Multimedia Systems

Part 7

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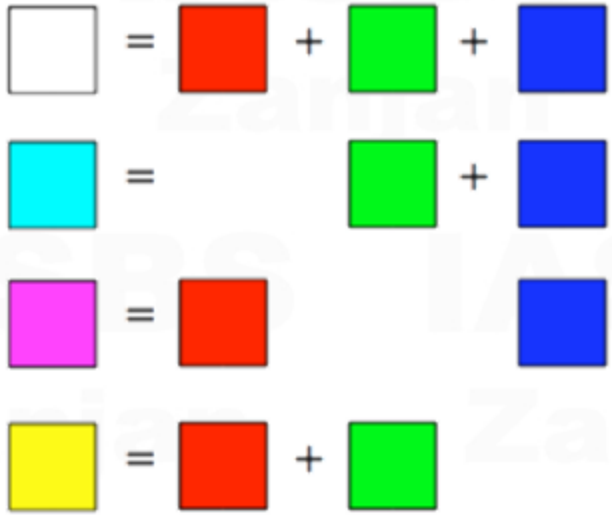
To discuss …

- Color Science
- Color Models in image

Color Matching

Grassmann's "Law"



Chromatic sensation is *linear*

Let:

- Beam 1 color-match (R_1, G_1, B_1)
- Beam 2 color-match (R_2, G_2, B_2)

Then:

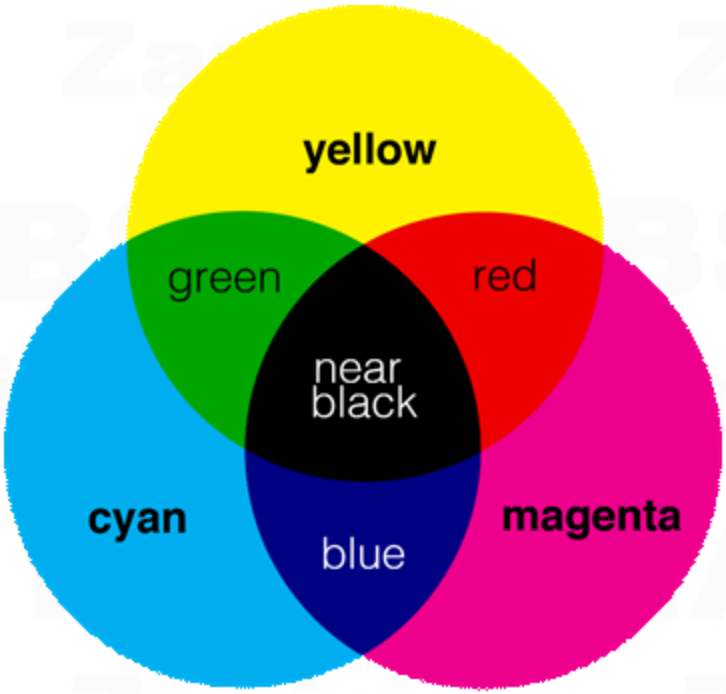
$\alpha \times$Beam 1 + $\beta \times$Beam 2 matches

($\alpha R_1 + \beta R_2$, $\alpha G_1 + \beta G_2$, $\alpha B_1 + \beta B_2$)

Holds for any set of primaries of any size, defines:

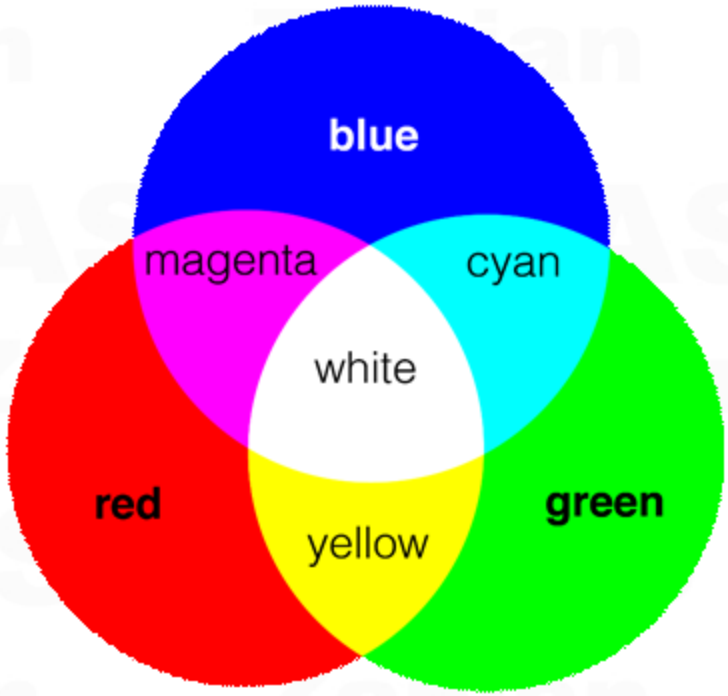
additive color model

Color Matching



Subtractive Model

pigment



Additive Model

light

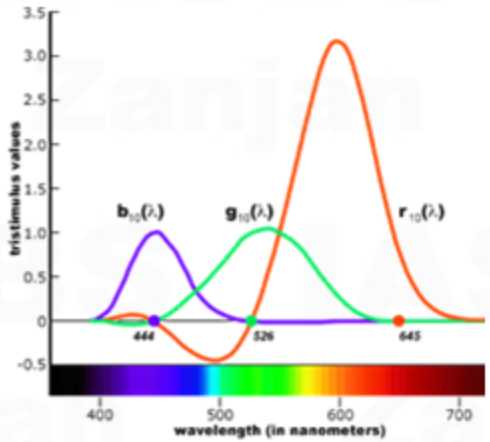
Color Matching

Wright and Guild experiments (1920s)

