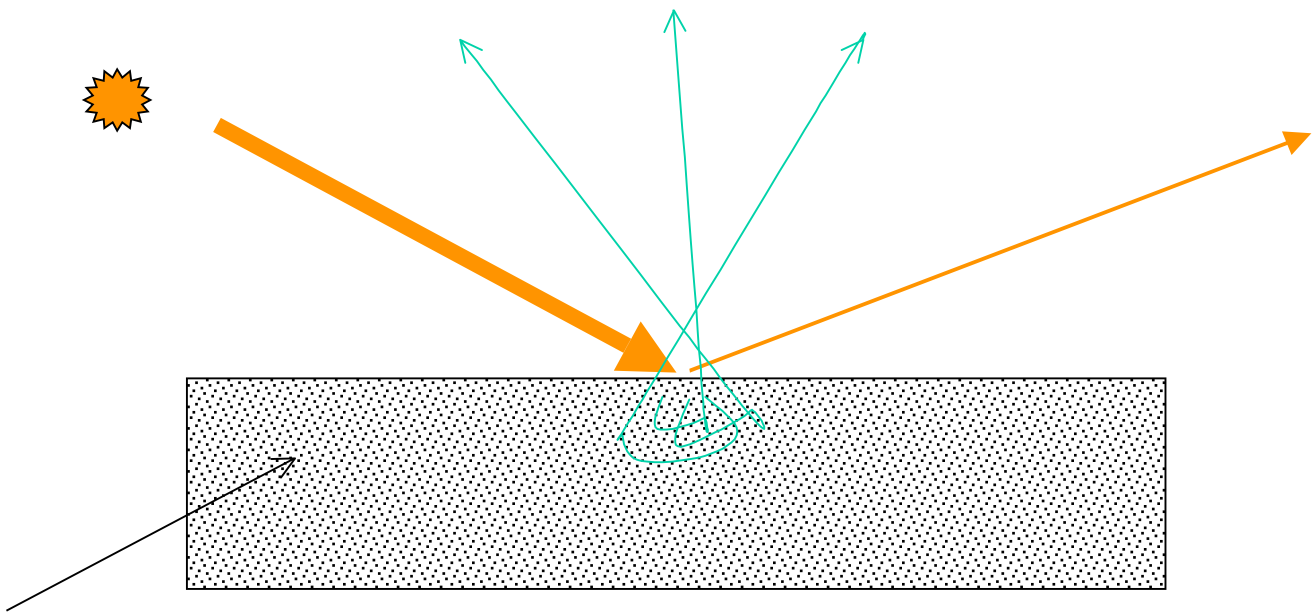
Example: Dielectrics

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



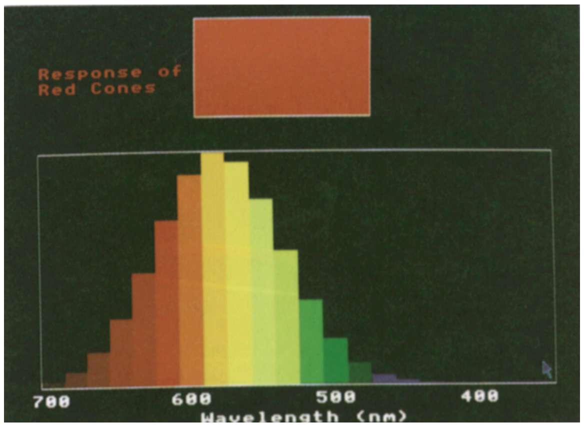
Non conductive matrix with scattering particles of the order of the wavelenth of light---note: the same general process explains why the sky is blue.

Trichromaticity

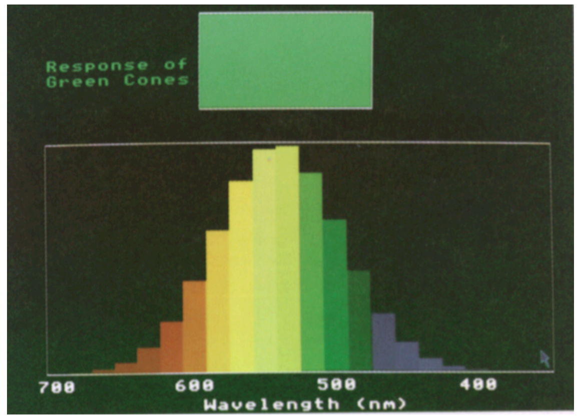
Empircal fact--colors can be approximately described/matched by three quantities (assuming normal color vision).

Need to reconcile this observation with the spectral characterization of light

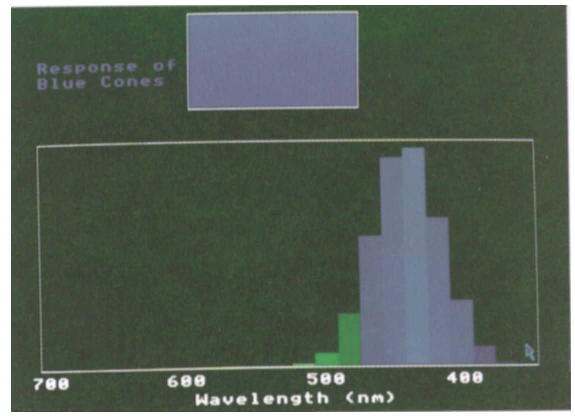
Color receptors



“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

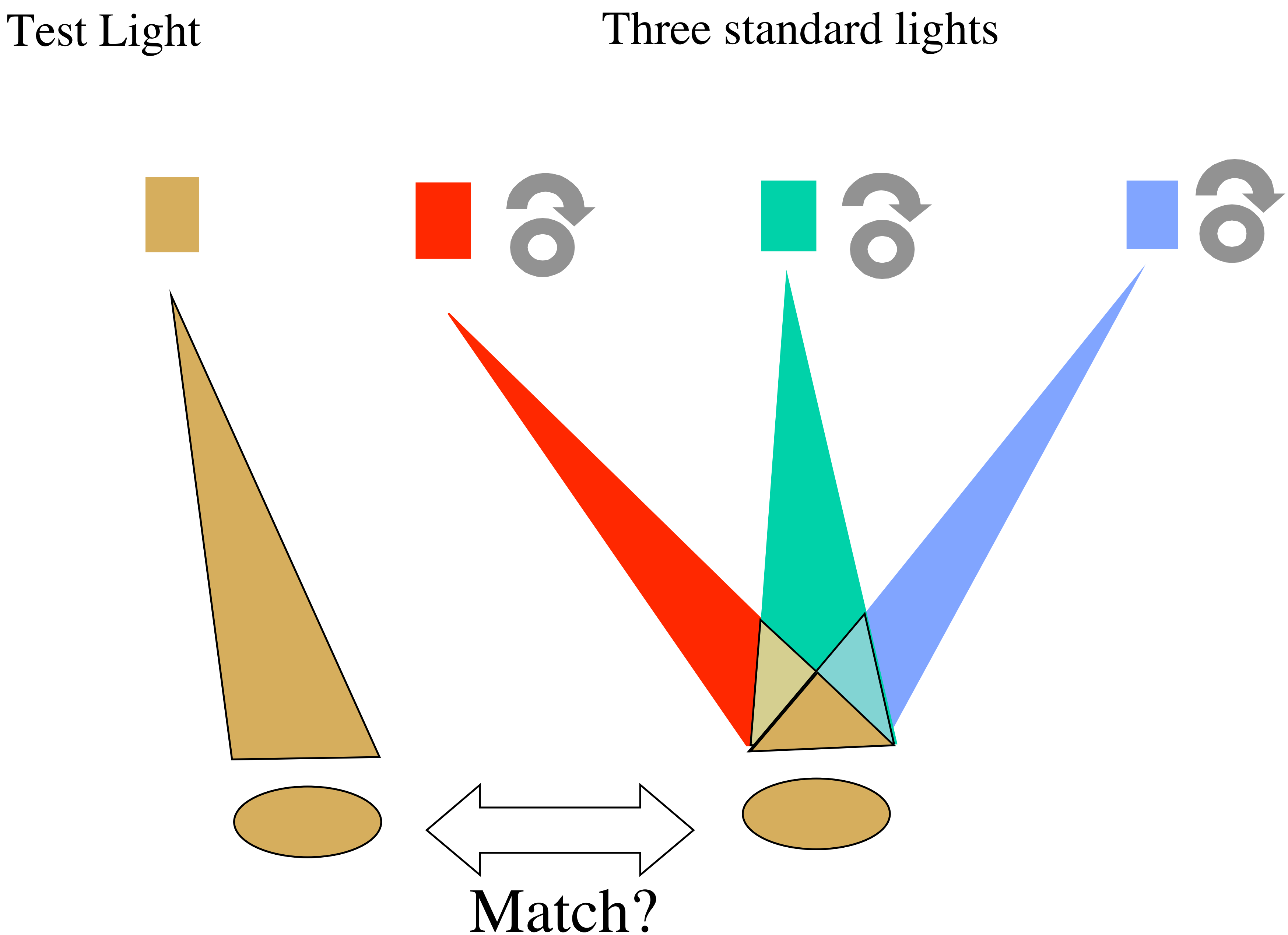
Response of k’th cone = $\int \rho_k(\lambda) E(\lambda) d\lambda$

