This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 619249

Towards a new colour rendition metric

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LED obstacles: early lessons learned

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_lessons-learned_2014.pdf

- 12 lessons learned
- Lesson 4: The range of color quality available with LED-based products and the **limitations of existing color metrics** may confuse users

Agenda

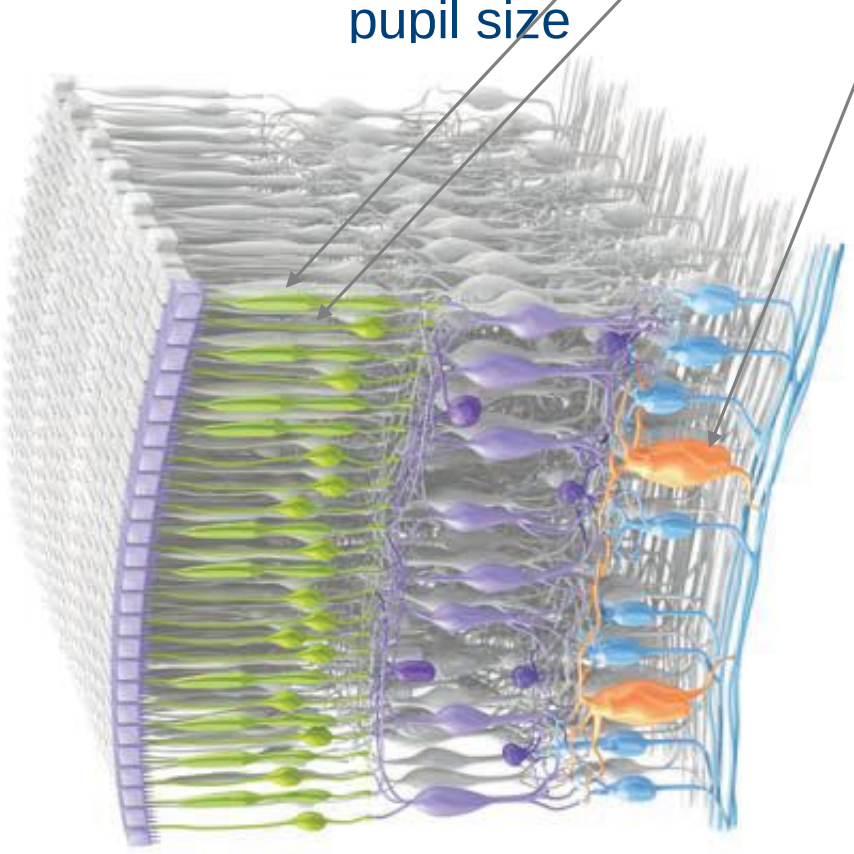
- What is colour?
- What is colour rendition?
- The current metric + limitations
- The new metric

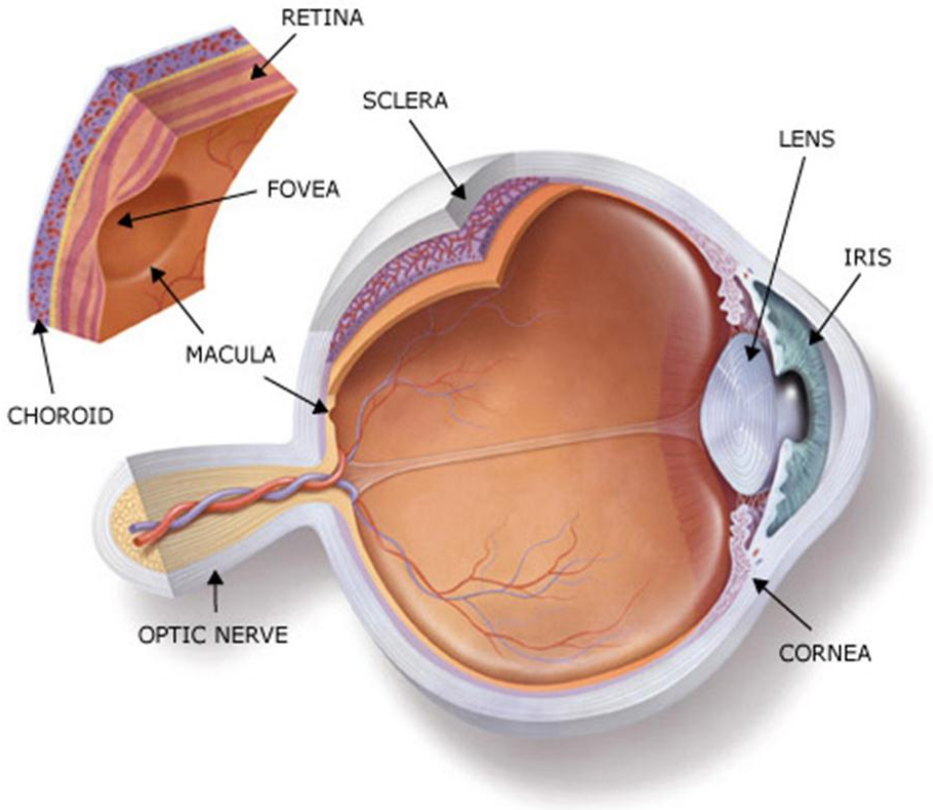
5 different light receptors

3 types of cones for colour

Rods for low light levels and movement

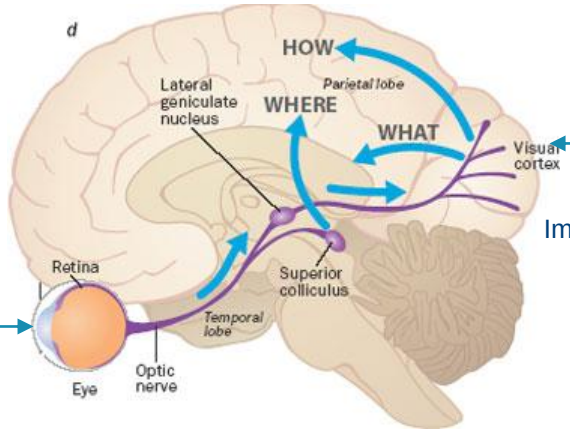
Photosensitive ganglion cell (ipRGC): day/night synchronisation, pupil size





