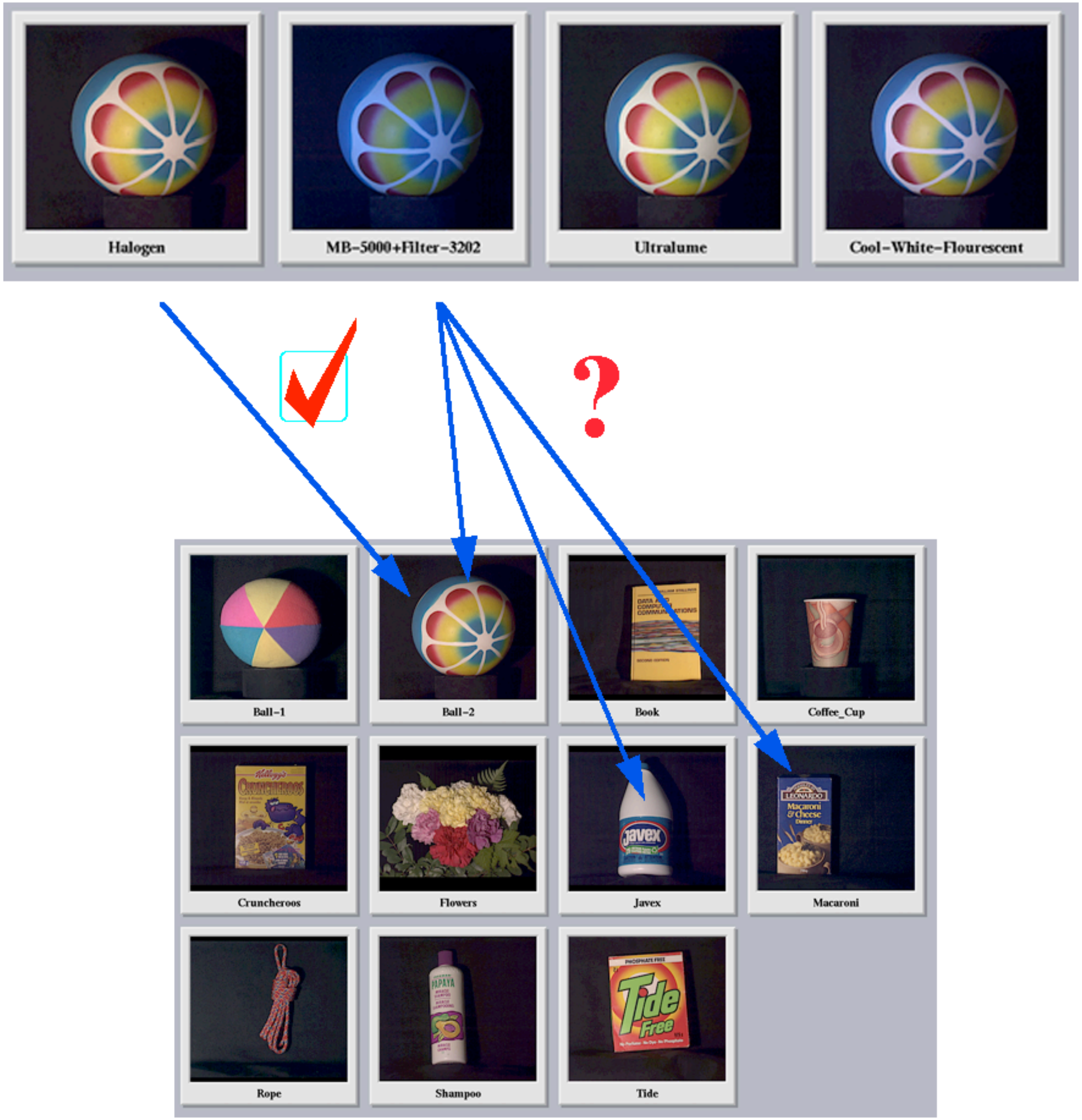
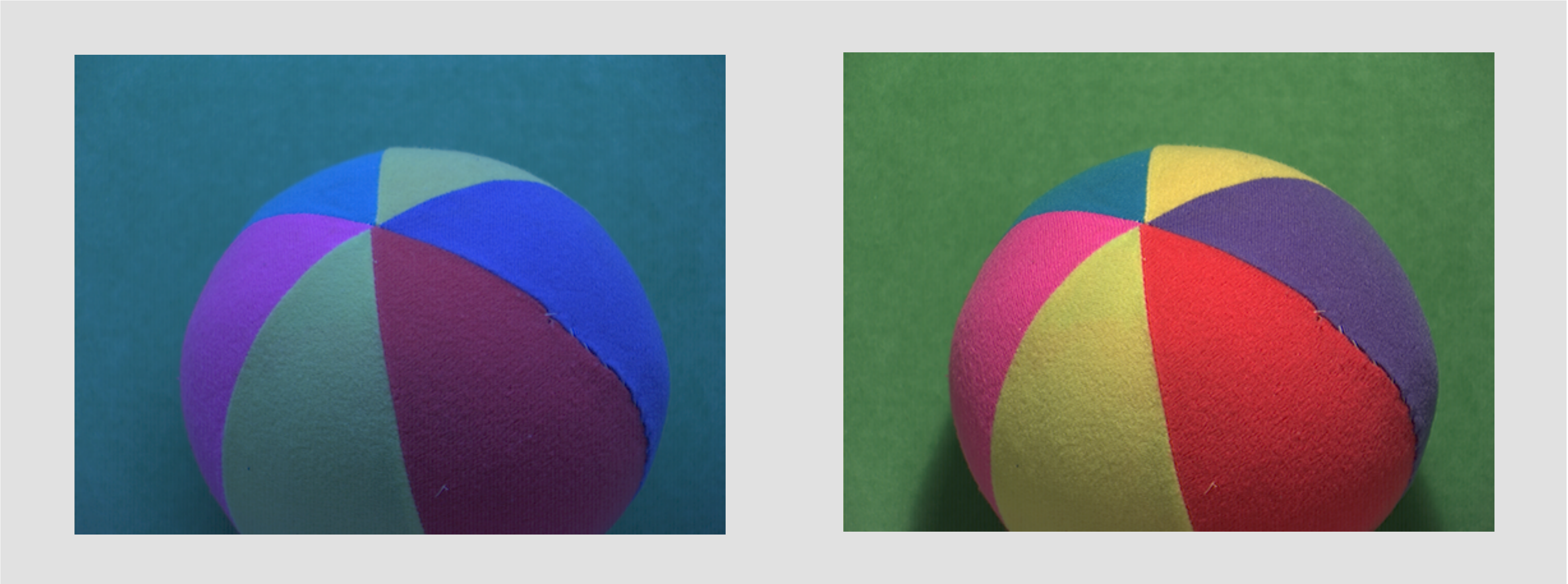
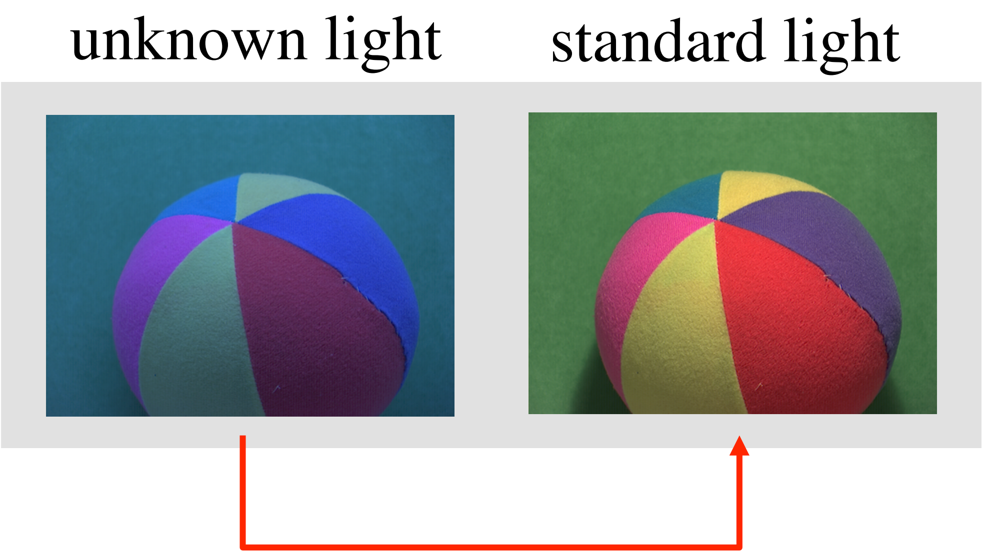

