3rd Chiba-Chulalongkon University Student Workshop, Oct. 17, 2012

Human Color Vision and Colorimetry

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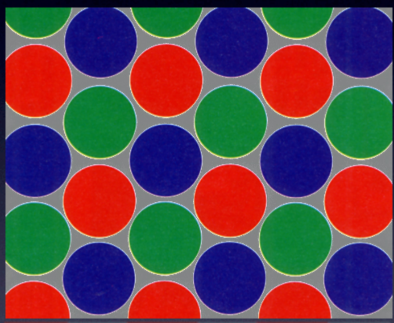
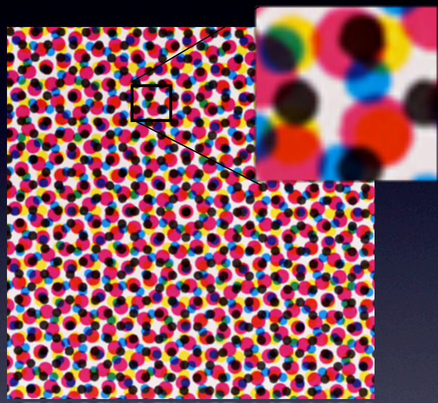
Contents

- Human color vision
- Various color phenomena
- Colorimetry

Color imaging



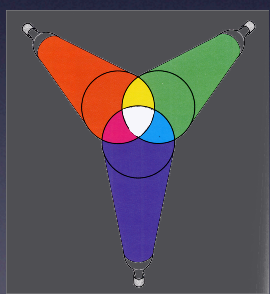
TV (CRT, LCD, etc)
additive color mixture