Images: Huffman, Psychology in Action
Bryan Christie for Scientific American

Perception

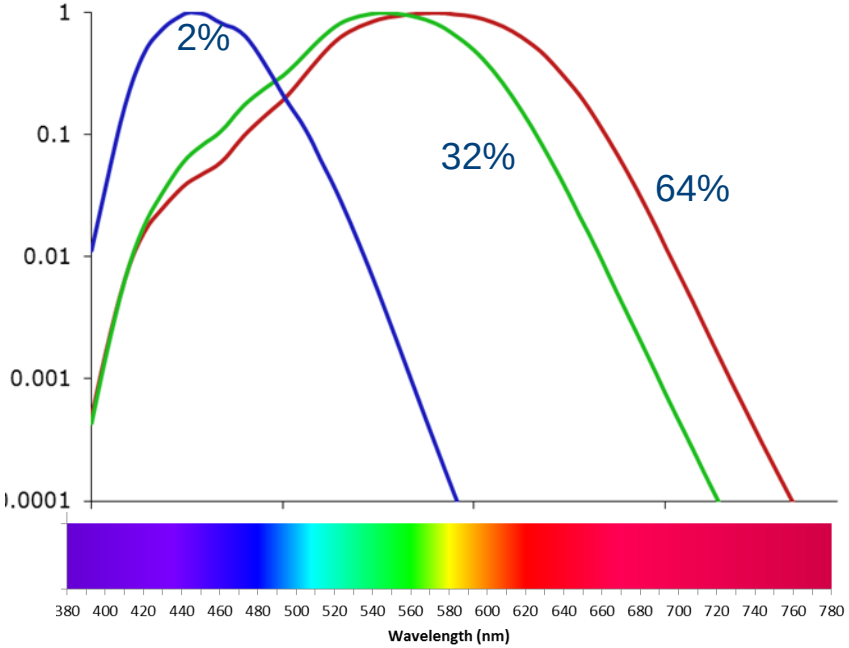


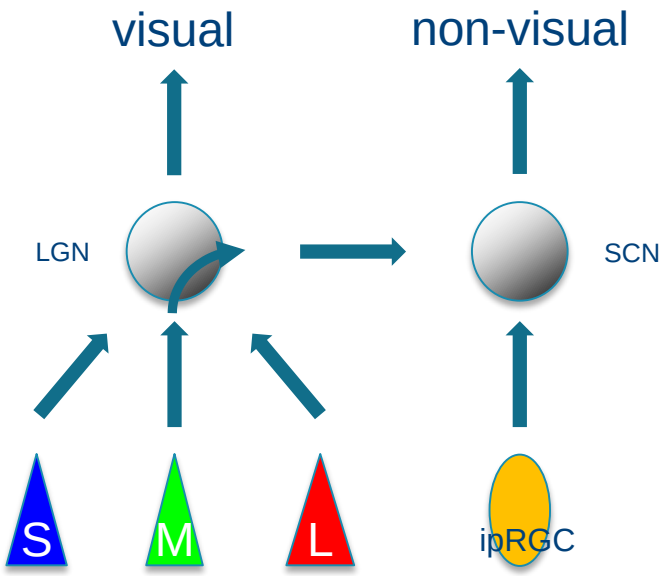
Colour

Spectra

Image: Scientific American Mind

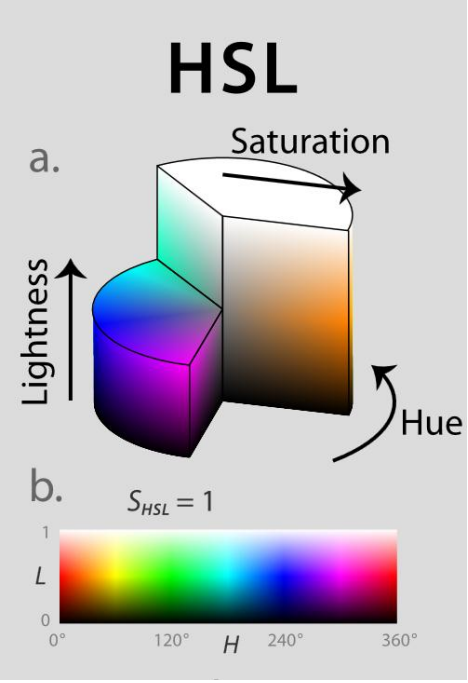
Cone sensitivity





Colour representation: 3 coordinates

- RGB
- XYZ
- xyY
- Lu'v'
- La*b*
- HSL
- HSV
- HCL

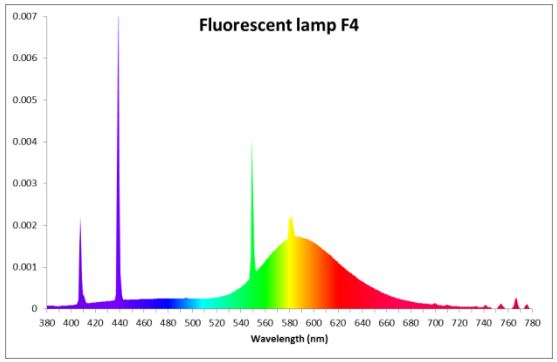


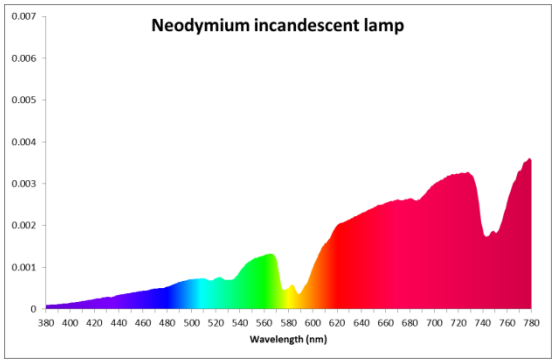
By Jacob Rus - Own work, CC BY-SA 3.0
https://commons.wikimedia.org/w/index.php?curid=9445469

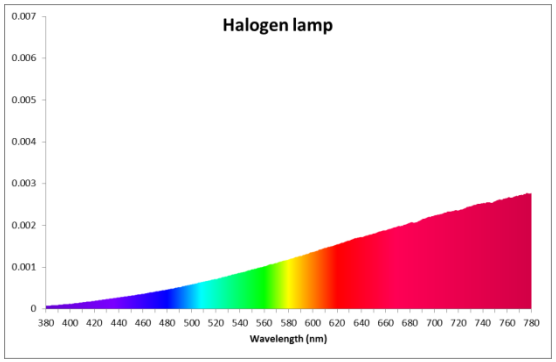
Spectra

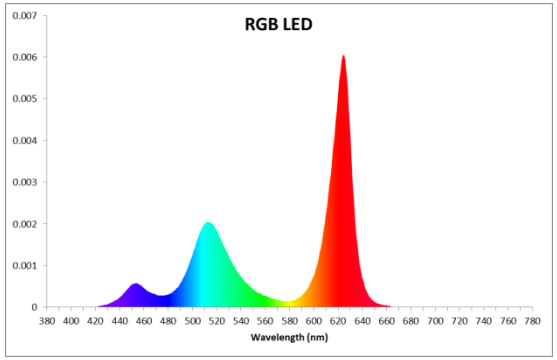
Different spectra with same tri-stimulus values =

