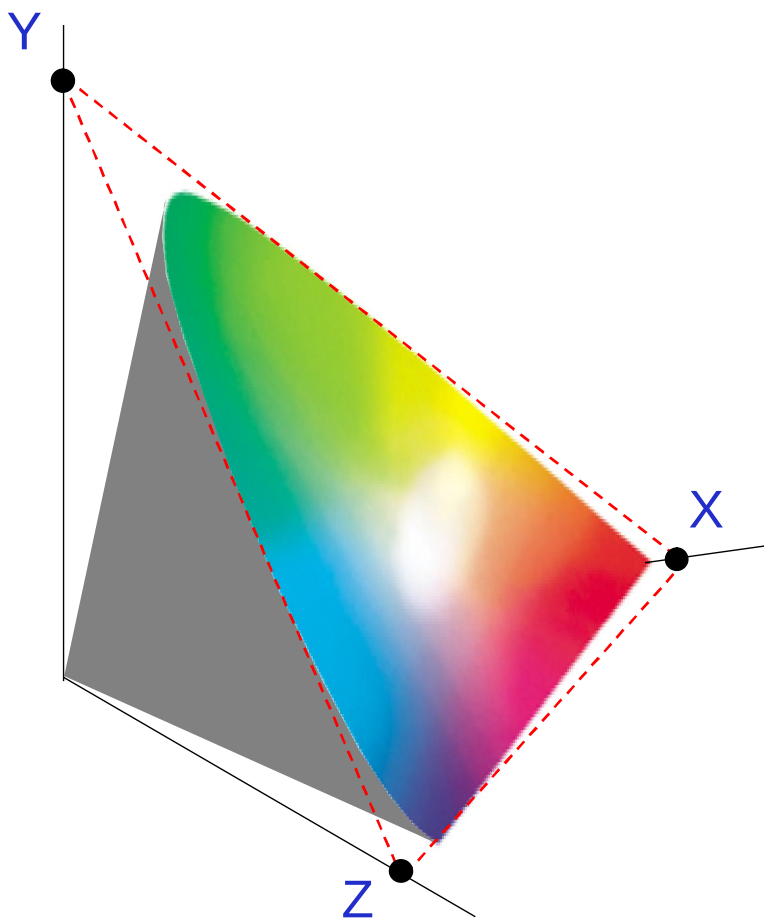
Lecture 3

Color Representation

CIEXYZ Color Space
CIE Chromaticity Space
HSL,HSV,LUV,CIELab



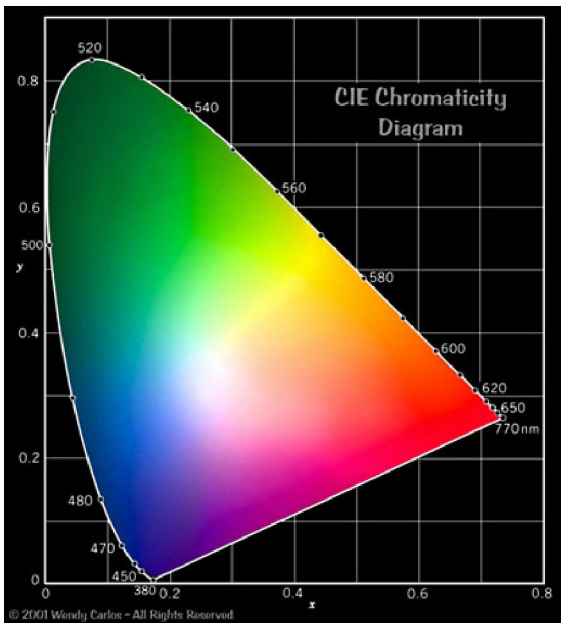
CIEXYZ
Color Coordinate System

1931 – The Commission International de l'Eclairage (CIE)
Defined a standard system for color representation.

The CIE-XYZ Color Coordinate System.

In this system, the XYZ *Tristimulus values* can describe any visible color.

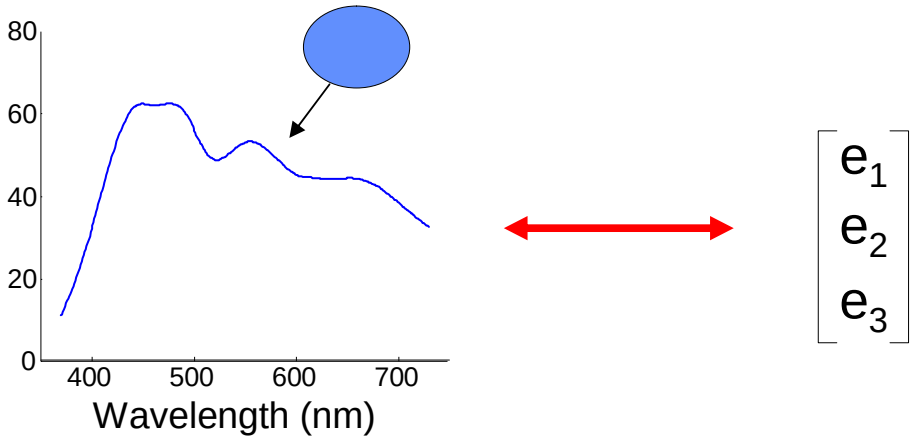
The XYZ system is based on the color matching experiments



Trichromatic Color Theory

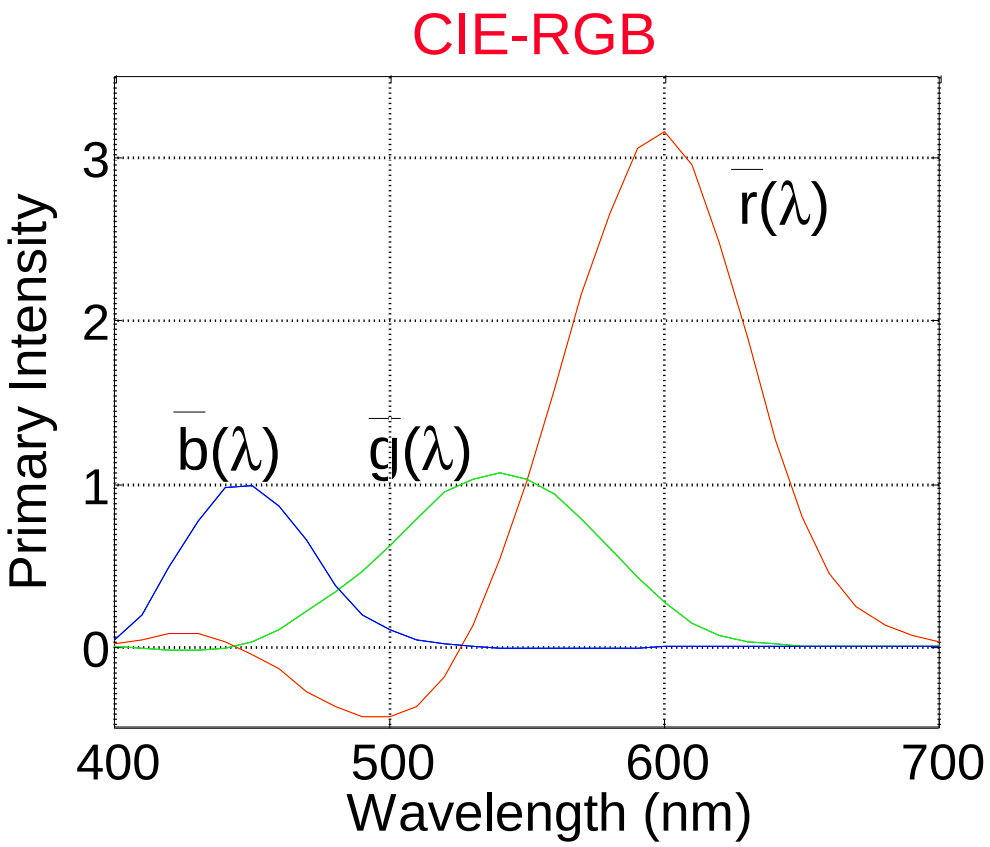
"tri"=three "chroma"=color

Every color can be represented by 3 values.



Space of visible colors is 3 Dimensional.

Calculating the CIEXYZ Color Coordinate System



David Wright 1928-1929, 1929-1930 & John Guild 1931
17 observers responses to Monochromatic lights between 400-700nm using viewing field of 2 deg angular subtense.

Primaries are monochromatic : 435.8 546.1 700 nm
2 deg field.

These were defined as CIE-RGB primaries and CMF.

XYZ are a linear transformation away from the observed data.

CIEXYZ
Color Coordinate System

CIE Criteria for choosing Primaries X,Y,Z and Color Matching Functions $\bar{x}$,$\bar{y}$,$\bar{z}$.

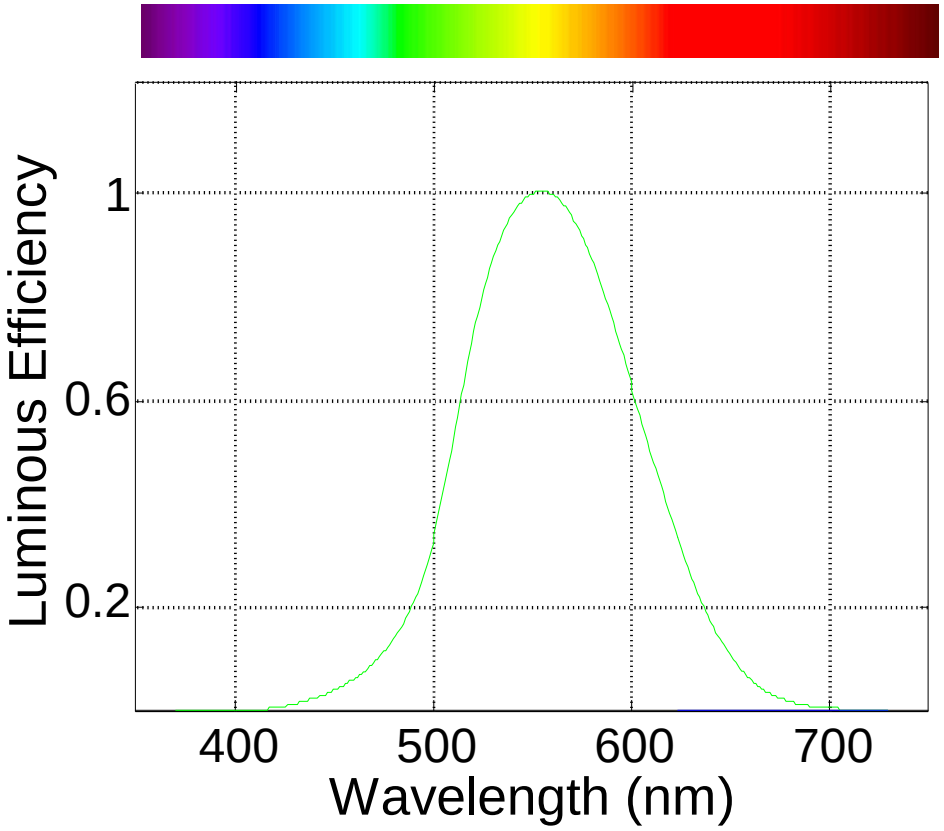
1) CMFs are non-negative over visible wavelengths. (i.e. any color is represented by 3 positive values).

2) Equal amounts of the Primaries produce white. (i.e. X=Y=Z for stimulus of equal luminance at each wavelength).

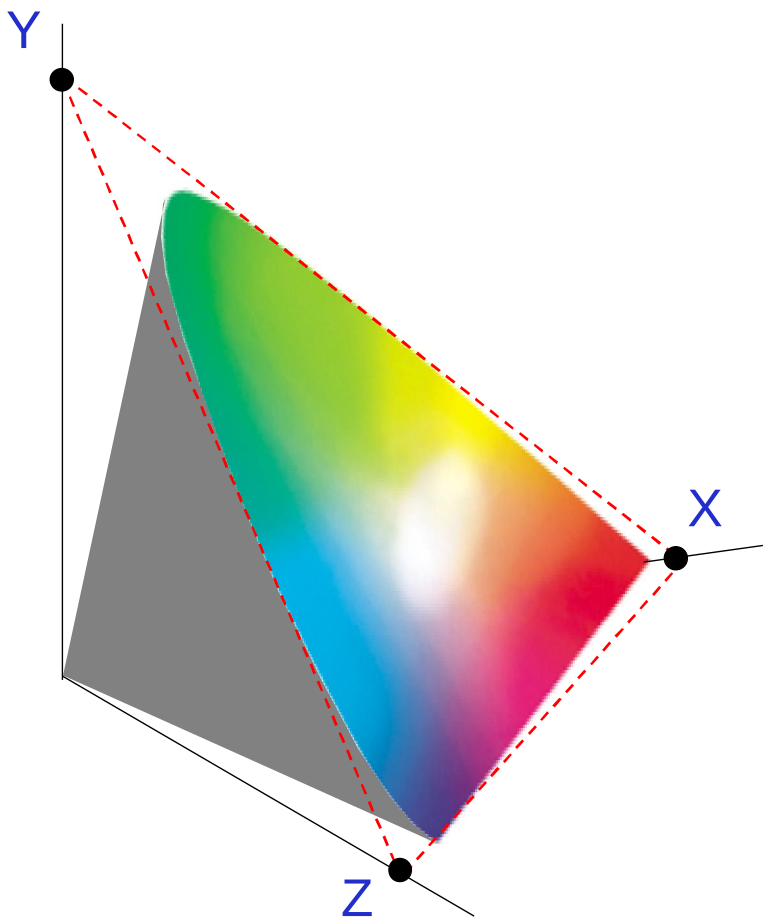
3) The $\bar{y}$ color matching function is defined to match the luminous-efficiency function of the human eye.

4) Primaries are as ‘tight’ as possible around the set of possible colors (Maxwell triangle Projects to equilateral in XYZ space).