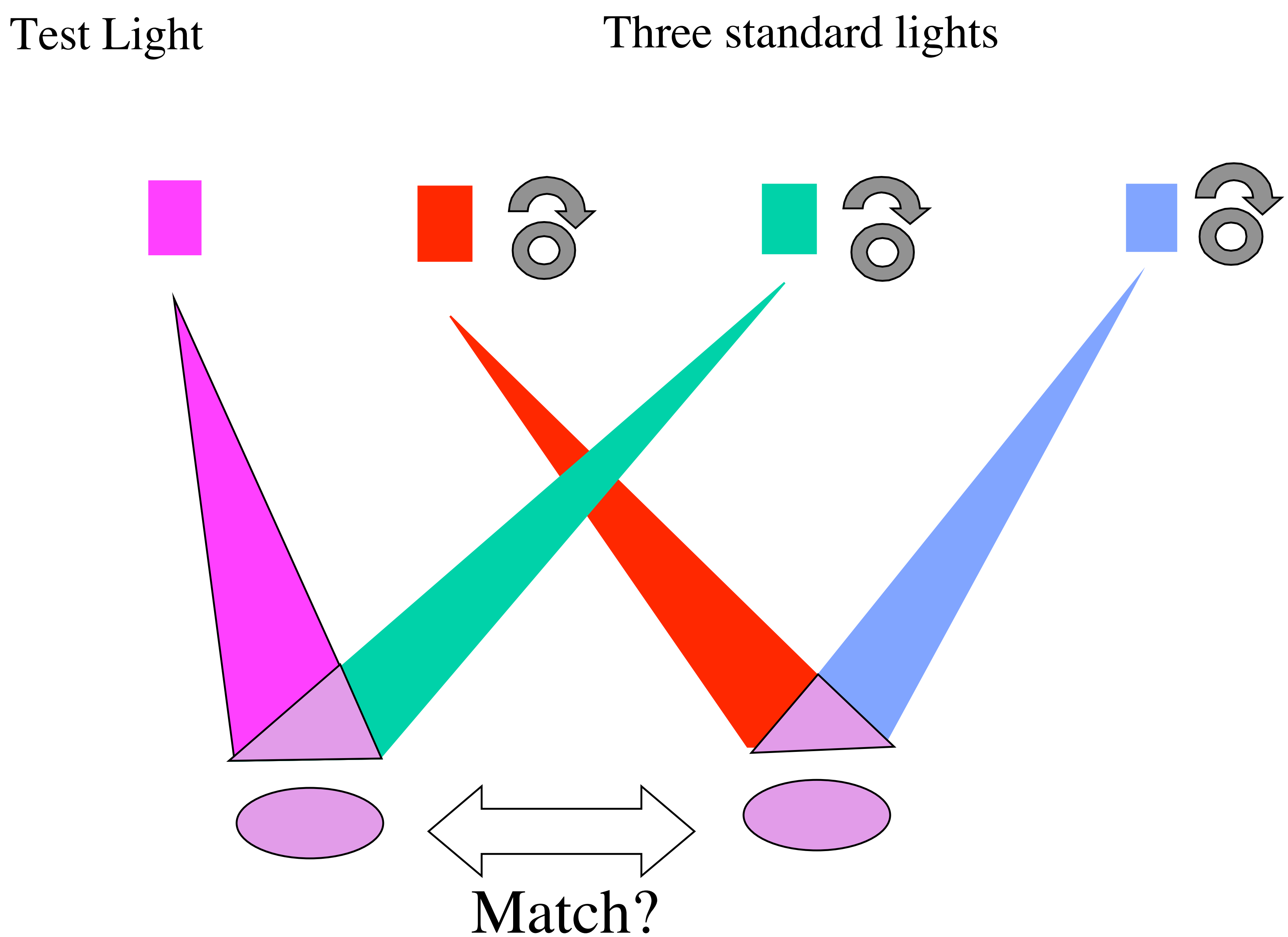
Colour Reproduction

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


Test Light
Three standard lights
Match?


Test Light
Three standard lights
Match?

Trichromacy

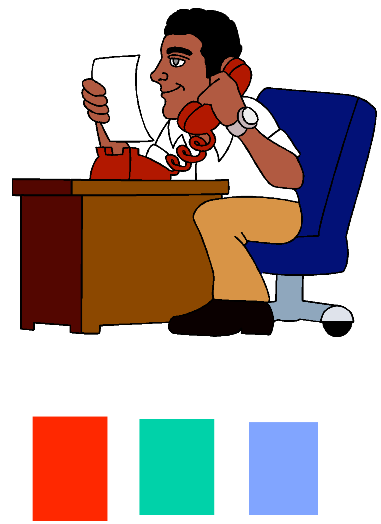
Experimental fact about people (with “normal” colour vision)---matching works (for reasonable lights), provided that we are sometimes allowed negative values.

