JCTVC-P0229
Quantitative quality evaluation for HDR and WCG

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Perceptual color spaces

Lab spaces

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YUV Euclidian space, a space for video broadcasting

- The color space coding experts are used to work with
  - from long ago and not built to be perceptual
  - the true name is Y'CbCr
  - Y for luminance
  - U,V (or CbCr) for chrominance
  - it is not linear (that's why there is ')
    - γ=2.2 or 2.4 (to make it simple)
  - derived from a RGB color space
    - YUV is a <u>relative</u> color space
    - primaries provided by sRGB, BT709, etc.

- Wrongly used as an Euclidian perceptual space
  - for coding, the color error as the sum of the three components errors $\varepsilon^2 = \Delta Y^2 + \alpha.\Delta U^2 + \alpha.\Delta V^2$
  - it is not perceptual as it is said that one is more sensitive to luma than chroma
  - trick by using weighted PSNR (6/8,1/8,1/8 for instance); chroma QP offset; etc.

Perceptual color spaces

- They are the given of
  - a 3D space
    - usually one luminance component + two chrominance components
  - a metric
    - the distance between two points is proportional to the perceived difference
    - for any two points!

- Just Noticeable Difference
  - This is the maximum distance such that no color difference is perceived
  - as a consequence of the definition, this JND threshold exists and is the same for any two points, i.e. this threshold is uniform
  - McAdam ellipses are spheres with a constant radius throughout the space <u>with the perceptual metrics (no necessarily Euclidian)</u>
    - ellipses = perceptual iso-contour relative to a given color point

Commonly used Lab spaces (1/3)

- the 3D Lab space
  - one luminance component L
  - two chrominance components a and b
    - saturation C is the radius in the (a,b) plane; hue h is the angle in the (a,b) plane

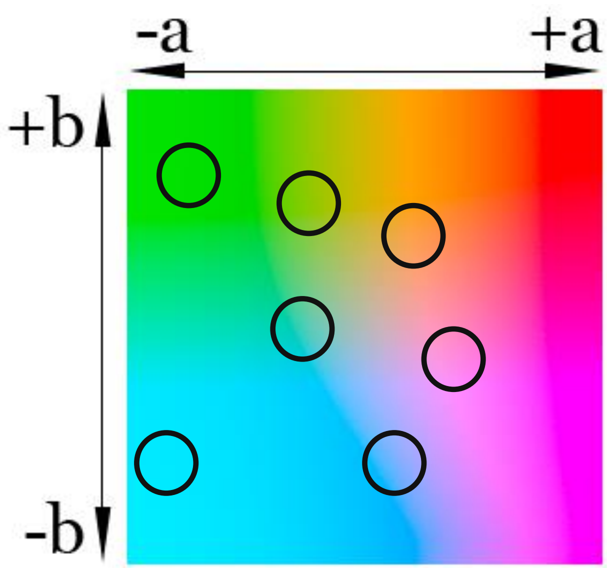
$$L^* = 116 f\left(Y/Y_n\right) - 16$$

$$a^* = 500\left[f\left(X/X_n\right) - f\left(Y/Y_n\right)\right]$$

$$b^* = 200\left[f\left(Y/Y_n\right) - f\left(Z/Z_n\right)\right]$$

(X_n, Y_n, Z_n) are the environmental parameters
=> scene illuminant

- different metrics lead to different Lab spaces
  - Lab 76
    - Euclidian metric $\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$



Perceptual spaces with the Euclidian distance are called UNIFORM

Coding experts like uniform spaces because the three components do not influence on each other. The codecs can encode components independently without risk. Moreover, the Parseval theorem insures that the Euclidian control in the transformed domain and in the pixel domain are equivalent.