Halogen
MB-5000+Filter-3202
Ultralume
Cool-White-Flourescent
?
Ball-1
Ball-2
Book
Coffee_Cup
Cruncheroos
Flowers
Javex
Macaroni
Rope
Shampoo
Tide

The Computational Color Constancy Problem



(Same scene, but different illuminant)

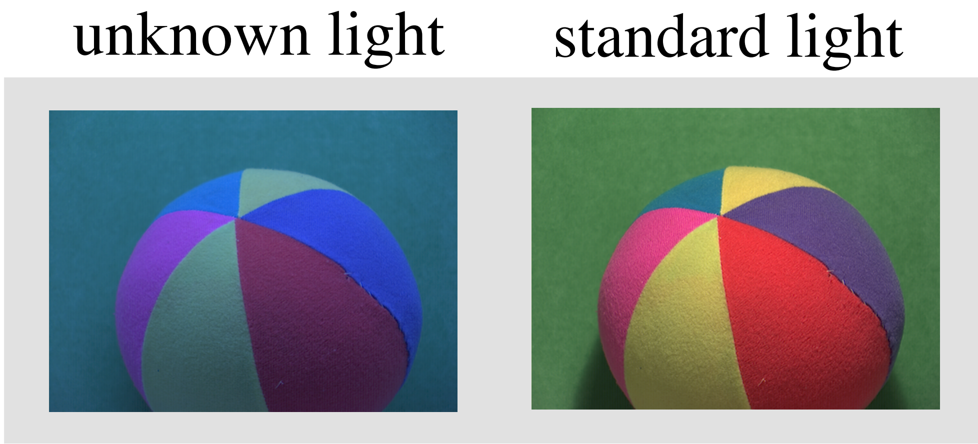
Color constancy



Color constancy algorithms strive to map image pixels to useful illuminant invariant values. One example is the image as if it was taken under the known standard light.

Often done by estimating the illuminant, followed by color correction (but there are other ways).

Color Correction



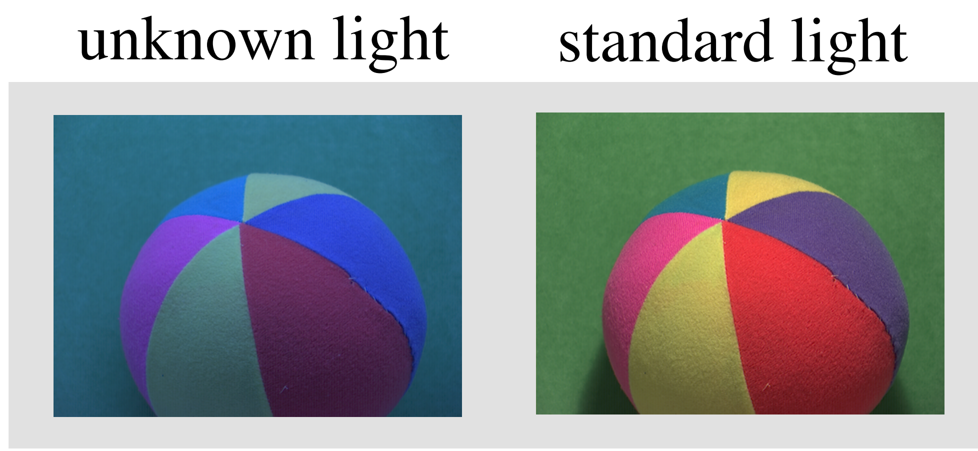
Suppose that the image on the right was how the scene on the left would look under a known, "standard" light.

Under that light a uniform reflective surface (white) is $\left(R_W^S, G_W^S, B_W^S\right)$

So, to correct the image on the left, we can estimate the color of white, under the unknown light. Suppose it is: $\left(R_W^U, G_W^U, B_W^U\right)$

Then we can correct the image using the diagonal matrix from a few slides back.

Estimating the color of the light



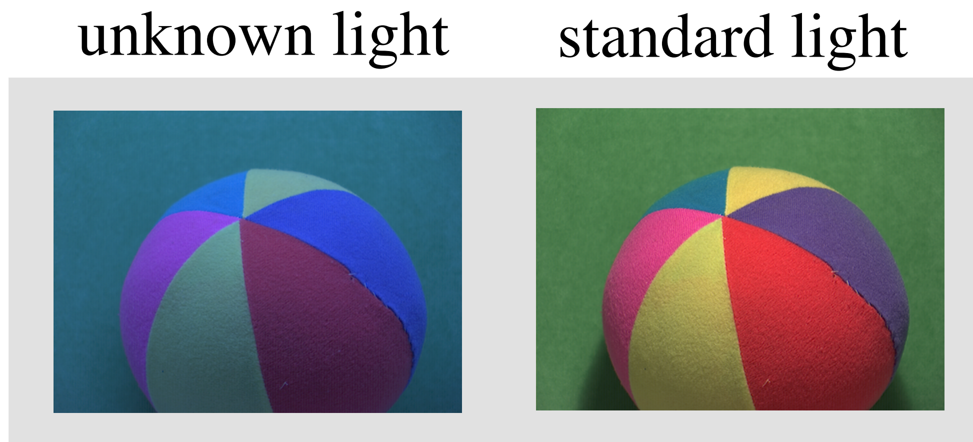
The hard part is to estimate the color of the light (i.e., $\left(R_W^U, G_W^U, B_W^U\right)$)

Many interesting algorithms have been developed. Two simple ones:

Max RGB: $R_W^U = \max_{pix}(R)$ (Similarly for G and B)

Gray world: $\left(\frac{1}{2}\right) R_W^U = \underset{pix}{ave}(R)$ (Similarly for G and B)

