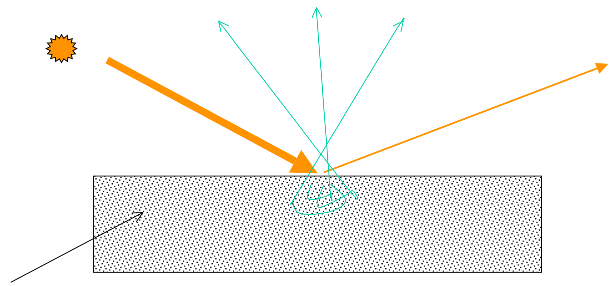
Example: Dielectrics

- Examples: Paints, plastics
- Reasonably well approximated by a specular part and a Lambertian body part.



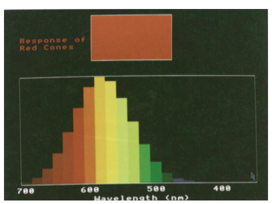
Non conductive matrix with scattering particles of the order of the wavelenth of light---note: the same general process explains why the sky is blue.

Trichromaticity

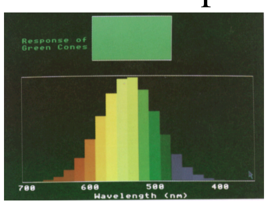
Empircal fact--colors can be approximately described/matched by three quantities (assuming normal color vision).

Need to reconcile this observation with the spectral characterization of light

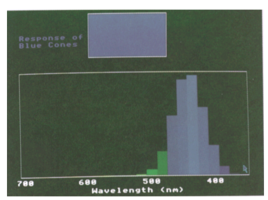
Color receptors



“Red” cone



“Green” cone



“Blue” cone

Principle of univariance: cones give the same kind of response, in different amounts, to different wavelengths. Output of cone is obtained by summing over wavelengths.
Responses measured in a variety of ways

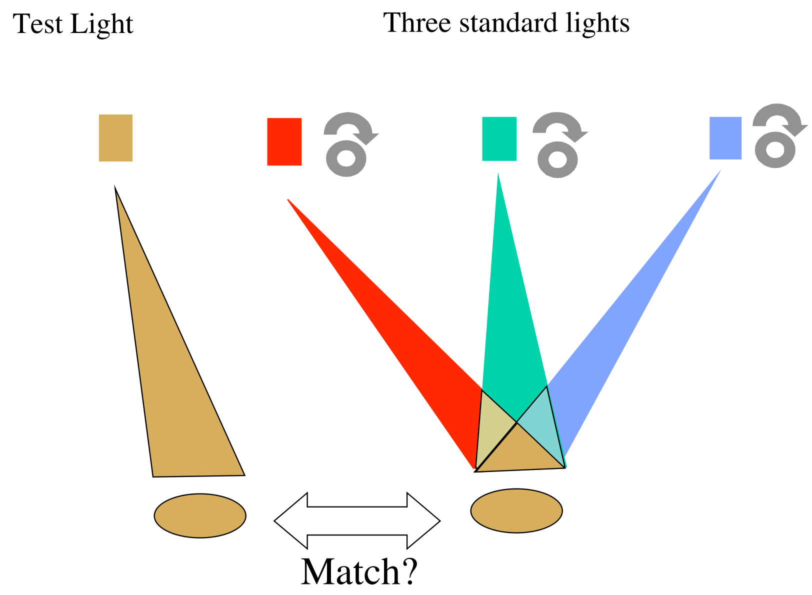
Response of k’th cone = $\int \rho_k(\lambda)E(\lambda)d\lambda$