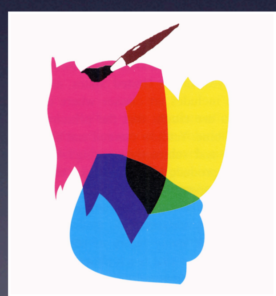
Printing
subtractive color mixture

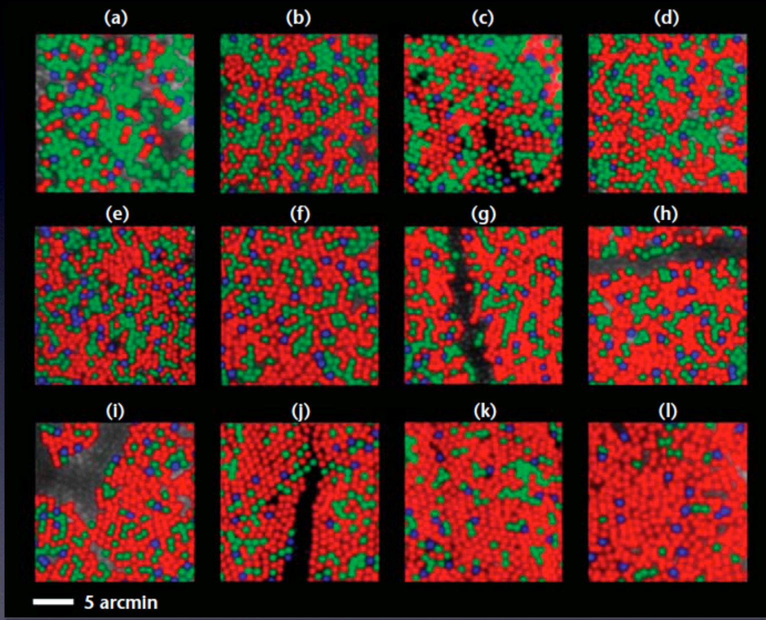
Thomas Young
(1802)
Trichromatic theory

RGB

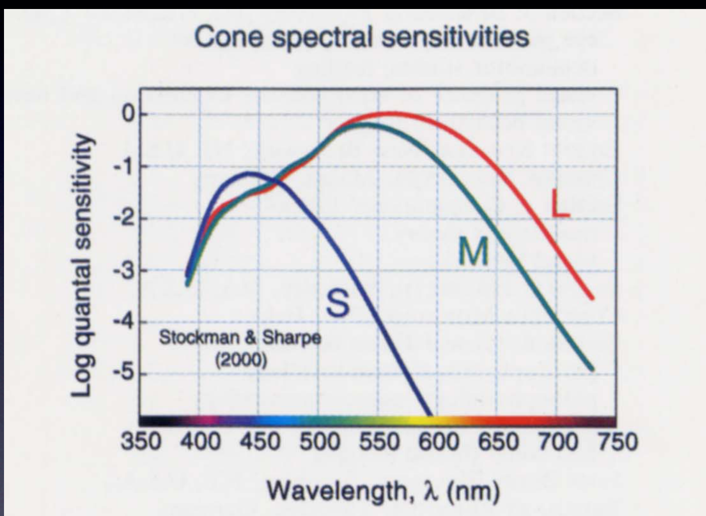


CMY





Joseph Carroll, Daniel C. Gray, Austin Roorda and David R. Williams,
Optics & Photonics News, vol. 16, 36-41 (2005)

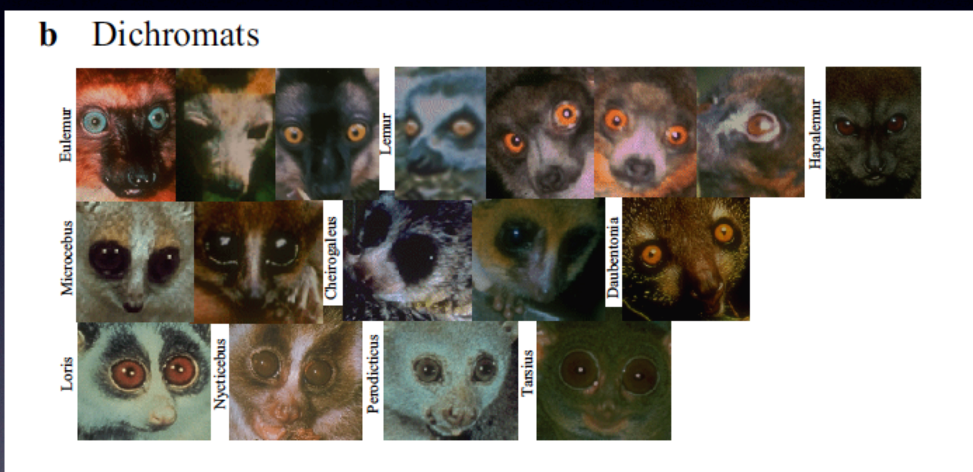


A. Stockman and L.T. Sharp, Vision Research, vol. 40, 1711-1737 (2000)

Why three?

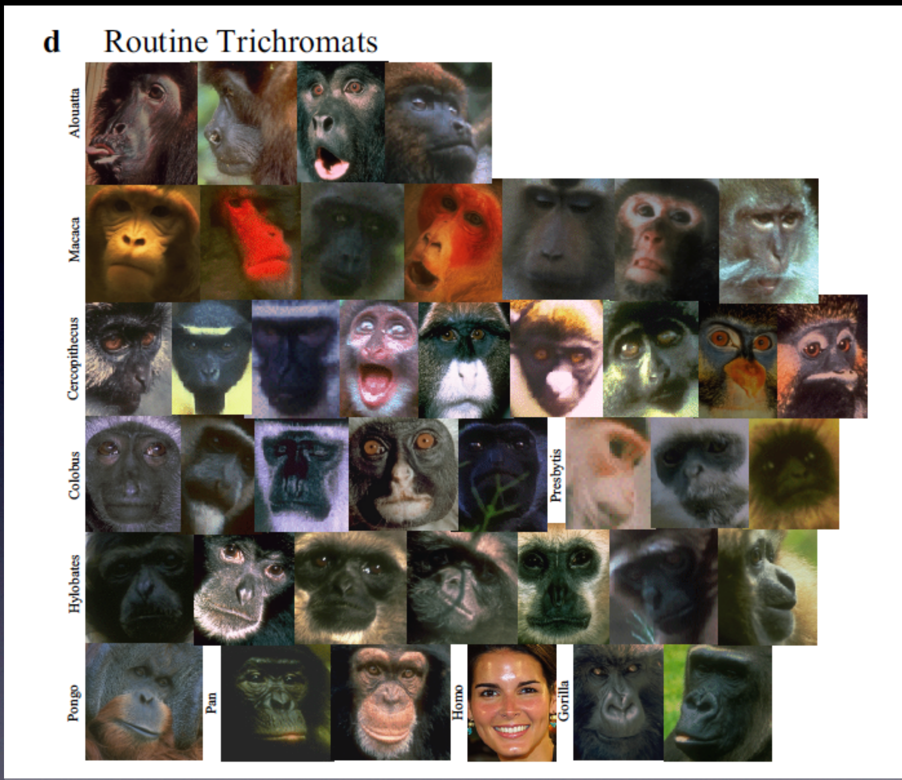
Dichromat

We are dichromats.