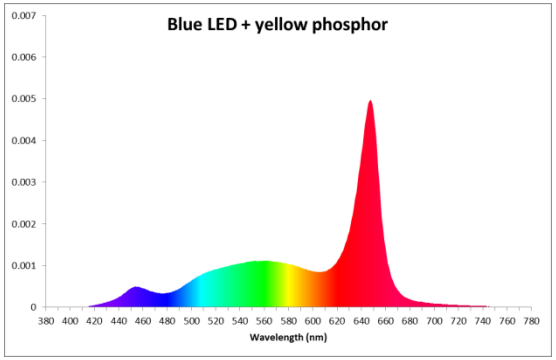
Same colour

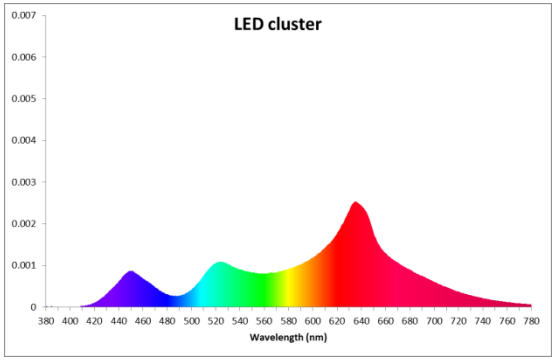






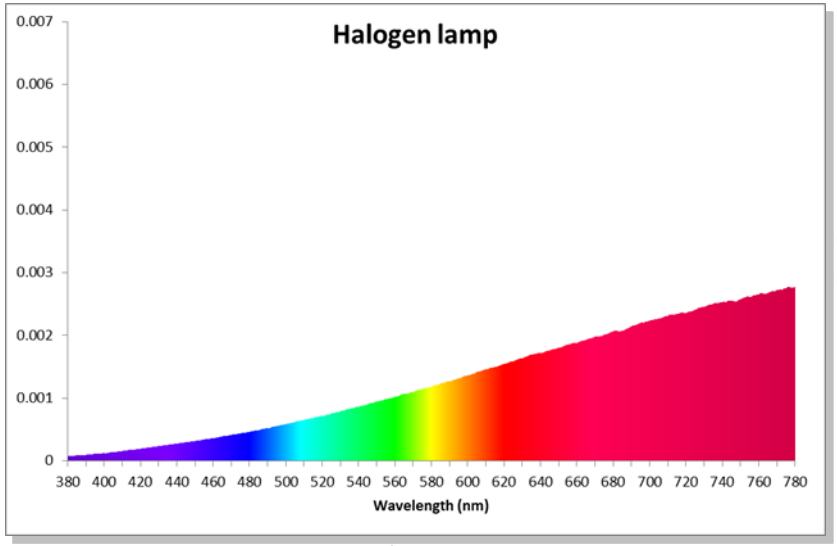


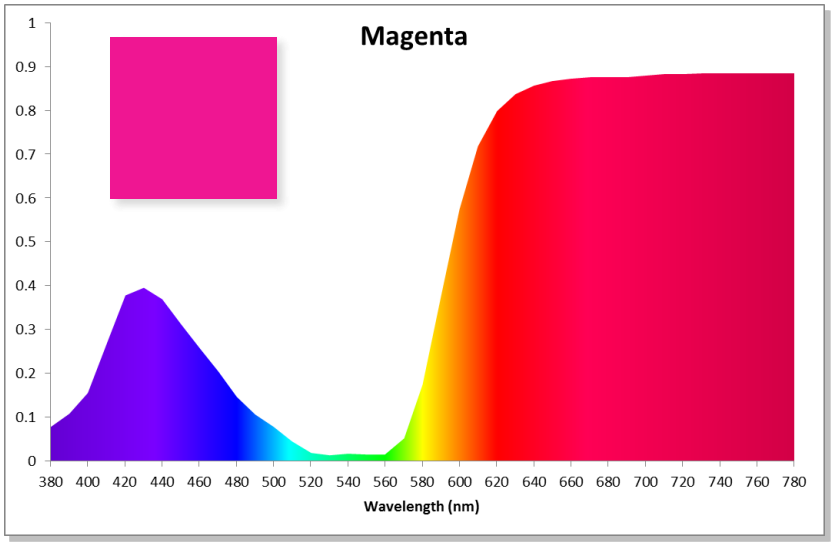




Object colour

Different illumination spectra give different reflected spectra. Although white can be the same for the different spectra, another object colour (e.g. magenta, orange-yellow) can be different.



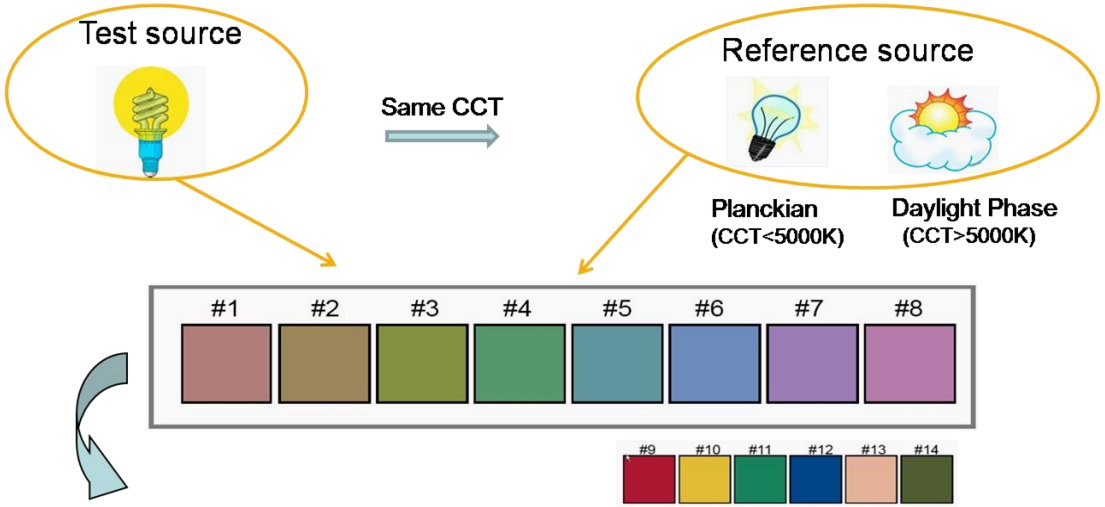


	x	y
Fluorescent lamp F4	0.540	0.295
Neodymium incandescent lamp	0.617	0.287
Halogen lamp	0.611	0.307
RGB LED	0.682	0.318
Blue LED + yellow phosphor	0.621	0.297
LED cluster	0.585	0.281

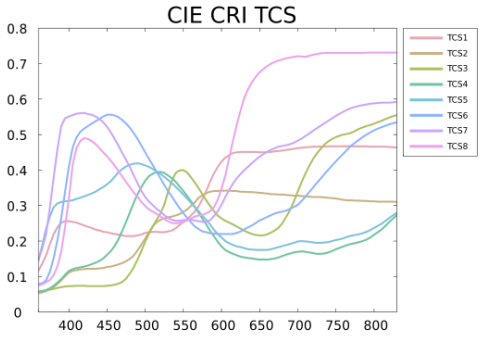
CIE colour rendering

"Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant."

Index:



$$R_a = 100 - 4.6 * \overline{\Delta E_{1-8}}$$



CIE colour rendering index

CIE CRI:

R_a : measure of **average** colour fidelity/colour shift

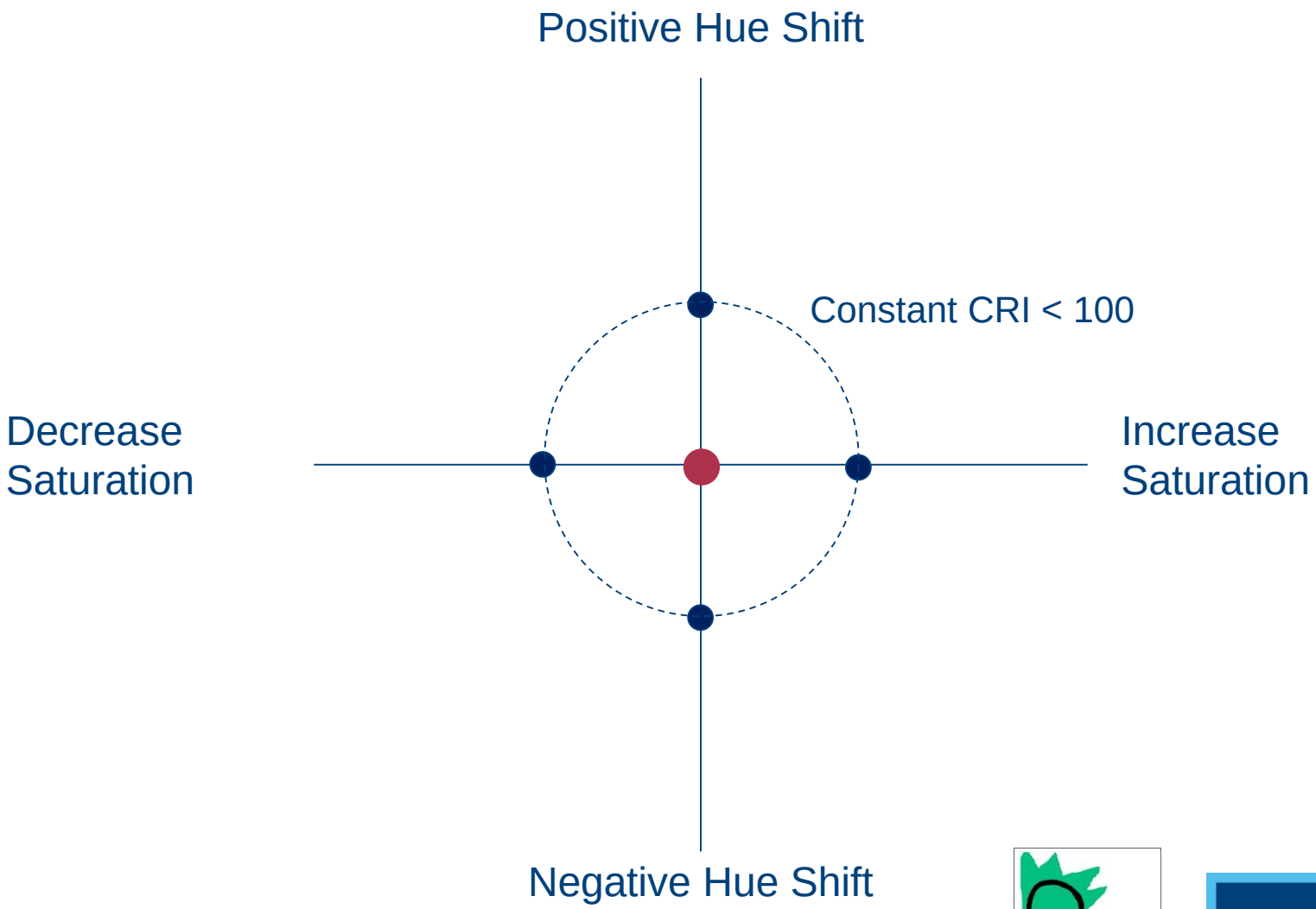
R_i : colour fidelity/colour shift for specific hue region