Estimating the color of the light

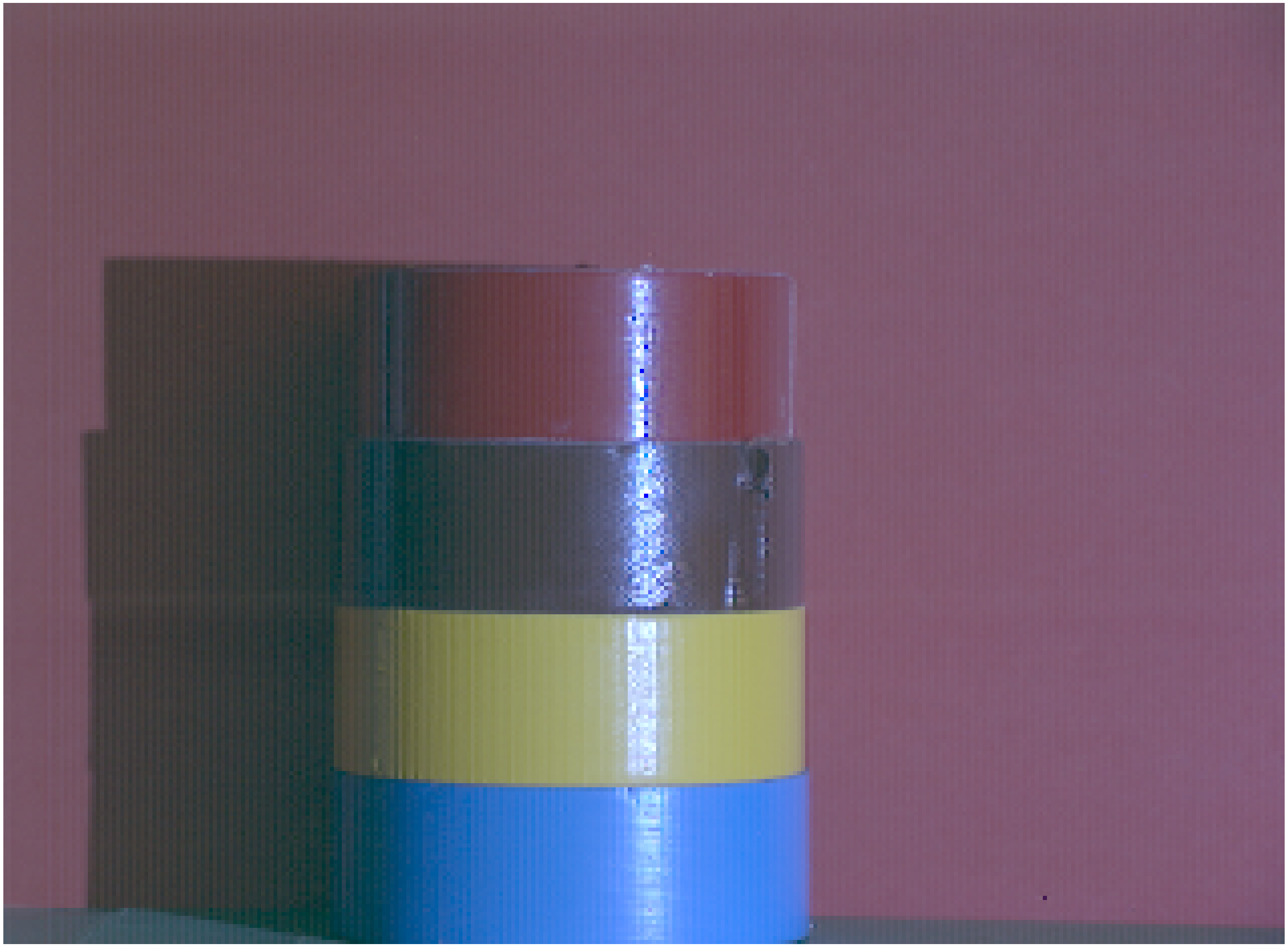


The two simple methods mentioned previously focus on the global statistics of the image.

More formally, one can set up an inference problem focused on estimating the probability that the light is a certain color, **given** the image data.

Another approach is find specularities (recall why this works!).

Dielectric Specularities



Human color perception and color reproduction

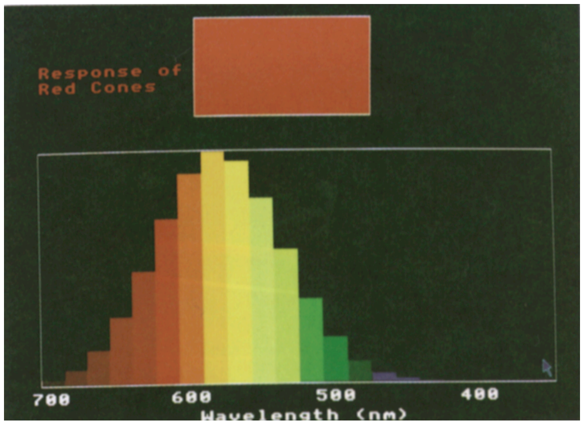
- The sensation of color is caused by the brain.
- One way to get it is through a **response** of the eye to the presence/absence of light at various wavelengths.
- Dreaming, hallucination, etc.
- Pressure on the eyelids

Trichromaticity

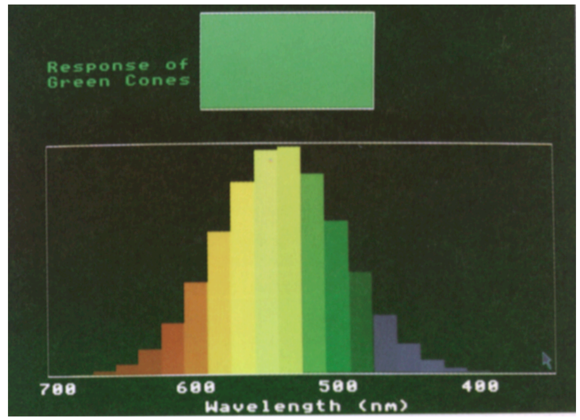
Empirical fact--colors can be approximately described/ matched by three quantities (assuming normal color vision).