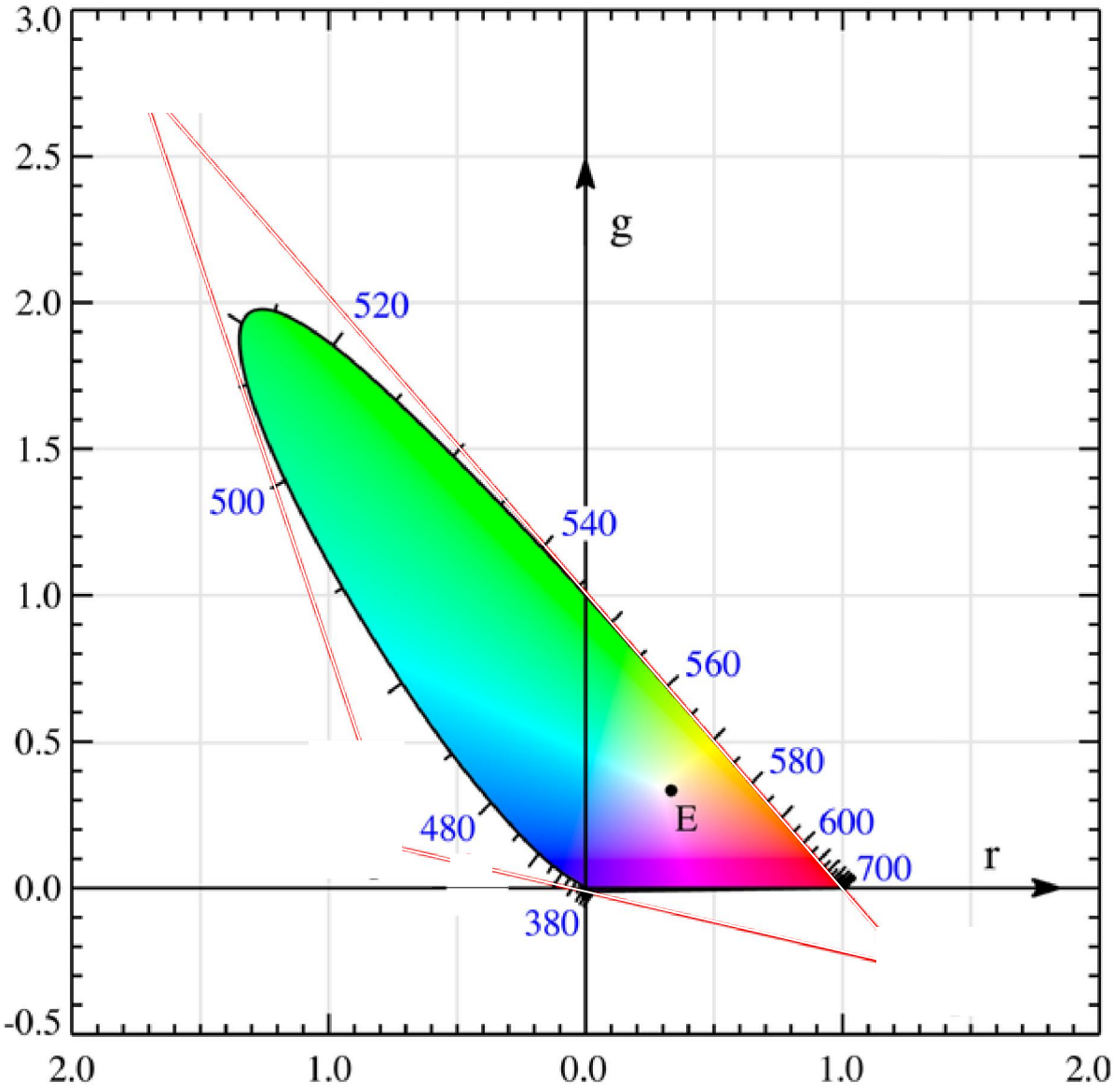
Luminous-Efficiency function of the human eye



CIEXYZ
Color Coordinate System



CIE-RGB to CIE-XYZ



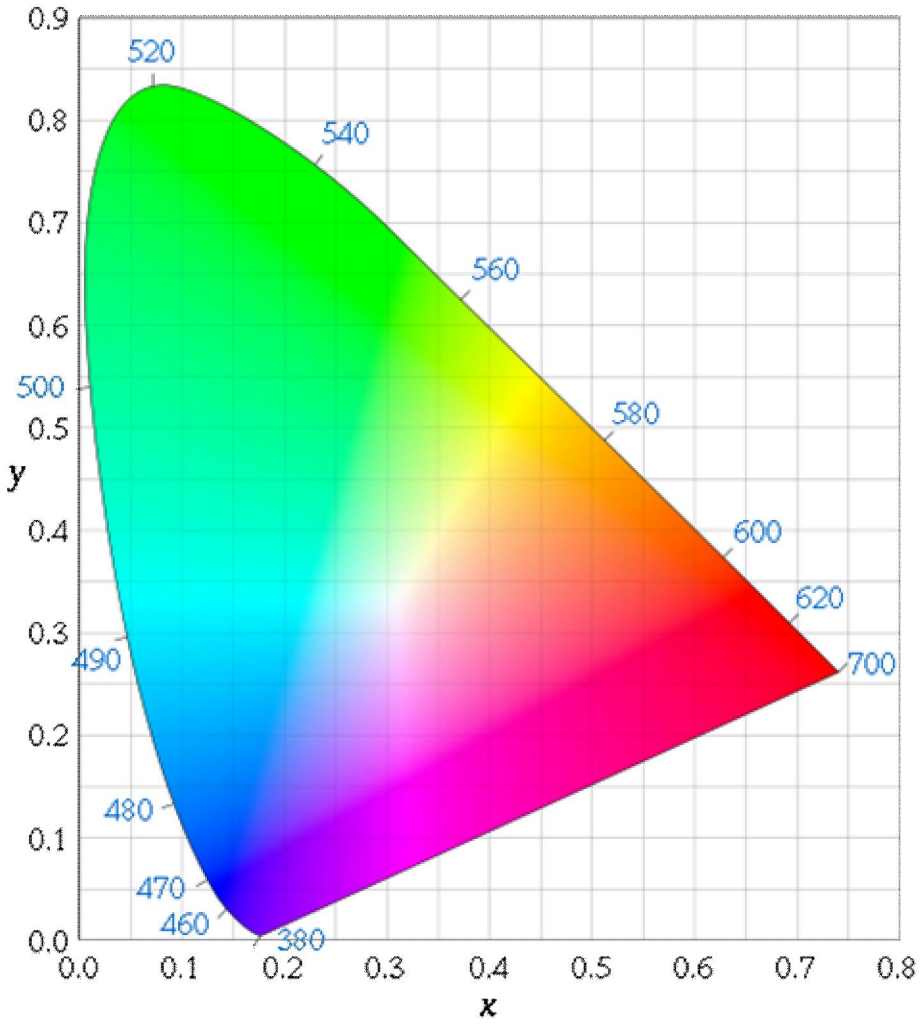
CIE-RGB Chromaticity space (rg).

* Cr, Cg, Cb must enclose the Gamut.
* Line Cb-Cr is defined by Y being Luminance Function. (the Alychne = line of zero luminance).
* Line Cr-Cg is tangent at 650+ (z is zero beyond 650).
* Thus Cr is defined.
* Equal Energy (x=y=z=1/3) puts constraint on Cb-Cg
* Tight around Gamut -> line Cb-Cg is close to green.
* Cb and Cg are defined.

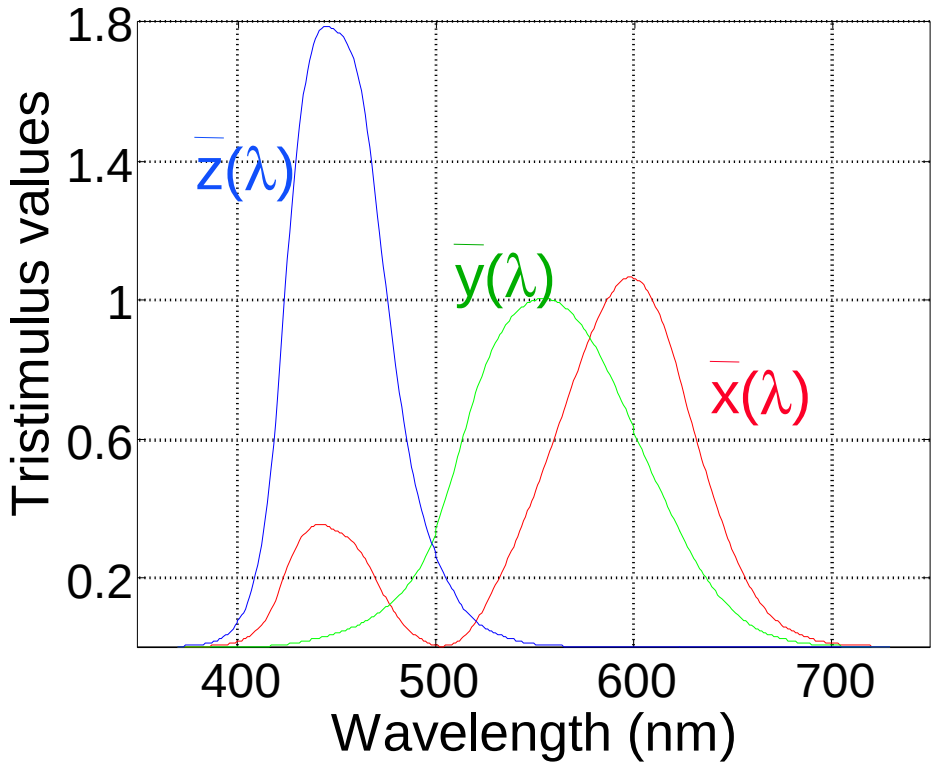
CIE-RGB to CIE-XYZ

CIE RGB space to XYZ space.
Map Cb Cg Cr to x=(0,0) y=(0,1) z=(1,0)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



CIE Color Standard - 1931



- $\bar{y}$ is predefined.
- Non negative over the visible wavelengths. (X,Z – Several Hundreds, Y – 0..100).
- The 3 primaries associated with x y z color matching functions are unrealizable (negative power in some of the wavelengths).
- Integral over the CMF gives equal values.
- CMF are linear transformation away from CIE-RGB and from LMS.

CIE Color Standard - 1964

Stiles and Birch data (1959):

Color Matching Experiment with:

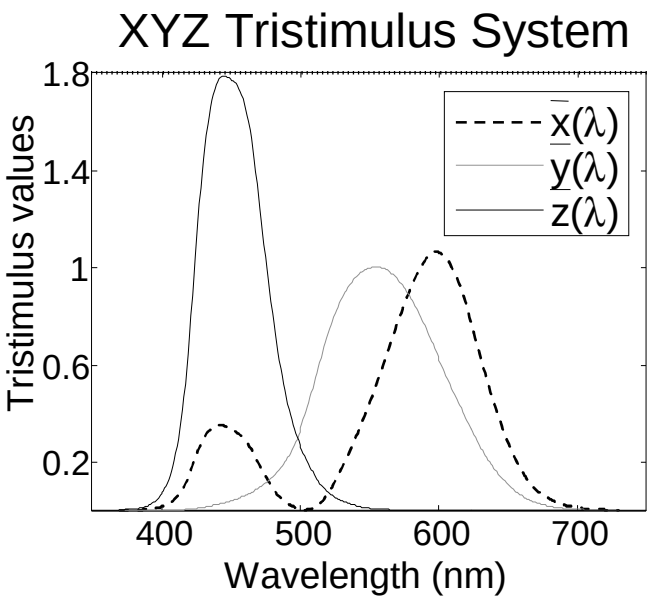
10 Deg view

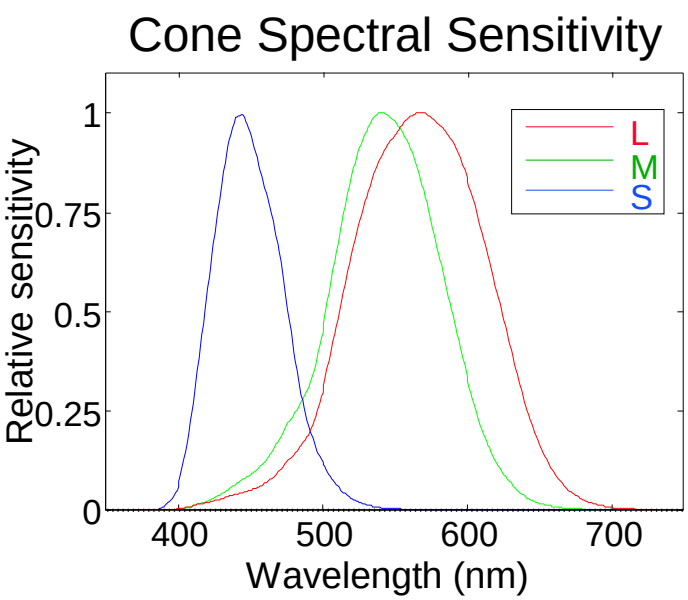
Primaries: 444.4 525.3 645.2

CIE-XYZ_{10}

Colorimeters

Color matching functions vs LMS - cone photoreceptor responses





The cone responses form a 3D linear system.
Cone responses are equivalent for metamers.

thus

The cone spectral sensitivities and the XYZ color matching functions are related by a 3 x 3 linear transformation.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.9023 & -1.4000 & 0.3544 \\ 0.6371 & 0.3933 & -0.0093 \\ 0.0007 & 0.0033 & 1.7462 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}$$