(disregarding limitations of samples and colour science)

But what about:

- Direction/type of colour shifts
- Information on human preference, naturalness, discrimination, …
- Difference in colour for any specific object
- How one source will make things look compared to another

Limitations of considering only fidelity



CRI = 95, Original Image

Slide: Kevin Houser

Original Image courtesy of Randy Burkett Lighting Design

CRI = 80, Desaturated Image

Slide: Kevin Houser

Original Image courtesy of Randy Burkett Lighting Design

CRI = 80, Saturated Image (Red Enhanced)

Slide: Kevin Houser

Original Image courtesy of Randy Burkett Lighting Design

Issues of CIE colour rendering index

- Test samples
  - Non saturated
  - Non independent samples (limited amount of dyes)
- Von Kries transformation is outdated
- Colour space used is not a colour appearance space
- Infinite number of reference sources:
  - R_a for unequal CCTs cannot be compared!
- Two types of reference source with discontinuity at 5000 K
  - e.g. Planck distribution: at 4999 K: $R_a = 100$ | at 5001 K: $R_a = 89$
- Risk of poor correlation with visual colour quality assessment of narrowband sources, such as LEDs !

CCT = (correlated) colour temperature

Motivation for a new rendition method

- The need for an improved measure of colour fidelity

  Use up-to-date colour science.

  Use improved sample set including saturated colours.

- The need to provide supplementary information about colour rendering ability of any given light source.

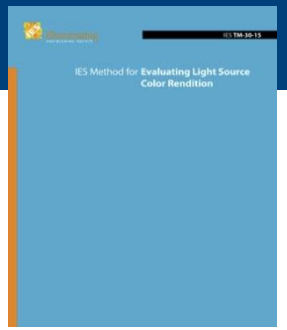
  One index is not enough.

  Add a colour gamut index.

  Add a colour vector / distortion diagram.

$\Rightarrow$ IES TM-30-15

IES Method for colour rendition

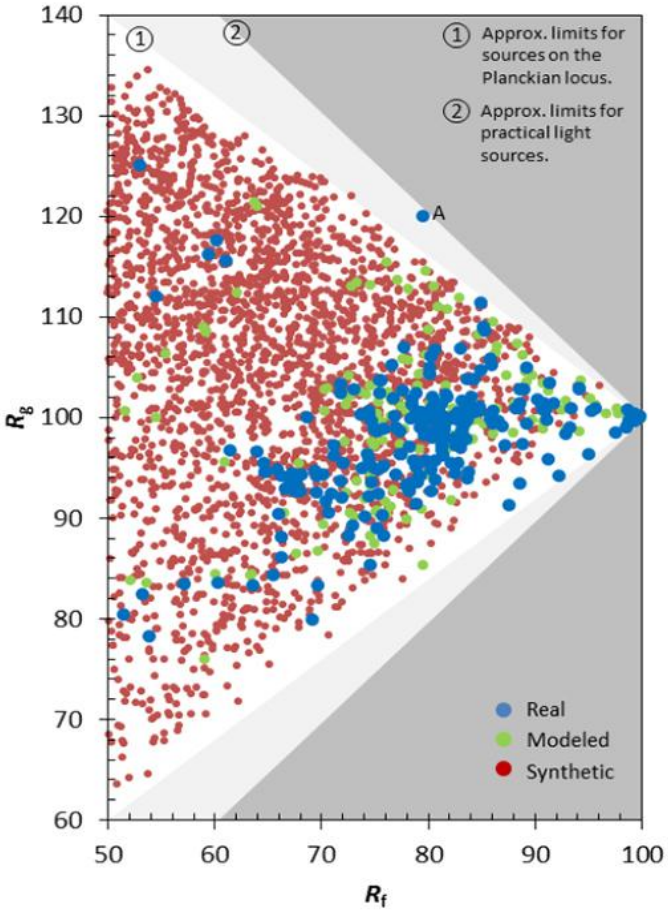


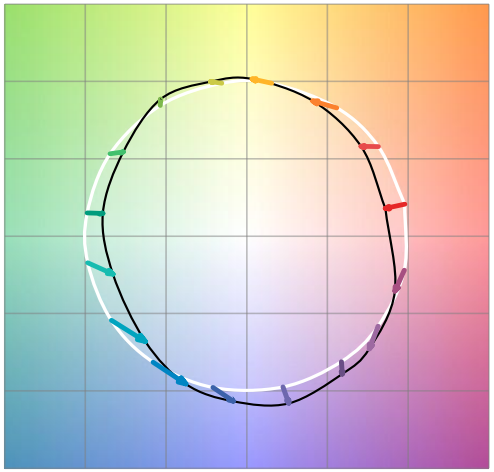
Contributors:

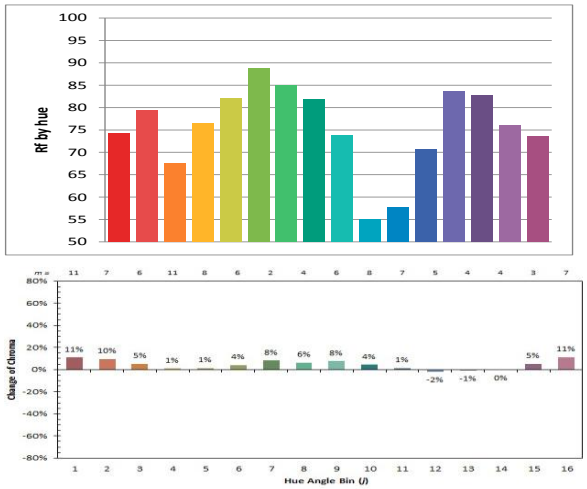
Academia (K. Houser, Y. Ohno, M. Royer, K. Smet, M. Wei, L. Whitehead),
Industry (A. David, P. Fini), Lighting Design (R. Burkett)

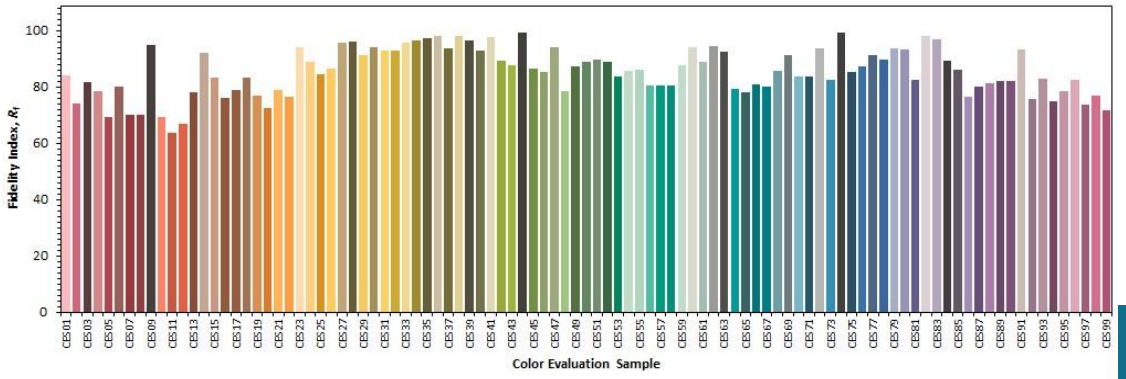
Colour fidelity index R_f

Colour gamut index R_g + lots of graphical info









IES TM-30 indices

R_f fidelity index

- Average similarity in appearance of test and reference sources
- Analogous to CIE *R*a, greater accuracy
- Scores 0 to 100
- Scale similar to CIE R_a, but high scores harder to achieve
- Equal weight to all directions of shift

R_g gamut index

- An R_g value greater than 100 indicates an average increase in saturation
- An R_g value less than 100 indicates an average decrease in saturation