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)



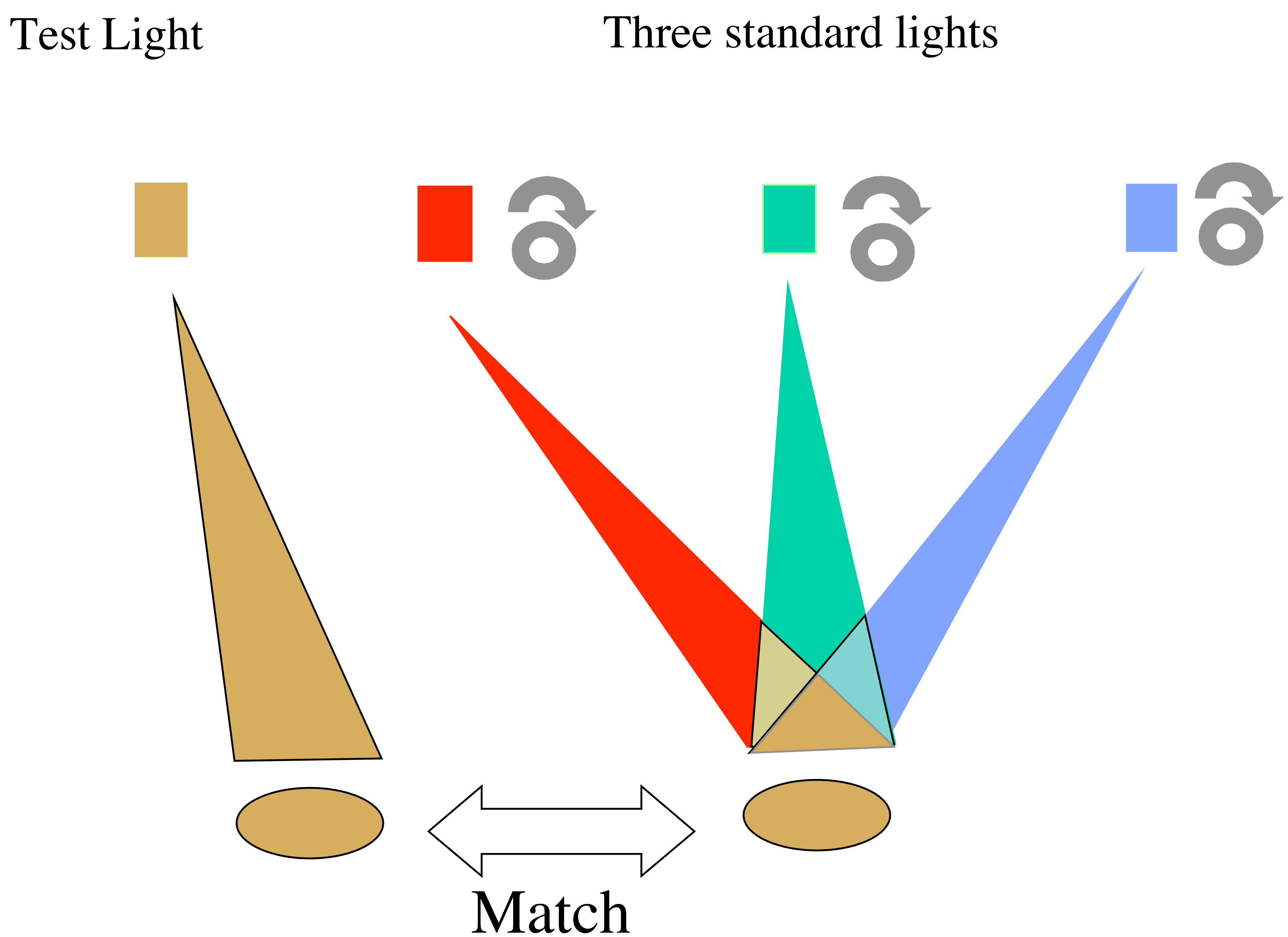
(50,150,75)

Specifying Colour

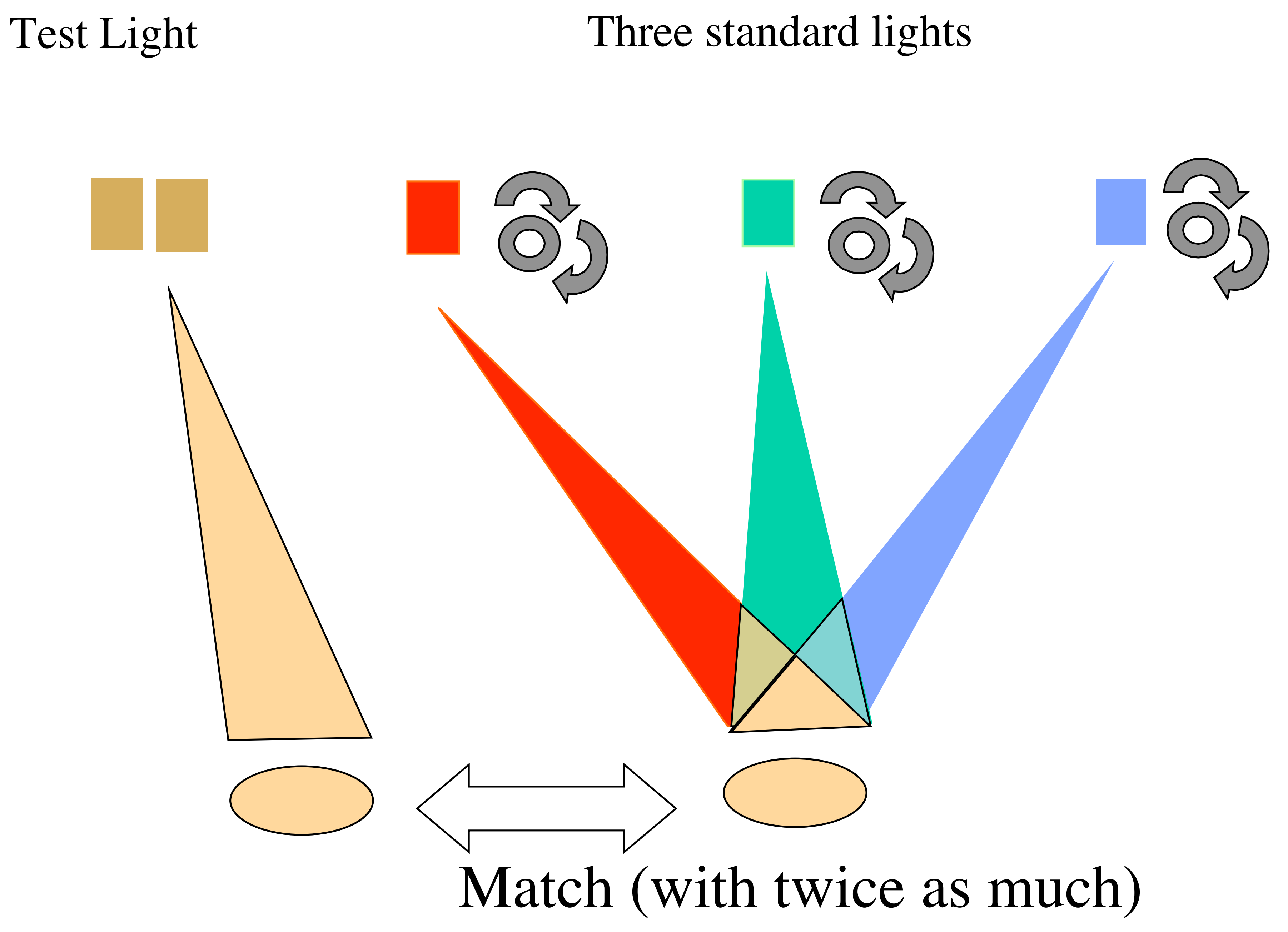
We don’t want to do a matching experiment every time we want to use a new color!