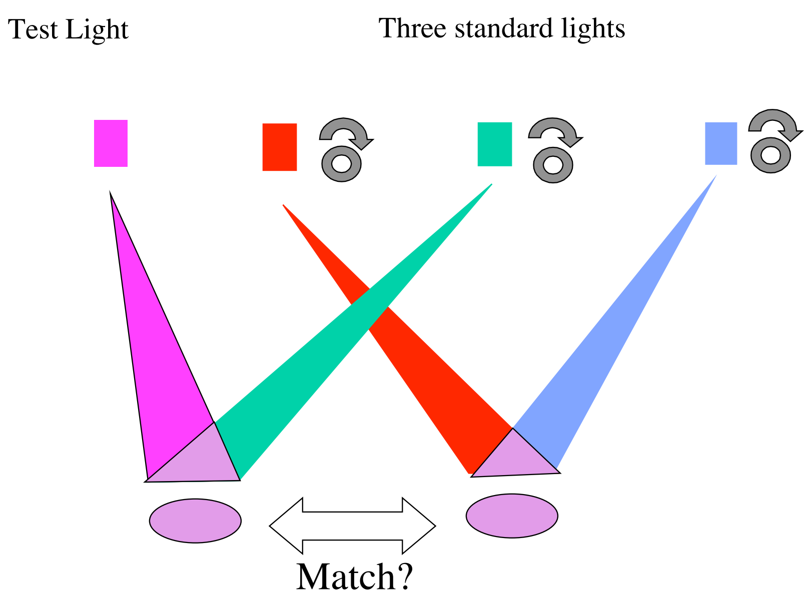
Colour Reproduction

Motivates specifying color numerically (there are other reasons to do this also)

General (man in the street) observation--color reproduction *sort of* works.

Specifying Colour





Trichromacy

Experimental fact about people (with "normal" colour vision)---matching works (for reasonable lights), provided that we are sometimes allowed negative values.

Our "knob" positions correspond to (X,Y,Z) in the standard colorimetry system.

Technical detail: (X,Y,Z) are actually arranged to be **positive** by a linear transformation, but these "knob" positions **cannot** correspond to any physical light.

Specifying Colour

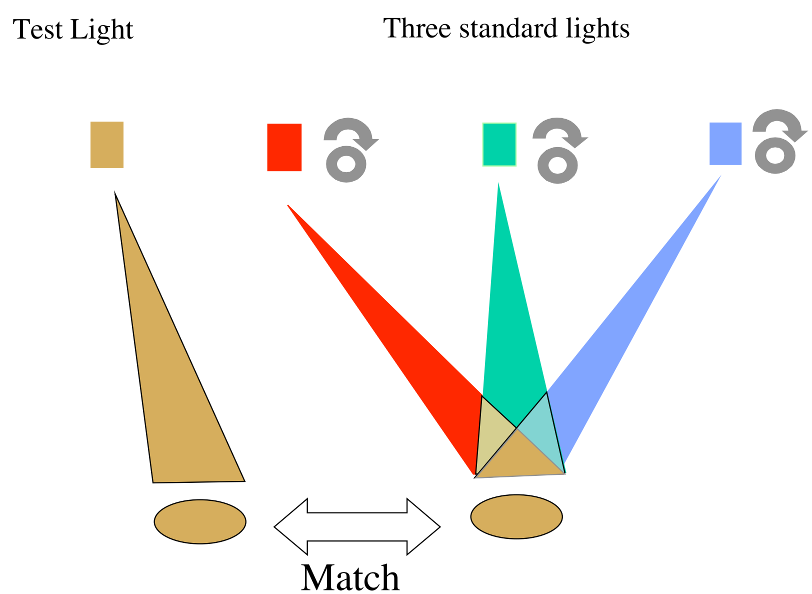
(50,150,75) (50,150,75)

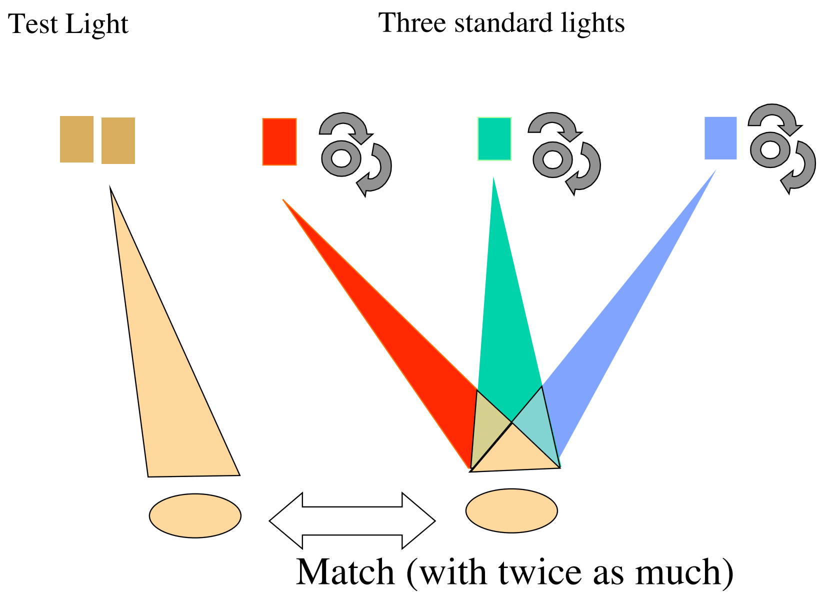
Specifying Colour

We don’t want to do a matching experiment every time we want to use a new color!