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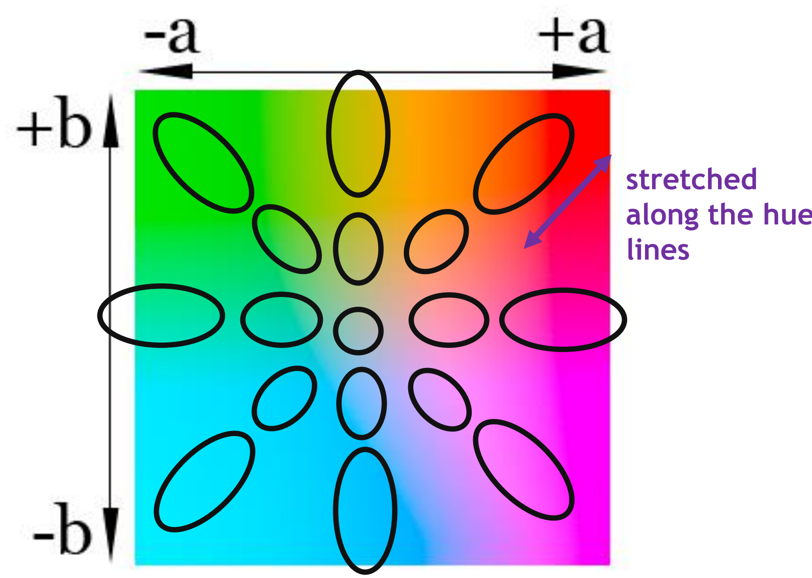
Commonly used Lab spaces (2/3)

- **different metrics lead to different Lab spaces (continued)**
  - **Lab 94**
    - (1) saturation correction for hue and saturation

$$\Delta E^*_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2}$$

1 1

less sensitive at high saturation



  - **Lab 2000**
    - (1) neutral color correction
    - (2) luminance correction
    - (3) saturation correction for hue and saturation
    - (4) correction for the blue region

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

1

2 3 3 4

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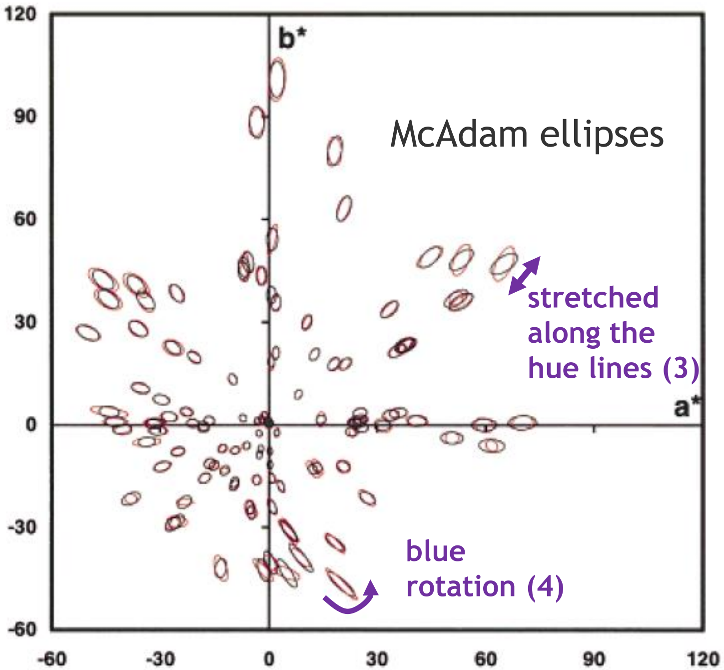
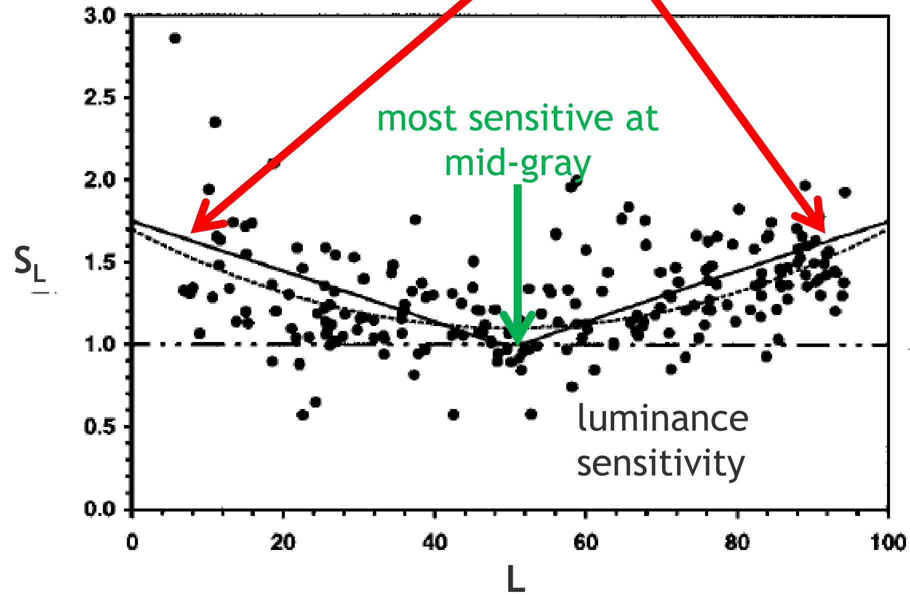
Commonly used Lab spaces (3/3)