Grassman’s Contribution

Colour matching is linear



Test Light
Three standard lights
Match

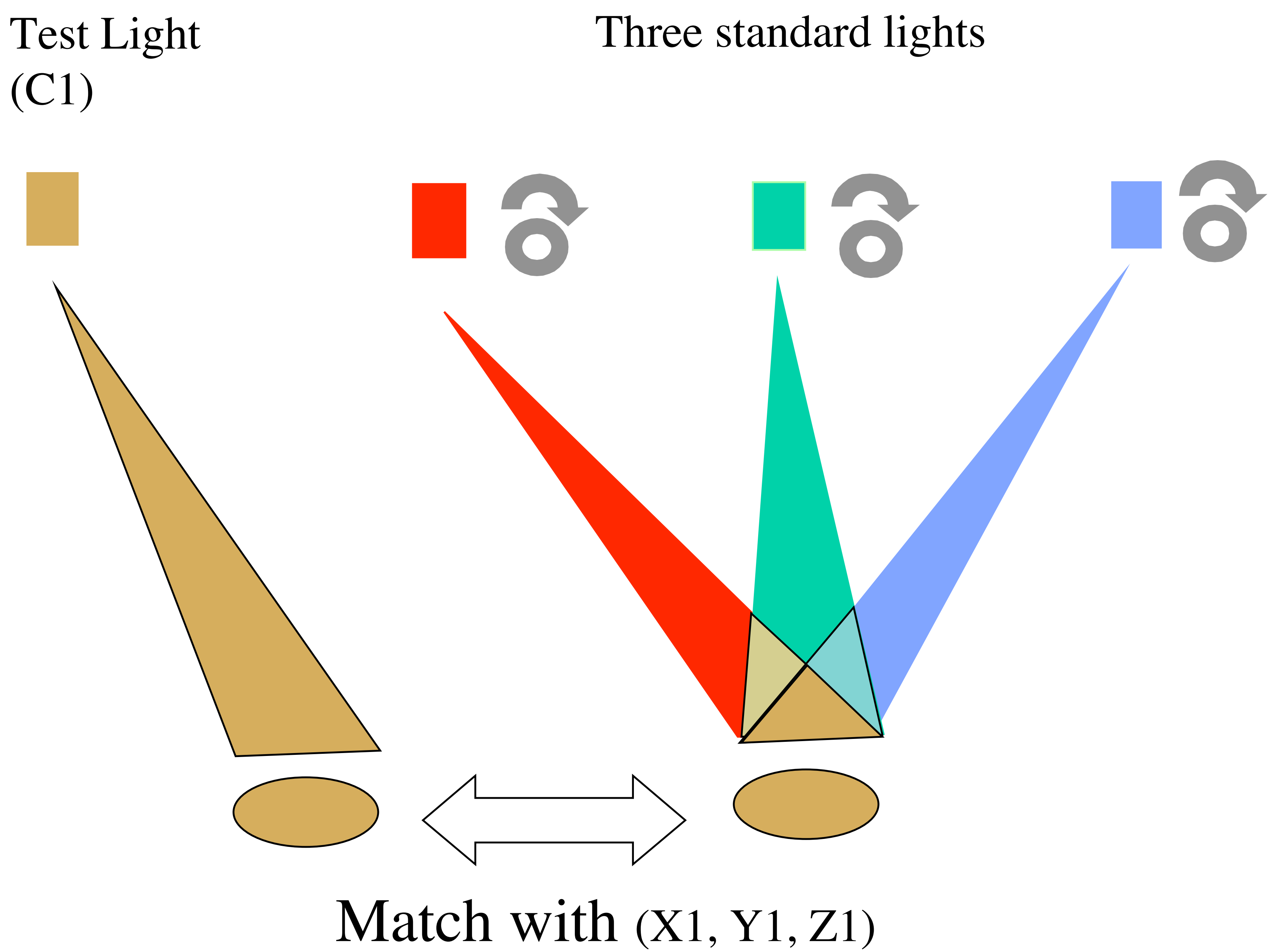

Test Light
Three standard lights
Match (with twice as much)

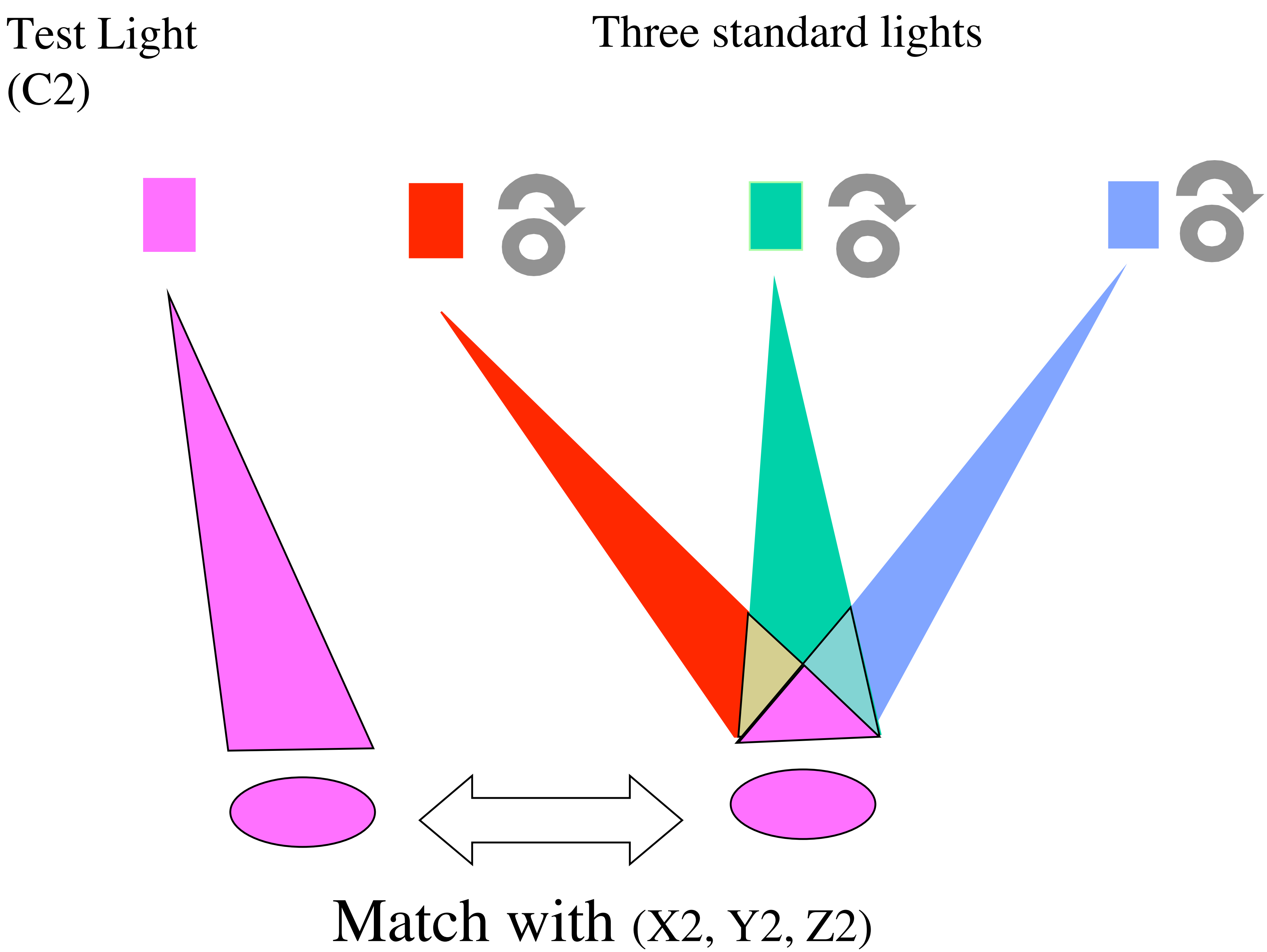
Matching is Linear (Part 1)

