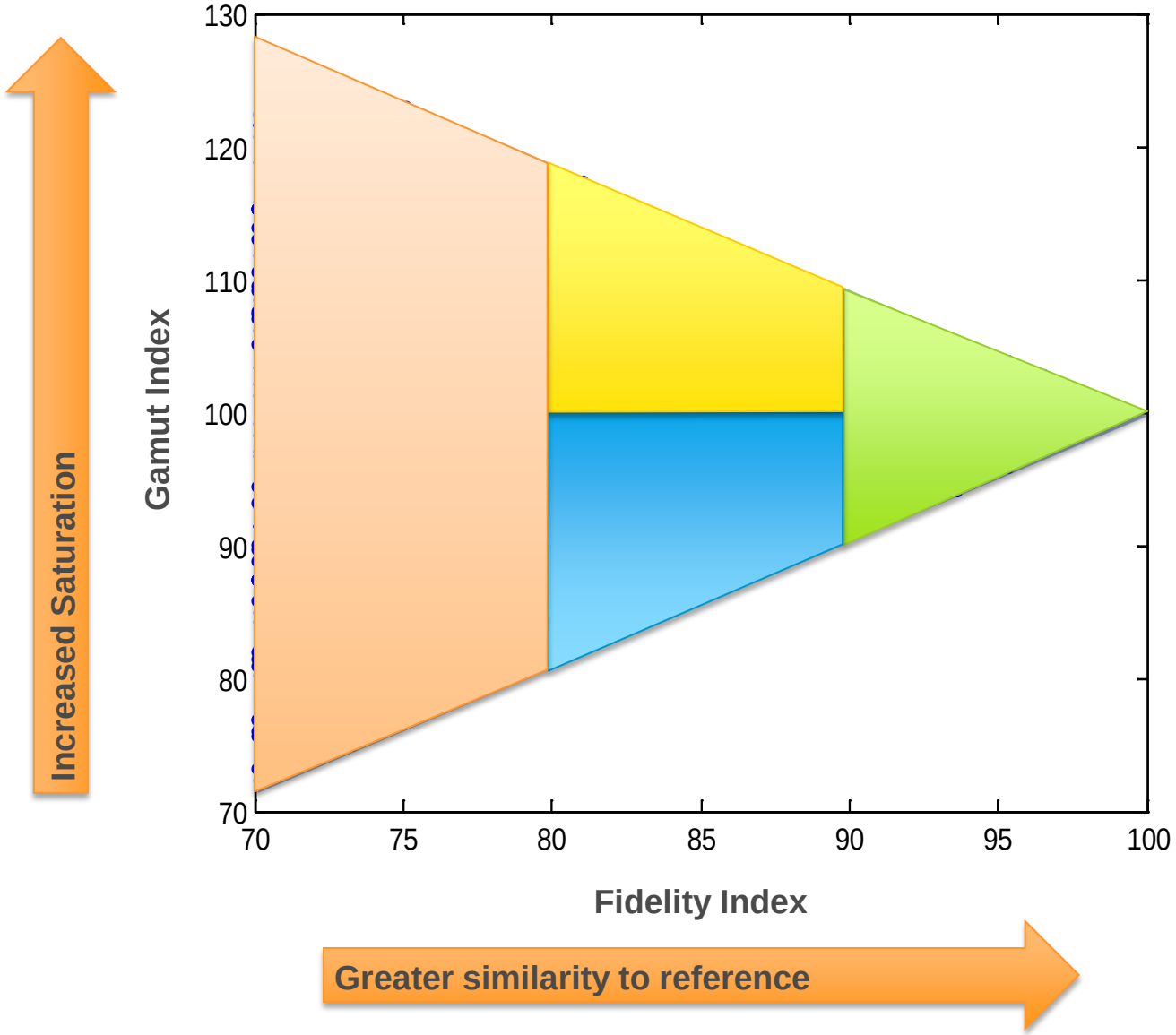
Outcome Hierarchy



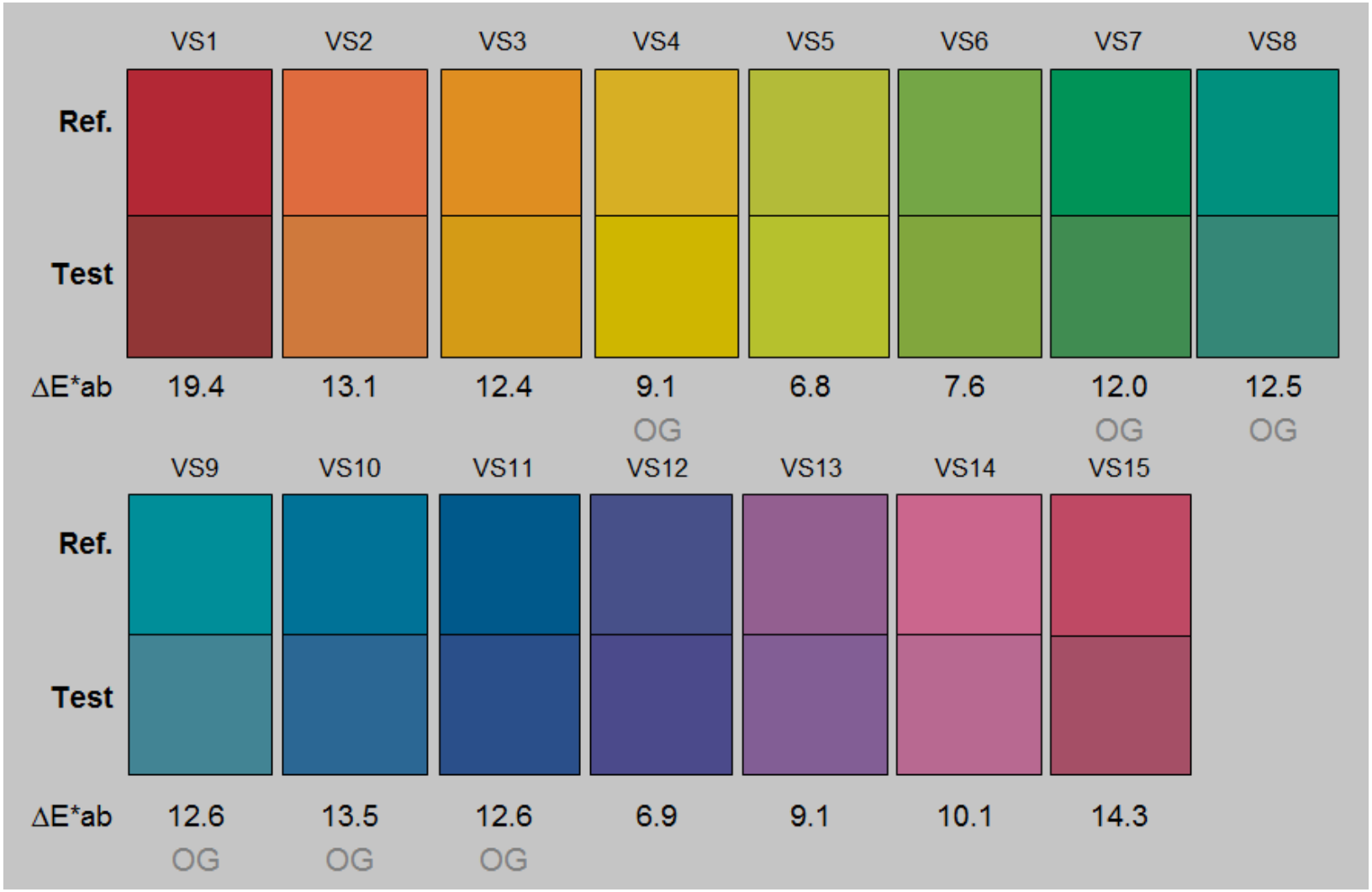
Two-Axis System (Concept)



Two-Axis System: Zonal Classification?