- Choose lights of 3 different primary colors
- Show a user single-wavelength light
- Ask to match it with a weighted combination of the primaries

Primaries standardized by the CIE in 1931

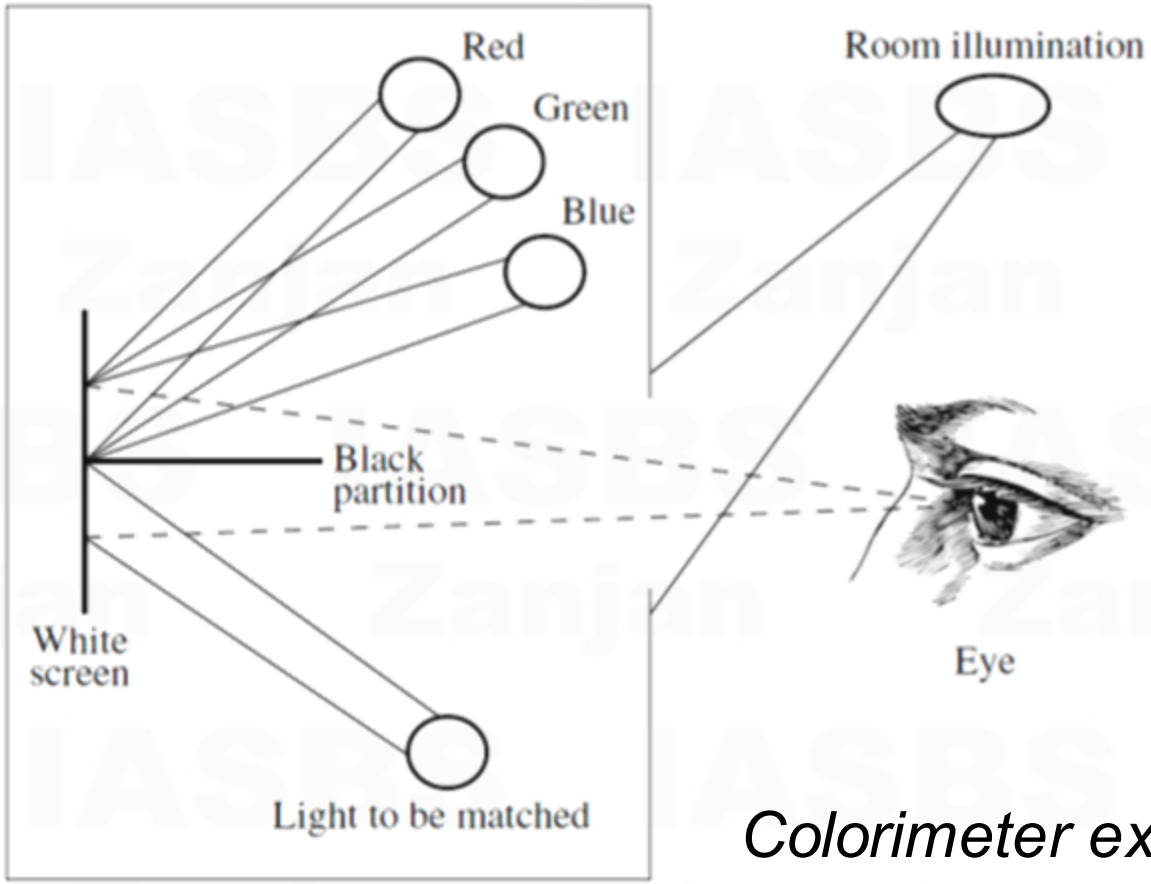
- Red (R): 700 nm
- Green (G): 546.1 nm
- Blue (B): 436 nm



1931 RGB Color-Matching Functions

Color Matching

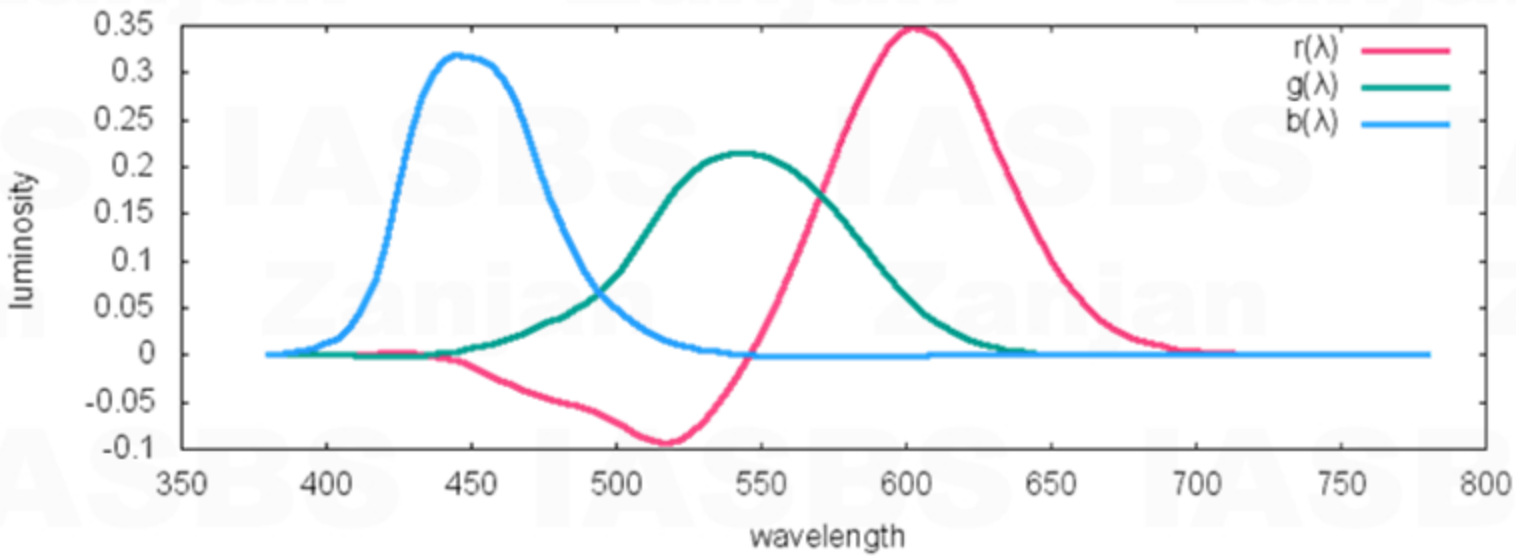
Wright and Guild experiments (1920s)