IES TM-30

Colour science update

= replace U*V*W* with state-of-the-art colour space CAM02-UCS

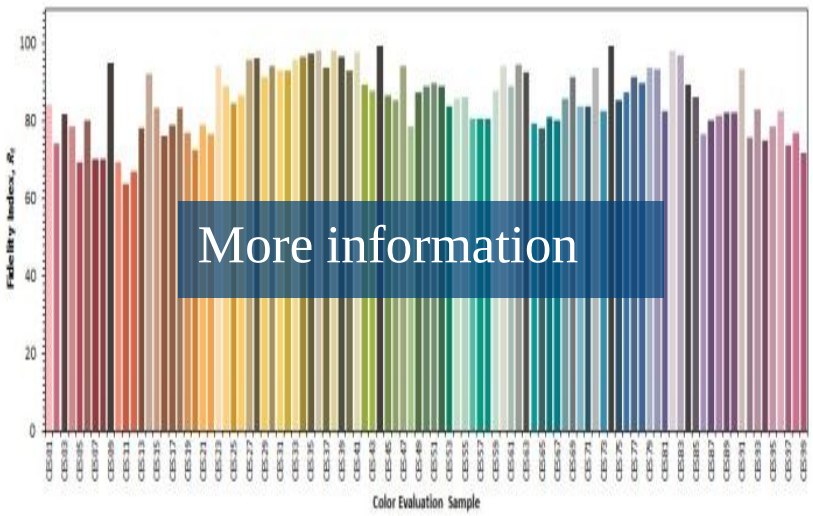
= replace Von Kries transformation with CAT02

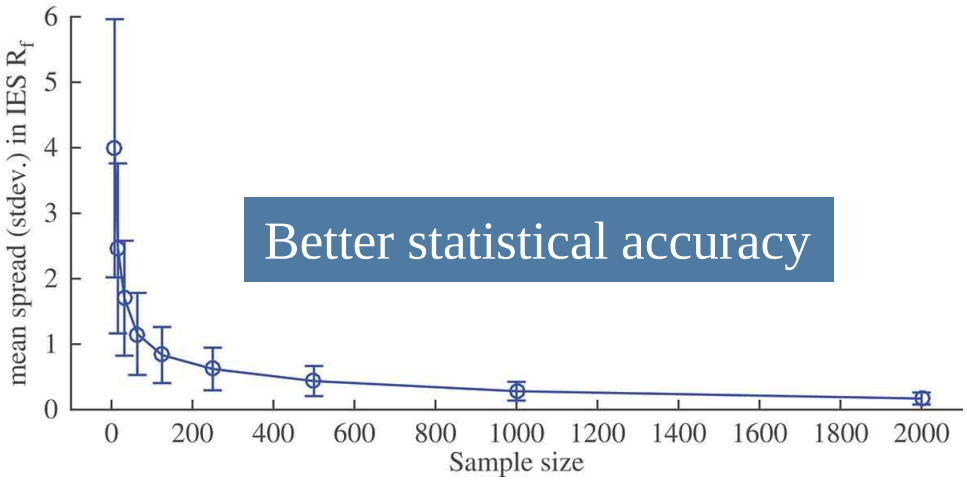
- good perceptual uniformity
- no CCT dependence
- includes a good chromatic adaptation formula
- includes a colour difference formula

Sample set improvement

Larger sample size

from 8 (14) to 99 samples





Kevin A. G. Smet, Aurelien David & Lorne Whitehead (2016) Why Color Space Uniformity and Sample Set Spectral Uniformity Are Essential for Color Rendering Measures, LEUKOS, 12:1-2, 39-50, DOI: 10.1080/15502724.2015.1091356

Sample set improvement

Uniform 3D distribution in color space

Start from ***105 000*** reflectance samples

Natural objects, Paints, Plastics, Fabrics,

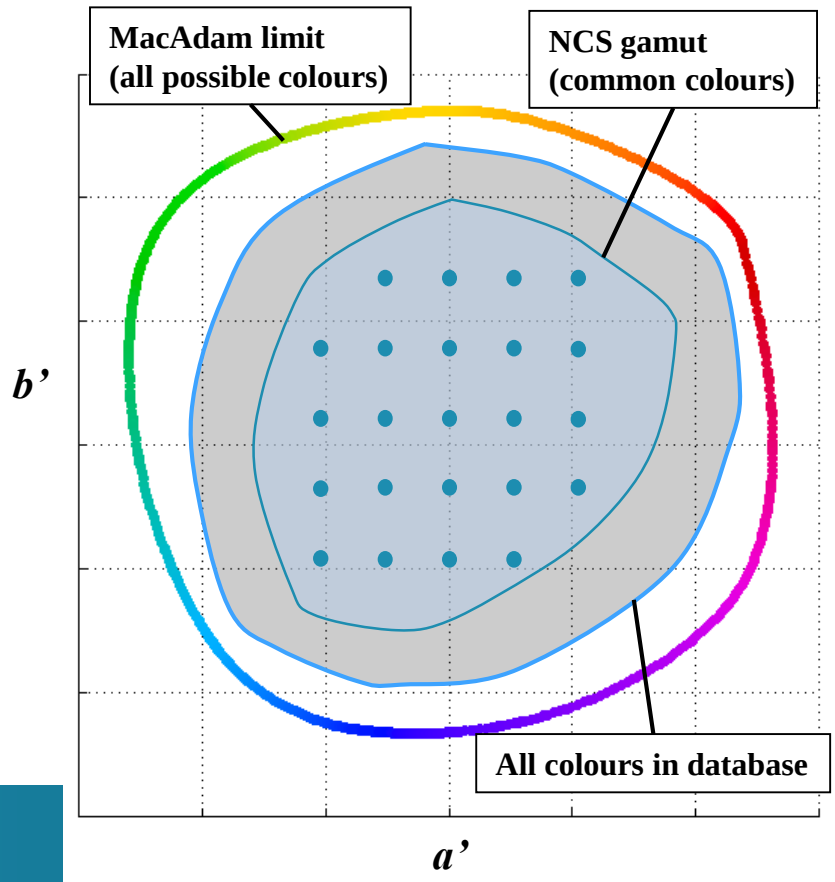
Printed materials, Skin tones…

Discard some colours:

- Extremely saturated or dark
- No colour-error formula

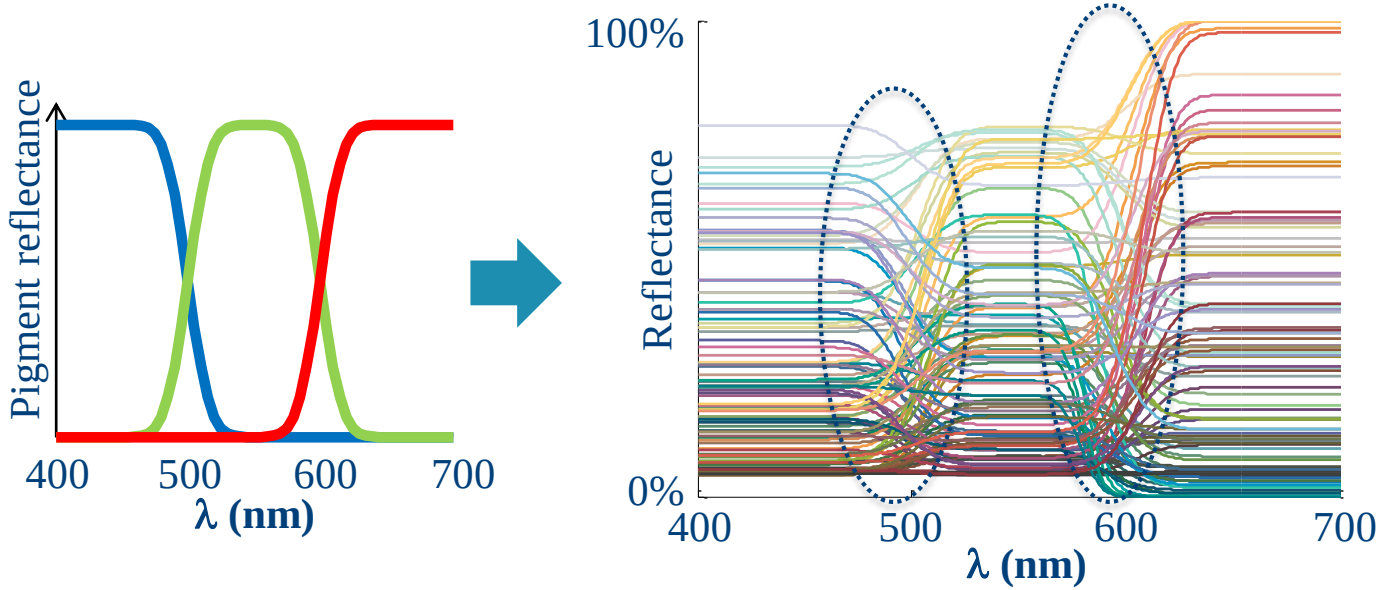
Uniformly distributed selection

4880 colour points



Wavelength uniformity

Make sure that samples treat all wavelengths equally.
Why? It is possible to generate many colours with only 3 “pigments”:

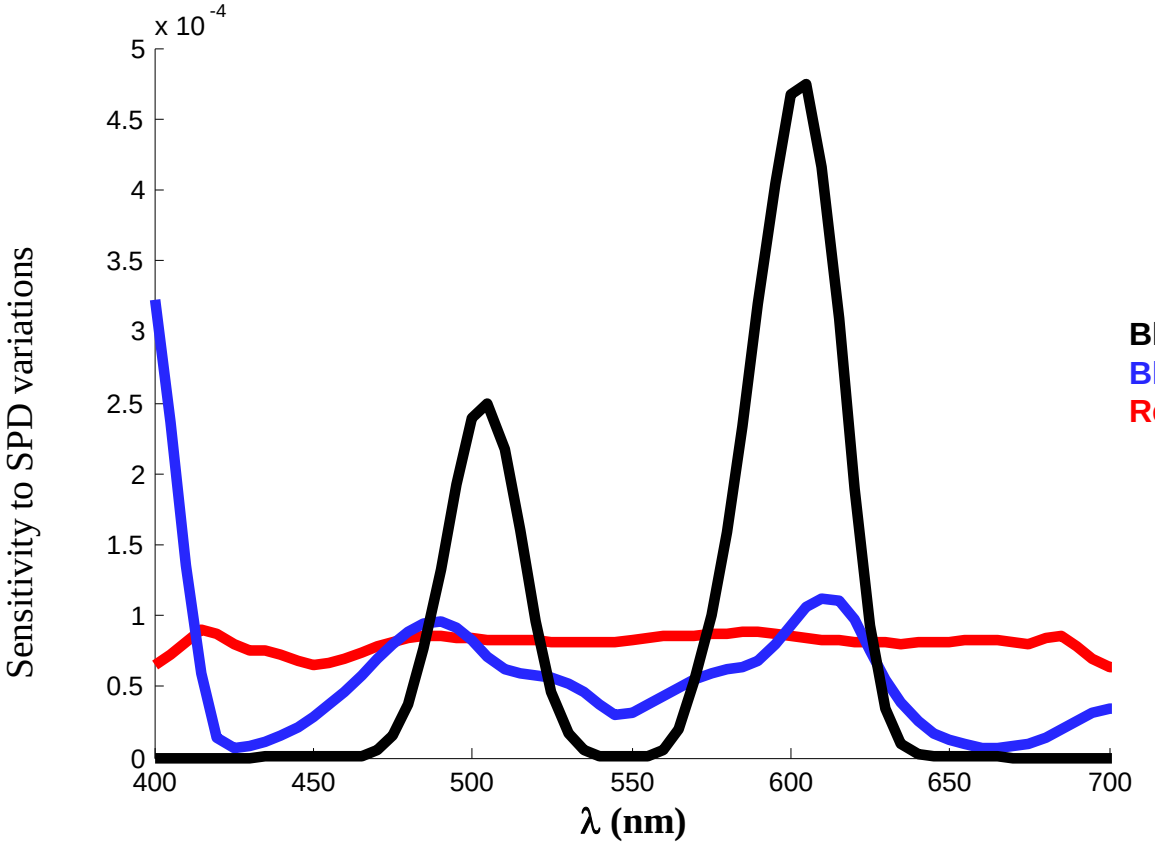


But the corresponding samples are mostly sensitive to a few wavelengths for differences in colour rendition

dx.doi.org/10.1080/15502724.2015.1091356

Wavelength uniformity

The “wavelength sensitivity” for a sample set (r’^{2}, r”^{2}…)

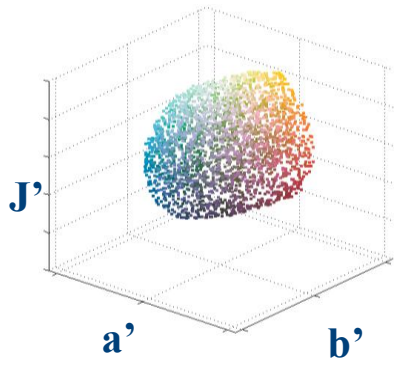


Black = 3-pigment set
Blue= TCS 1-8
Red = 4880 reference set

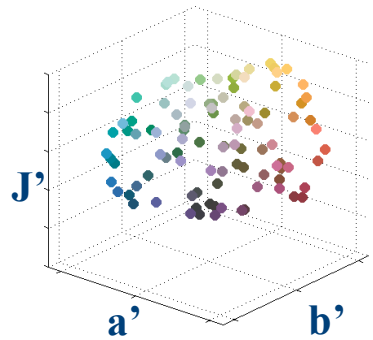
dx.doi.org/10.1080/15502724.2015.1091356