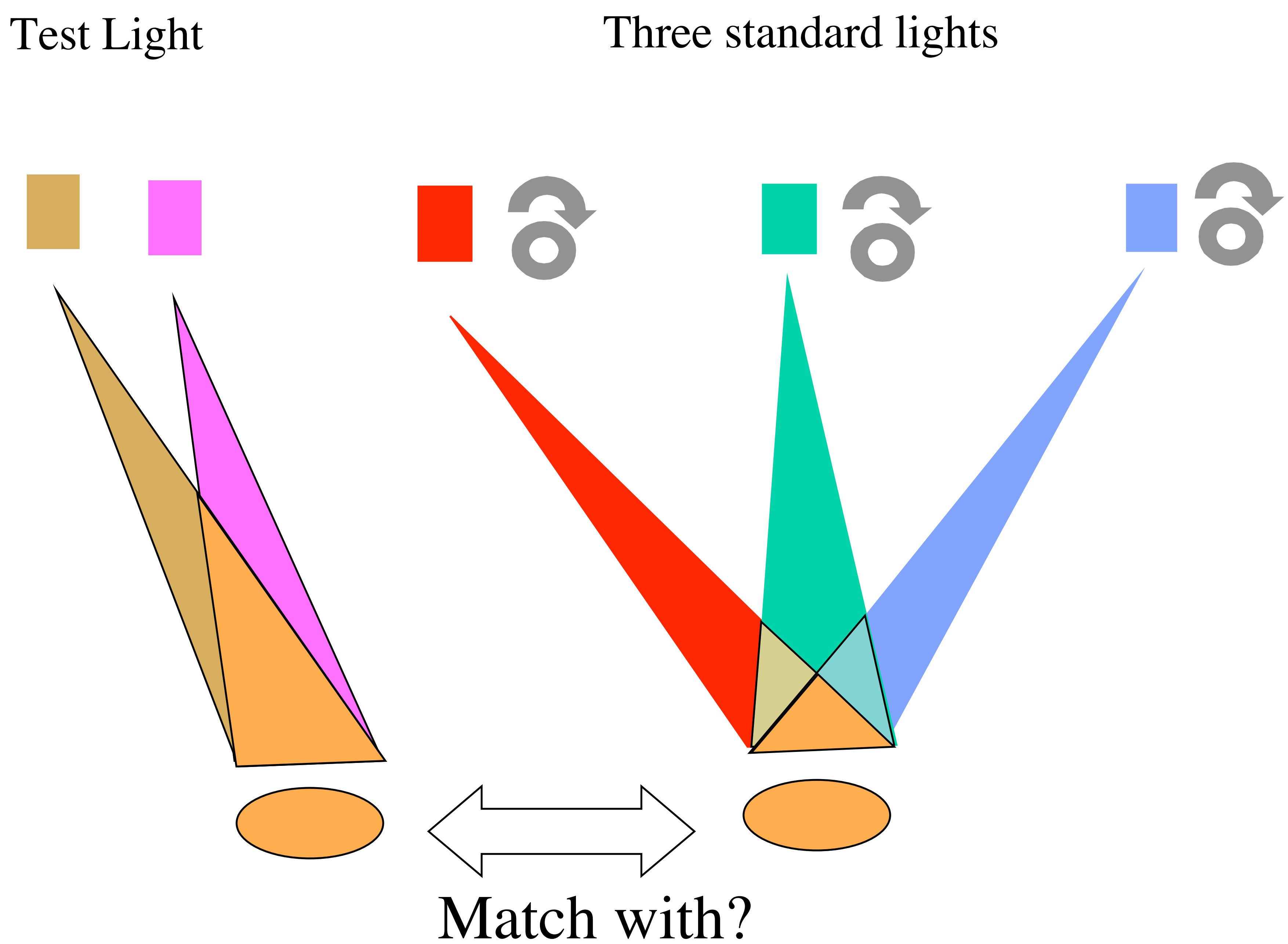
C1 is matched with (X1,Y1,Z1)

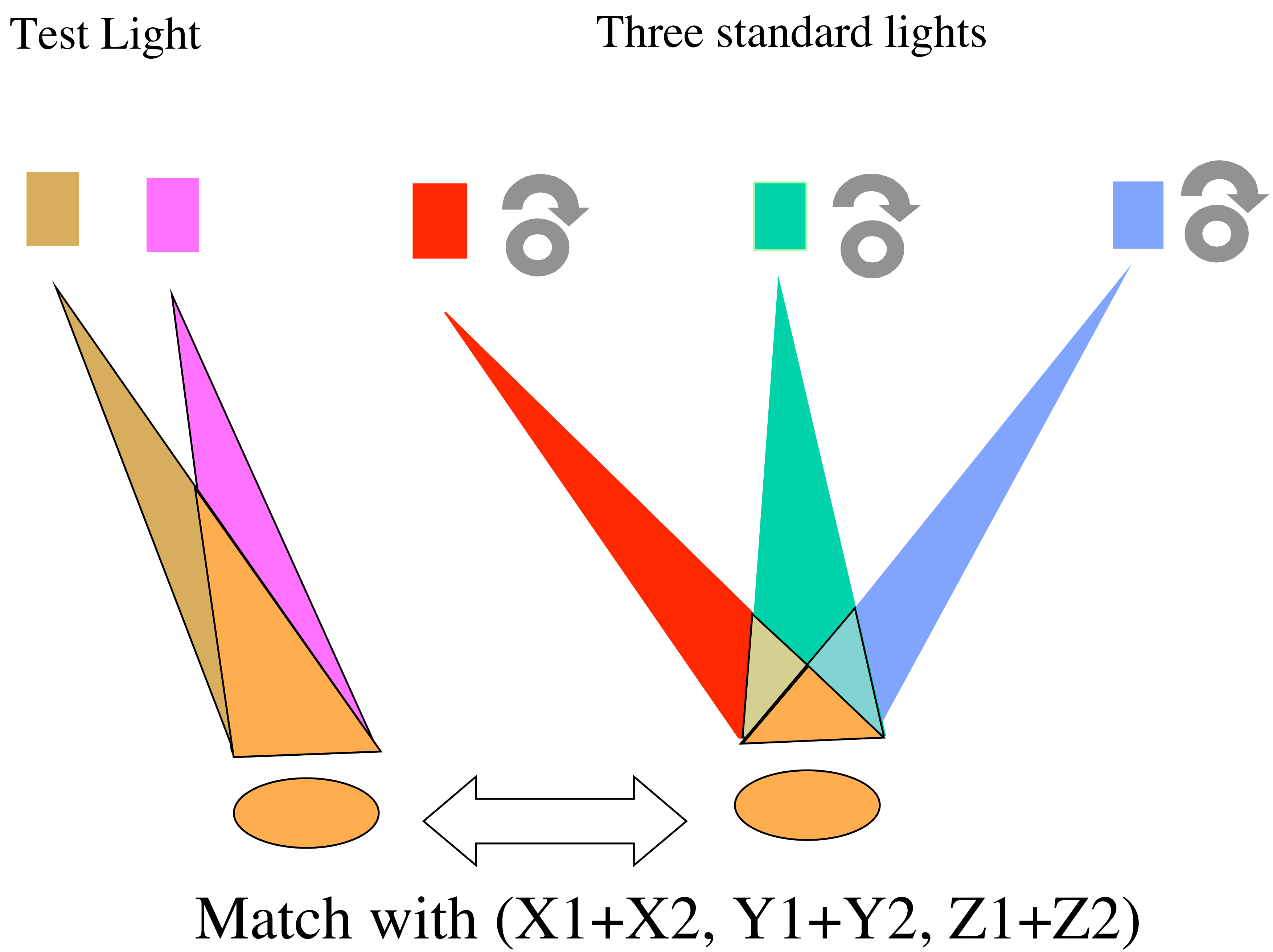
C = a*C1

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


Test Light
(C1)
Three standard lights
Match with (X1, Y1, Z1)


Test Light
(C2)
Three standard lights
Match with (X2, Y2, Z2)


Test Light
Three standard lights
Match with?