Colorimeter experiment

Color Matching

the 1931 RGB color matching functions



Primaries standardized by the CIE in 1931

- Red (R): 700 nm
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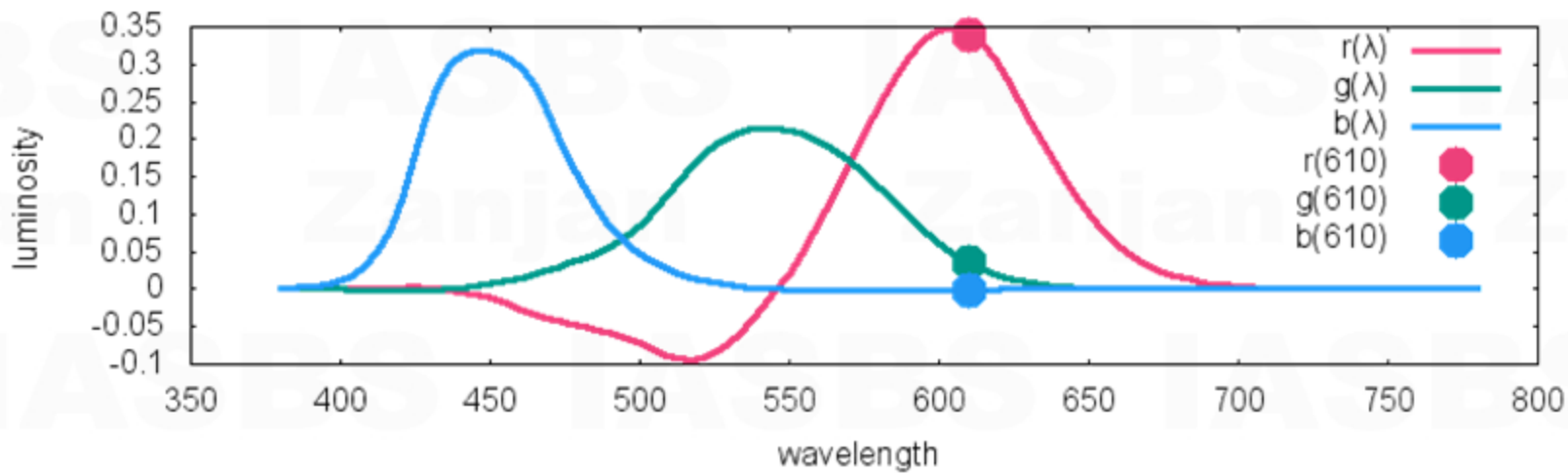
Color Matching

Suppose a target wavelength of 610nm. the goal is to reproduce the color of this light with our primary lights.