M.A. Changizi, Q. Zhang, S. Shimojo, Bare skin, blood and evolution of the primate colour vision, Biol. Lett., doi.10.1098/rebl.2006.0440

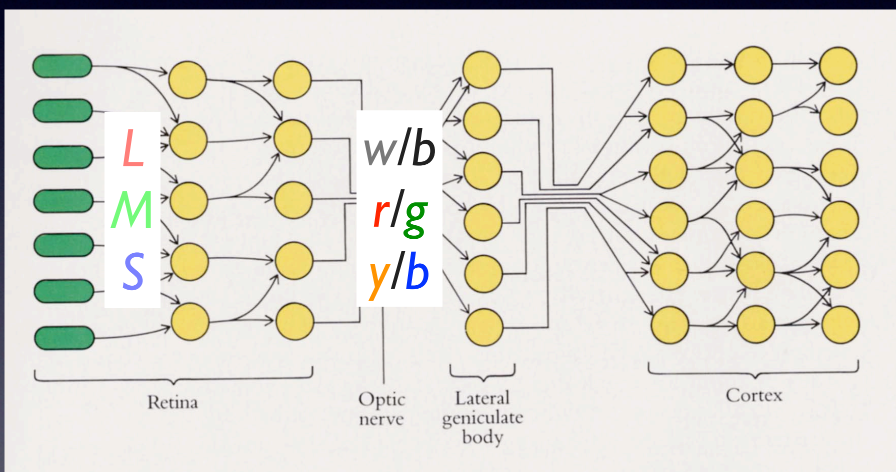
We are trichromats.



M.A. Changizi, Q. Zhang, S. Shimojo, Bare skin, blood and evolution of the primate colour vision, Biol. Lett., doi.10.1098/rebl.2006.0440

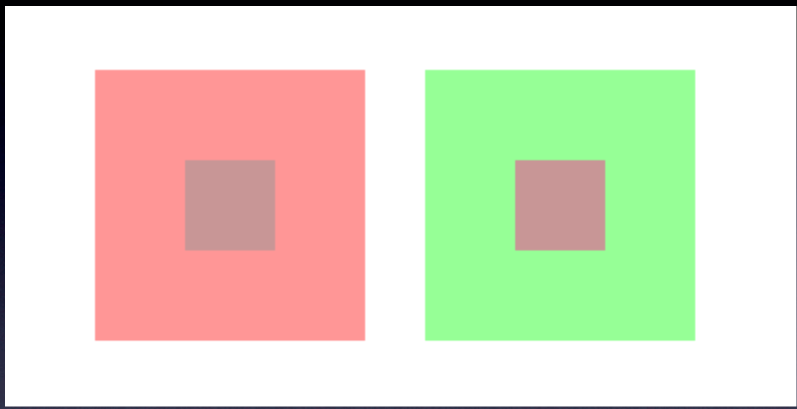
Light→Eye→Brain→Color

$L_{e,\lambda}$



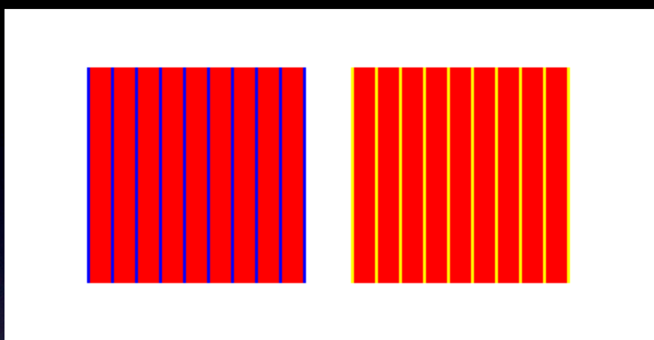
red
green
yellow
blue
purple
brown
pink
orange
gray
white
black