Test Light
Three standard lights
Match with (X1+X2, Y1+Y2, Z1+Z2)

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

On my monitor it's
(R,G,B) = (75,150,100)

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)

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

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix}_{\text{apple}} = M^{-1} \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_{\text{apple}}$$

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix}_{apple} = M^{-1} \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_{apple}$$

Possible problems?

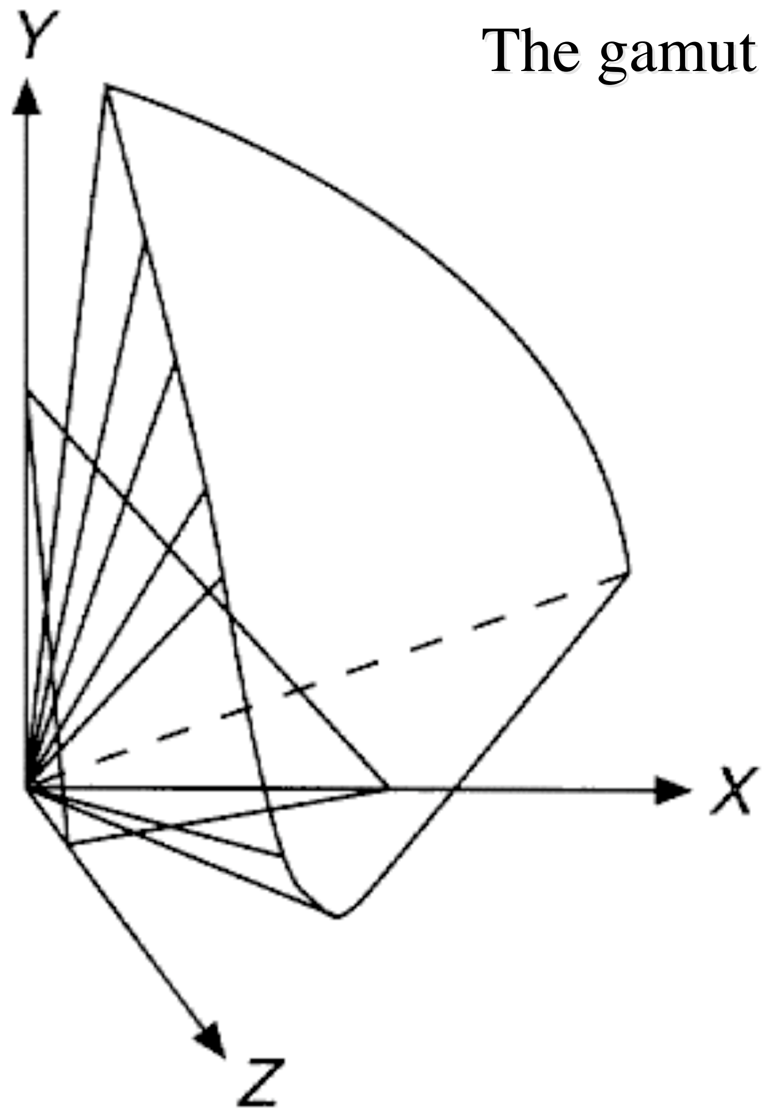
XYZ color space

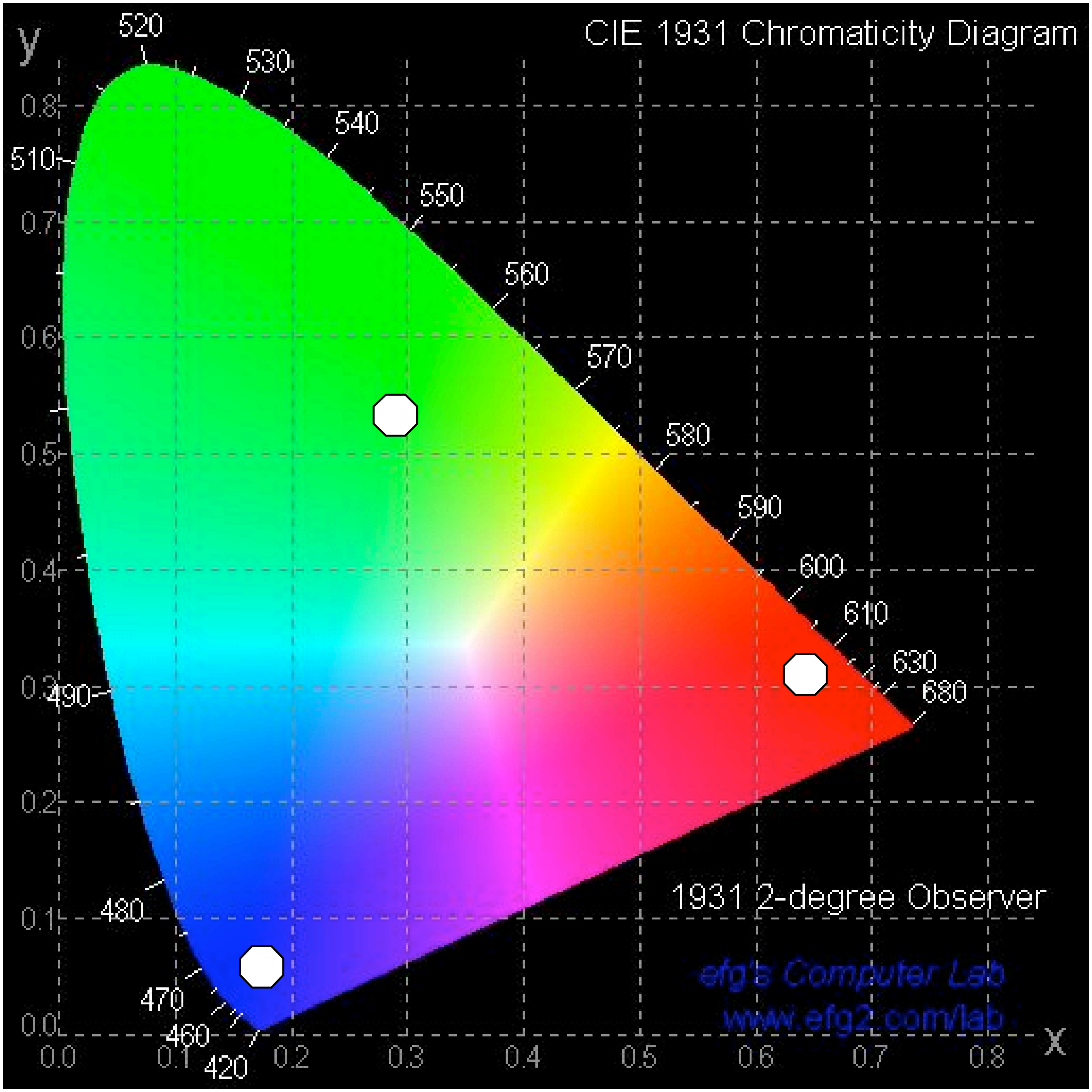
XYZ color space is a linear transformation of the matches to standard lights.