- **different metrics lead to different Lab spaces (continued)**
  - **Lab 2000 (continued)**



hue/saturation correction (3) + (4)
- red : measured
- black : model Lab 2000



luminance correction (2)
- dot : measured
- line : model Lab 2000

figures from *The Development of the CIE 2000 Colour-Difference Formula: CIEDE2000*, M. R. Luo, G. Cui, B. Rigg, Color research and application

HDR oriented perceptual color spaces

Why classical spaces fail

Lab spaces not compliant with HDR

- **Lab spaces historically built for LDR**
  - not valid on a wide range of luminance
  - NB: Wide Color Gamut (=high saturation) is only partially covered by Lab spaces
  - no HDR devices at that time

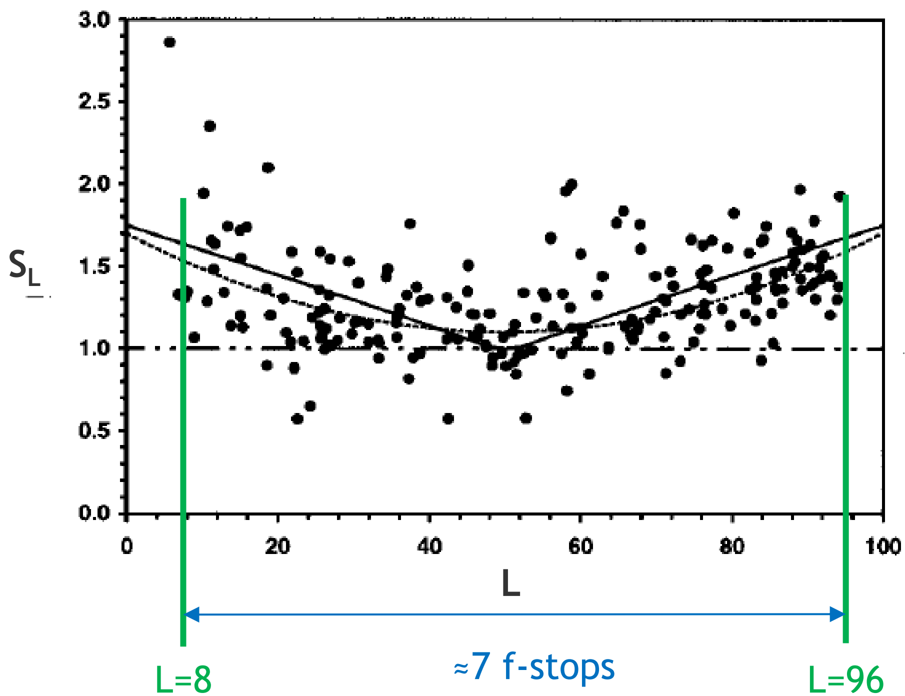


figure from *The Development of the CIE 2000 Colour-Difference Formula: CIEDE2000*, M. R. Luo, G. Cui, B. Rigg, Color research and application