λ = 610nm

r(λ) = 0.34756

g(λ) = 0.04776

b(λ) = -0.00038

Color Matching

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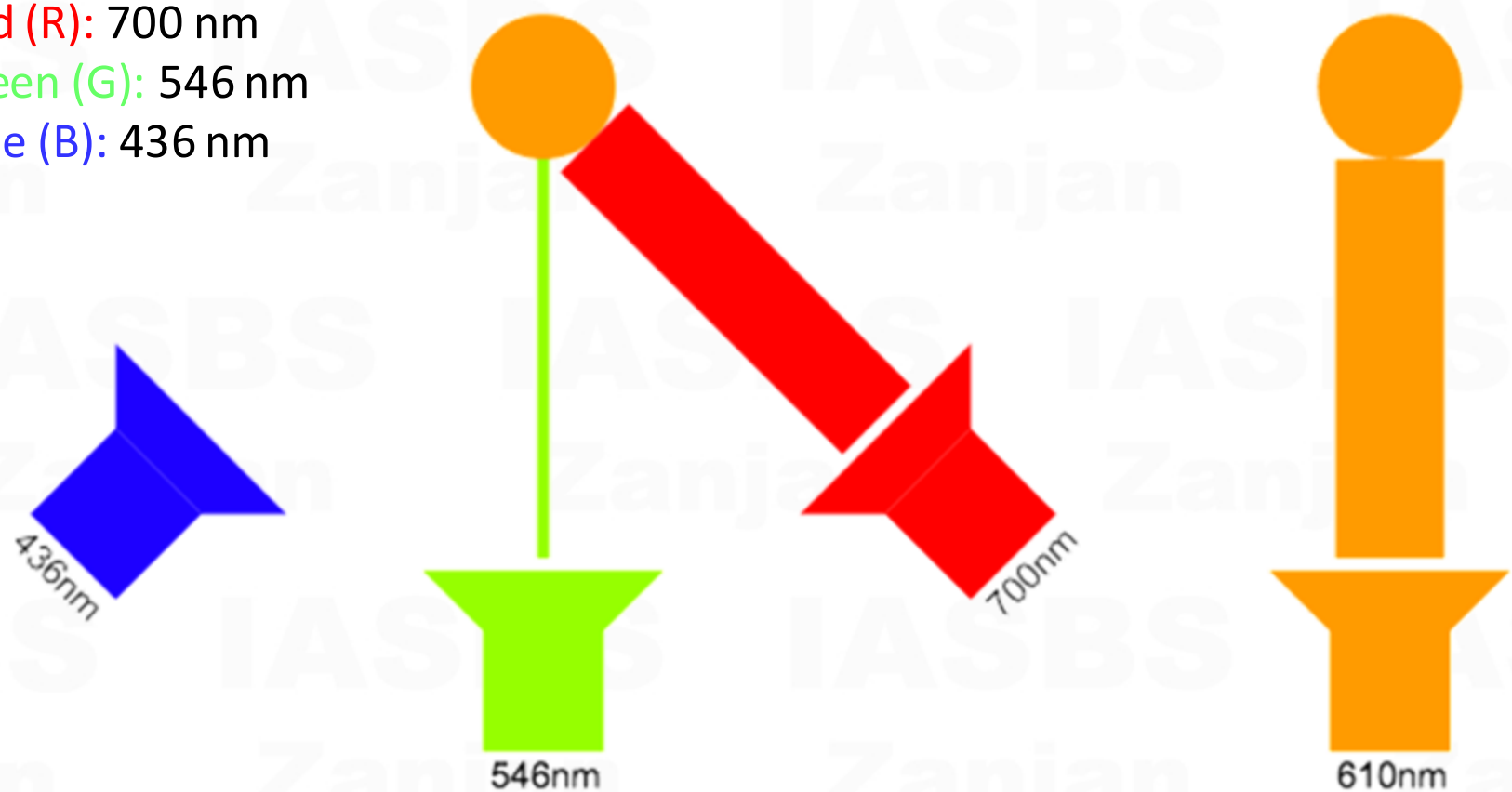
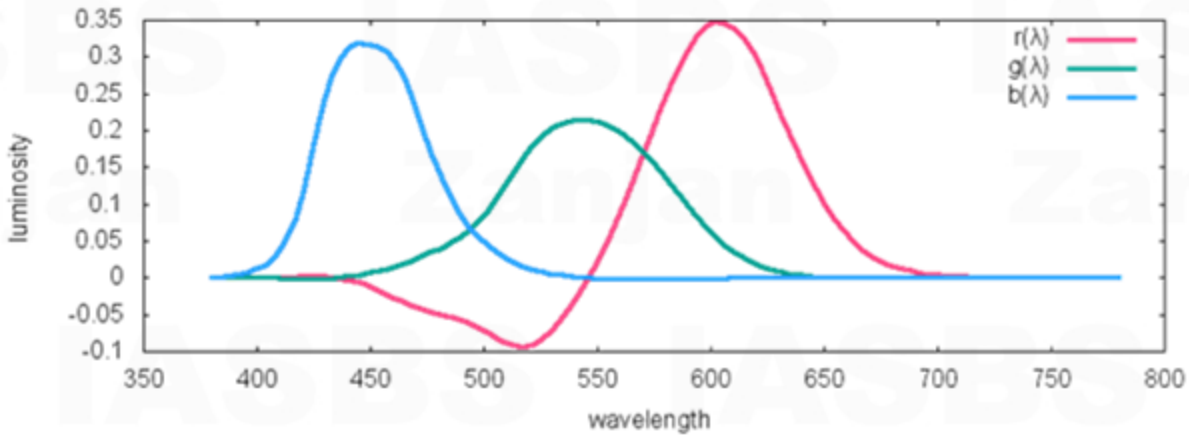
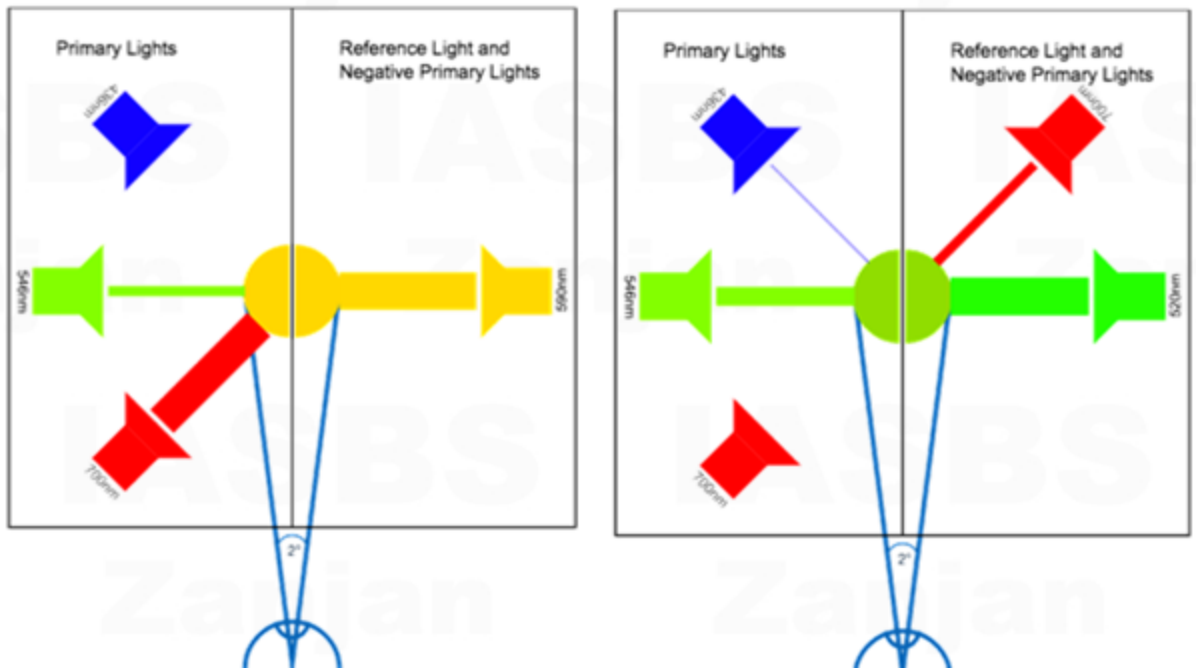