David Hubel, *Eye, Brain and Vision,* Scientific American Library, 1988

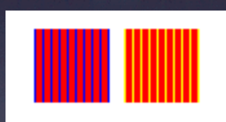


http://www.psy.ritsumei.ac.jp/~akitaoka/LorealWS2005.html

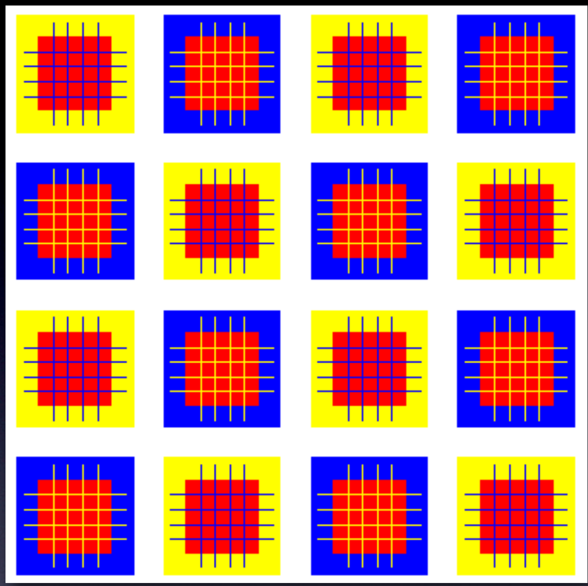
Color contrast



http://www.psy.ritsumei.ac.jp/~akitaoka/LorealWS2005.html



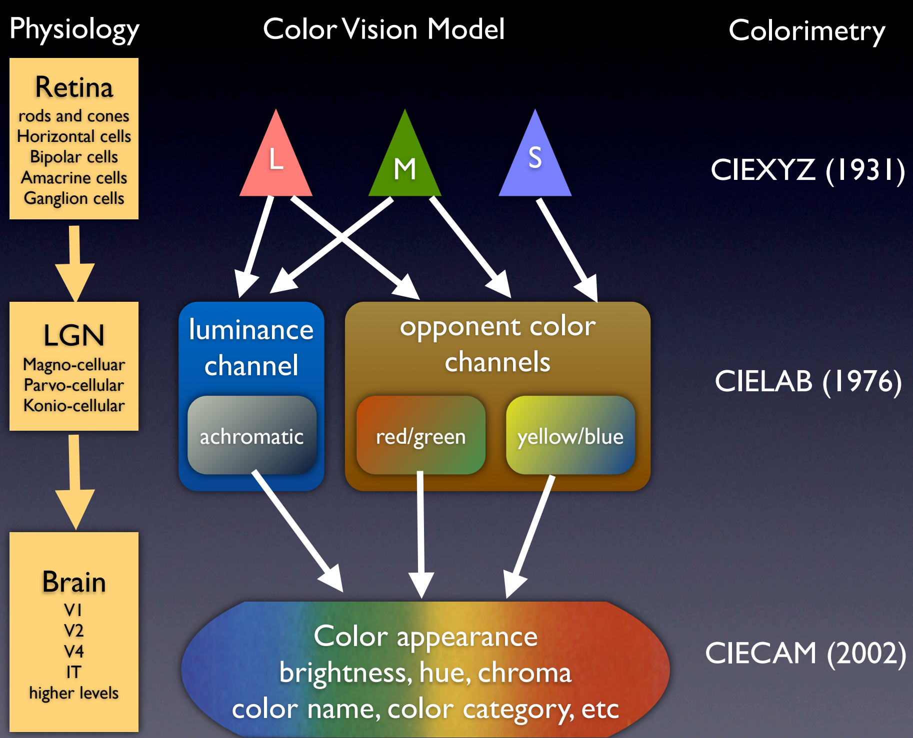
Color assimilation



http://www.psy.ritsumei.ac.jp/~akitaoka/LorealWS2005.html

Color contrast and color assimilation

Color Vision and History of Colorimetry



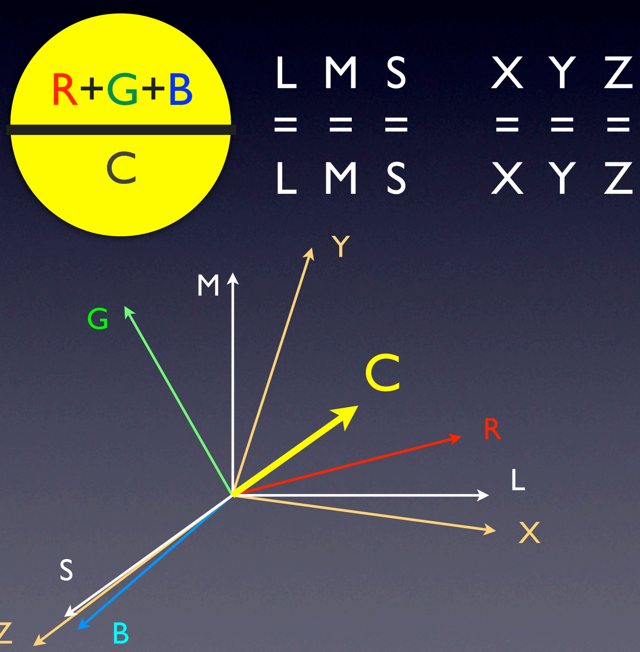
Basic Colorimetry

Wyszecki (1973)

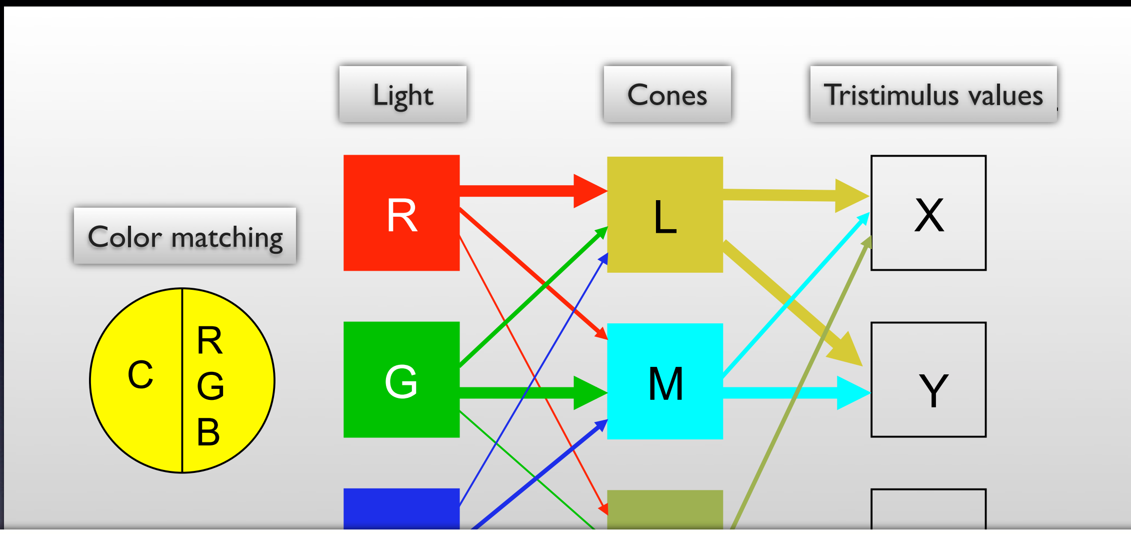
- Colorimetry is a tool used to making a prediction on whether two lights of different spectral power distributions will match in color for certain given conditions of observation. The prediction is made by determining the tristimulus values of the two visual stimuli. If the tristimulus values of a stimulus are identical to those of the other stimulus, a color match will be observed by an average observer with normal color vision.

Color matching and colorimetry (Three colorimetric systems)

- Physical system (RGB)
- Physiological system(LMS)
- Mathematical system (XYZ)