Grassman’s Contribution

Colour matching is linear



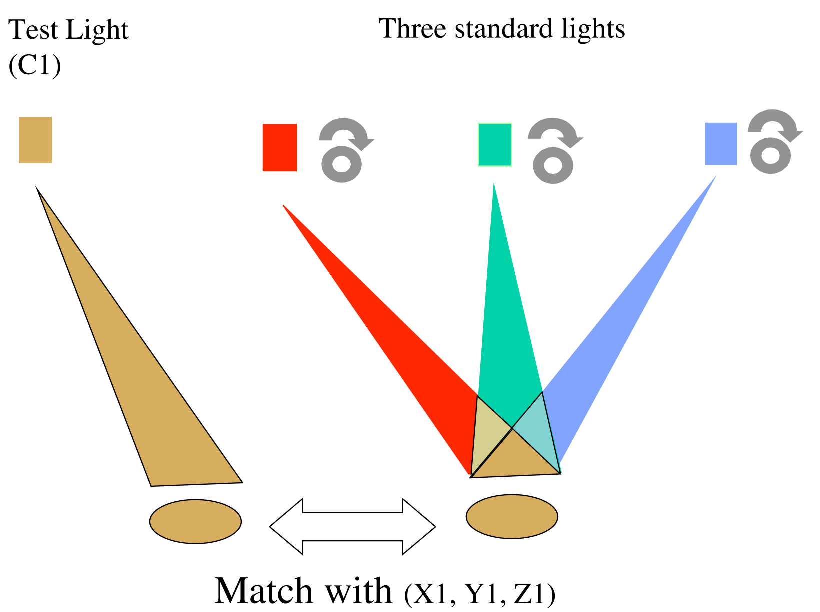


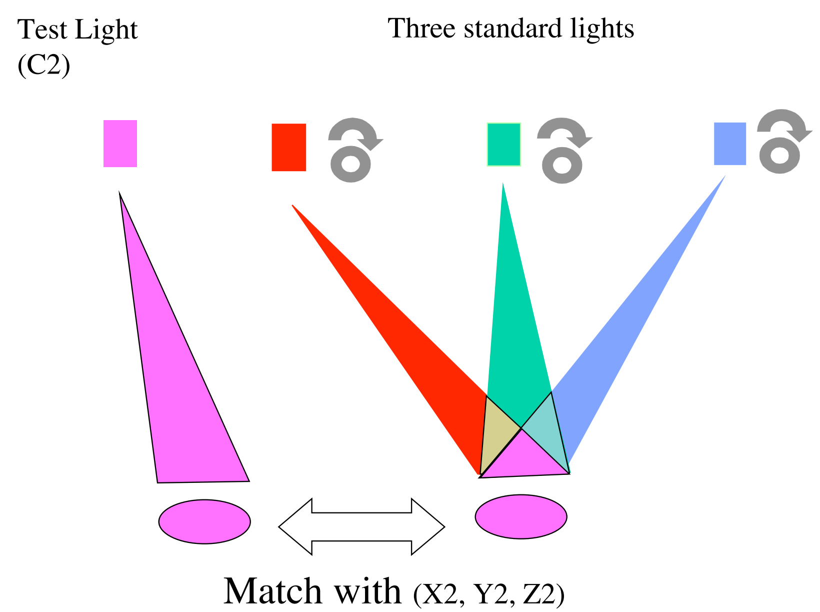
Matching is Linear (Part 1)