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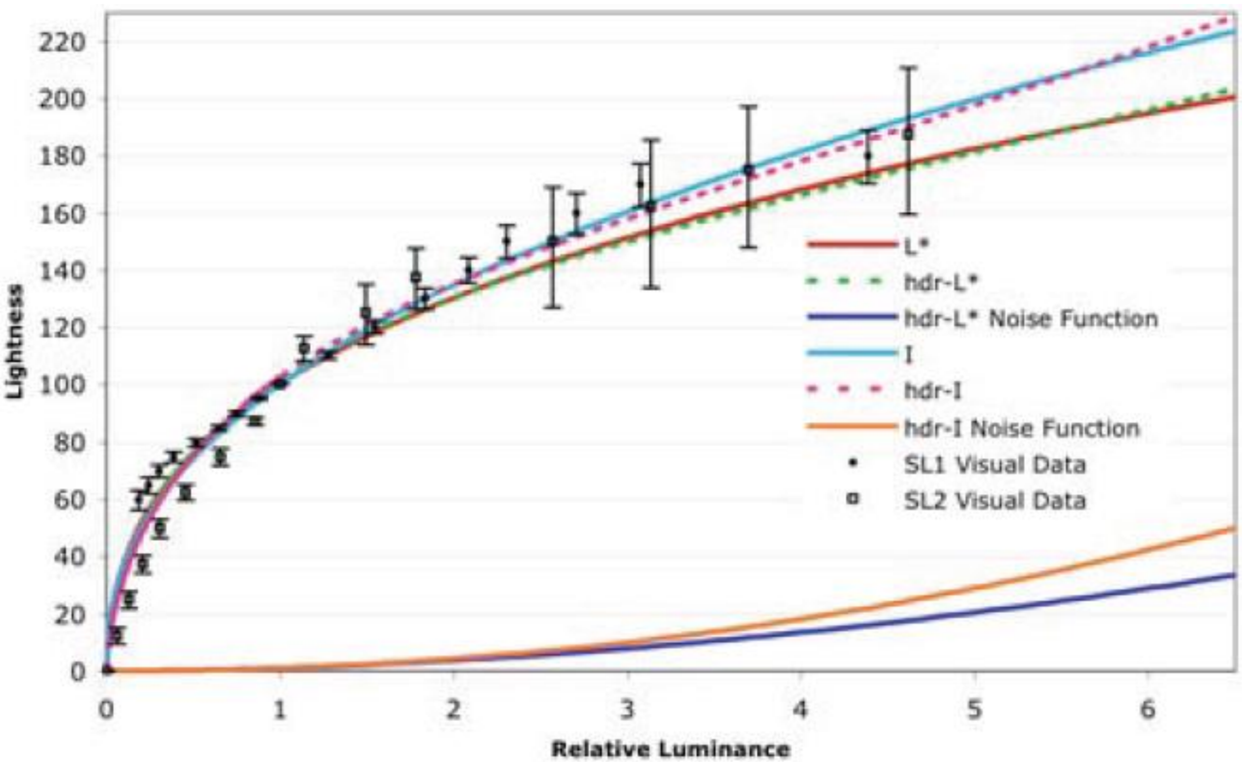
A Lab space for HDR

- **Lab space extended for HDR**
  - larger range of luminosity
  - essentially same hue linearity; adapted for very saturated colors
  - just a change of the f function and keep the metric
  - Is it the ultimate answer?



$$L^* = 116 f\left(Y / Y_n \right) - 16L^*$$

$$f(\omega) = 253 \frac{\omega^{0.61}}{\omega^{0.61} + 2^{0.61}} + \omega^{1.88}$$

Brightness, Lightness, and Specifying Color in High-Dynamic-Range Scenes and Images, Mark D. Fairchild