Need to reconcile this observation with the spectral characterization of light

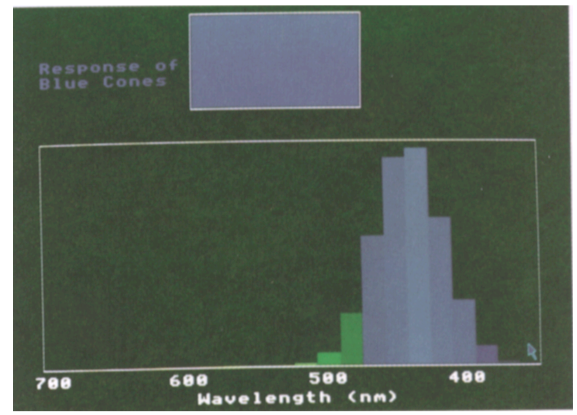
Color receptors



"Long" cone



"Medium" cone



"Short" cone

Some understanding results from an analogy with camera sensors

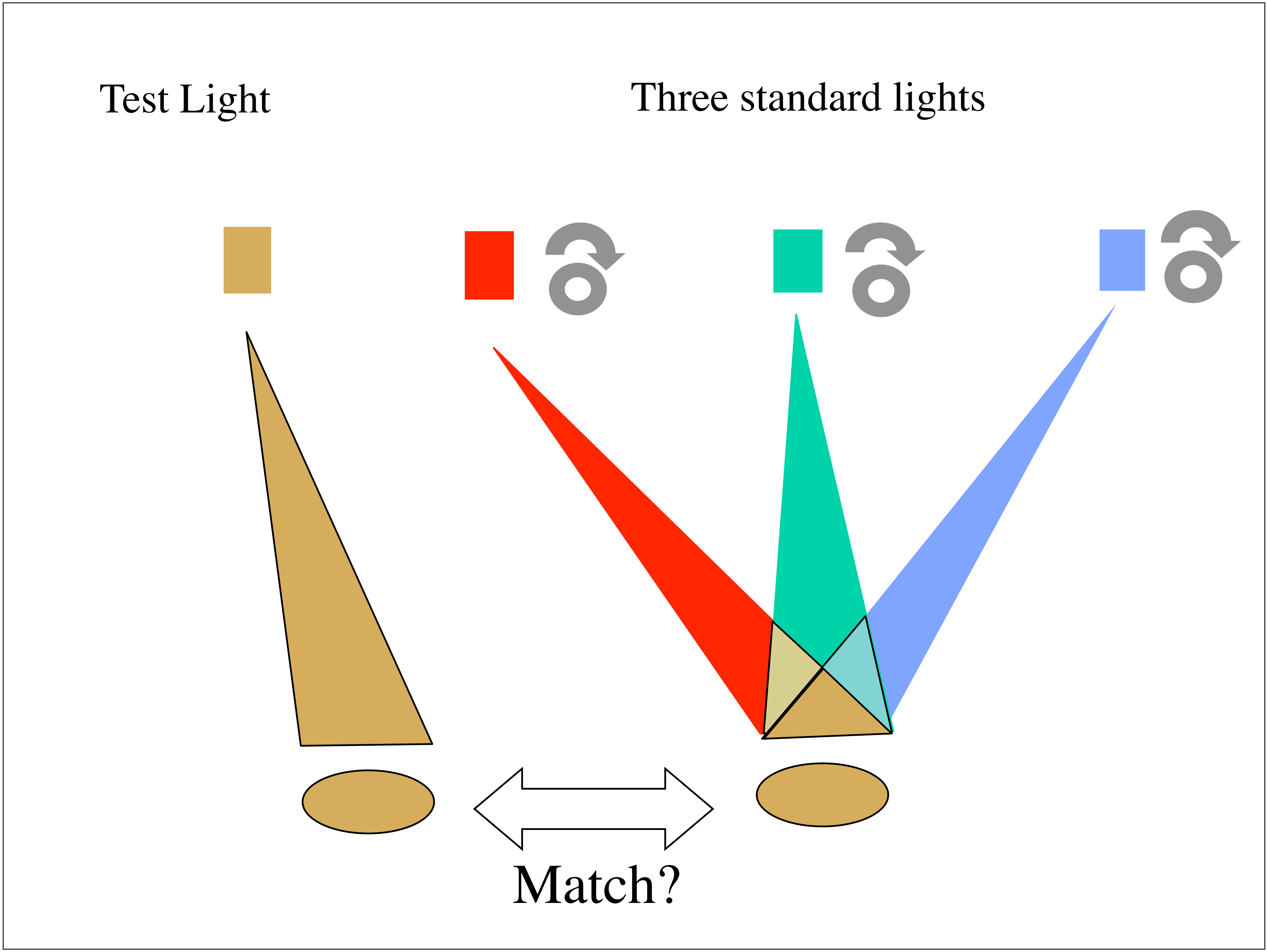
Directly determining the camera like sensitivity response is hard!

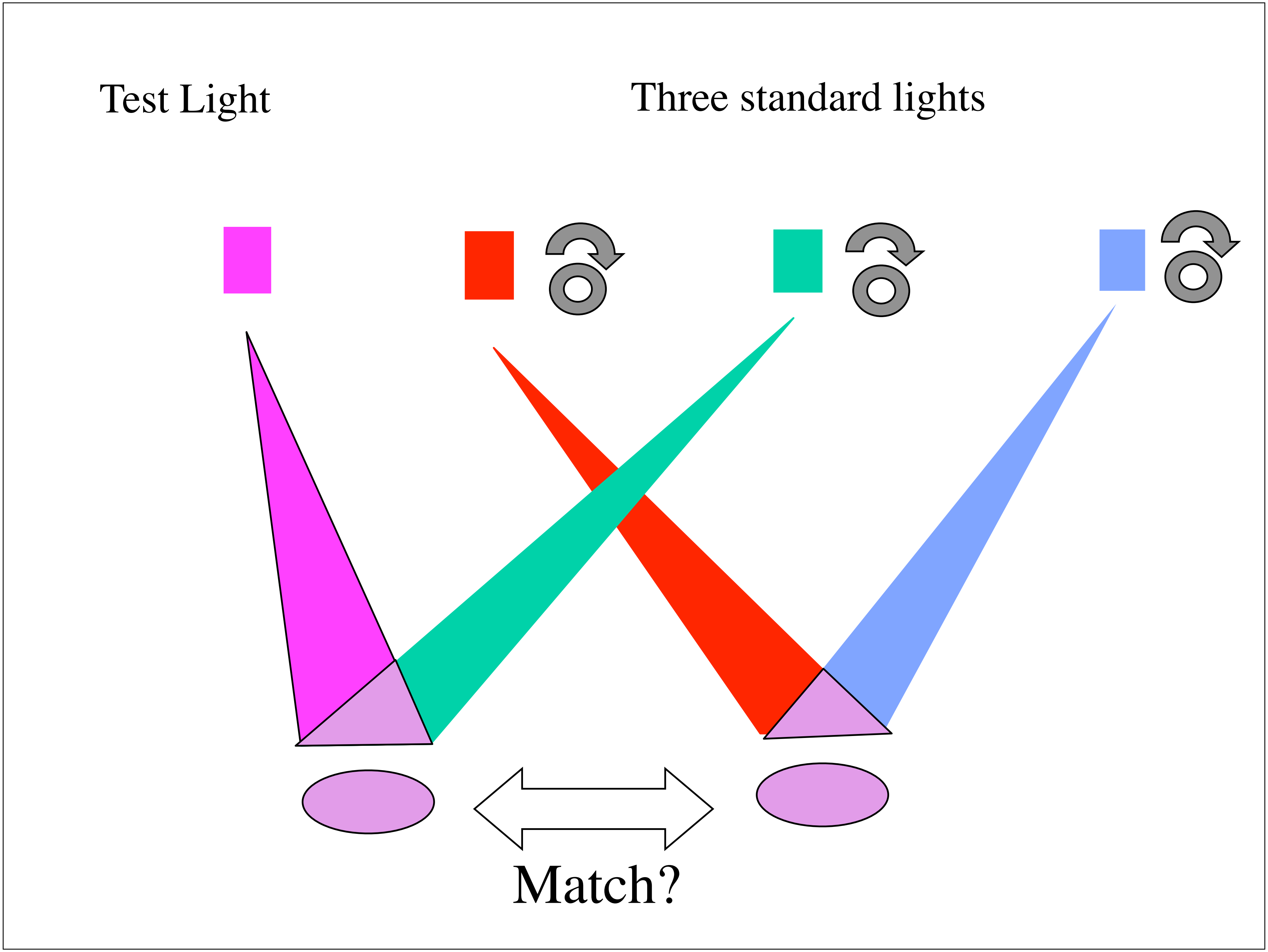
Color Reproduction

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

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

Specifying Color


Test Light
Three standard lights
Match?


Test Light
Three standard lights
Match?

Trichromacy

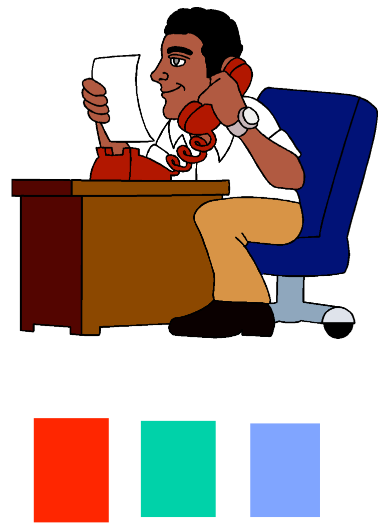
Experimental fact about people (with “normal” color vision)---matching works (for reasonable lights), provided that we are sometimes allowed negative values.