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

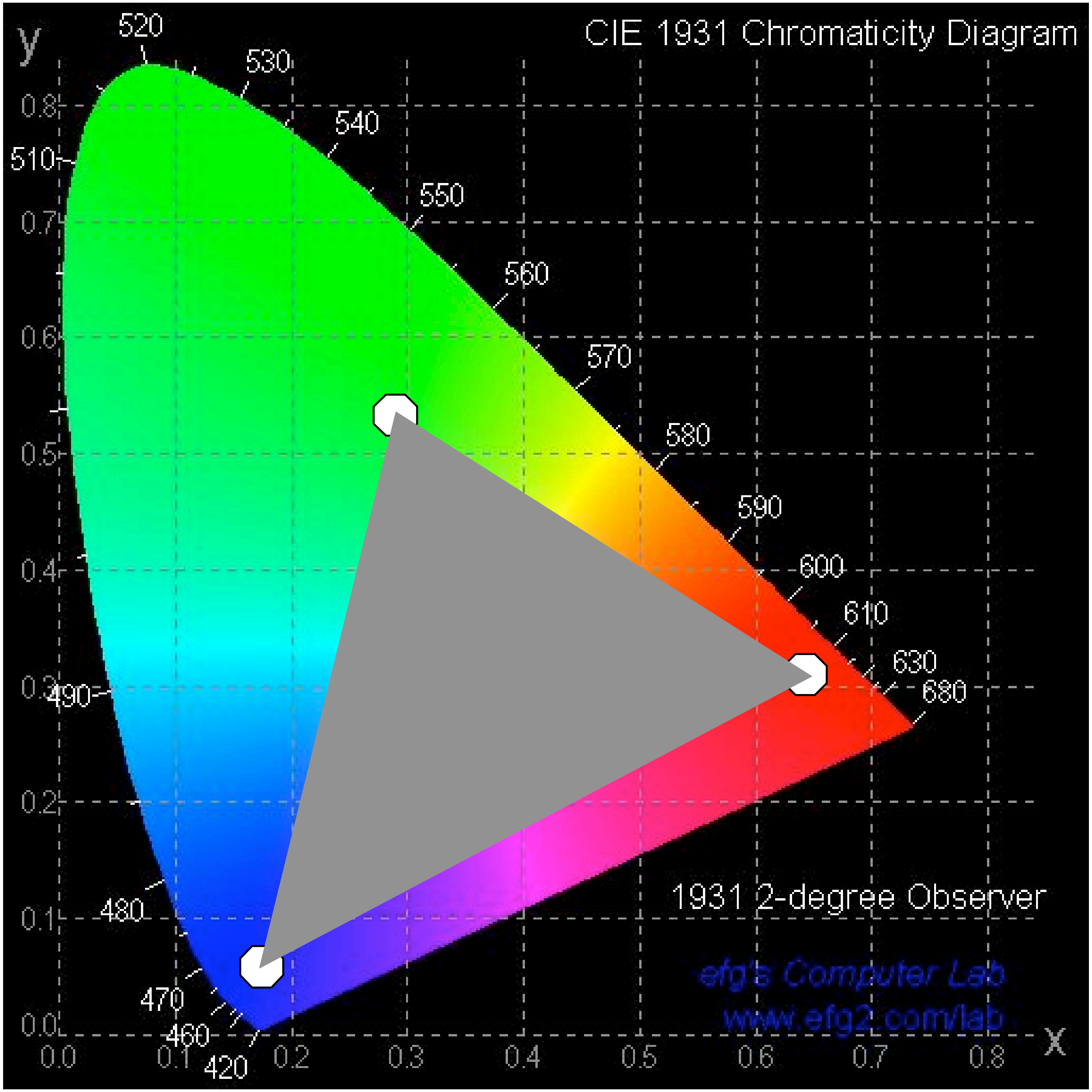
This means that XYZ corresponds to matches of fictitous (physically impossible) lights.