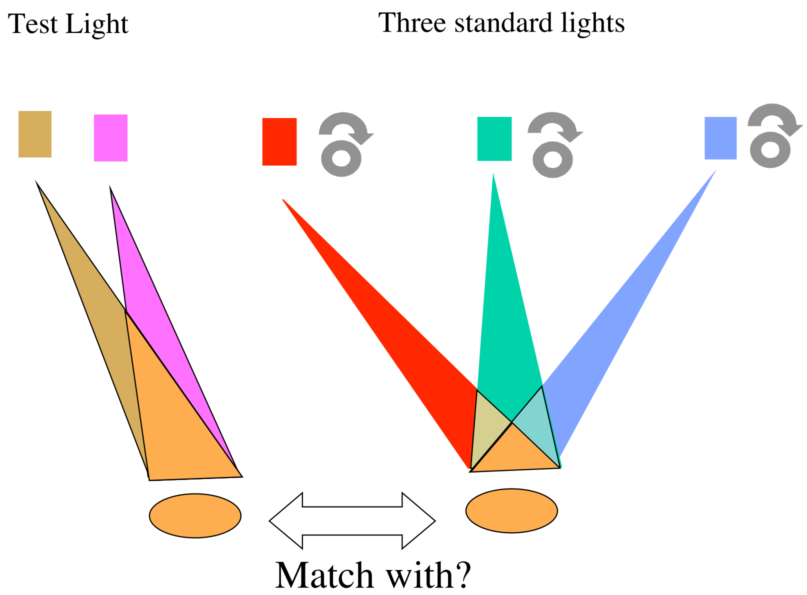
C1 is matched with (X1,Y1,Z1)

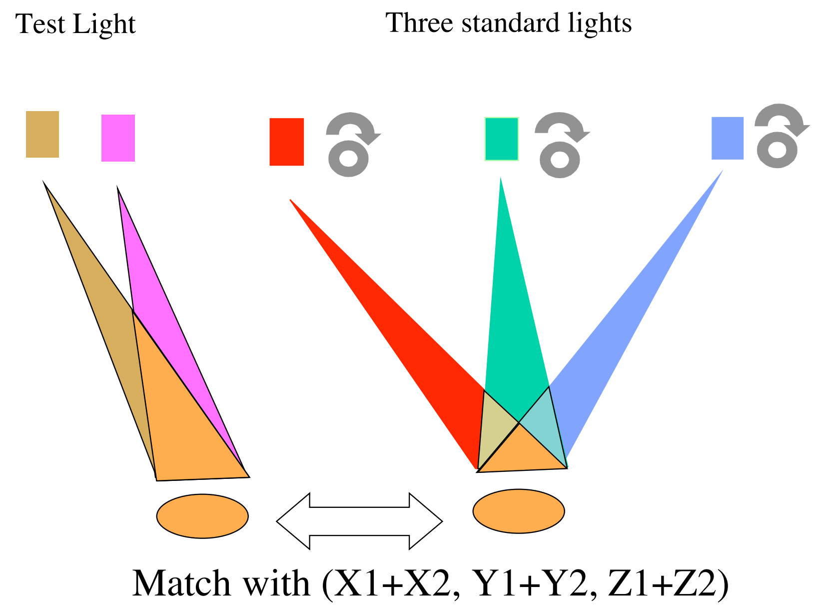
C = a*C1

C is matched with a * (X1, Y1, Z1)









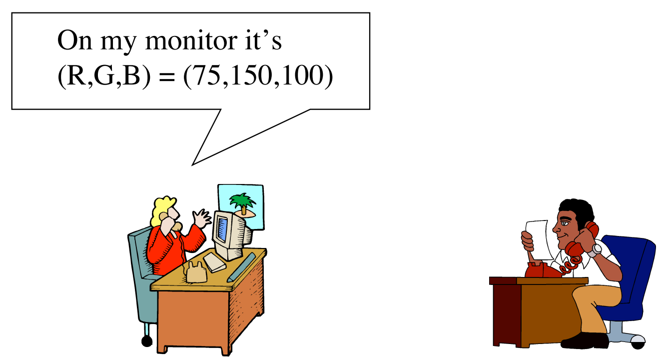
Matching is Linear (formal)

C = a*C1 + b*C2

C1 is matched with (X1,Y1,Z1)
C2 is matched with (X2,Y2,Z2)

C is matched by
a*(X1,Y1,Z1) + b*(X2,Y2,Z2)

Specifying Color



Specifying Colour

But what is (R,G,B)?

Specifying Colour

R matches (X_r, Y_r, Z_r)

G matches (X_g, Y_g, Z_g)

B matches (X_b, Y_b, Z_b)

Specifying Colour

Then by
(R,G,B)=(75,150,100)
you mean (X,Y,Z),
where …..

$$X = 75^* X_r + 150^* X_g + 100^* X_b$$

$$Y = 75^* Y_r + 150^* Y_g + 100^* Y_b$$

$$Z = 75^* Z_r + 150^* Z_g + 100^* Z_b$$

(No need to match--just compute!)