99 test samples

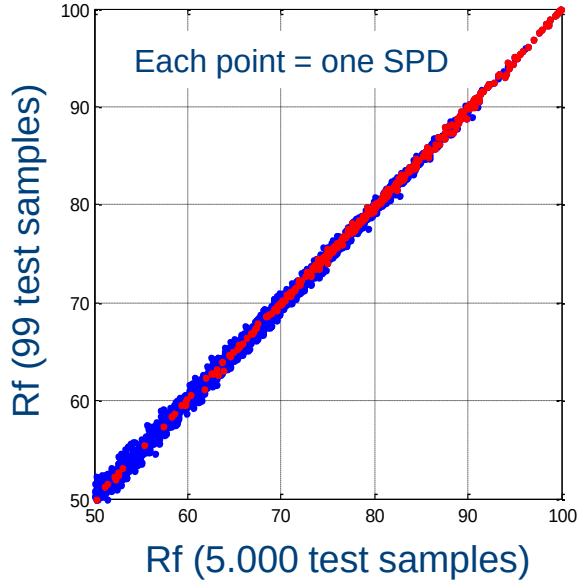
4880 Reference set

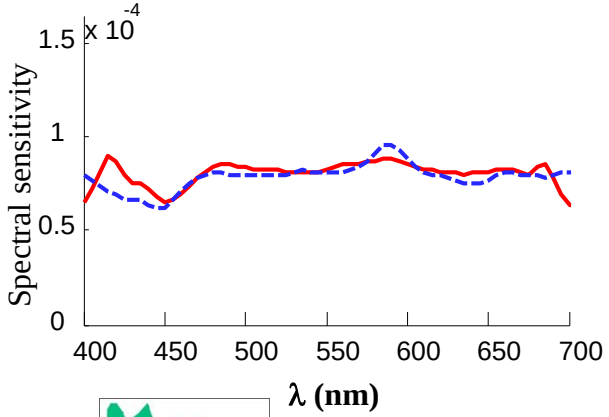


99 Color Evaluation Samples



criteria





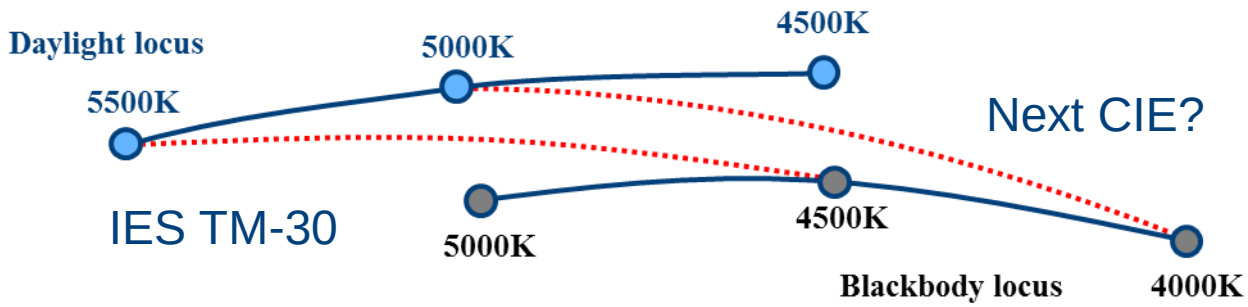
SSL-erate

Groen Licht Vlaanderen

KU LEUVEN

No discontinuity at 5000 K

Gradual change by mixing blackbody and daylight reference illuminants



Theoretical Example

Original

CRI = 95

R_f = 93

R_g = 100

Desaturated

CRI = 80

R_f = 78

R_g = 90

Red-Enhanced

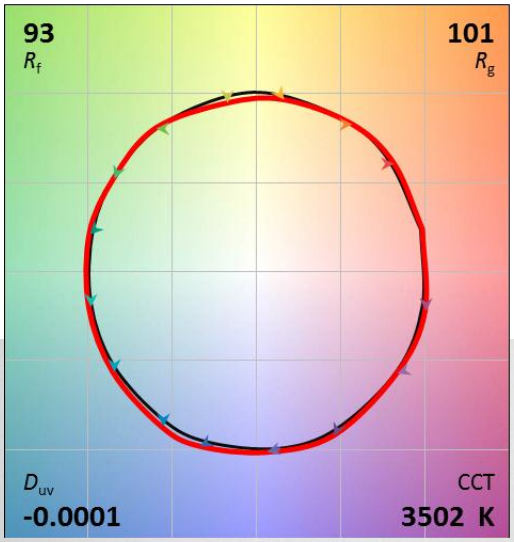
CRI = 80

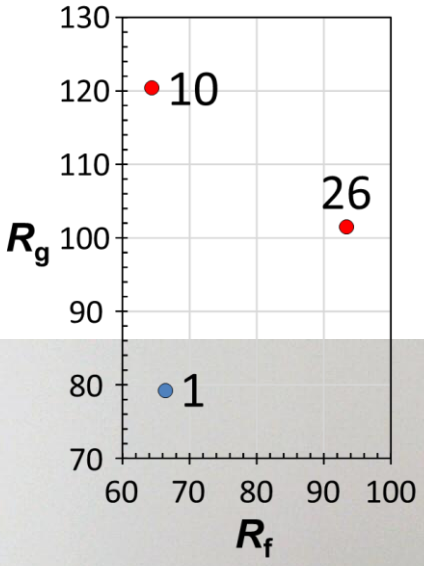
R_f = 78

R_g = 110

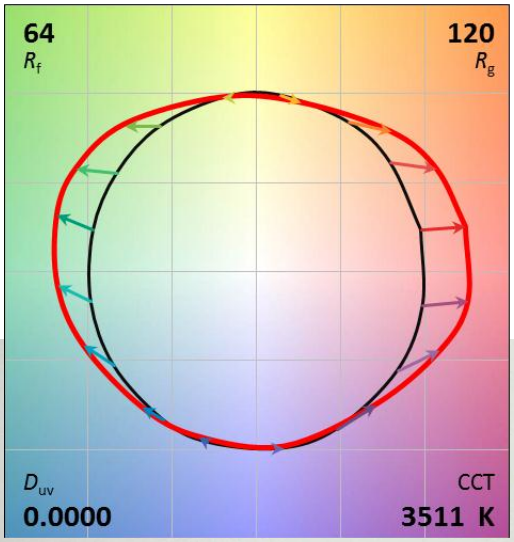
Slide: Kevin Houser

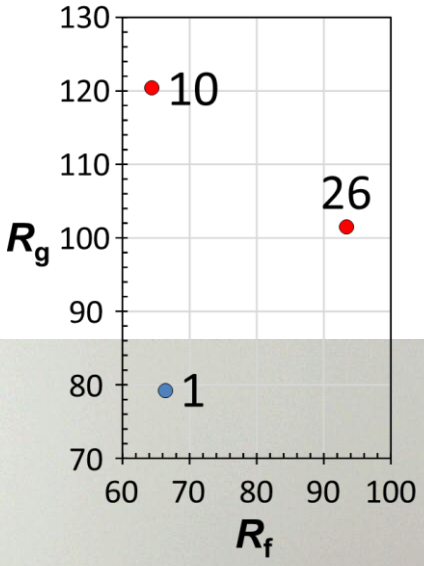
Original Image courtesy of Randy Burkett Lighting Design



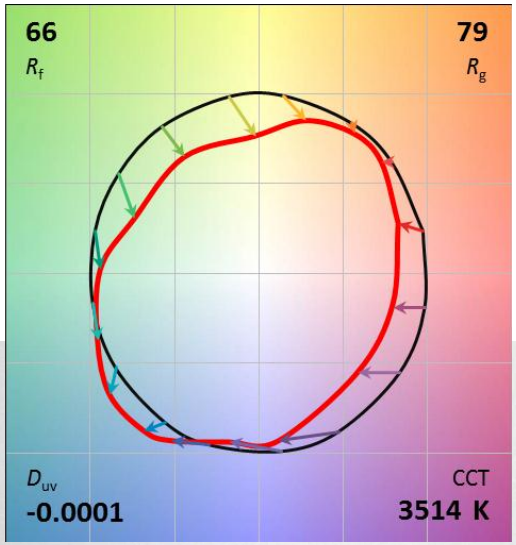


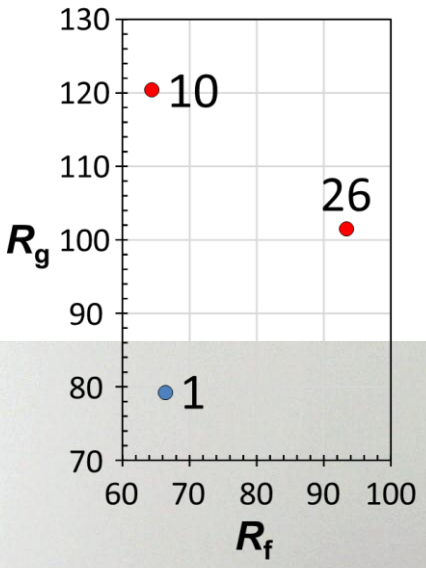
Slide: Kevin Houser





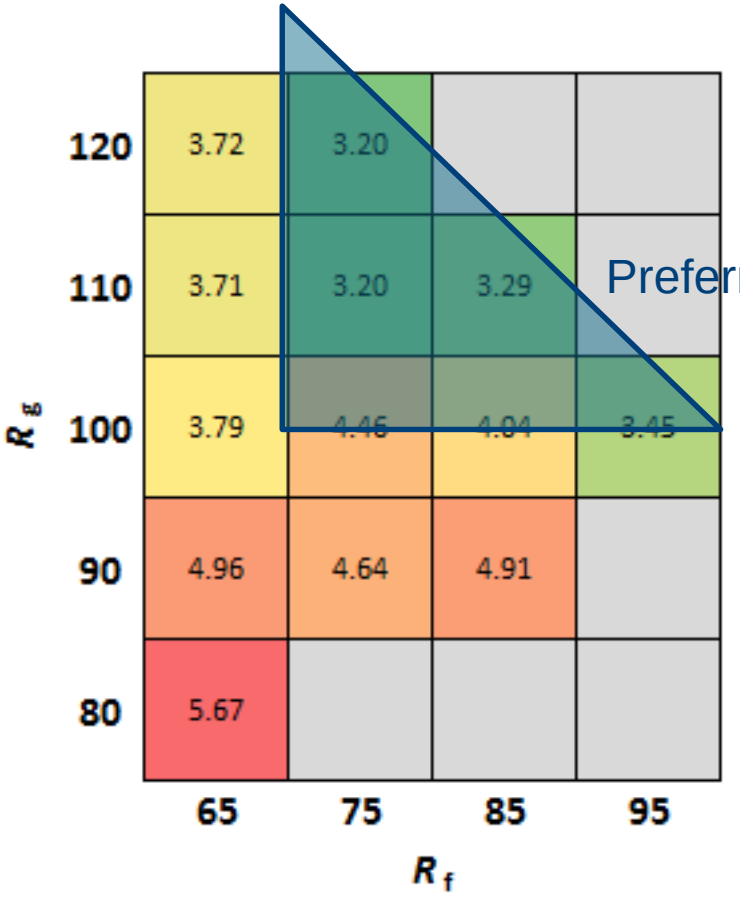
Slide: Kevin Houser





Slide: Kevin Houser

Preference



Preferred zone:
high colour saturation is short-term preferred but long-term?