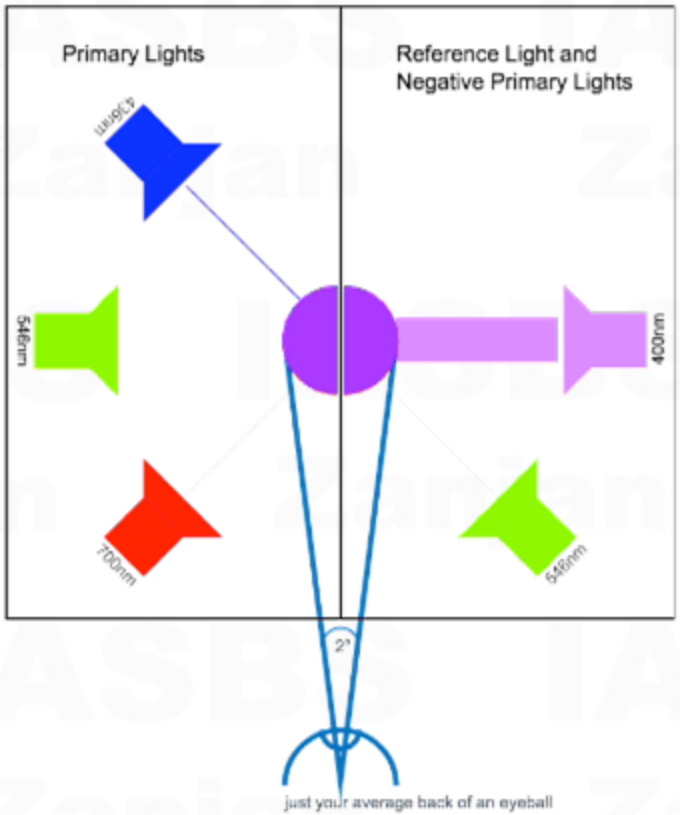
Color Matching

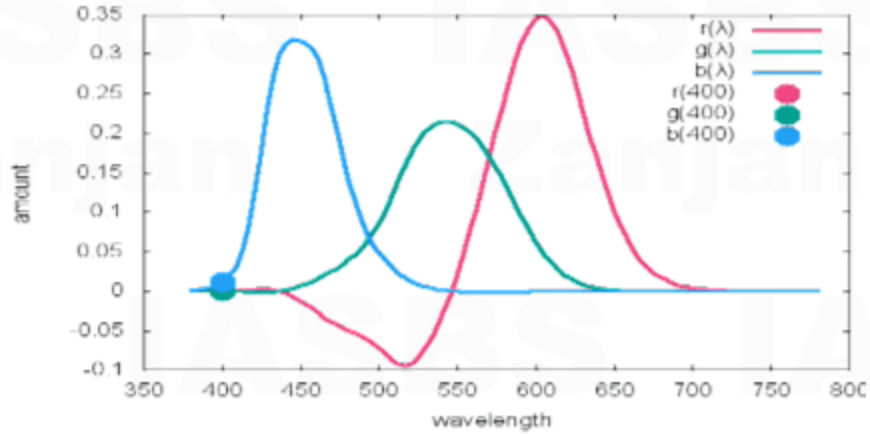


Why are some parts of the curves negative?



Color Matching



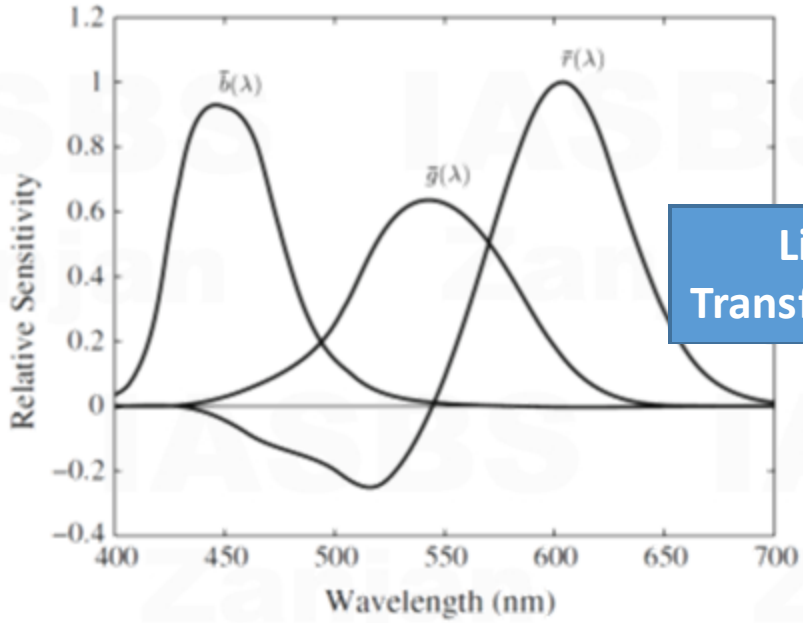


The CIE decided to use imaginary lights :