Specifying Colour

… , now that we have specified the colour, I can print it!

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{vmatrix} \begin{vmatrix} 75 \\ 100 \\ 150 \end{vmatrix}$$

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{vmatrix} \begin{vmatrix} R \\ G \\ B \end{vmatrix}$$

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = M \begin{vmatrix} R \\ G \\ B \end{vmatrix}$$

Colour Reproduction
(Monitors & Projectors)

$$\left| \begin{matrix} X \\ Y \\ Z \end{matrix} \right|_{apple}$$

Find (R,G,B)

$$\left| \begin{matrix} X \\ Y \\ Z \end{matrix} \right|_{apple} = M \left| \begin{matrix} R \\ G \\ B \end{matrix} \right|_{apple}$$

$$\left| \begin{matrix} R \\ G \\ B \end{matrix} \right|_{apple} = M^{-1} \left| \begin{matrix} X \\ Y \\ Z \end{matrix} \right|_{apple}$$

$$\left| \begin{matrix} R \\ G \\ B \end{matrix} \right|_{apple} = M^{-1} \left| \begin{matrix} X \\ Y \\ Z \end{matrix} \right|_{apple}$$

Possible problems?

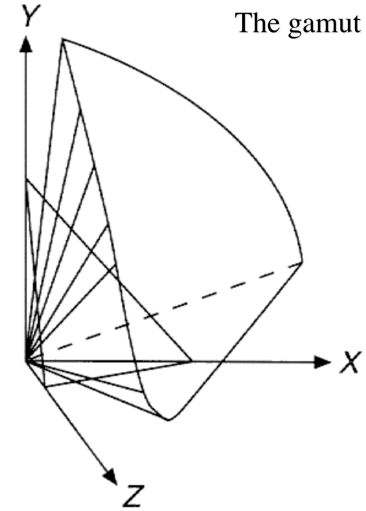
XYZ color space

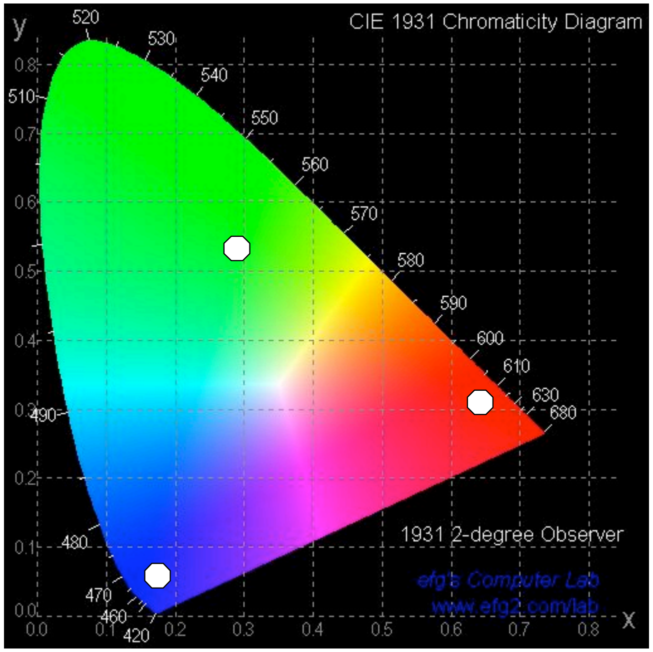
XYZ color space is a linear transformation of the matches to standard lights.

The transformation is used to ensure that all color co-ordinates are positive

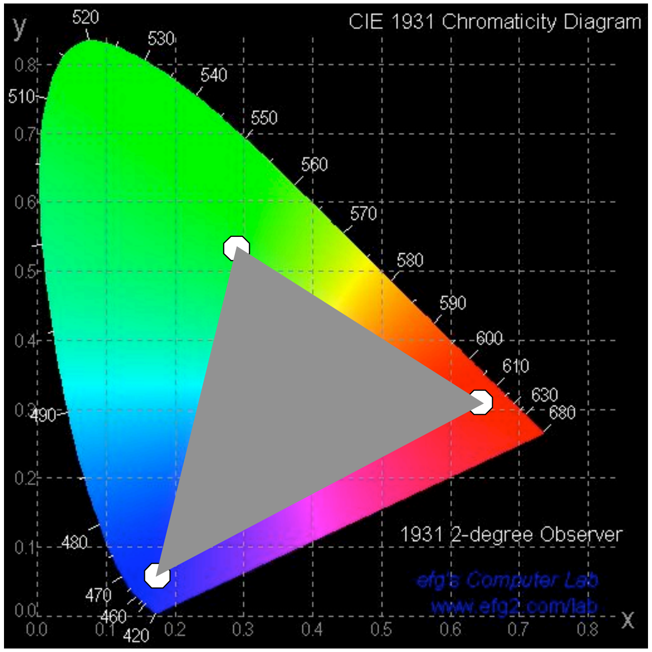
This means that XYZ corresponds to matches of fictitous (physically impossible) lights.