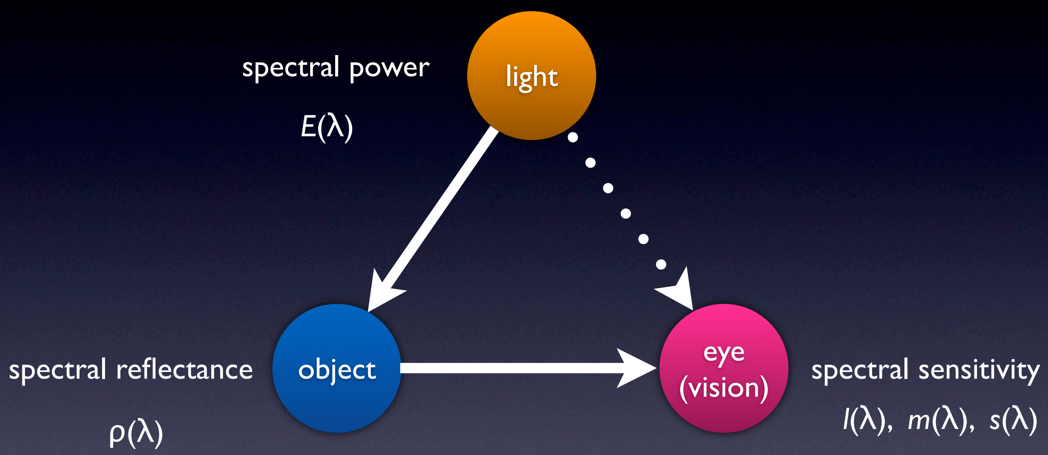


Color matching and colorimetry



$$\begin{bmatrix}L\\M\\S\end{bmatrix}=\begin{bmatrix}k_{\mathrm{lr}}&k_{\mathrm{lg}}&k_{\mathrm{lb}}\\k_{\mathrm{mr}}&k_{\mathrm{mg}}&k_{\mathrm{mb}}\\k_{\mathrm{sr}}&k_{\mathrm{sg}}&k_{\mathrm{sb}}\end{bmatrix}\begin{bmatrix}R\\G\\B\end{bmatrix},\quad \begin{bmatrix}X\\Y\\Z\end{bmatrix}=\begin{bmatrix}k_{\mathrm{xl}}&k_{\mathrm{xm}}&k_{\mathrm{xs}}\\k_{\mathrm{yl}}&k_{\mathrm{ym}}&k_{\mathrm{ys}}\\k_{\mathrm{zl}}&k_{\mathrm{zm}}&k_{\mathrm{zs}}\end{bmatrix}\begin{bmatrix}L\\M\\S\end{bmatrix},\quad \begin{bmatrix}R\\G\\B\end{bmatrix}=\begin{bmatrix}k_{\mathrm{rx}}&k_{\mathrm{ry}}&k_{\mathrm{rz}}\\k_{\mathrm{gx}}&k_{\mathrm{gy}}&k_{\mathrm{gz}}\\k_{\mathrm{bx}}&k_{\mathrm{by}}&k_{\mathrm{bz}}\end{bmatrix}\begin{bmatrix}X\\Y\\Z\end{bmatrix}$$

Three factors define color



Color = Light • object • eye

$L = \int E(\lambda)\rho(\lambda)\, l(\lambda)d\lambda$

$M = \int E(\lambda)\rho(\lambda)\, m(\lambda)d\lambda$

$S = \int E(\lambda)\rho(\lambda)\, s(\lambda)d\lambda$

Tristimulus values are obtained by the spectral power and the color matching functions.

$$R = \int L_{e,\lambda} \bar{r}(\lambda) d\lambda$$
$$G = \int L_{e,\lambda} \bar{g}(\lambda) d\lambda$$
$$B = \int L_{e,\lambda} \bar{b}(\lambda) d\lambda$$

Unrelated color (aperture color)

$$X = \mathrm{K_m} \int L_{e,\lambda} \bar{x}(\lambda) d\lambda$$
$$Y = \mathrm{K_m} \int L_{e,\lambda} \bar{y}(\lambda) d\lambda$$
$$Z = \mathrm{K_m} \int L_{e,\lambda} \bar{z}(\lambda) d\lambda$$
$$\mathrm{K_m} = 683\ (\mathrm{lm/W})$$