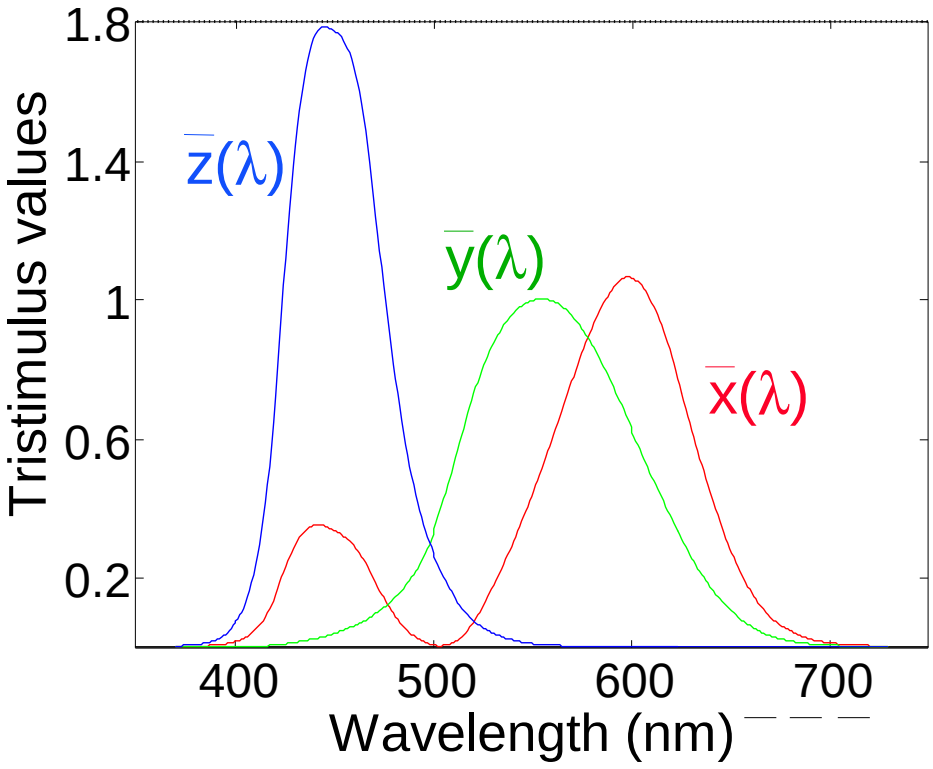
CIE – RGB

Primaries are monochromatic : 435.8 546.1 700 nm

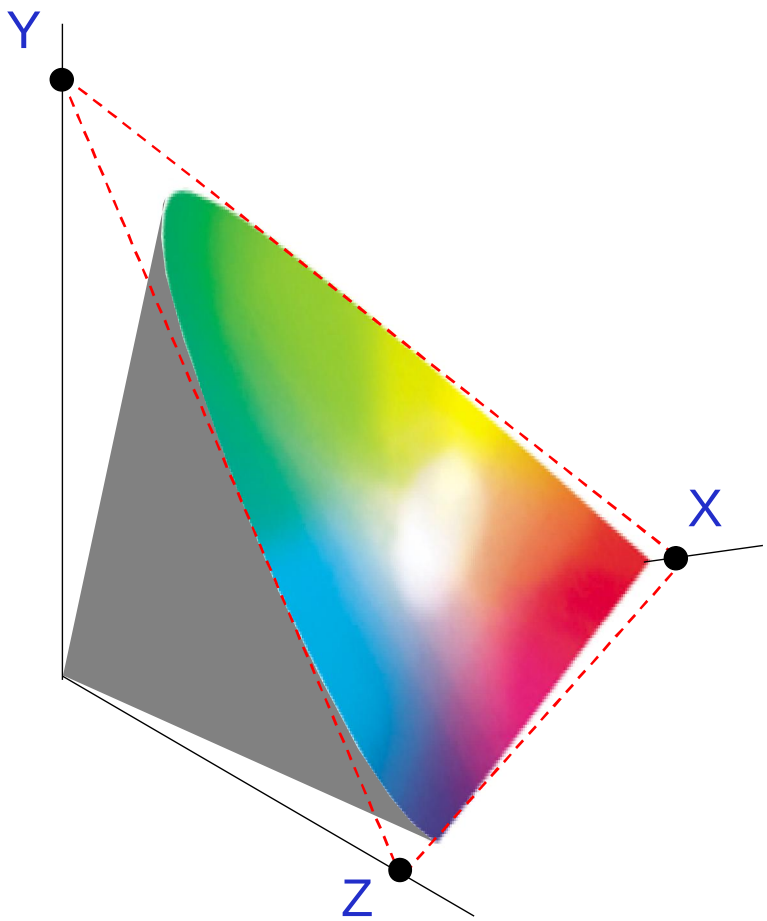
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.9023 & -1.4000 & 0.3544 \\ 0.6371 & 0.3933 & -0.0093 \\ 0.0007 & 0.0033 & 1.7462 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIEXYZ
Color Coordinate System

$\bar{x}\ \bar{y}\ \bar{z}$ Color Matching Functions



CIEXYZ
Color Coordinate System



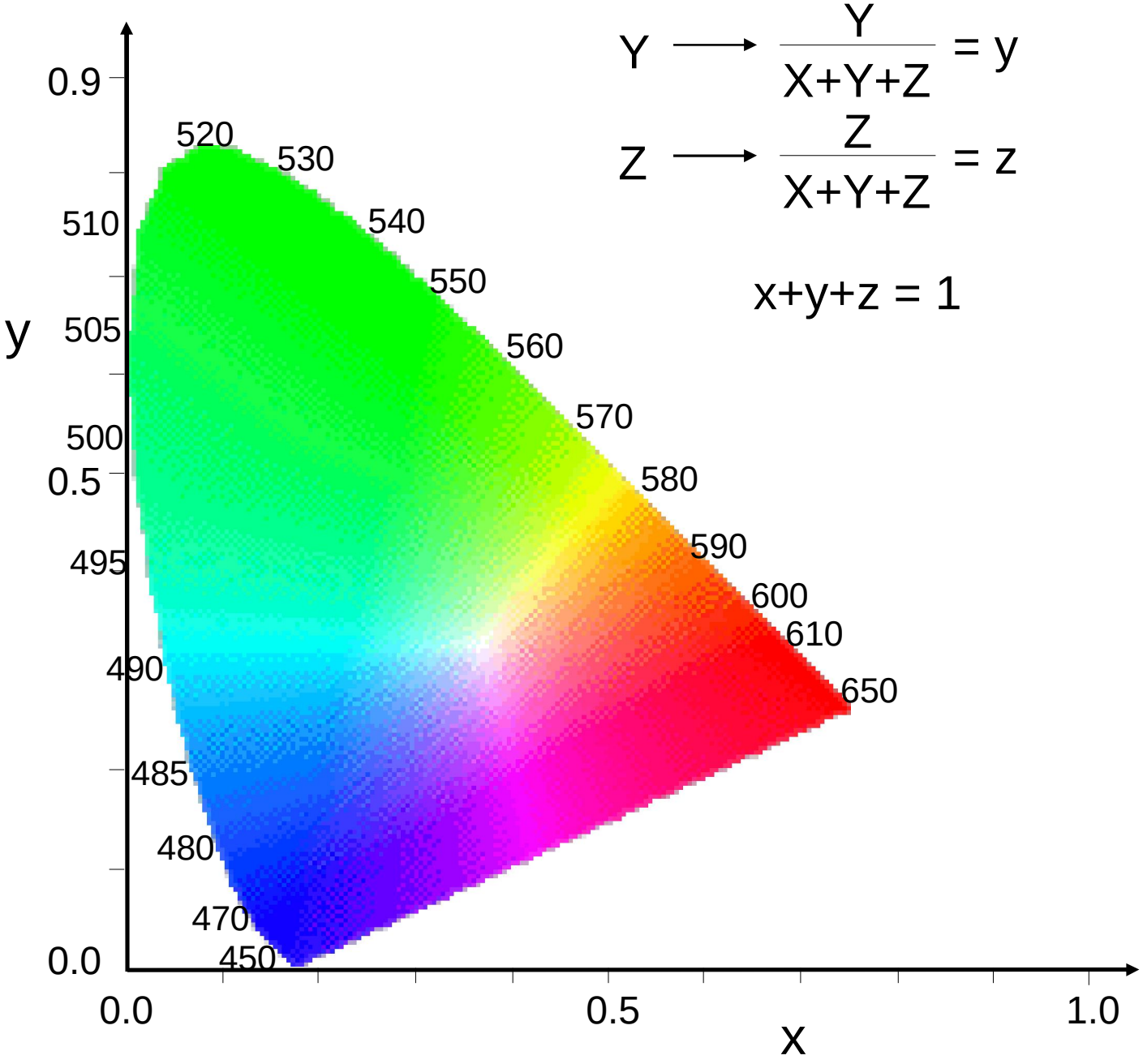
CIE Chromaticity Diagram

$$X \longrightarrow \frac{X}{X+Y+Z} = x$$

$$Y \longrightarrow \frac{Y}{X+Y+Z} = y$$

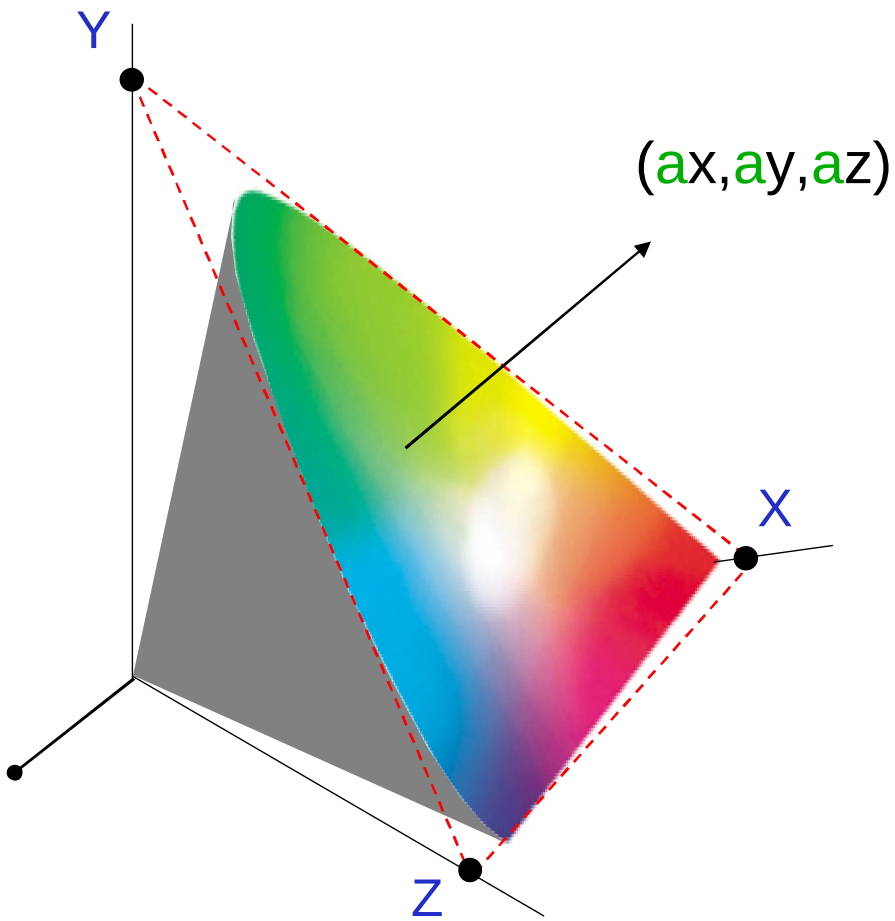
$$Z \longrightarrow \frac{Z}{X+Y+Z} = z$$

$$x+y+z = 1$$

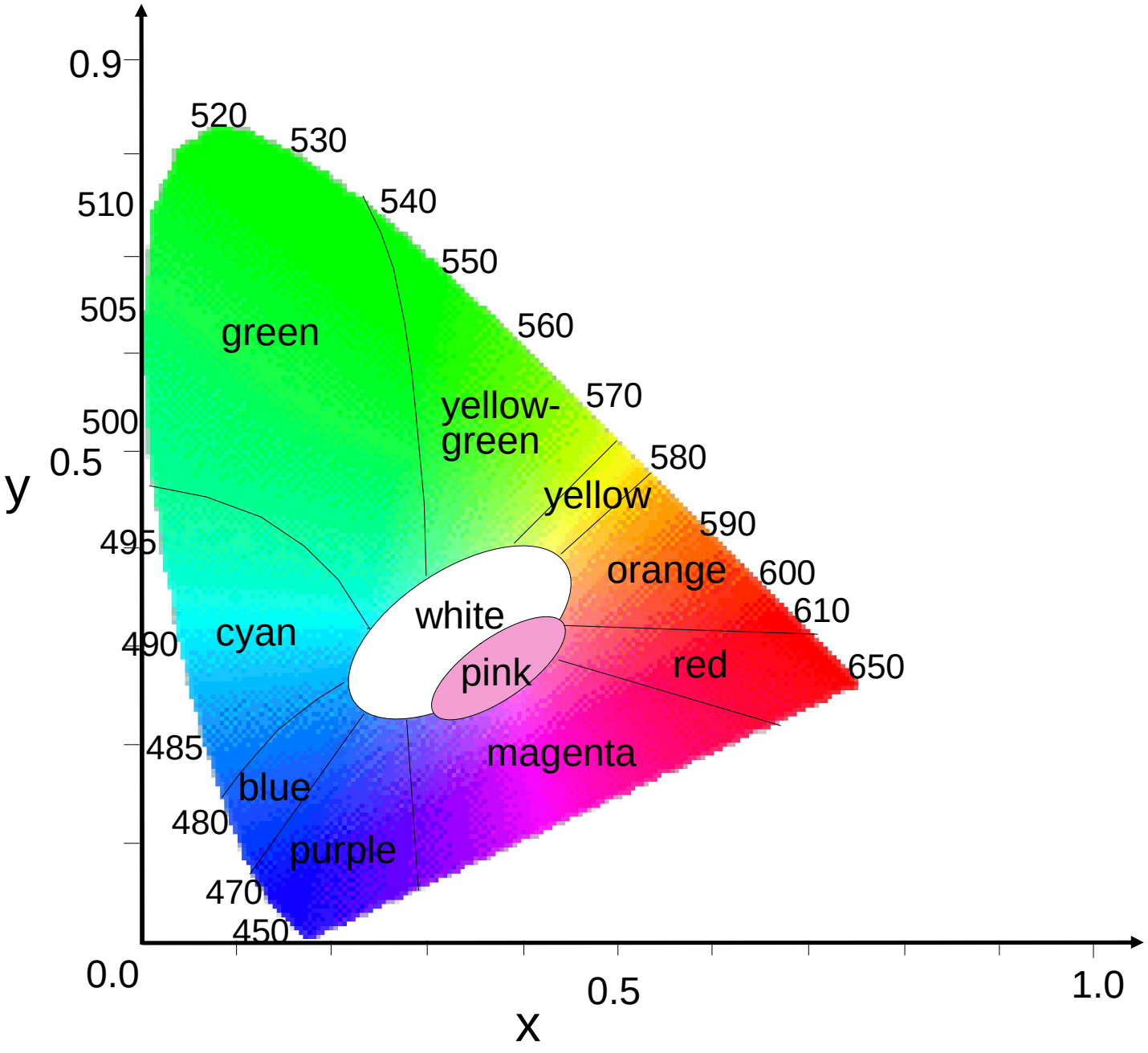


A common representative of color signal: [x,y,Y]