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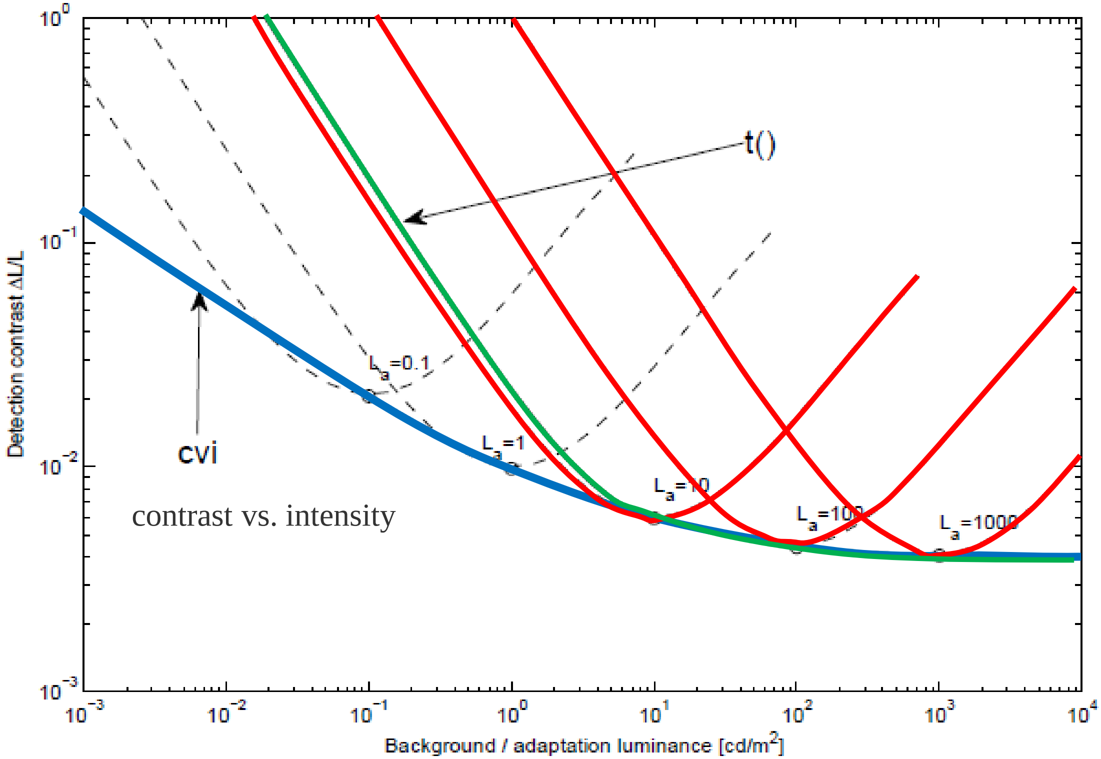
Contrast masking on a wide luminosity range

- **Contrast masking depends on the adaptation!**



Extending Quality Metrics to Full Luminance Range Images, Tunc Ozan Aydın, Rafal Mantiuk, Hans-Peter Seidel

Full adaptation
No adaptation
Partial adaptation

To make our extension spatially independent and possibly compatible with the sRGB non-linearity, we make two simplifying assumptions about the luminance adaptation process. Firstly, we assume that there is a minimum luminance level to which the eye can adapt, L_{a-min}. When viewing complex images, the darkest areas are usually affected by the glare (light scattering in the eye's optics), therefore the minimum luminance level that reaches the retina and to which the eye can adapt is elevated. Secondly, we assume that the eye is perfectly adapted for all luminance levels above L_{a-min}, that is the adapting luminance is equal the luminance of the pixel ($L_a = L$). The second assumption results in the most conservative estimates of the contrast detection thresholds (refer to Figure 4). Our final estimates of the detection thresholds are:

$$t(L) = cvi(L, max(L, L_{a-min})). \qquad (6)$$

Displaying environment

Localization of the environment

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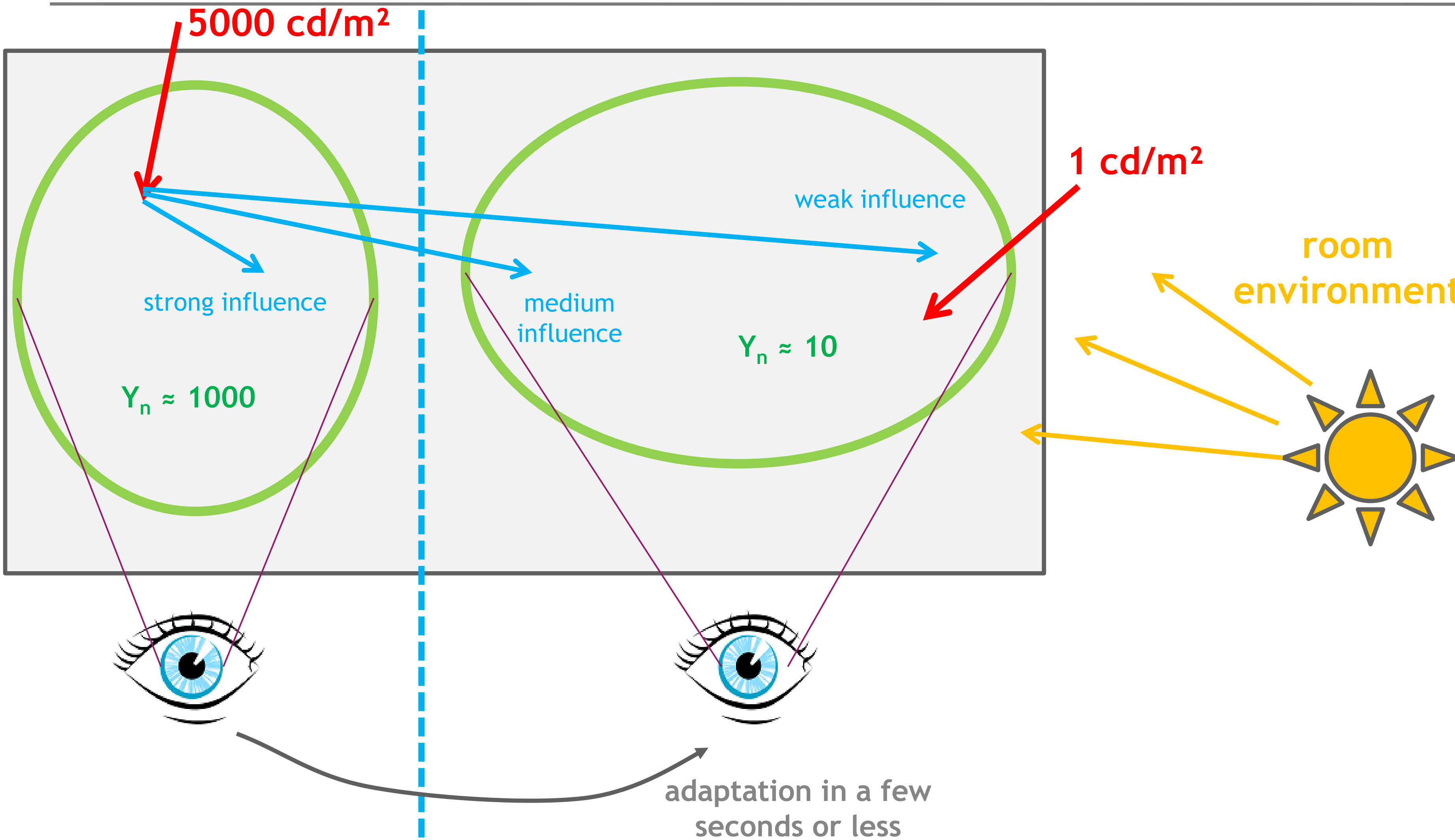
Environment induced by the image itself

- **Does the environment depends on the part of the image we look at?**
  - (we will show you this on a HDR display…)

Several local environments for one image



influence decreases with the distance => zone of influence

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To conclude…

Conclusion

- Not all perceptual spaces exhibit the same perceptual accuracy
- Coding experts like uniform perceptual spaces but none of them is very accurate
- Most of spaces were NOT designed on a wide range of dynamics. They cannot be directly used for HDR evaluation
- Environment variables must be determined as an input to perceptual spaces because perception a relative (not absolute) process
- Room environment plays a role but it is not the end of the story
- The image itself influences the environment of its own perception
- many parameters (environment, image, 3D color space metrics, etc.) influence the perception - using a single pre-assigned transfer function looks risky to guarantee a perceptually uniform (=> adapted to existing codecs) luminance/color representation for HDR images

References

- *A review of RGB color spaces… from xyY to R'G'B'*, Danny Pascale, 2003, The BabelColor campany
- *The Development of the CIE 2000 Colour-Difference Formula: CIEDE2000*, M. R. Luo, G. Cui, B. Rigg, Color research and application
- *The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations*, Gaurav Sharma, Wencheng Wu, Edul N. Dalal, COLOR research and application, Volume 30, Number 1, February 2005
- *Extending Quality Metrics to Full Luminance Range Images*, Tunc Ozan Aydın, Rafal Mantiuk, Hans-Peter Seidel
- *hdr-CIELAB and hdr-IPT: Simple Models for Describing theColor of High-Dynamic-Range and Wide-Color-Gamut Images*, Mark D. Fairchild and David R. Wyble, 2010, Society for Imaging Science and Technology
- *Brightness, Lightness, and Specifying Color in High-Dynamic-Range Scenes and Images*, Mark D. Fairchild and Ping-Hsu Chen, Munsell Color Science Laboratory, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology
- *The LogLuv Encoding for Full Gamut, High Dynamic Range Images*, Gregory Ward Larson Silicon Graphics, Inc.