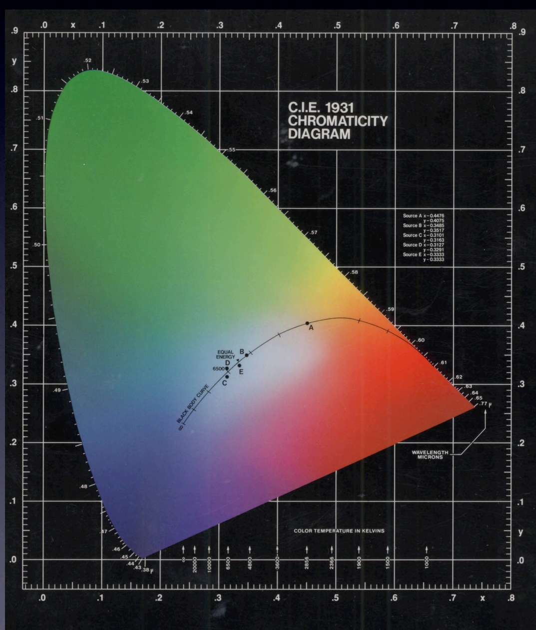
Related color (object color)

$$X = k \int E(\lambda) \rho(\lambda) \bar{x}(\lambda) d\lambda$$
$$Y = k \int E(\lambda) \rho(\lambda) \bar{y}(\lambda) d\lambda$$
$$Z = k \int E(\lambda) \rho(\lambda) \bar{z}(\lambda) d\lambda$$
$$k = \frac{100}{\int E(\lambda) \bar{y}(\lambda) d\lambda}$$

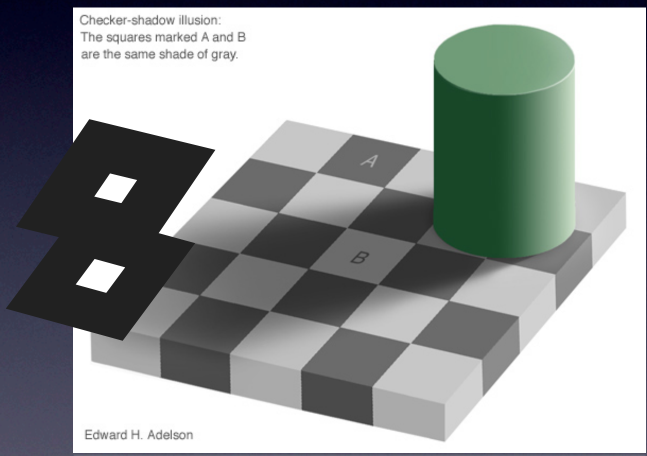
$$L = \int L_{e,\lambda} \bar{l}(\lambda) d\lambda$$
$$M = \int L_{e,\lambda} \bar{m}(\lambda) d\lambda$$
$$S = \int L_{e,\lambda} \bar{s}(\lambda) d\lambda$$

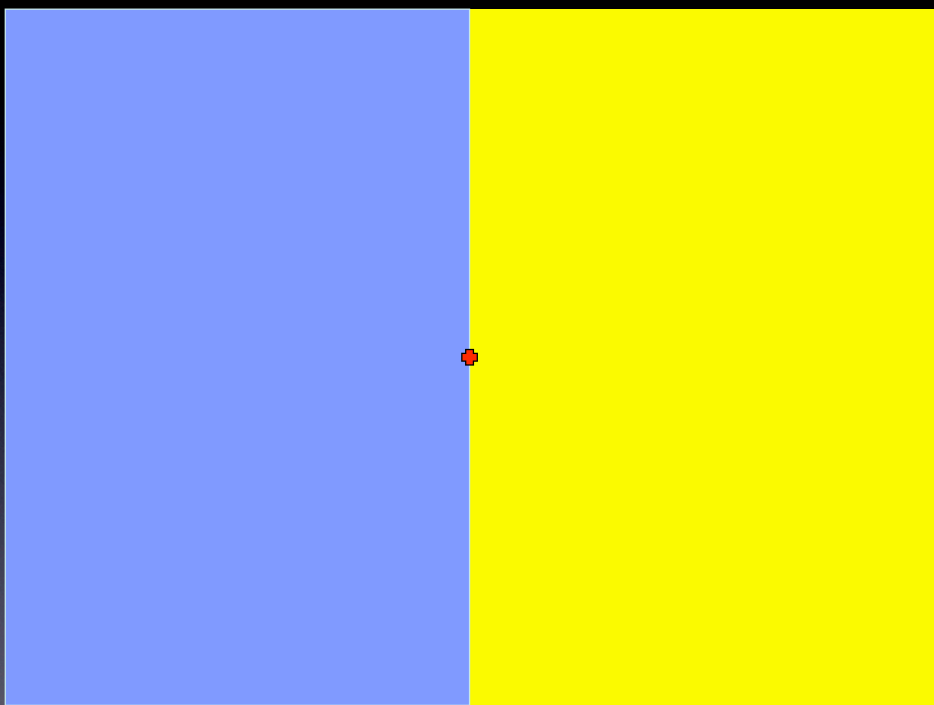
Color address

CIE1931 (x, y) chromaticity diagram



We don’t see light but the object.