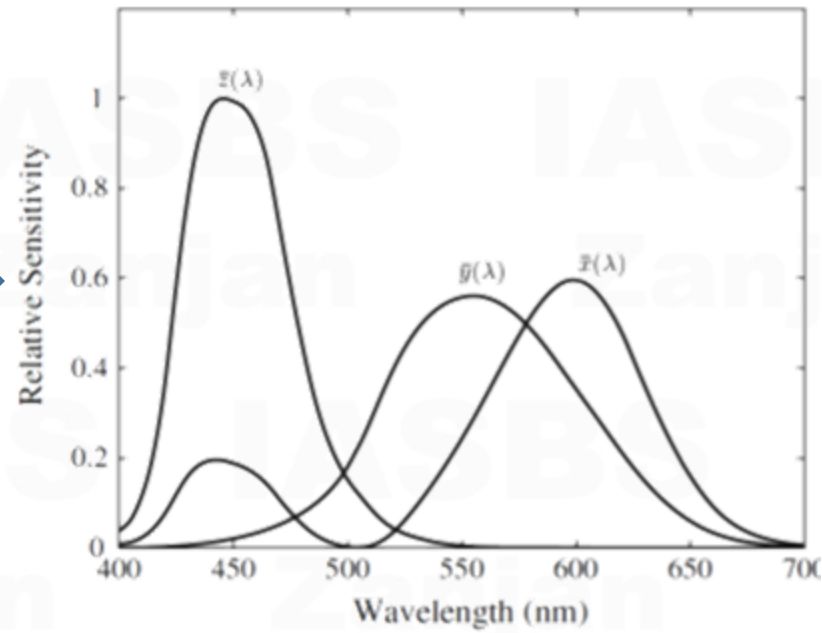
- one of the lights is “gray” and provides no hue information
- the other two lights have zero luminance and provide only hue

XYZ color space

The resulting curves (color-matching functions)



Linear Transformation

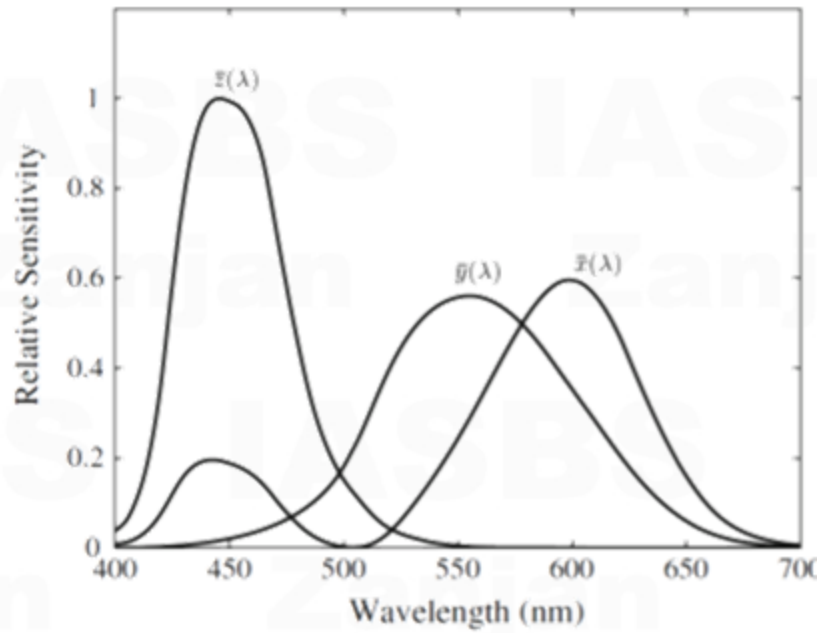


$$\begin{bmatrix}\bar{x}\\ \bar{y}\\ \bar{z}\end{bmatrix} = \mathrm{M}\begin{bmatrix}\bar{r}\\ \bar{g}\\ \bar{b}\end{bmatrix} \qquad M = \begin{bmatrix}0.49 & 0.31 & 0.20\\ 0.17697 & 0.81240 & 0.01063\\ 0.00 & 0.01 & 0.99\end{bmatrix}$$

XYZ color space

color-matching functions

For a general SPD, E(λ), The response for these three lights is defined by the triple (*X*, *Y*, *Z*) where ***Y*** is the ***luminance*** (brightness/perceived intensity)



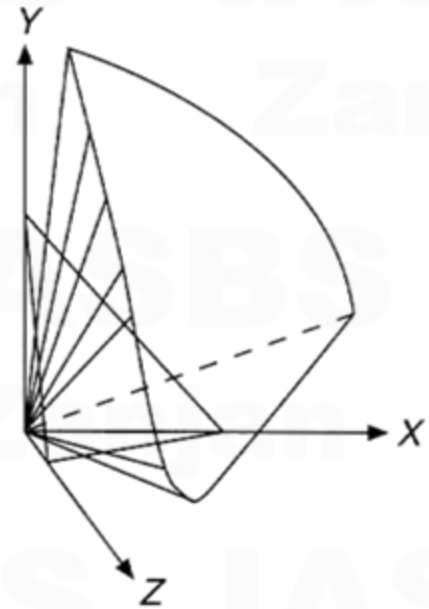
$$X = \int E(\lambda)\,\bar{x}(\lambda)\,d\lambda$$
$$Y = \int E(\lambda)\,\bar{y}(\lambda)\,d\lambda$$
$$Z = \int E(\lambda)\,\bar{z}(\lambda)\,d\lambda$$

tristimulus values

XYZ color space

Increasing the brightness of illumination (E) increases the tristimulus values (X,Y & Z) by a scalar multiple.

CIE devised a 2D diagram based on the values of (X, Y, Z) by factoring out the magnitude of vectors (X, Y, Z)