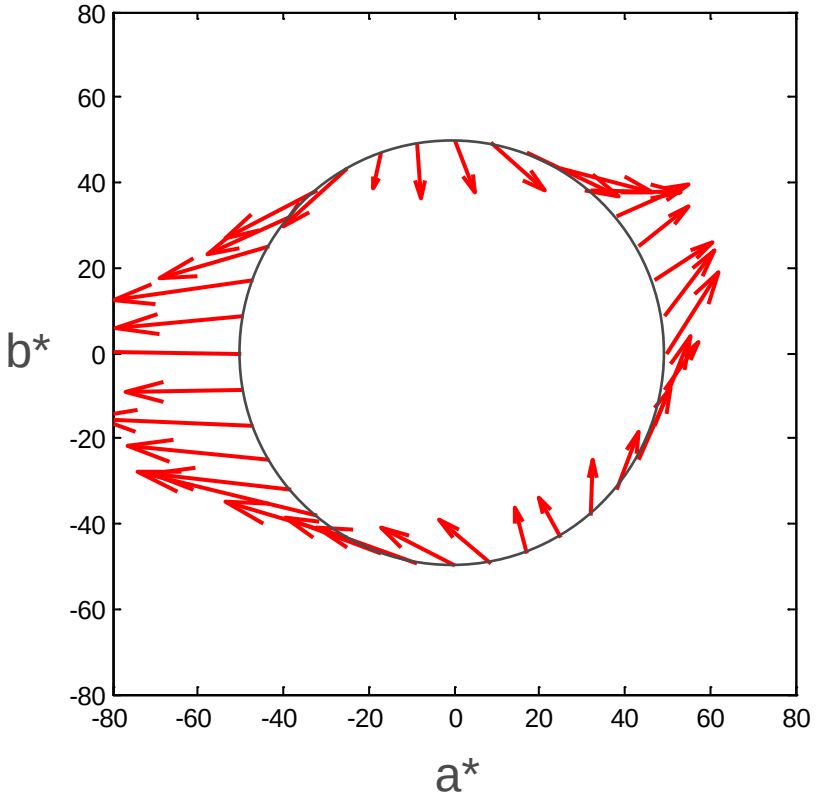


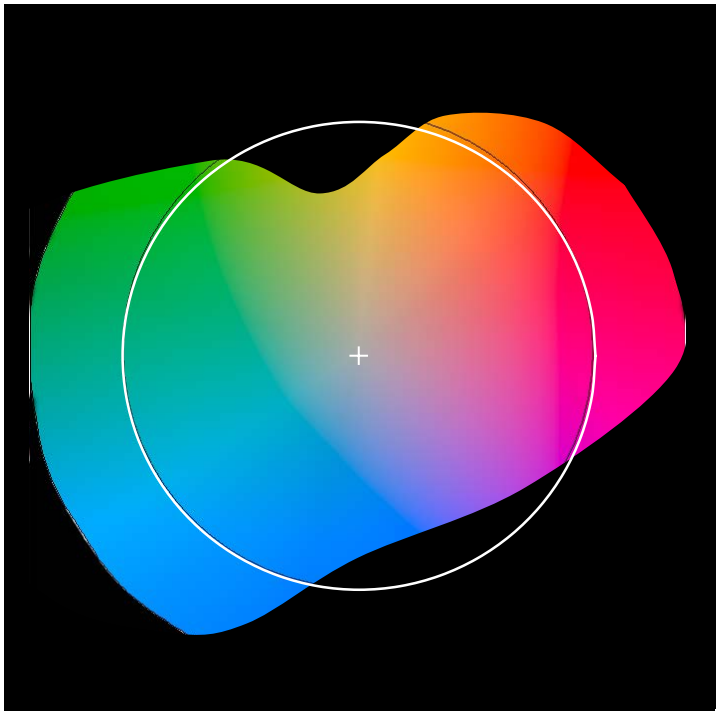
Visual Evaluation (Concept)



Example from NIST CQS Spreadsheet

Color Saturation Icon (Concept)





Discussion

- What is “good enough” for a color rendering metric?
- Should color metrics try to capture preference?
- Does color preference vary from person to person?
- What about different applications?
- Is CRI inaccurate?
- What is more important, fidelity or preference?
- What is more important, numerical fidelity or perceived fidelity?
- Is there a color metric that can tell my how _____ will look?
- Do LEDs have better color quality than CFLs?
- What thresholds should be set for color quality?
- Should color rendition metrics consider energy efficiency?
- Are there tradeoffs between energy efficiency and color rendering?