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 Color

(50,150,75)



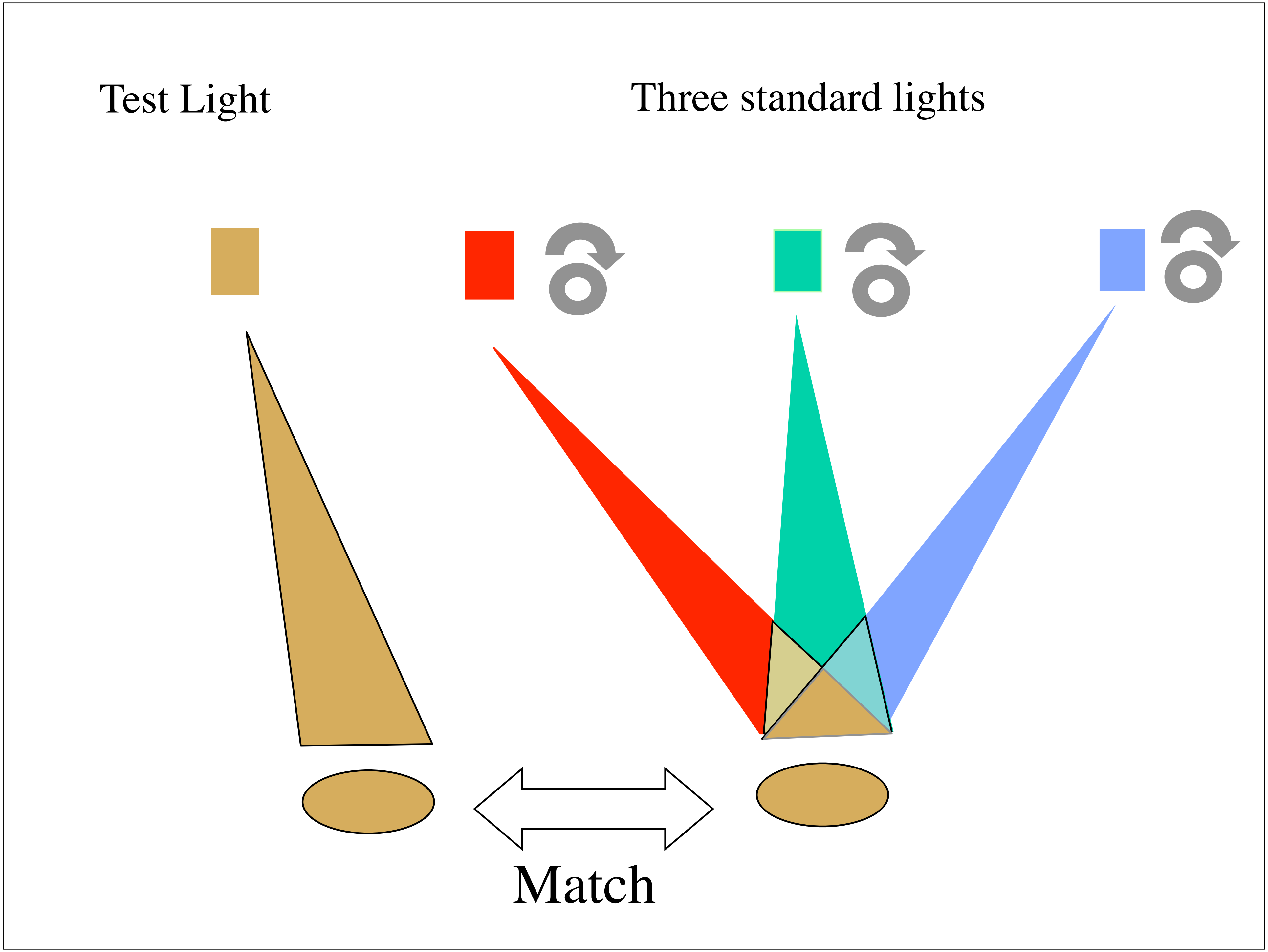
(50,150,75)