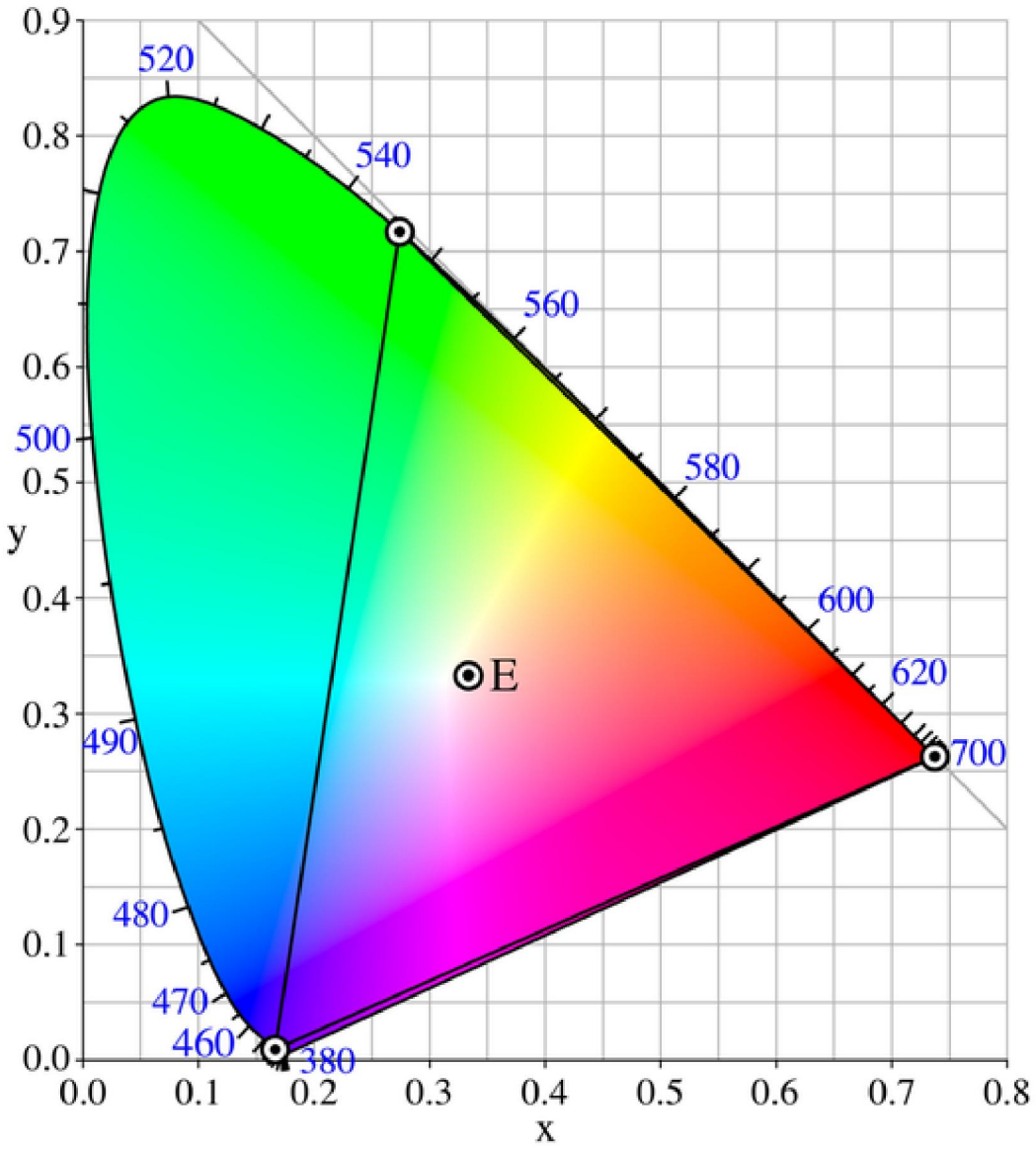
CIE Chromaticity Diagram



Color Naming



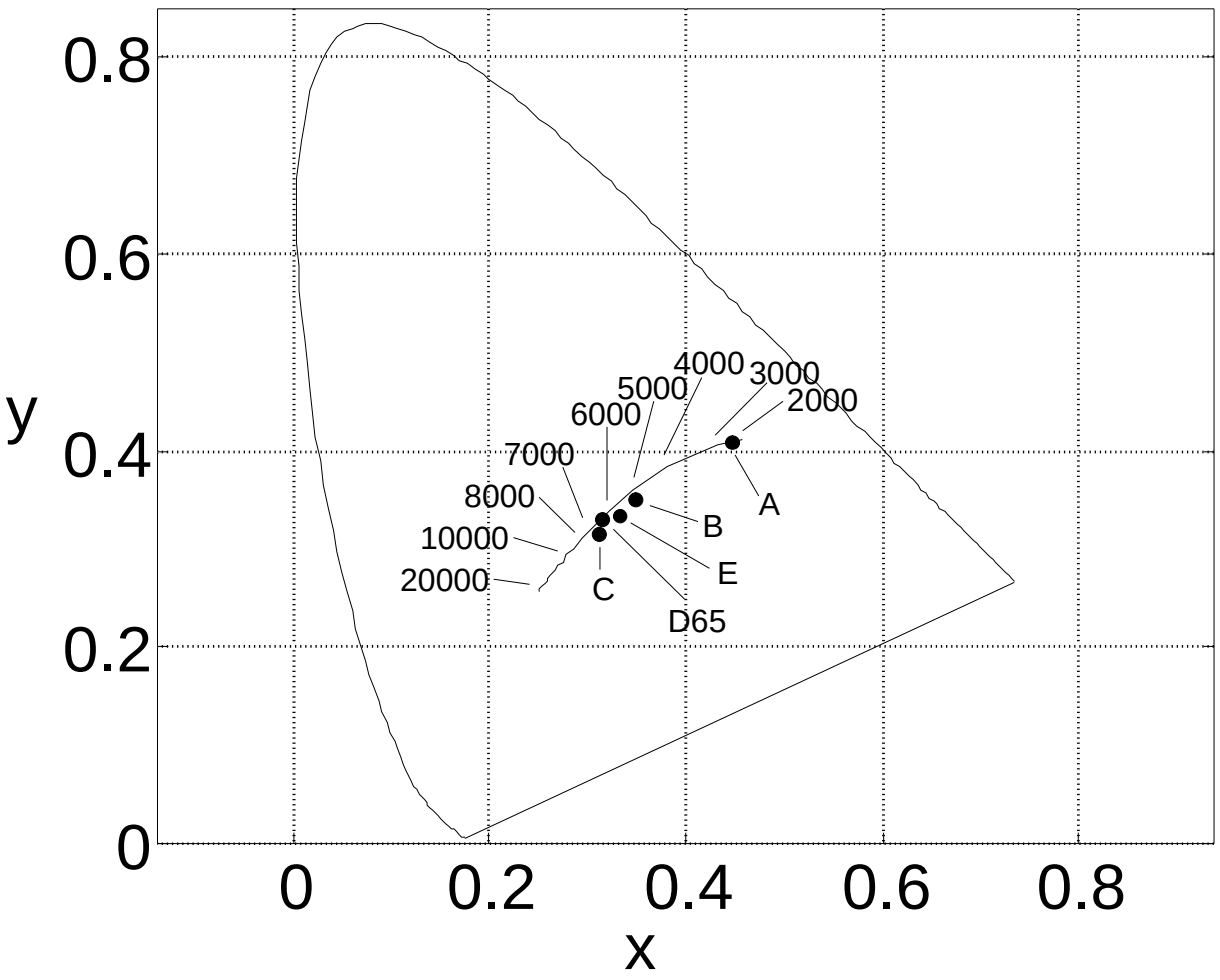
CIE-RGB Primaries



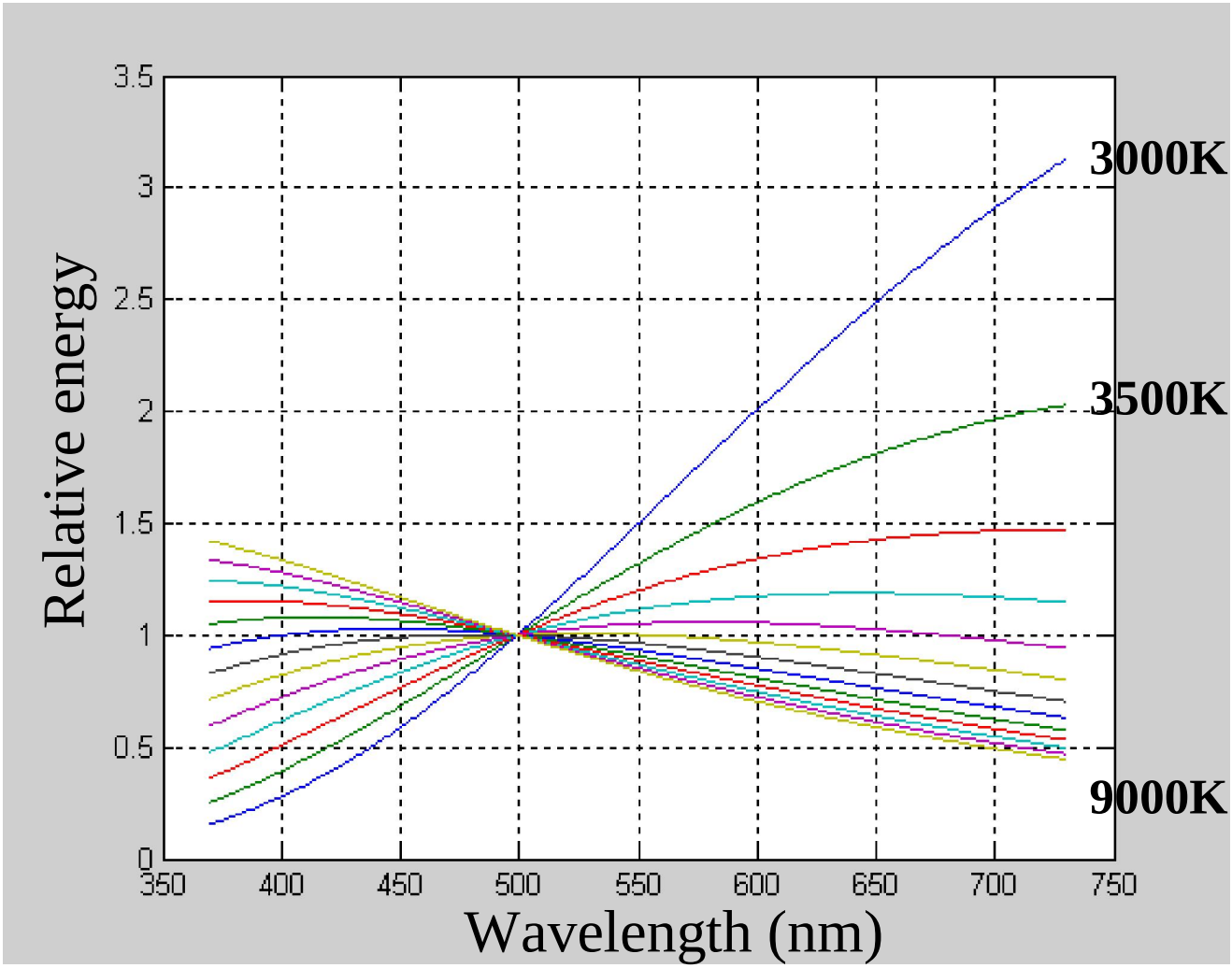
Blackbody Radiators and CIE standard Illuminants

CIE Standard Illuminants:

- A - tungsten light
- B - Sunset
- C - blue sky
- D65 - Average daylight
- E - Equal energy white (x=y=z=1/3)