ISO 400

Advanced Colorimetry

Wyszecki (1973)

- Colorimetry is its broader sense includes methods of assessing the appearance of color stimuli presented to the observer in complicated surroundings as they may in occur in everyday life. This is considered the ultimate goal of colorimetry, but because of its enormous complexity, this goal is far from being reached.

CIELAB (CIE 1976 L*a*b*)

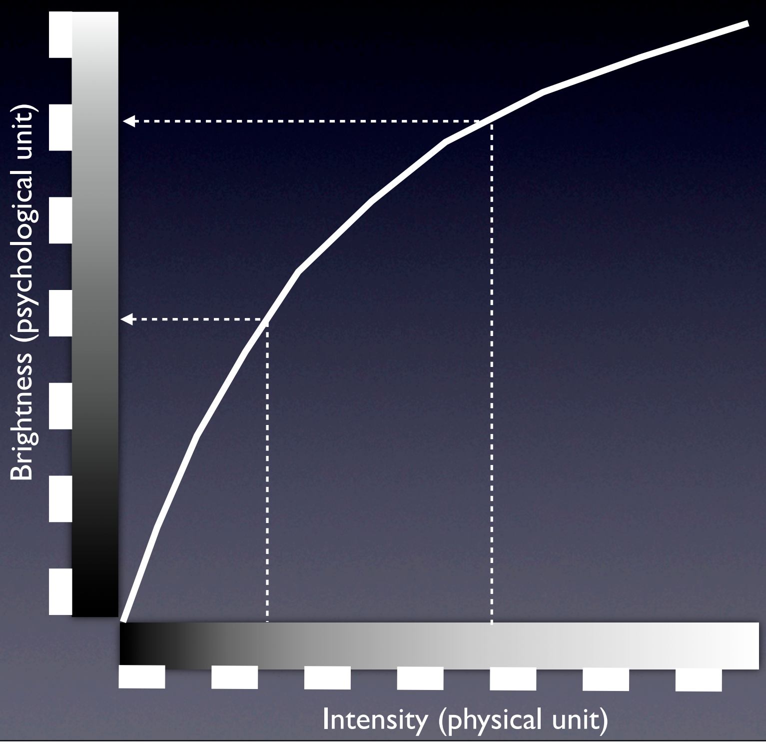
$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left\{\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right\}$$

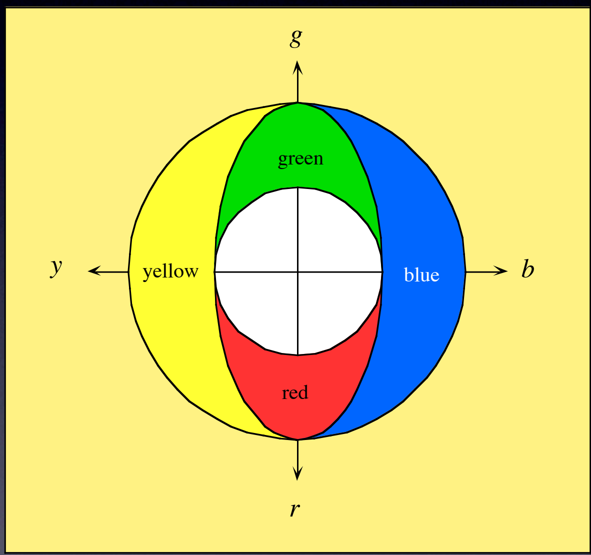
$$b^* = 200\left\{\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right\}$$

- Color adaptation
  - White is always white
- Non-linearity
  - Physical unit to psychological unit
- Color opponency
  - Luminance and chromaticness

Non-linearity



Color opponency



The most advanced CIE colorimetric system (CIECAM02)