The gamut of all colors





Avalable from efg2.com



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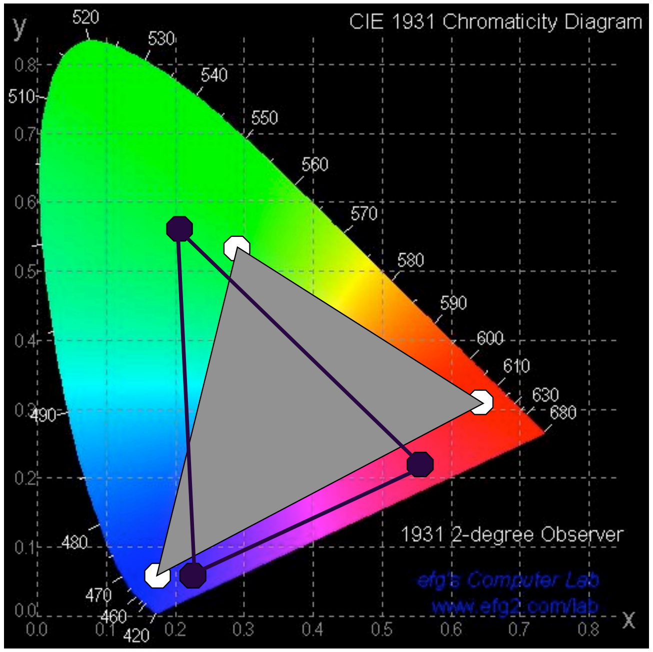
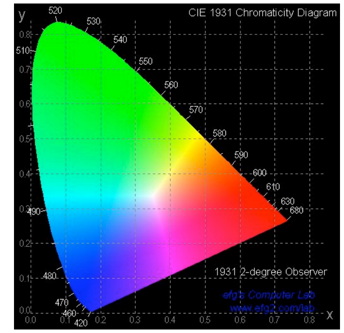


Avalable from efg2.com

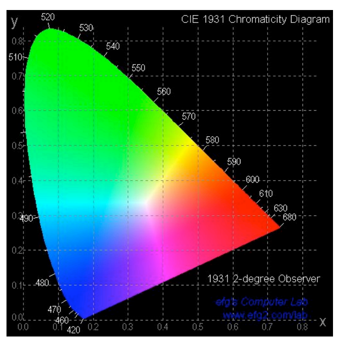
Qualitative features of CIE x, y

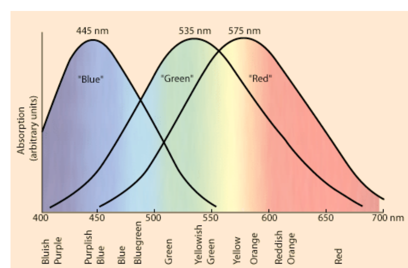
- Linearity implies that colors obtainable by mixing lights with colors A, B lie on line segment with endpoints at A and B
- Monochromatic colours (spectral colors) run along the "Spectral Locus"



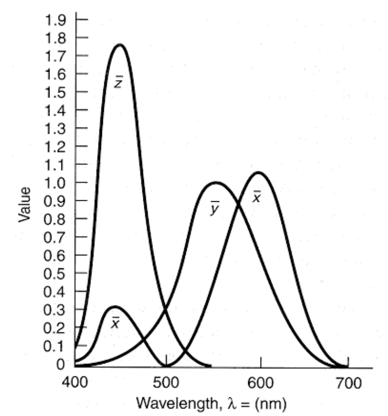
Qualitative features of CIE x, y

- Why the funny shape?





One measurement of human cone absorbtion



XYZ response curves