Blackbody Radiators

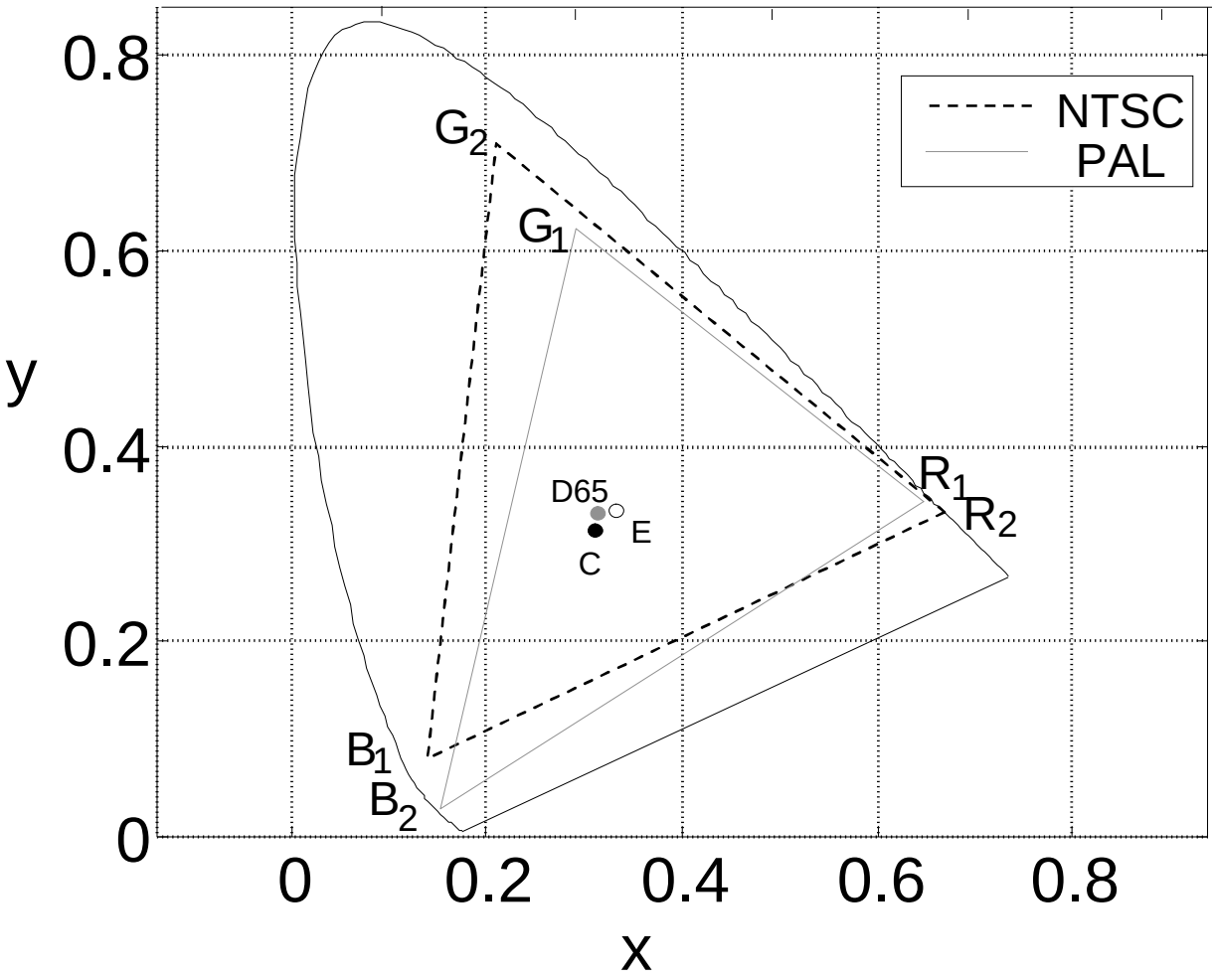


http://www.olympusmicro.com/primer/java/colortemperature/index.html

Television Primaries and Gamut

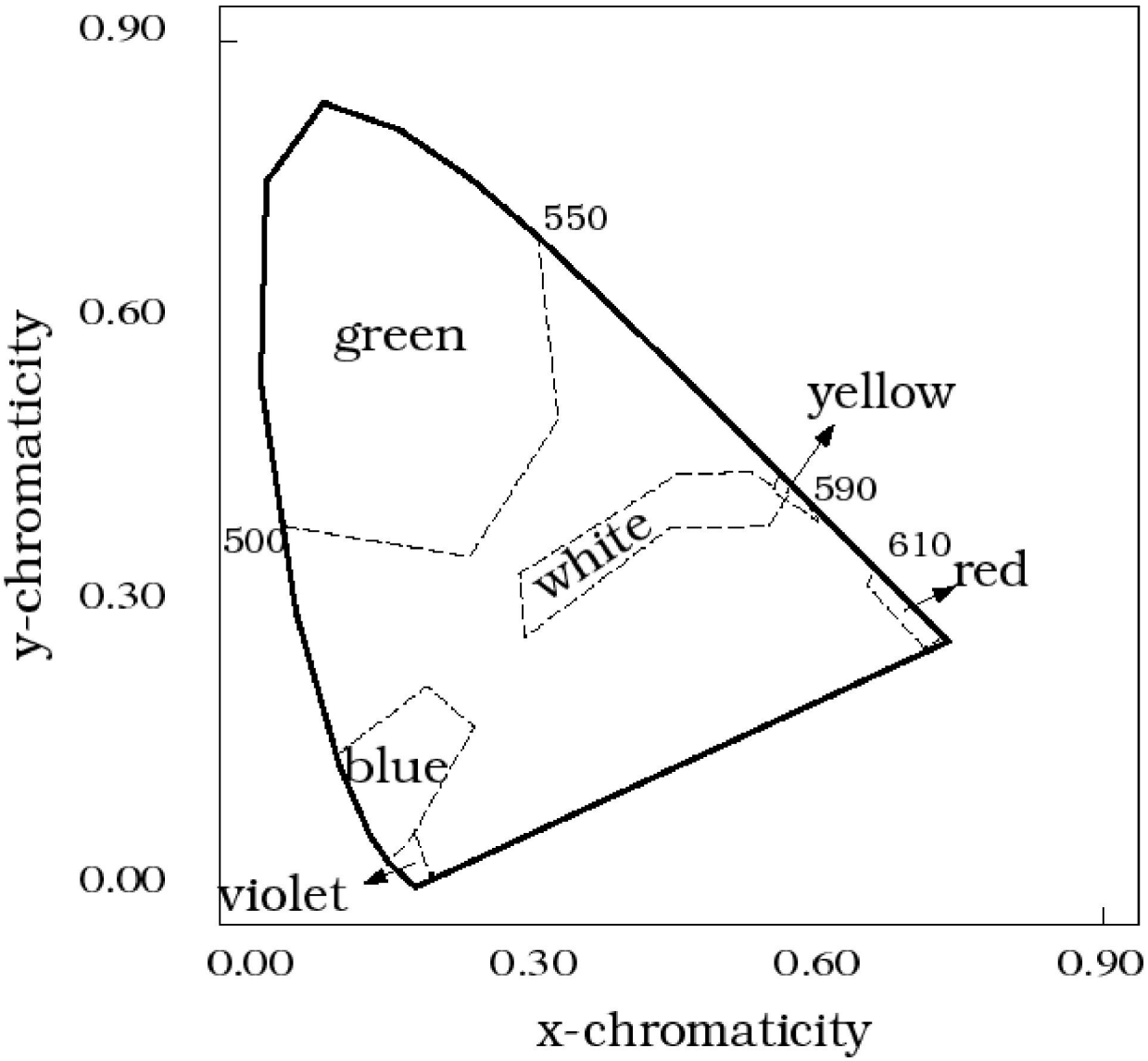
$R_1G_1B_1$ - Primaries used for PAL
$R_2G_2B_2$ - Primaries used for NTSC

D65 - reference white for PAL
C - reference white for NTSC



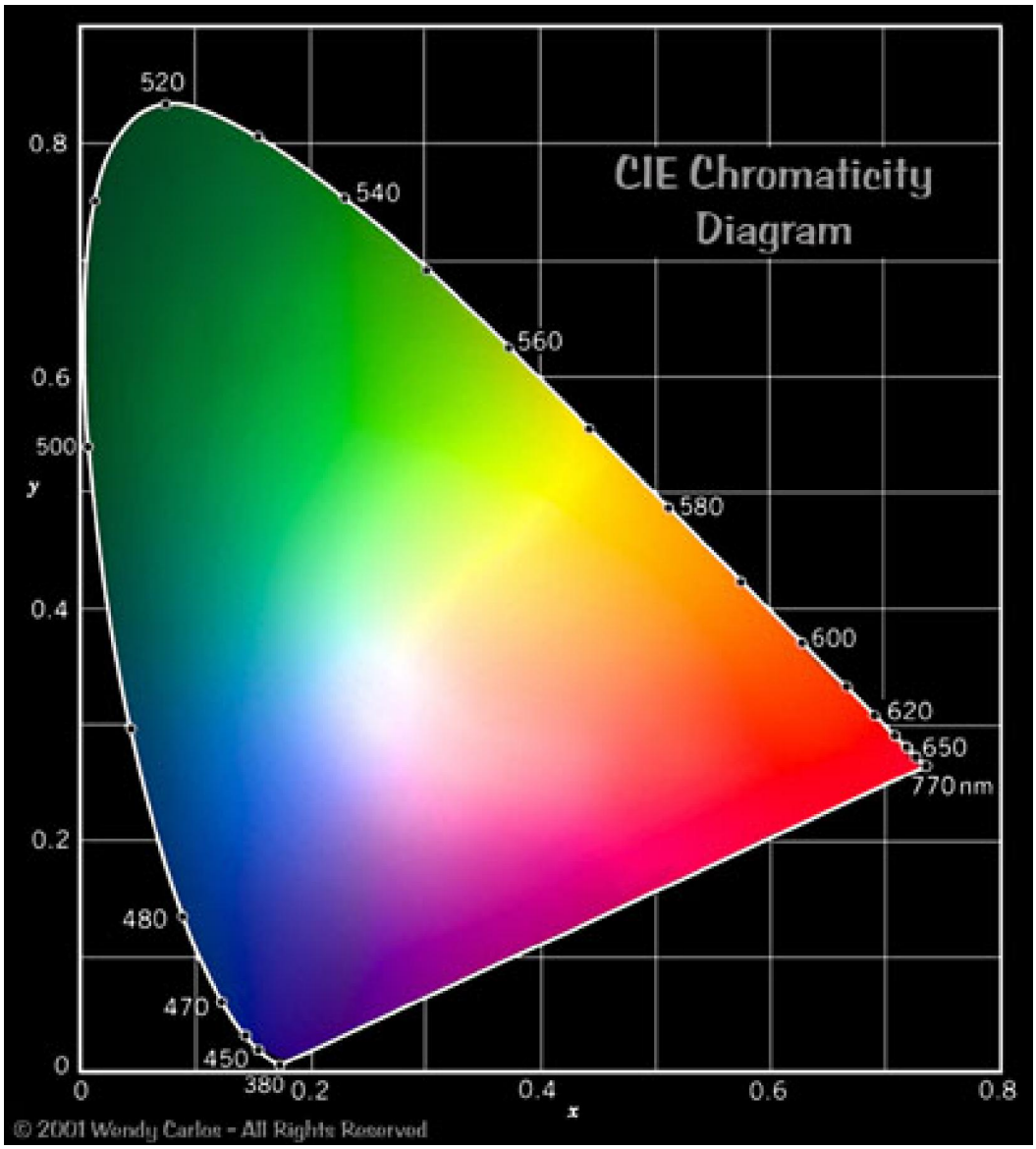
CIE Chromaticity + Gamut applet :
http://www.cs.rit.edu/~ncs/color/a_chroma.html

Signal Lights



XYZ Color Space

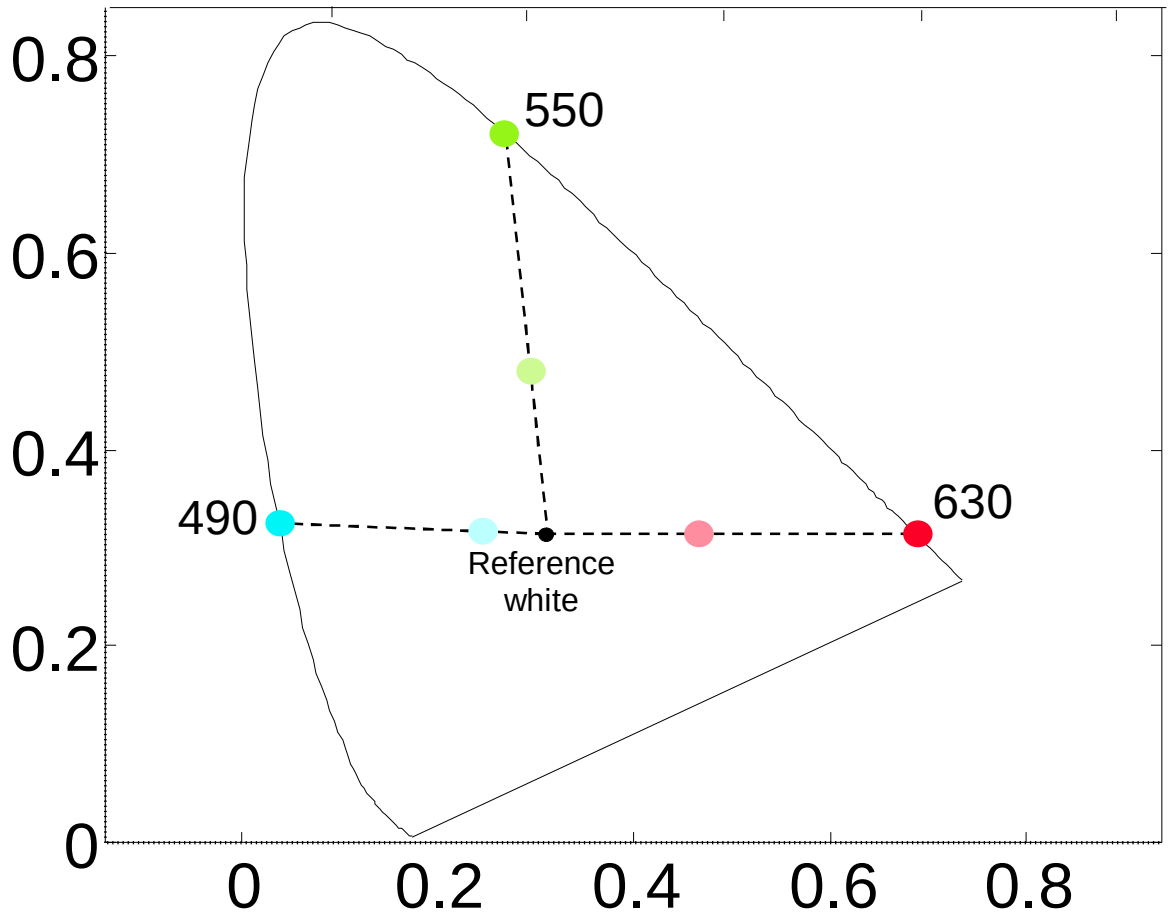
Hue vs Saturation



Chromaticity in Polar Coordinates

Given a reference white.

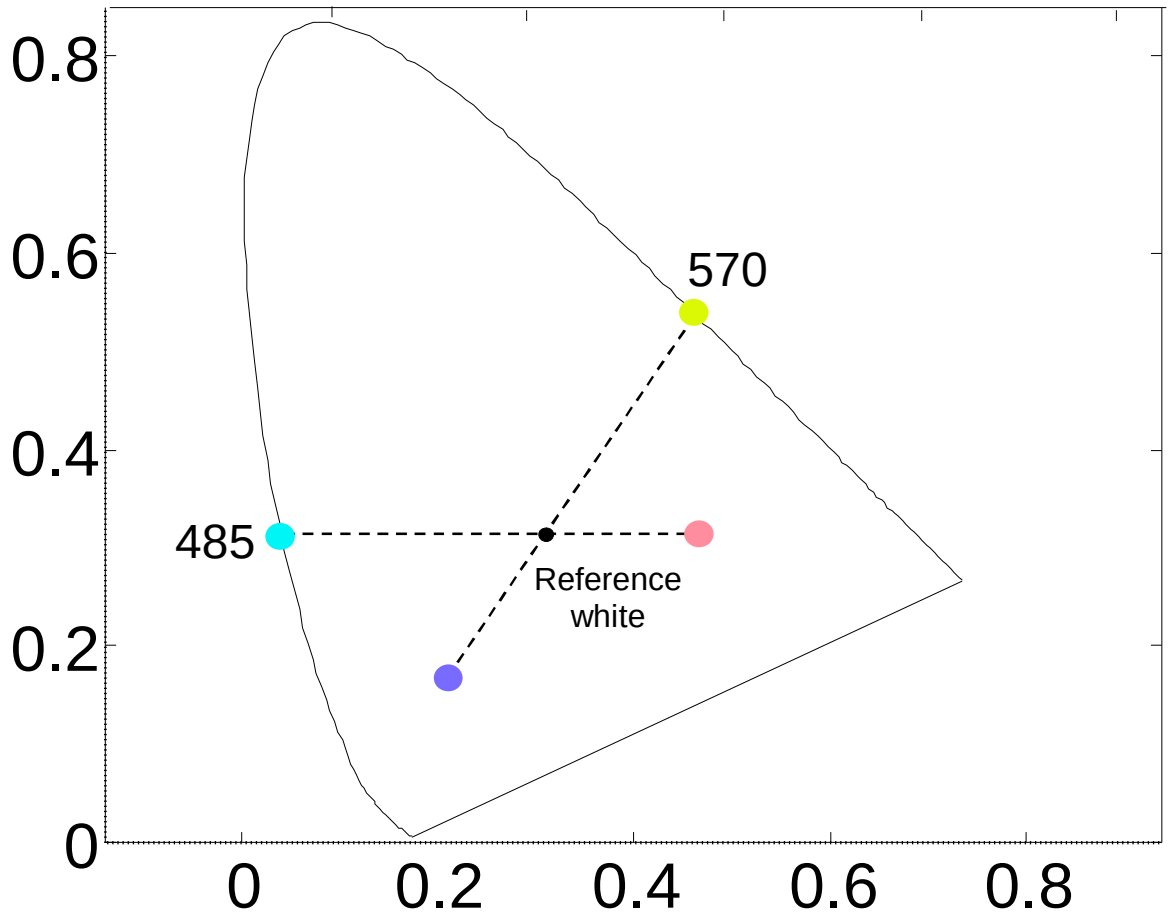
Dominant Wavelength –
wavelength of the spectral color which added to the reference white, produces the given color.



Chromaticity in Polar Coordinates

Given a reference white.

Complementary Wavelength –
wavelength of the spectral color which added to the given color, produces the reference white.