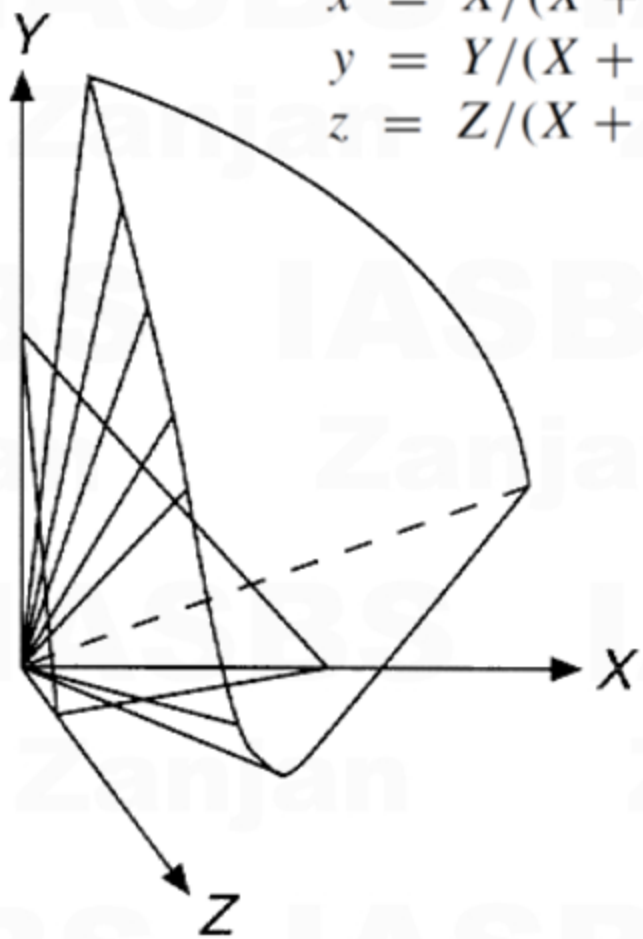
$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z)$$
$$z = Z/(X+Y+Z)$$

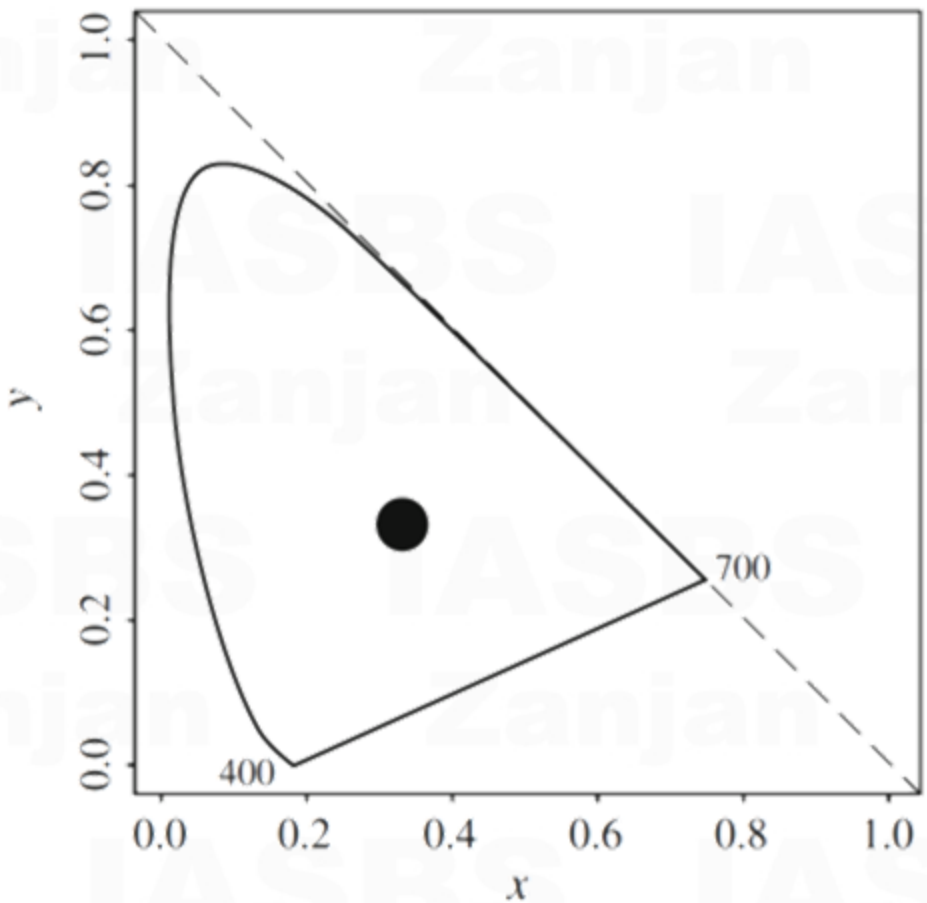
$$x + y + z = \frac{X+Y+Z}{X+Y+Z} \equiv 1$$

$$z = 1 - x - y$$

XYZ color space

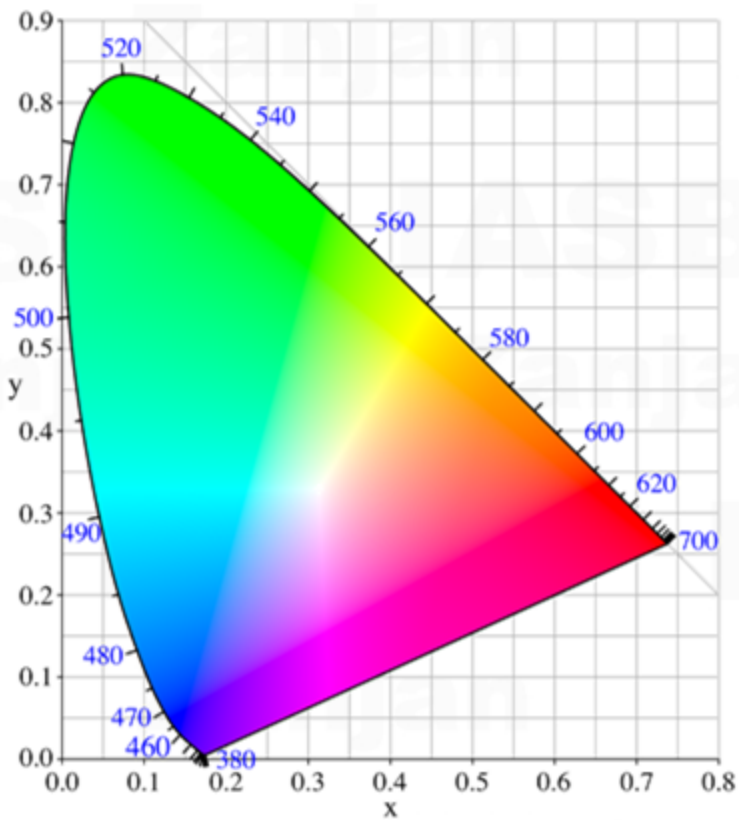
$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z)$$
$$z = Z/(X+Y+Z)$$