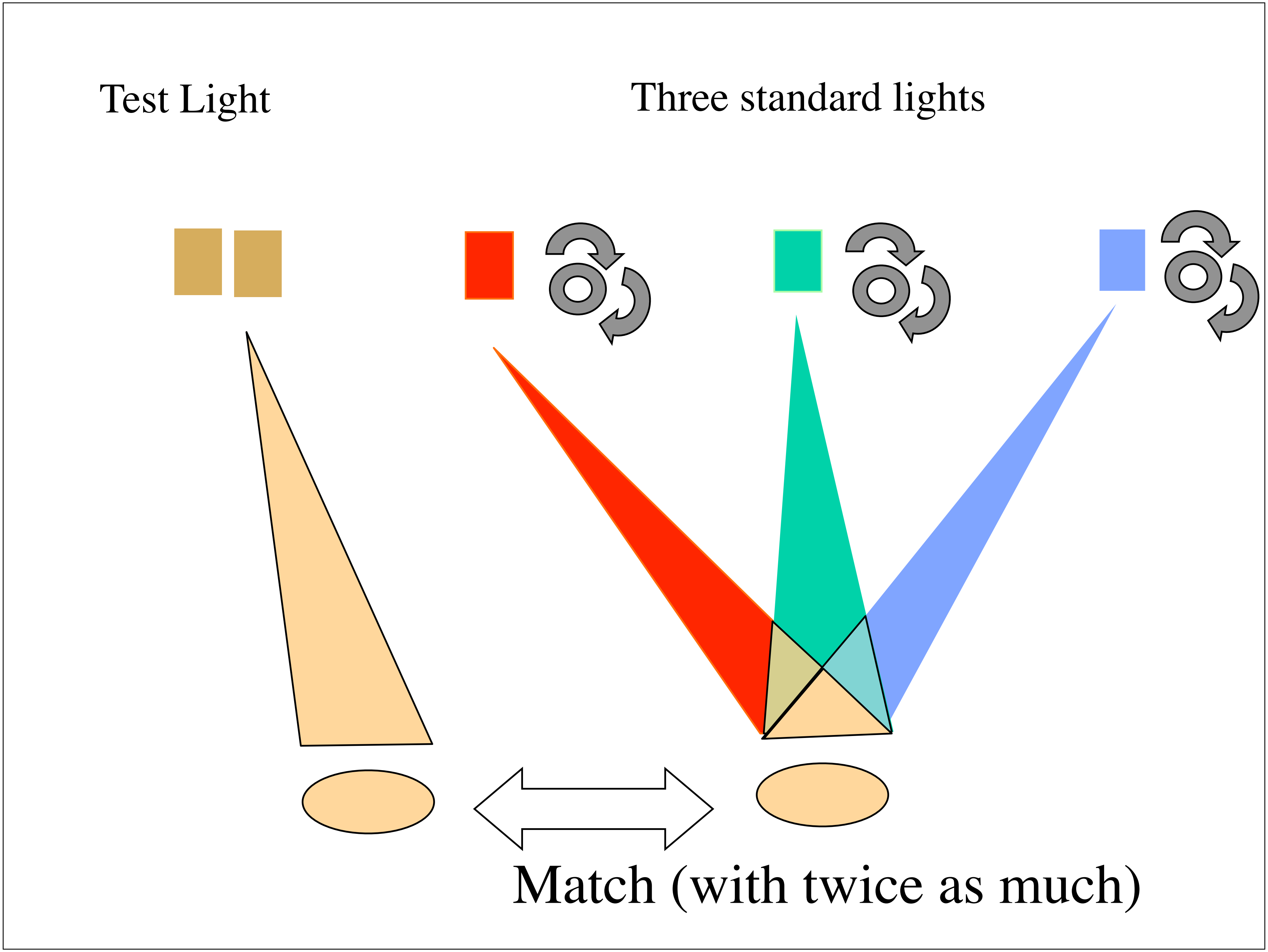
Specifying Color

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

Grassman’s Contribution

Color matching is linear


Test Light
Three standard lights
Match

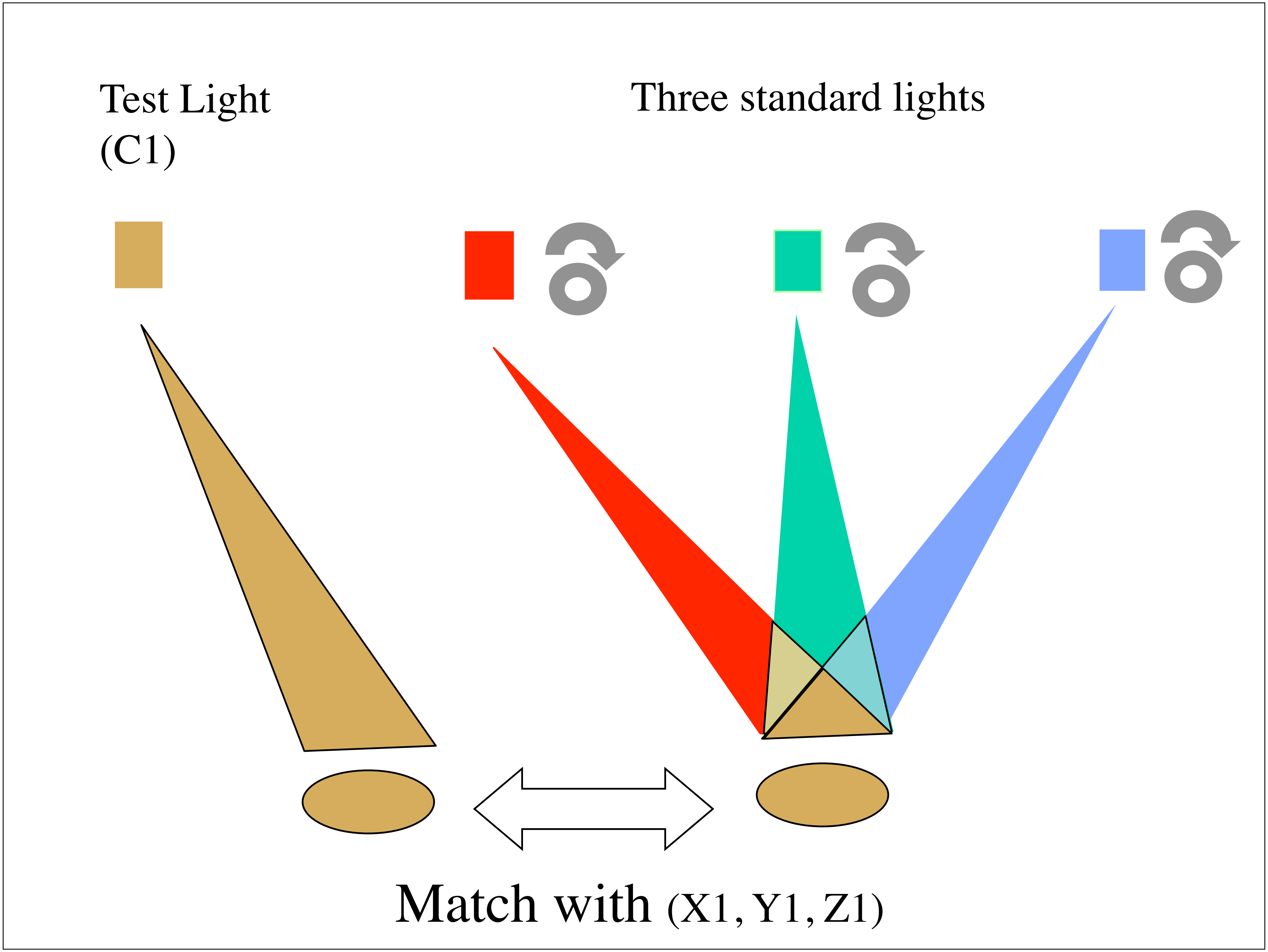

Test Light
Three standard lights
Match (with twice as much)

Matching is Linear (Part 1)

C1 is matched with (X1,Y1,Z1)