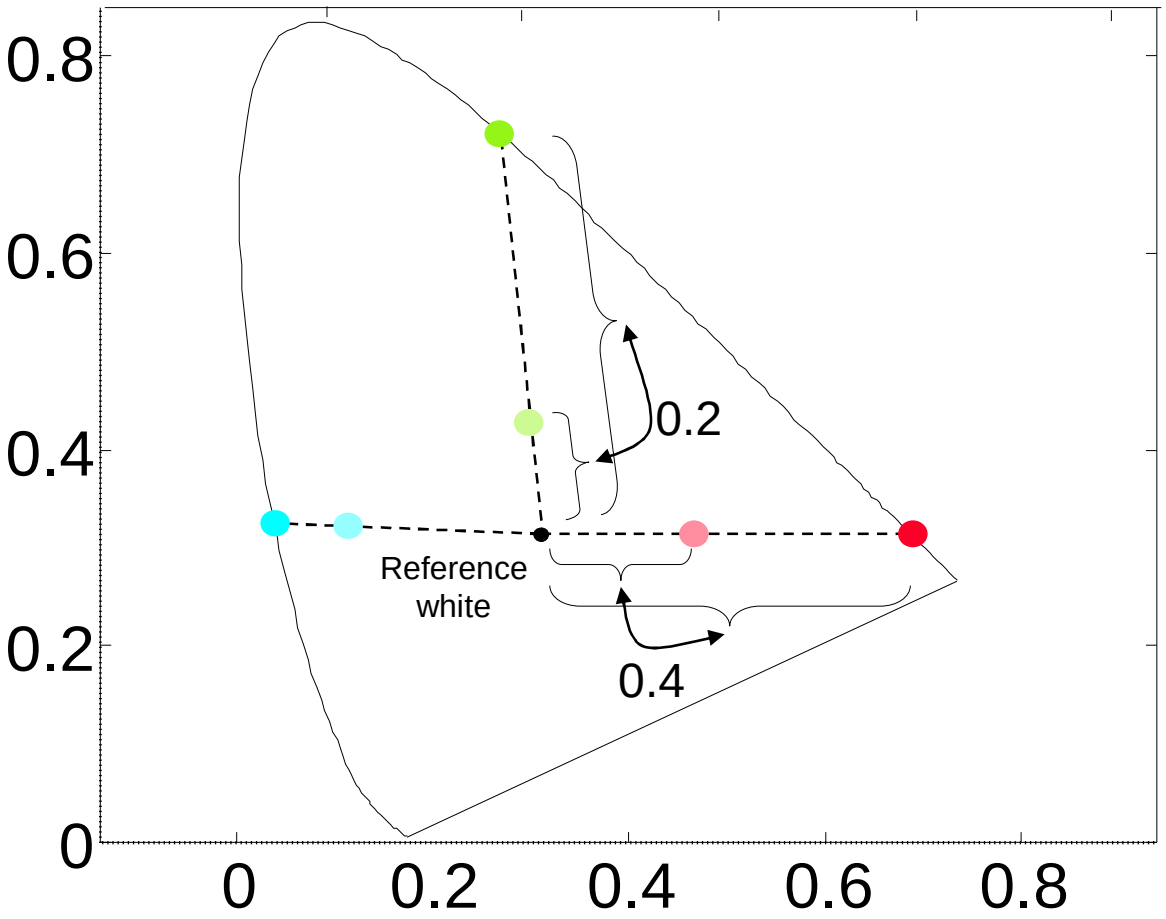


Chromaticity in Polar Coordinates

Given a reference white.

Purity –

the ratio of the lengths between the given color and reference white and between the dominant wavelength and reference white. Ranges between 0 .. 1.



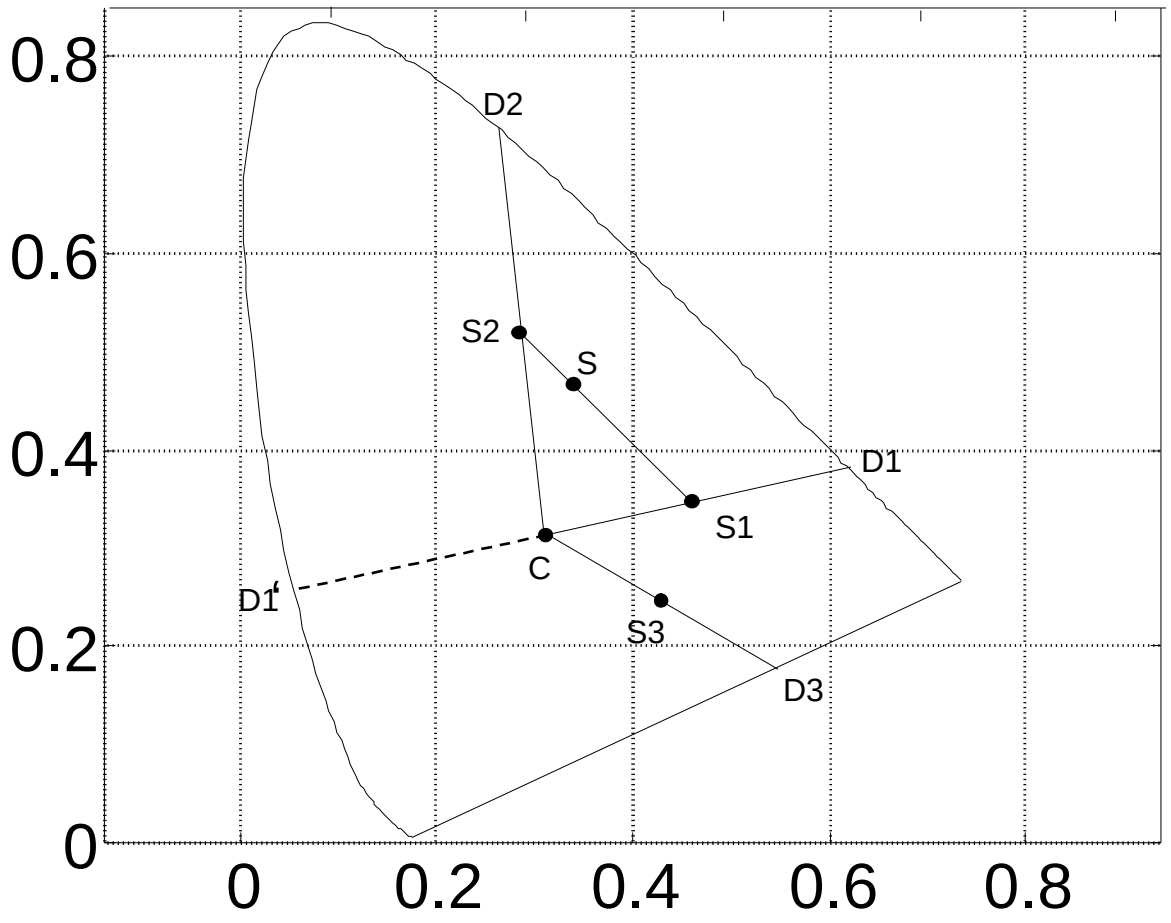
EXAMPLE:

Reference white is CIE standard illuminant - C.

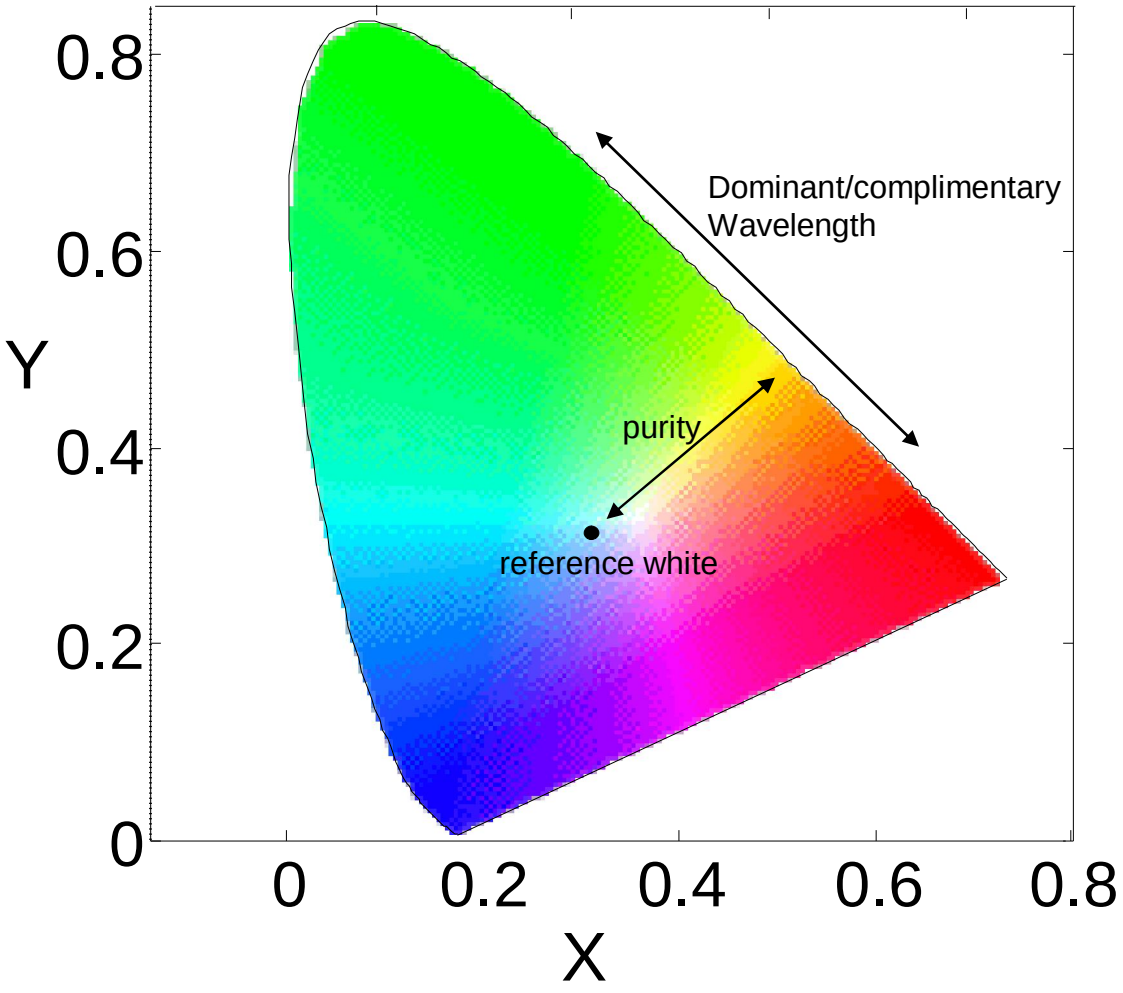
Dominant Wavelength of color S_1 is D_1
of color S_2 is D_2.

Complementary Wavelength of color S_1 is D_1.
S2 does not have a complimentary wavelength.

Excitation Purity of S_1 is the ratio CS_1/CD_1
of S_2 is the ratio CS_2/CD_2
of S_3 is the ratio CS_3/CD_3



Chromaticity in Polar Coordinates

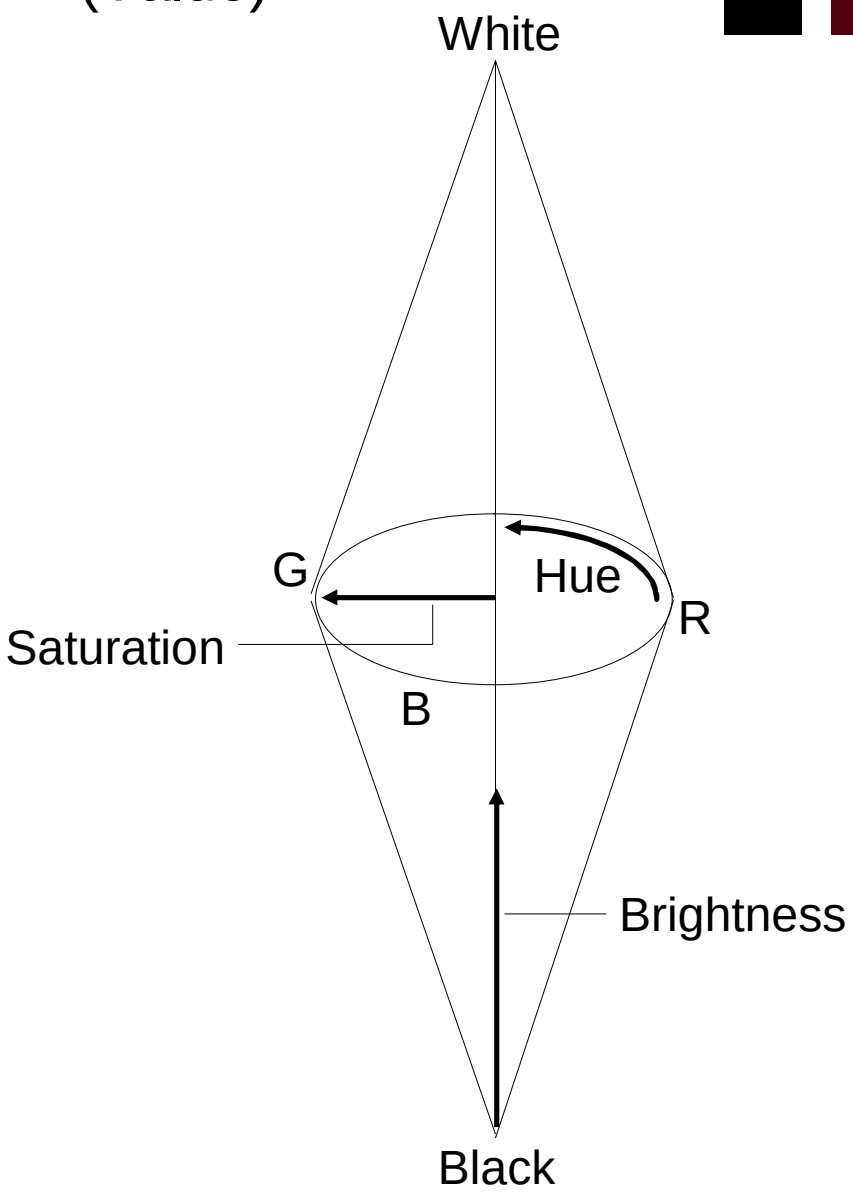


Color Description

Hue (red, green, yelow, blue ...)

Saturation (pink,bright red, ...)