The gamut of all colors

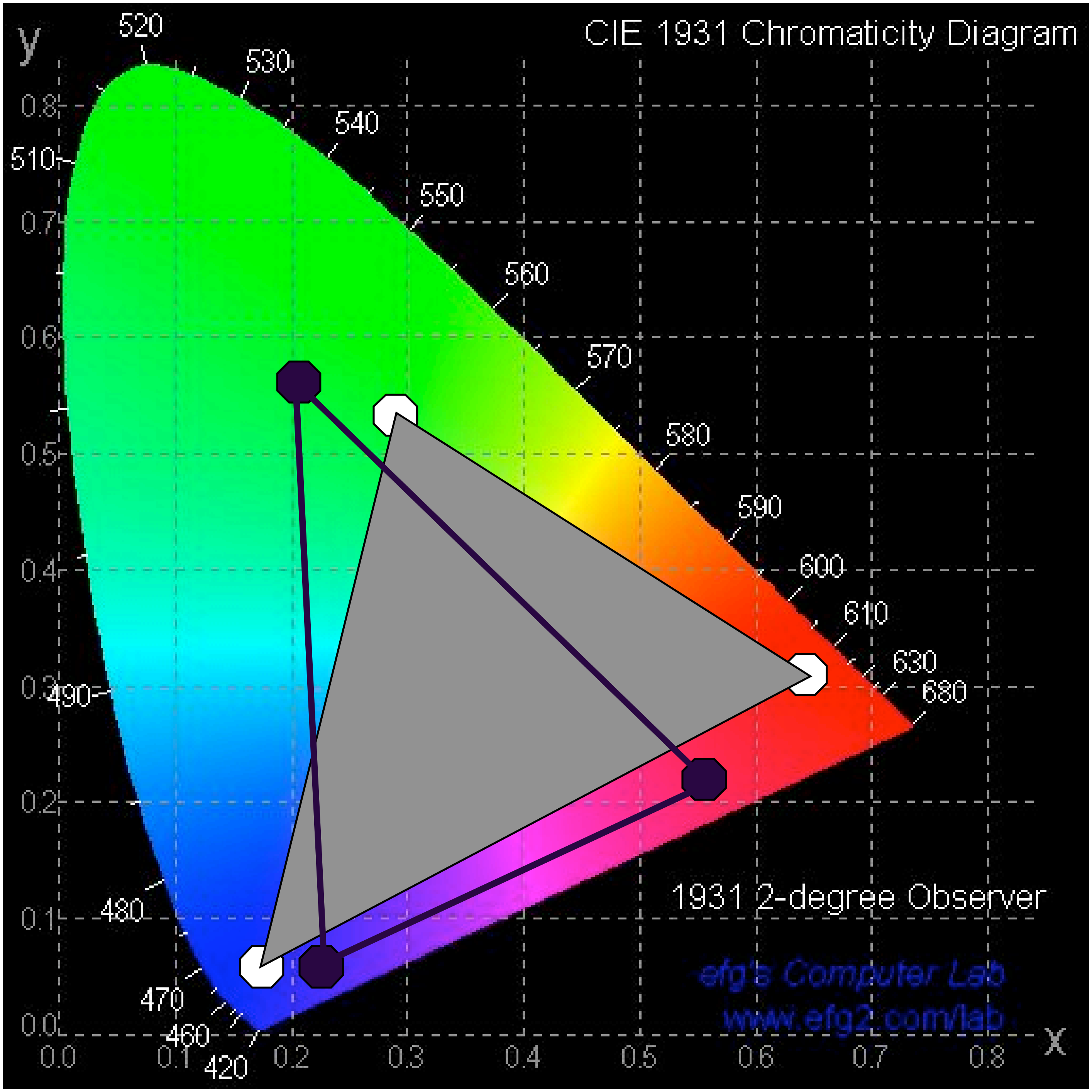




Avalable from efg2.com



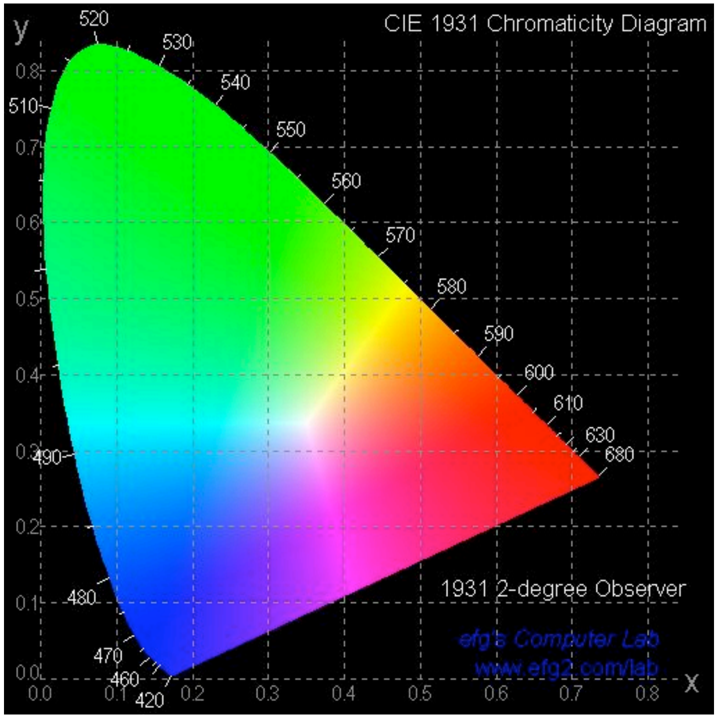
Avalable from efg2.com



Avalable from efg2.com

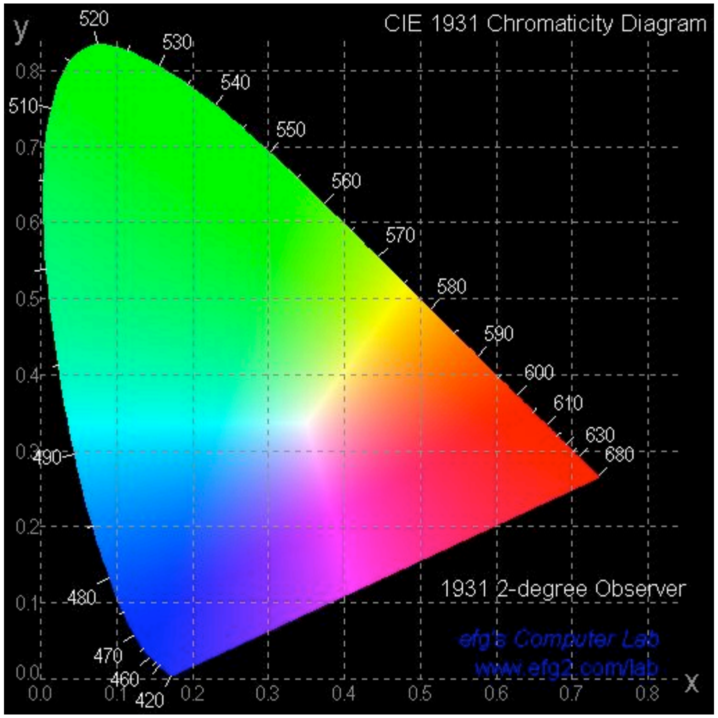
Qualitative features of CIE x, y

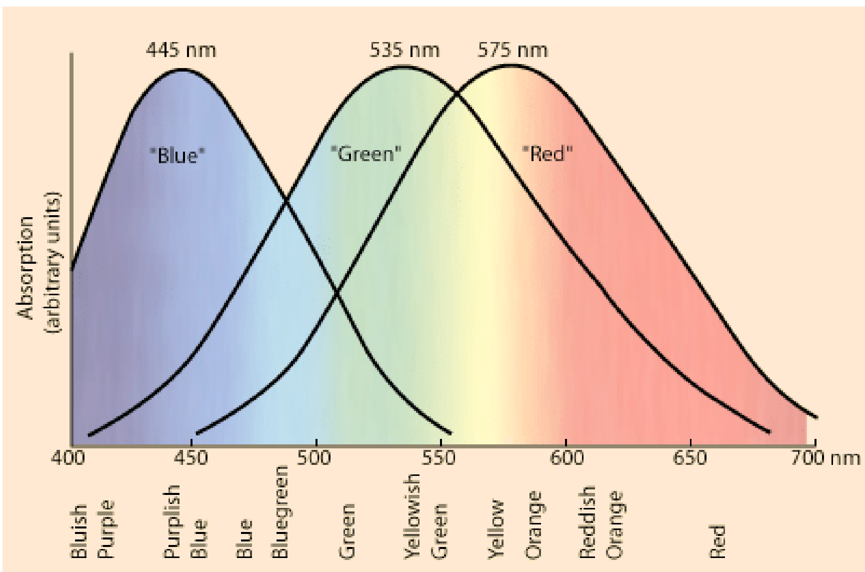
- Linearity implies that colors obtainable by mixing lights with colors A, B lie on line segment with endpoints at A and B
- Monochromatic colours (spectral colors) run along the "Spectral Locus"



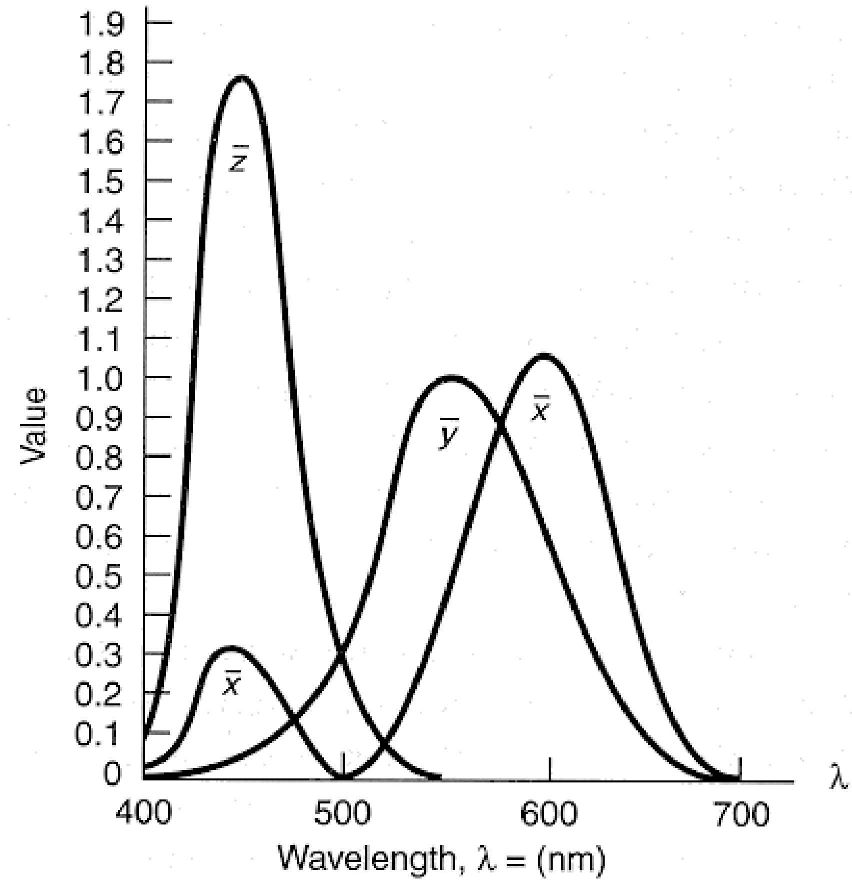
Qualitative features of CIE x, y

- Why the funny shape?





One measurement of human cone absorbtion



XYZ response curves