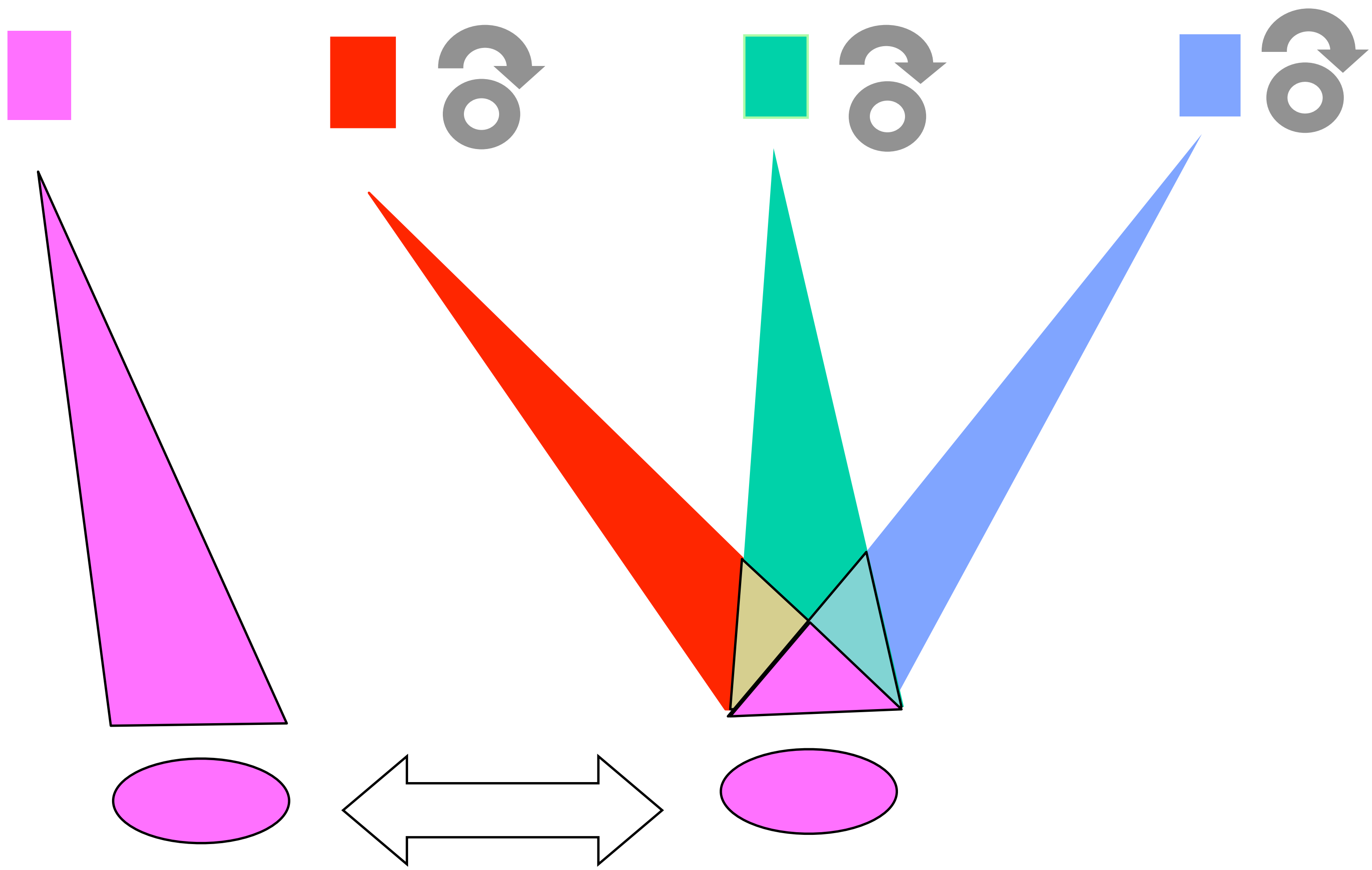
C = a*C1

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

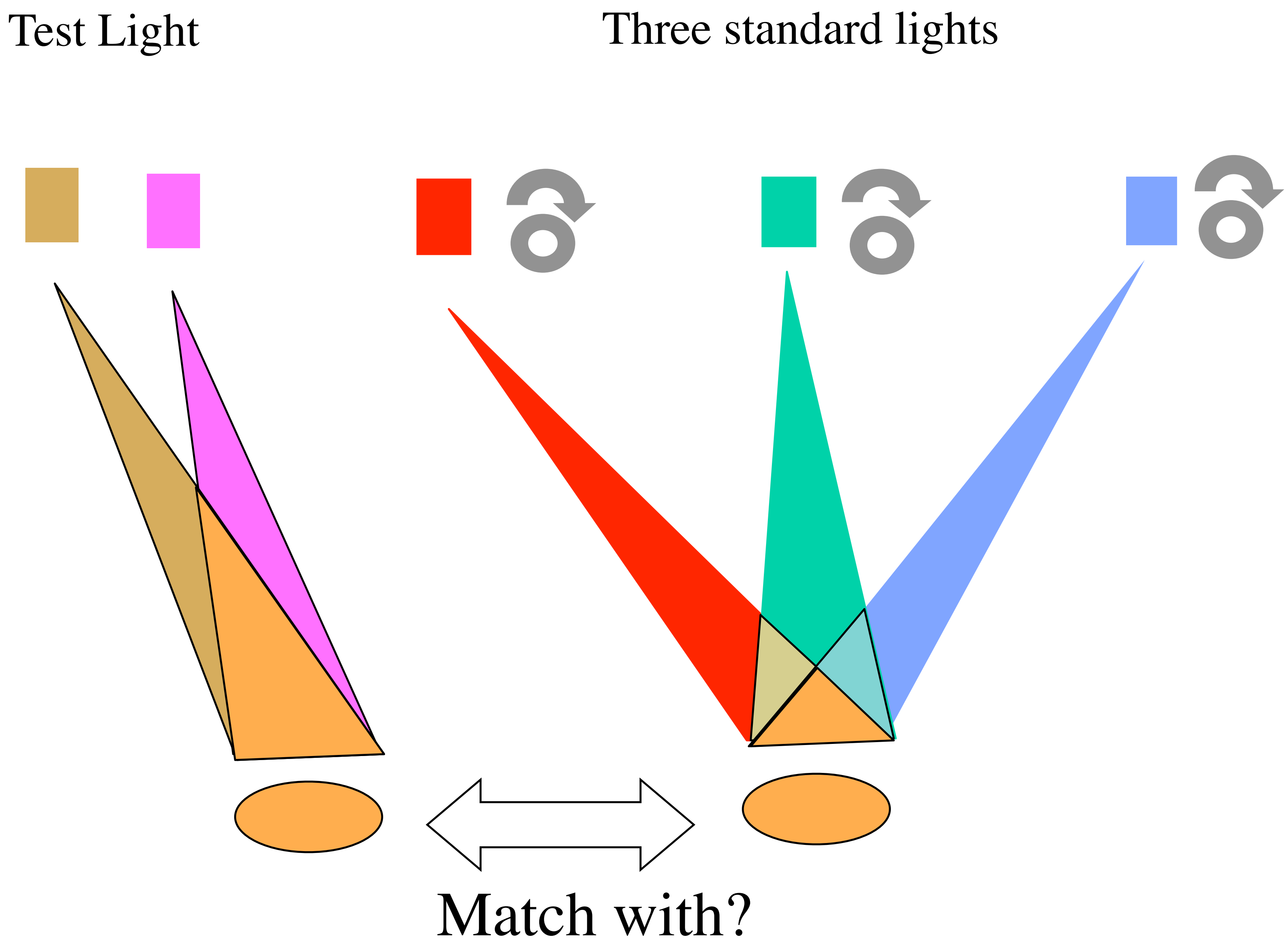

Test Light
(C1)
Three standard lights
Match with (X1, Y1, Z1)

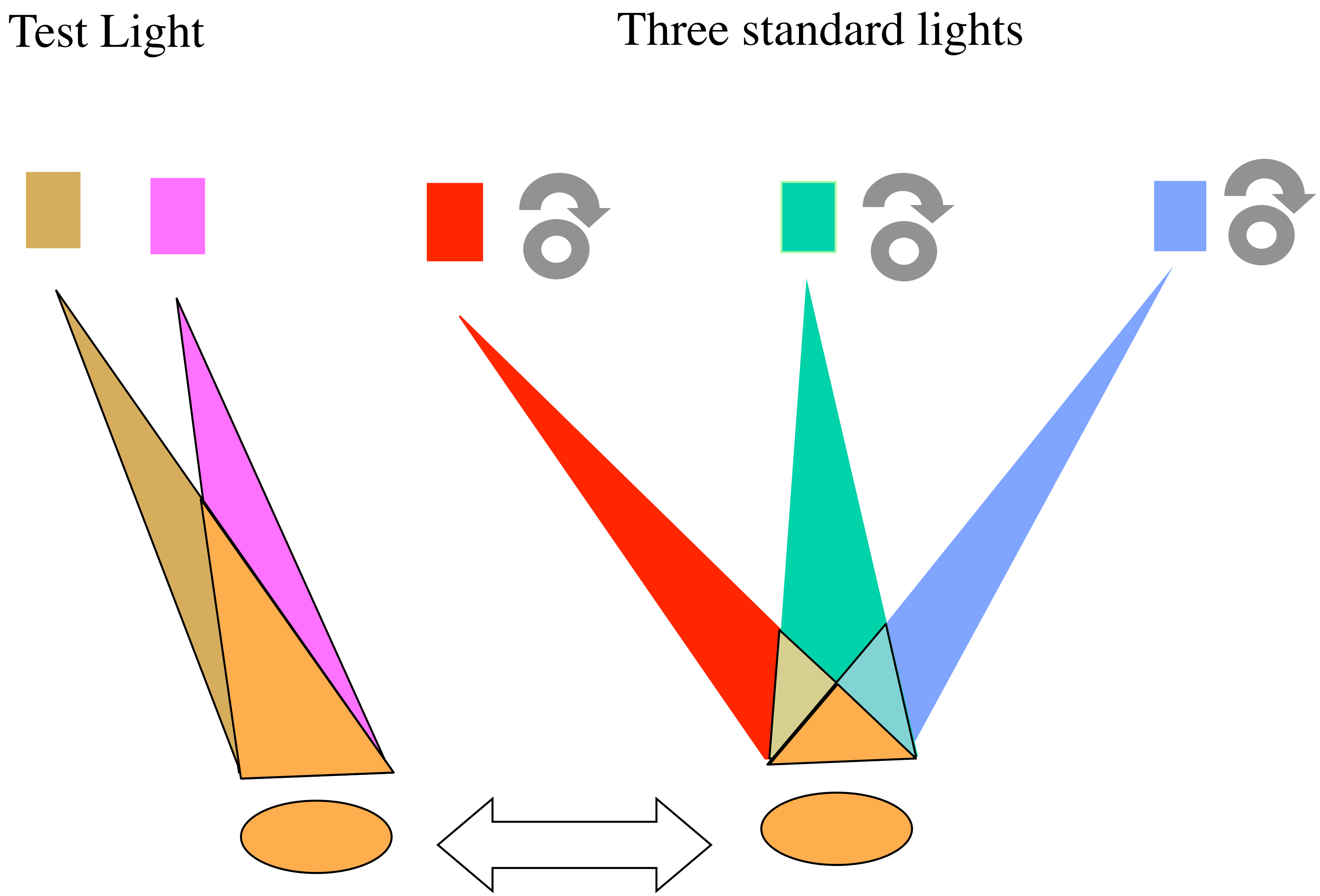
Test Light (C2)

Three standard lights



Match with (X2, Y2, Z2)


Test Light
Three standard lights
Match with?