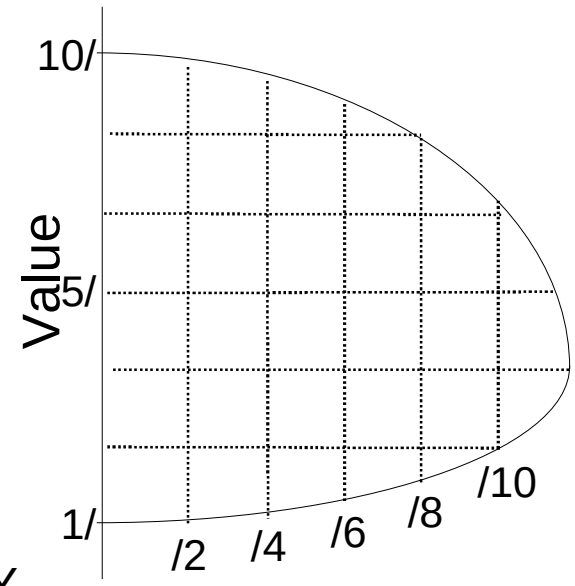
Lightness (black, grey, white ....)
(Value)

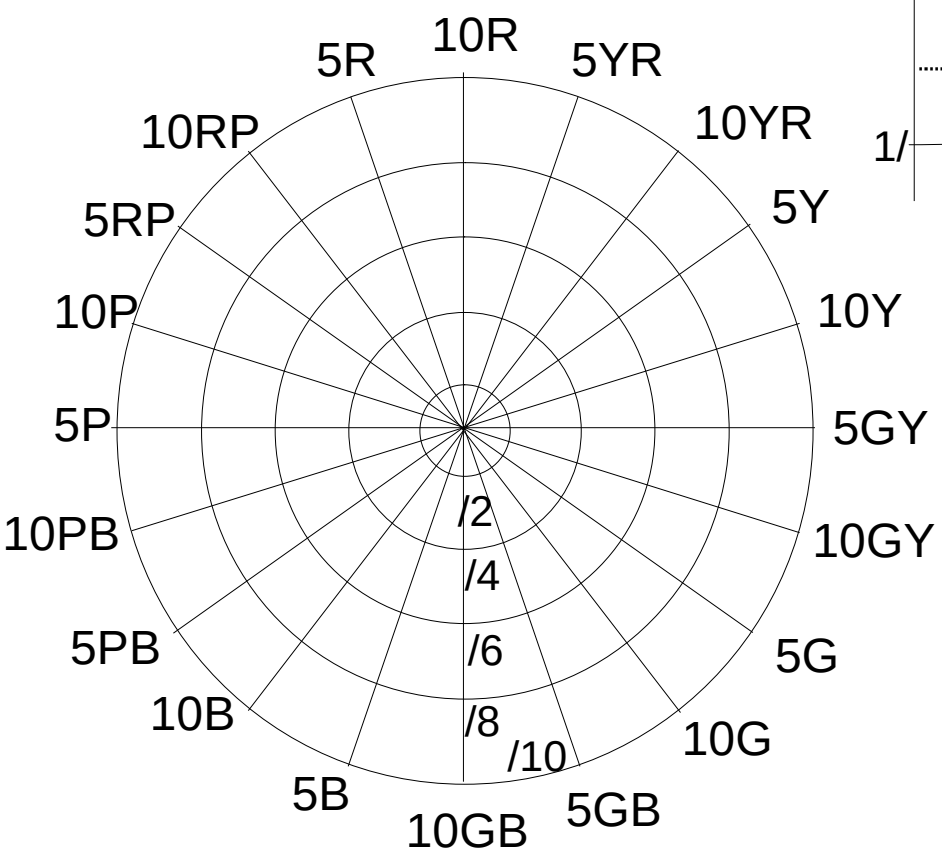


Munsell Color System (1915)

Equal perceptual steps in Hue Saturation Value.

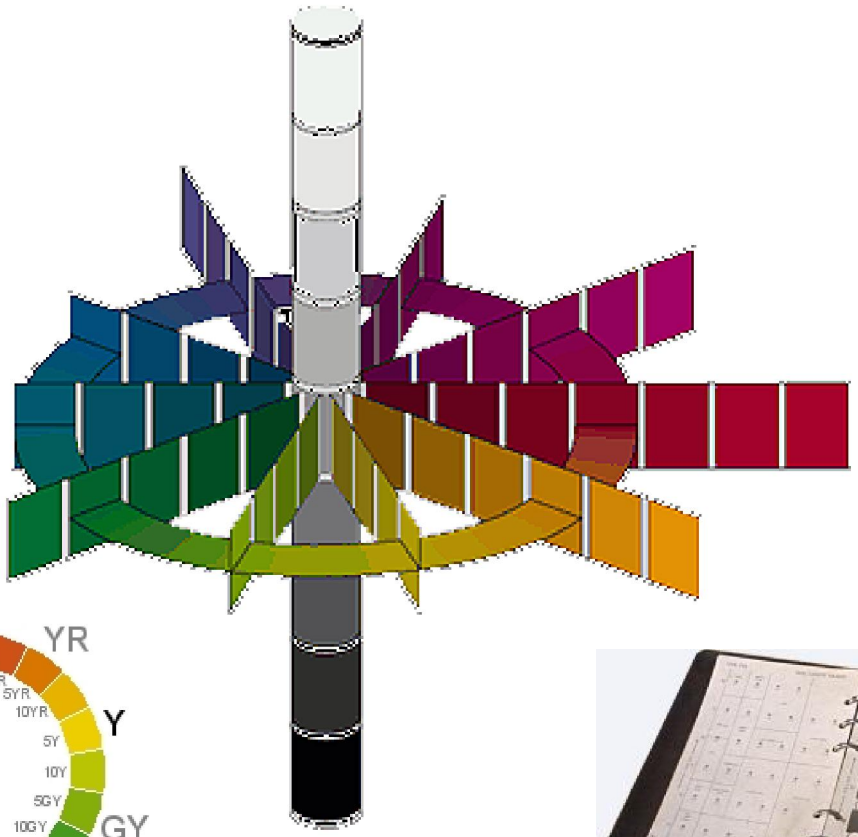
Hue: R, YR, Y, GY, G, BG, B, PB, P, RP
(each subdivided into 10)
Chroma: 0 ... 20 (neutral ... saturated)
Value: 0 ... 10 (dark ... pure white)

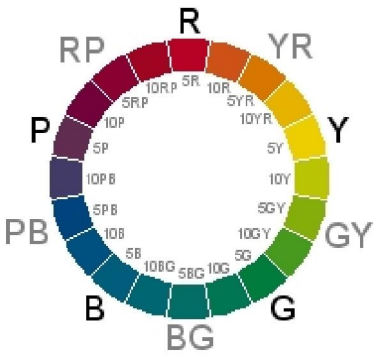


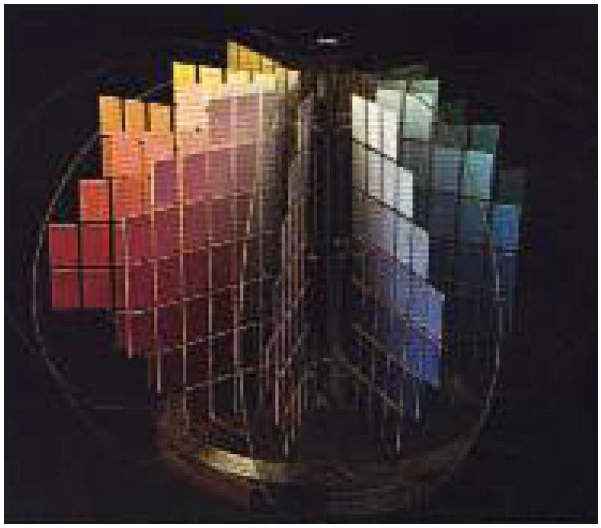


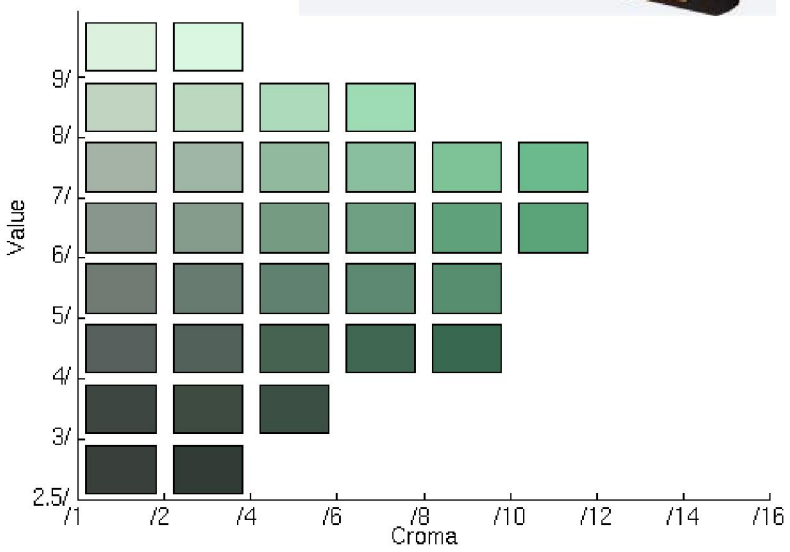
Example:
5YR 8/4

Munsell Book of Colors



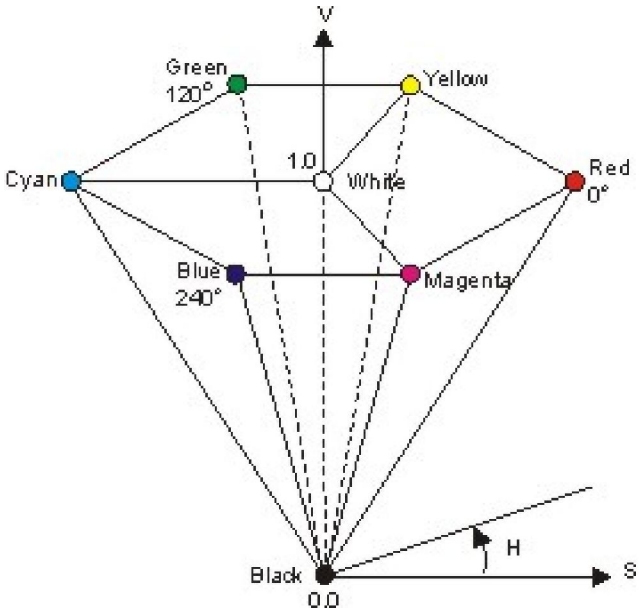


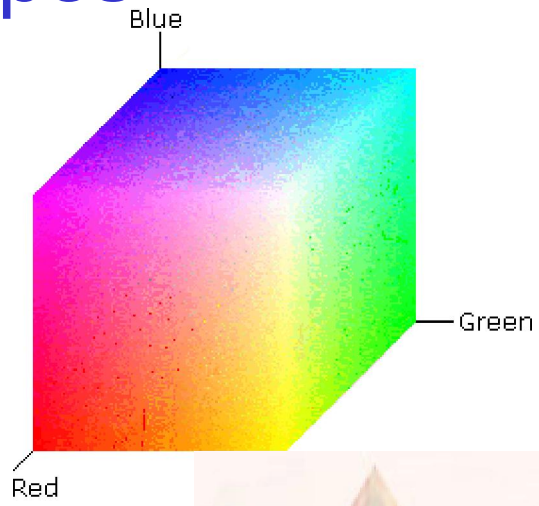


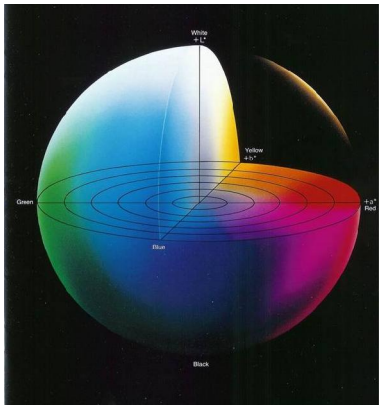


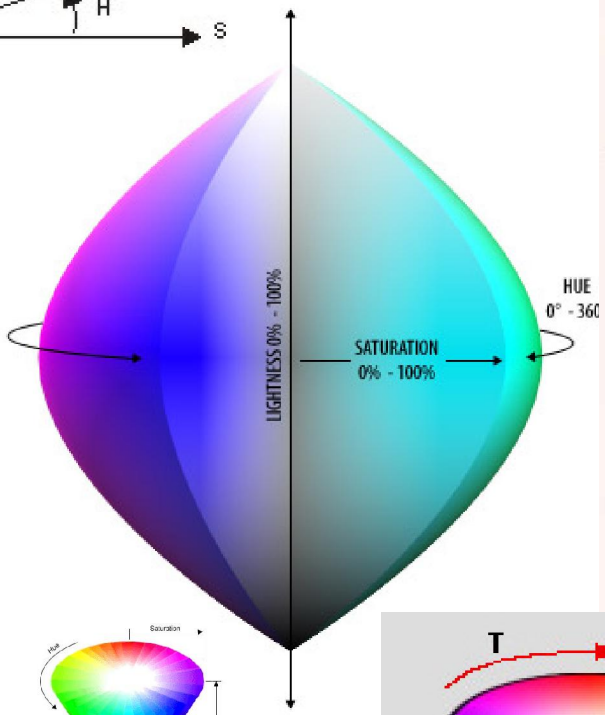
Atlas of thr Munsell Color System (1915)