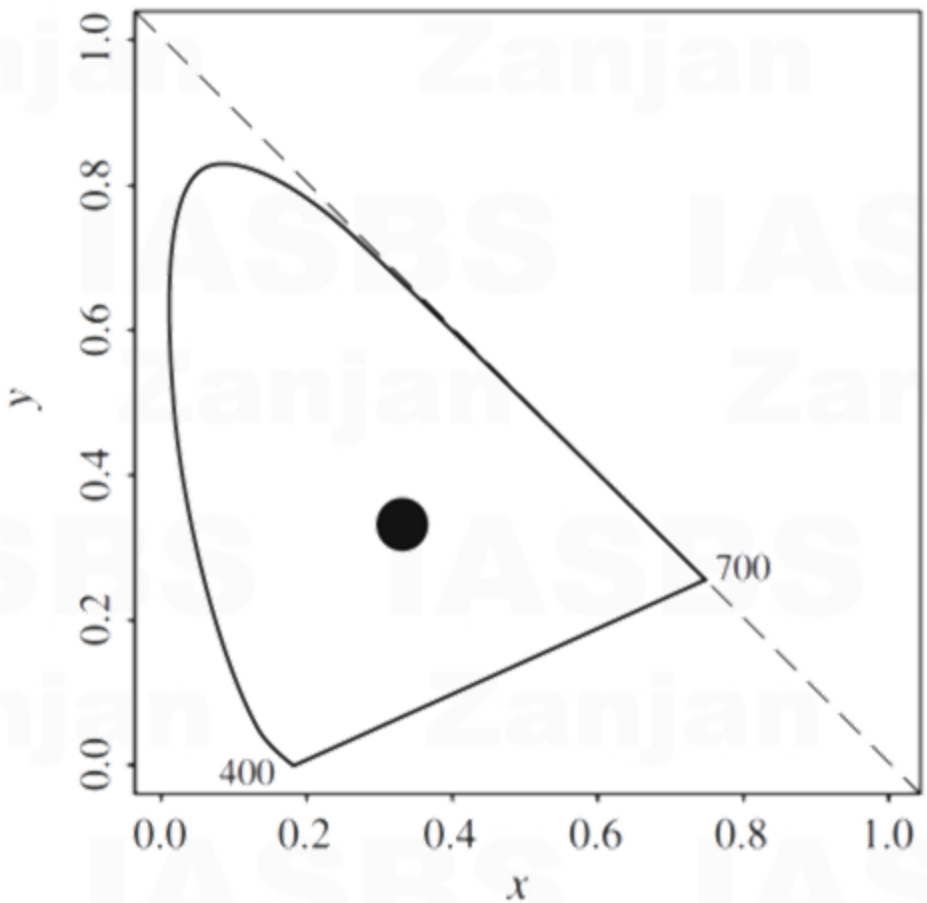


we are projecting each tristimulus vector (X, Y, Z) onto the plane connecting points (1, 0, 0), (0, 1, 0), and (0, 0, 1).

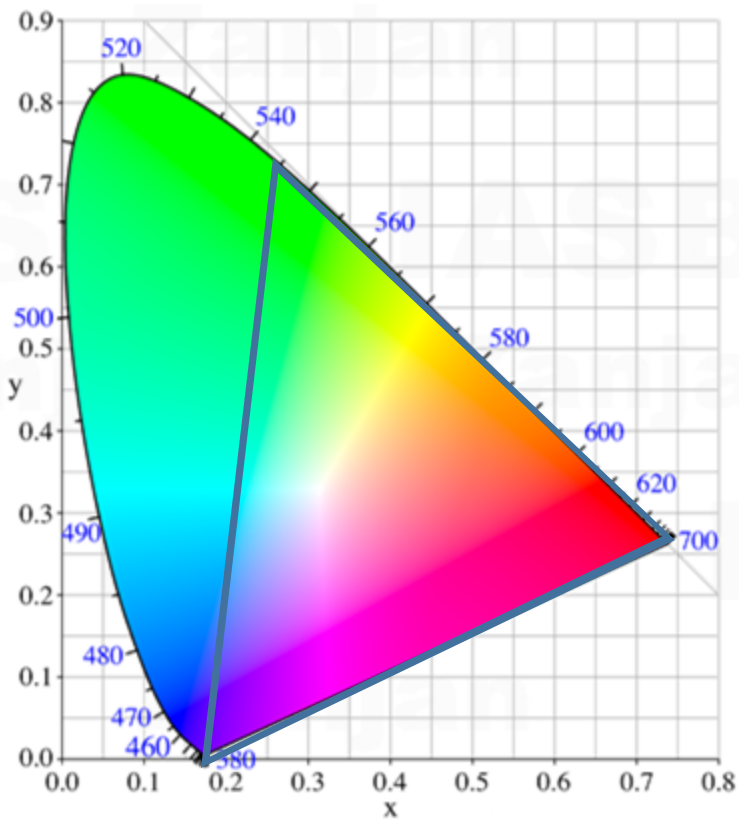
XYZ color space



CIE chromaticity diagram



XYZ color space



- spectral colors on the outer curve
- non-spectral colors inside the curve
- no realizable color outside the curve
- original RGB primaries fall on the curve

- Every point inside the triangle formed by the primaries is a chromaticity that can be created with those lights.

white illuminant

- illuminant C (0.310063, 0.316158)
- D65 (0.312713, 0.329016)