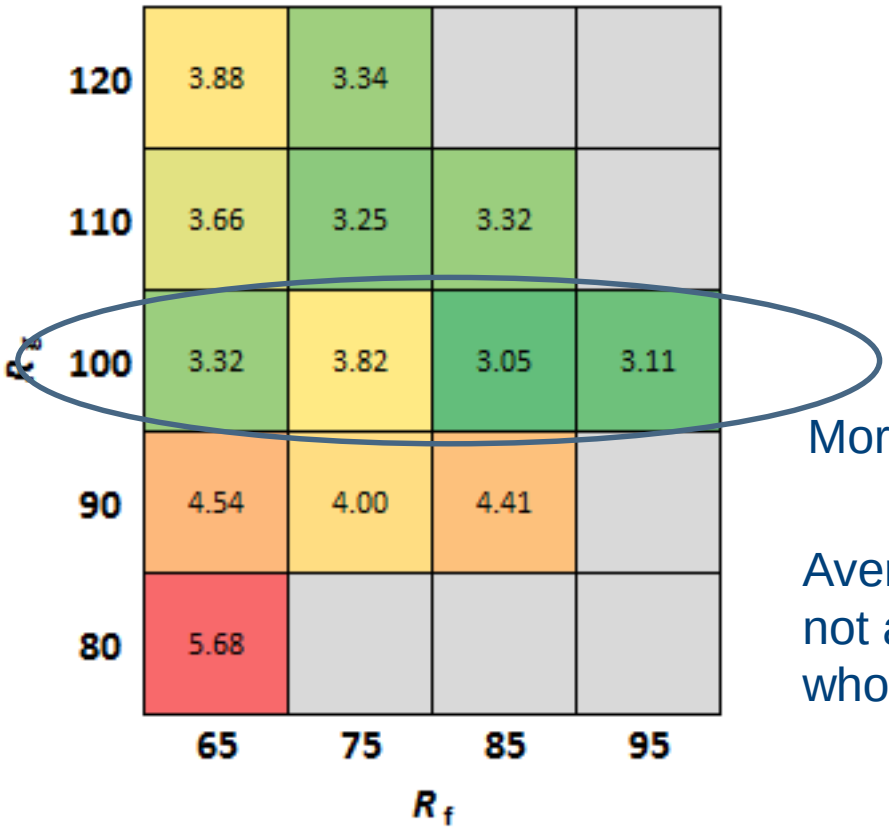
The 2 new indices are better colour rendition indications

More Liked — Less Liked

http://www.personal.psu.edu/kwh101/TM30/PLDC2015__HouserRoyerDavid.pdf

Preference for red saturation?

Red more saturated



More liked

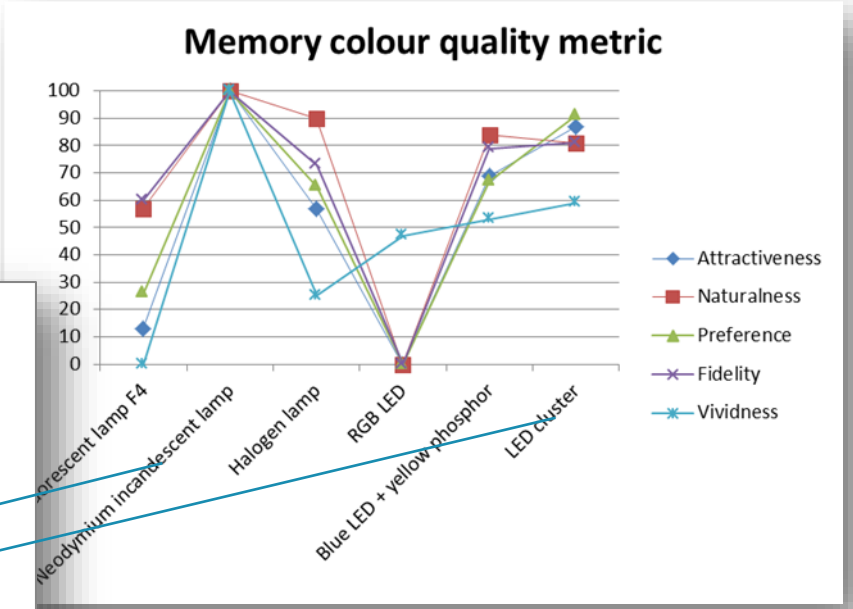
Average indices do not always convey the whole story

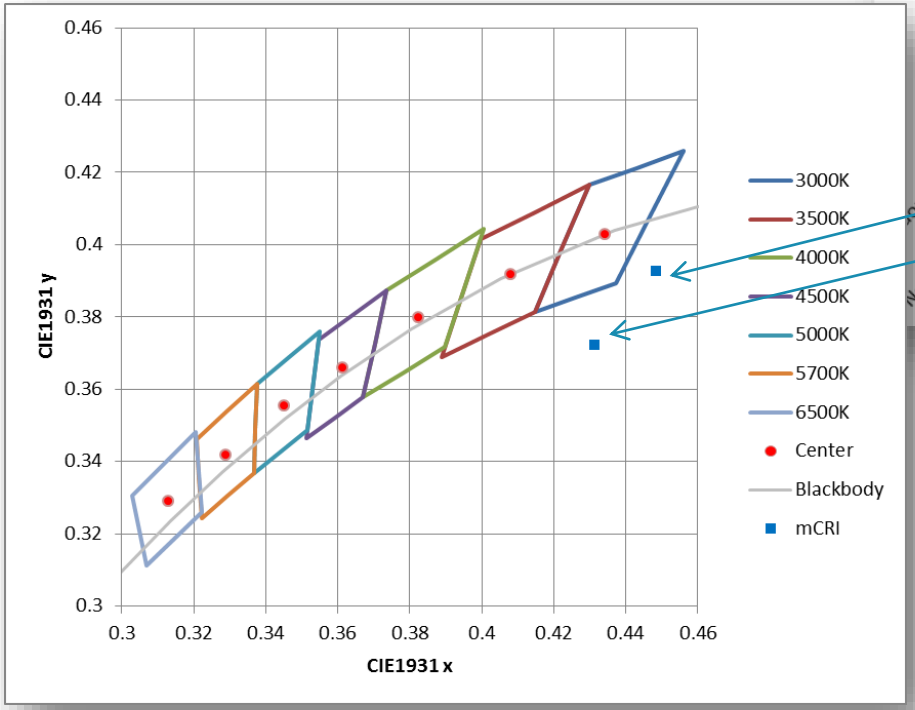
More Liked — Less Liked

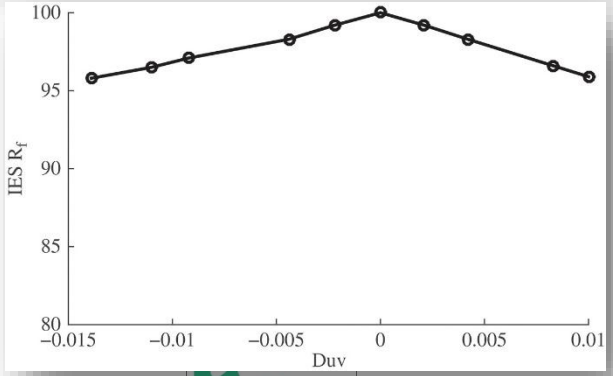
http://www.personal.psu.edu/kwh101/TM30/PLDC2015__HouserRoyerDavid.pdf

Preferred white

Is not on blackbody curve







Some additional resources

http://energy.gov/eere/ssl/tm-30-frequently-asked-questions

Watch the 8:45 minute movie!

Kevin Smet slides:

http://www.lichttechnologie.be/sites/default/files/downloads/KSMET_KU%20Leuven_Is%20the%20new%20CIE%20color%20rendering%20index%20finally%20in%20sight_40m.pdf

Kevin Houser slides:

http://www.personal.psu.edu/kwh101/TM30/PLDC2015__HouserRoyerDavid.pdf

Michael Royer slides:

http://energy.gov/sites/prod/files/2016/04/f30/royer-tm30-color-lightfair2016.pdf