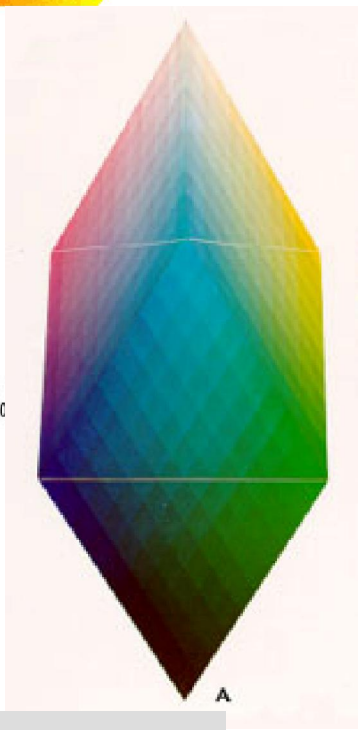
Color Polytopes

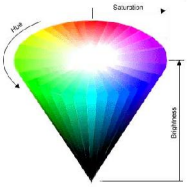


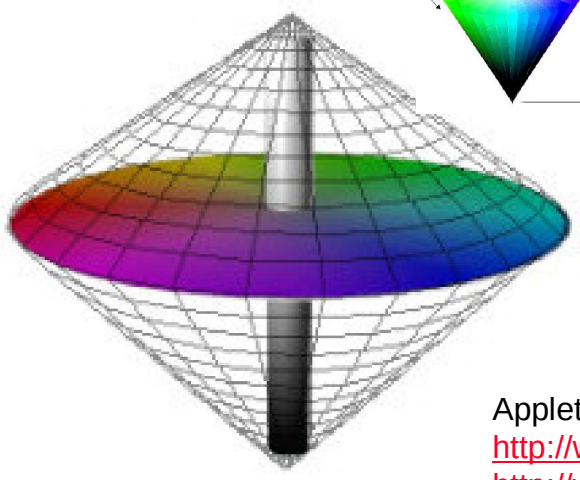


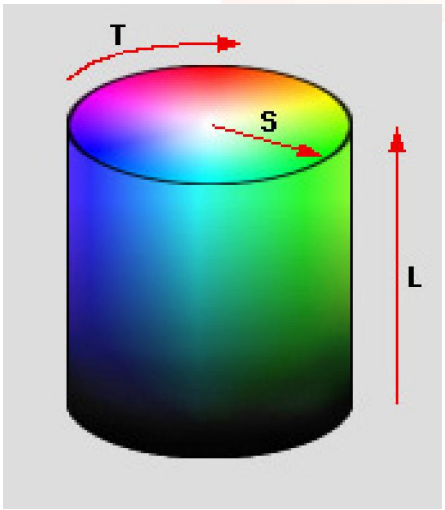






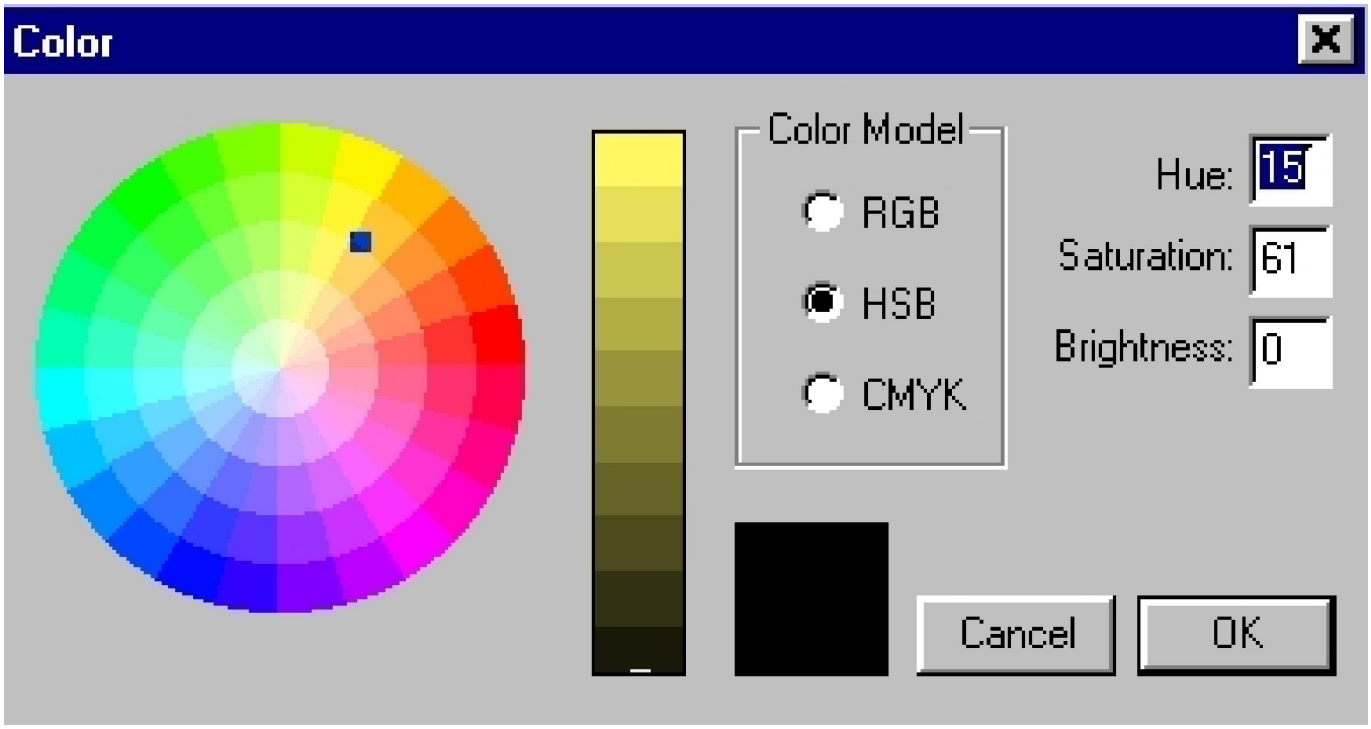




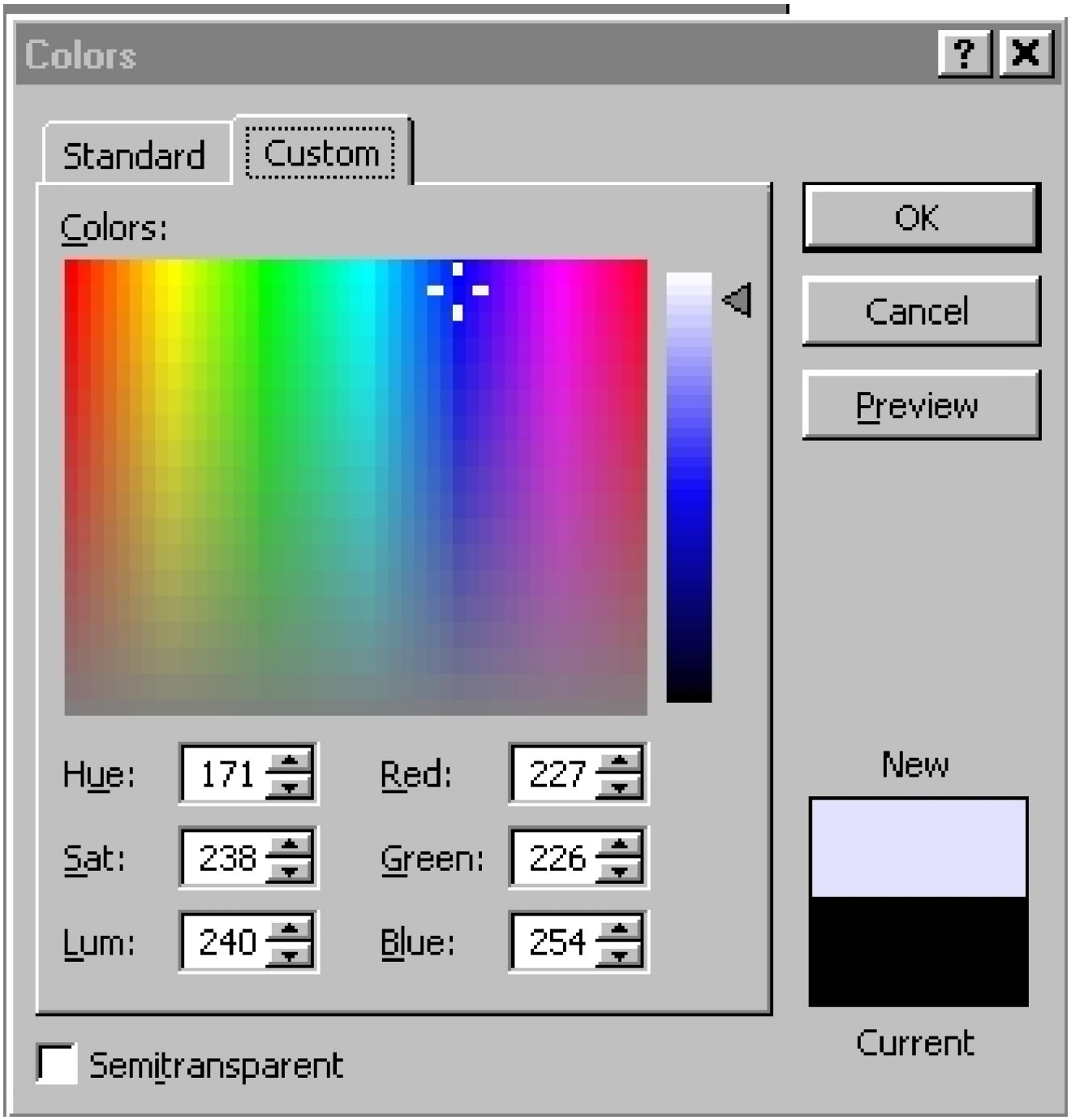


Applets:
http://www.cs.rit.edu/~ncs/color/a_spaces.html
http://www.nacs.uci.edu/~wiedeman/cspace/me/rgbhsv.html

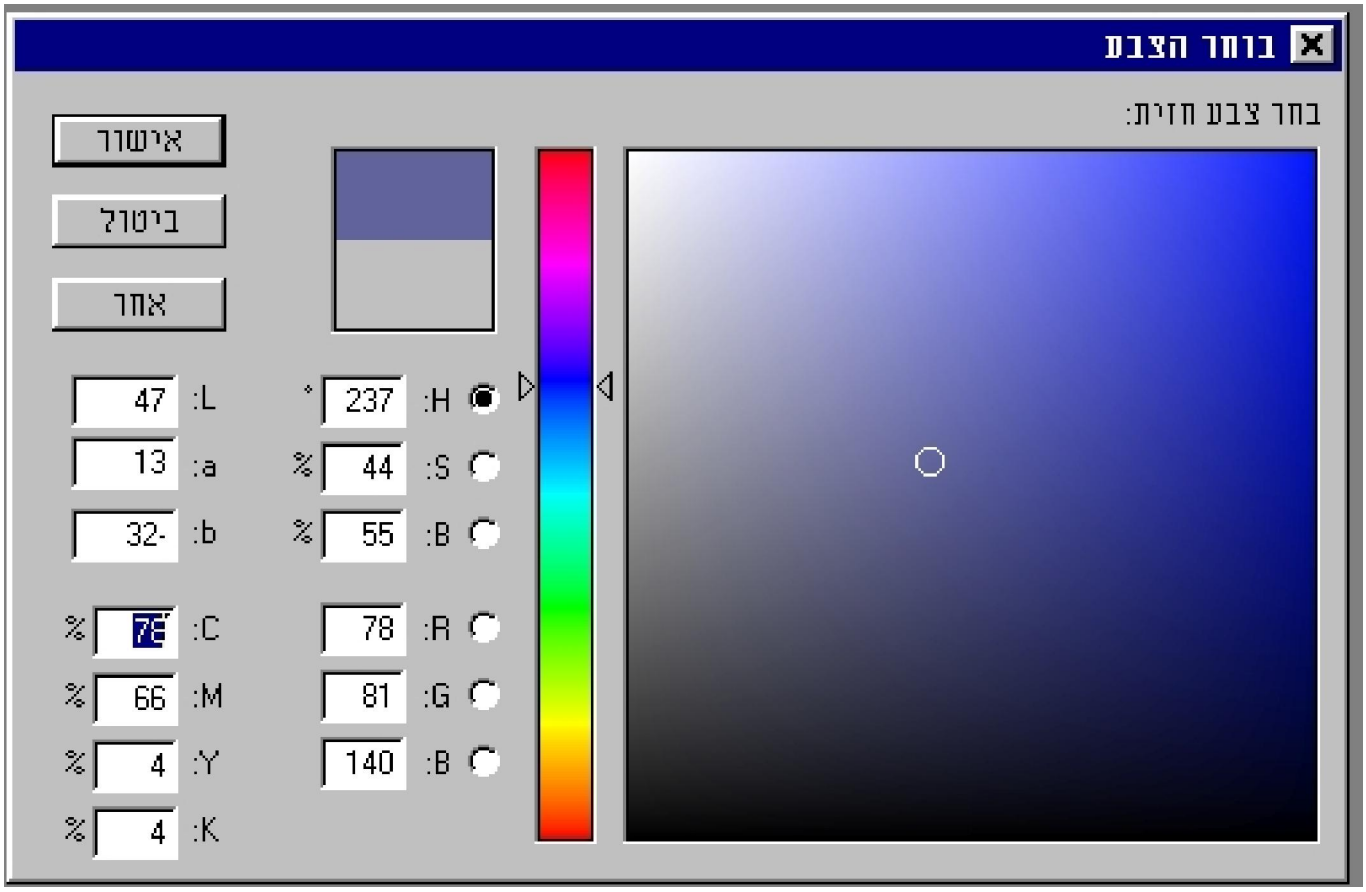
MayuraDraw



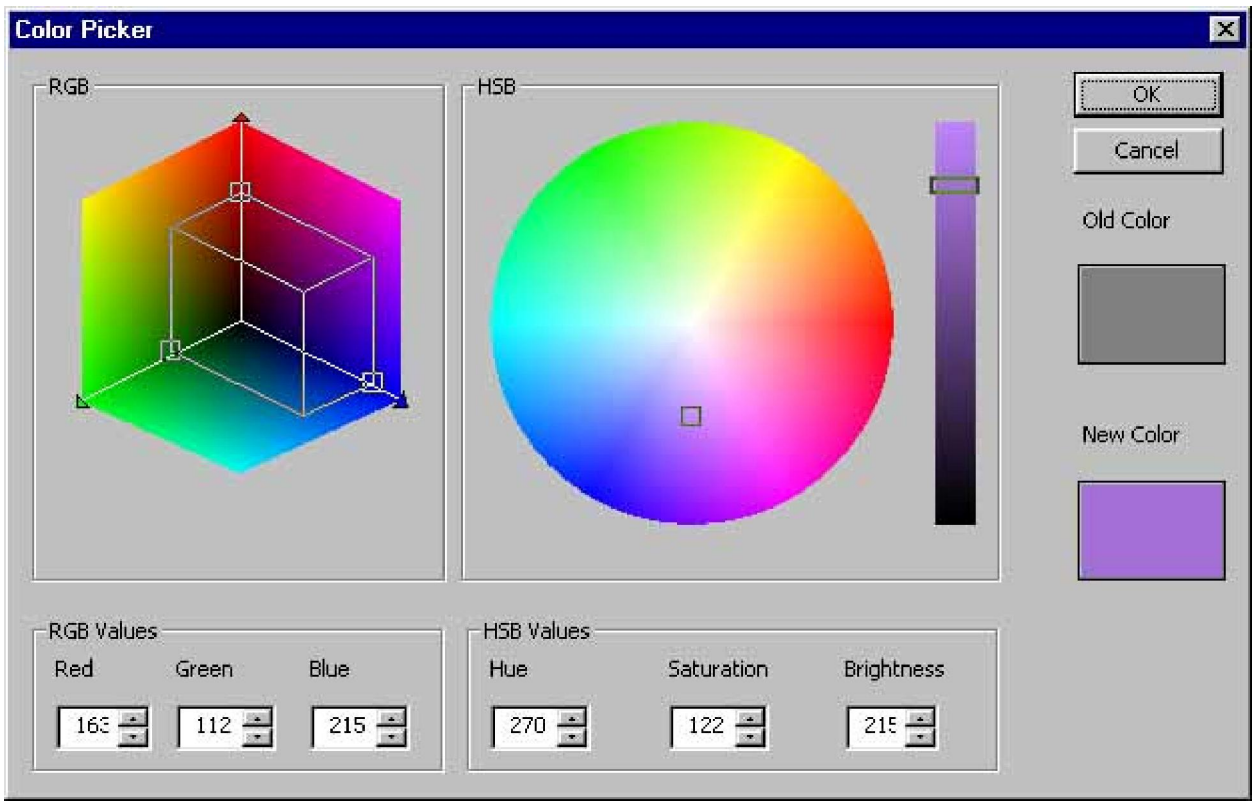
PowerPoint



Photoshop



Color Picker



Color Space Summary

Spectral Power Distribution (SPD) – High Dimensional

3 Dimensional Spaces:

LMS -
Human Cone responses. Given by the cone sensitivity curves.

CIE–RGB -
Based on color Matching Experiments by Wright+Guild.
Defined by Primaries R G B (monochromatic 435.8 546.1 700 nm) and cmf $\bar{r}$ $\bar{g}$ $\bar{b}$.

CIE-XYZ -
Standard Color space. Linear transformation of above that confirms to set of constraints.
Defined by Primaries X Y Z (unrealizable) and cmf $\bar{x}$ $\bar{y}$ $\bar{z}$.

Munsell Color Space –
Perceptually equally spaced samples in 3 dimensions: Hue, Chroma, Value.