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 Color

But what is (R,G,B)?

Specifying Color

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 Color

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 Color

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

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

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

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

Color Reproduction (Monitors & Projectors)

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_{apple}$$

Find (R,G,B)

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

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

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

If our imaging system is sensible, M is invertible.

However, we are not guaranteed that the R,G,B are inside [0,255].

Values greater than 255 just means we should reduce brightness.

Negative values are more problematic. These are out of “gamut”.

Not all colors can be reproduced from three primary ones.
(Fundamental property due to the nature of human vision).

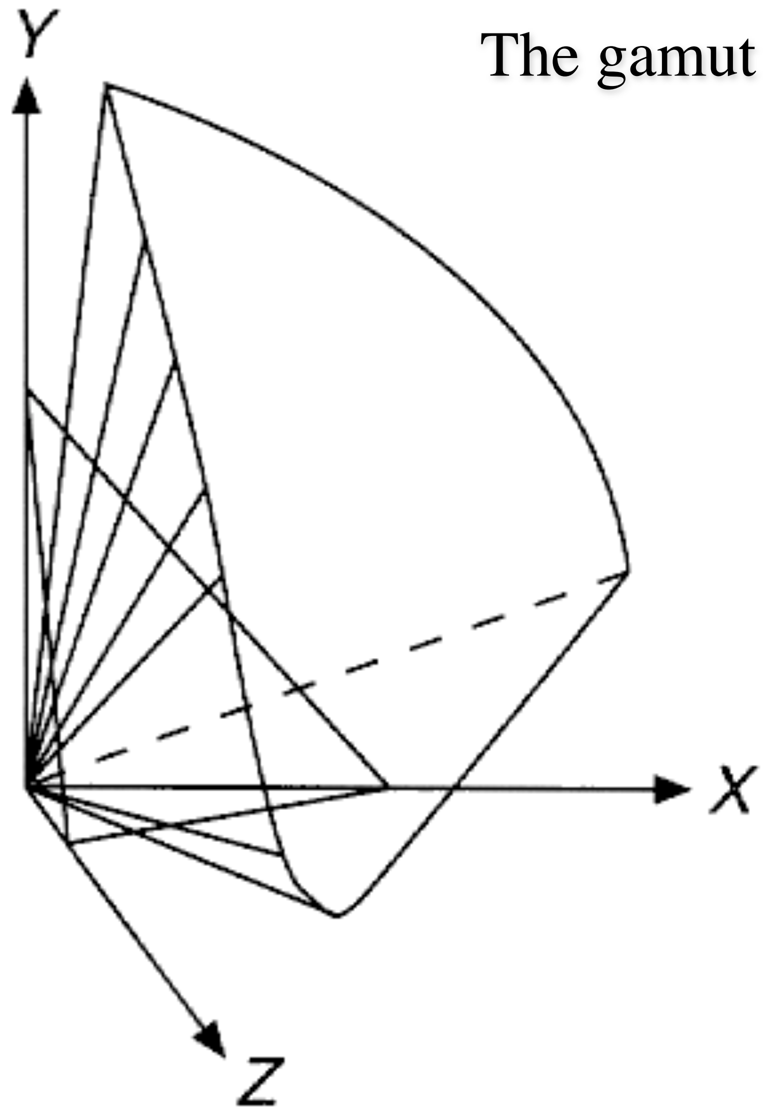
XYZ color space

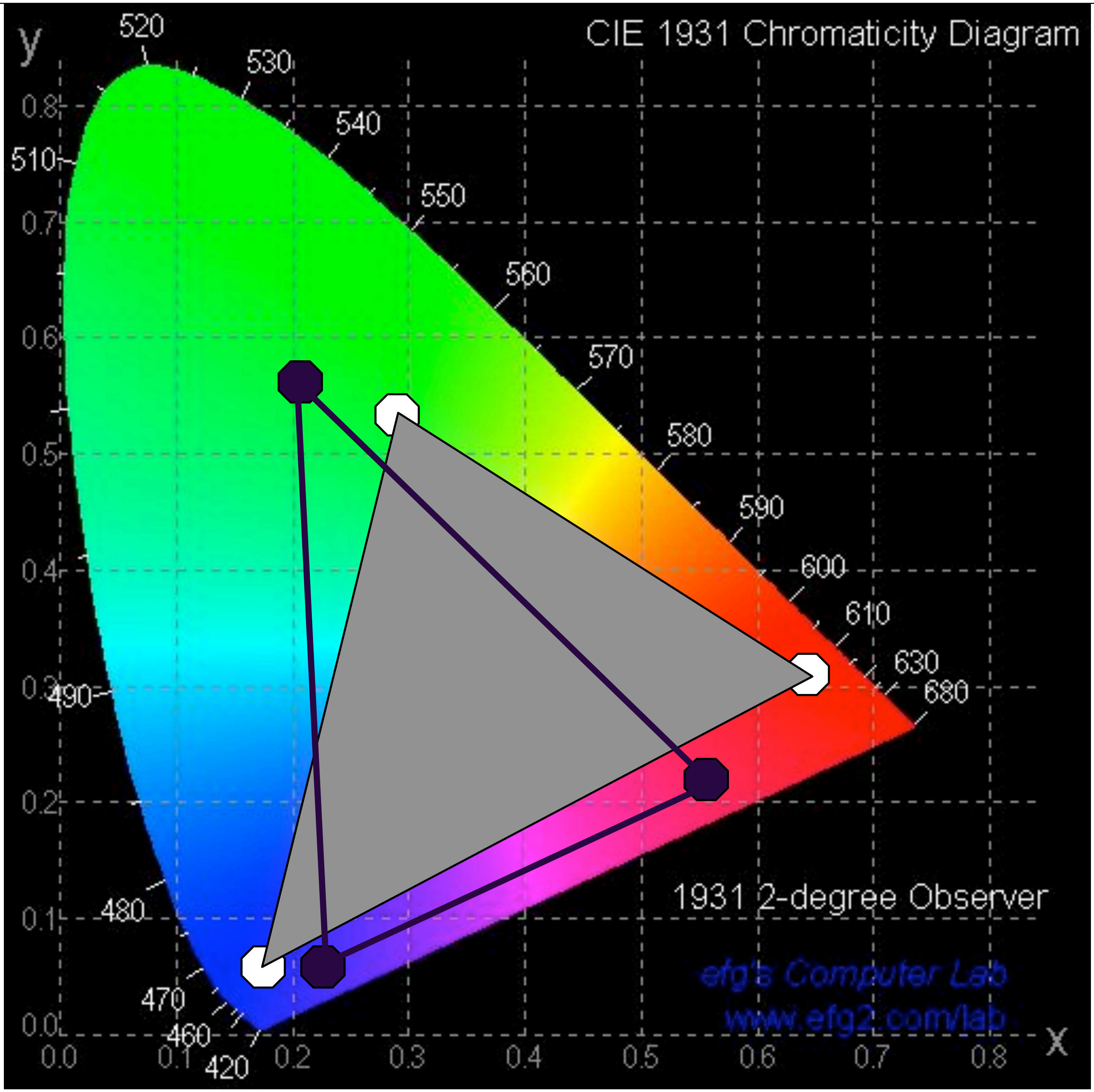
XYZ color space is a linear transformation of the matches to standard lights.

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

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

The gamut of all colors

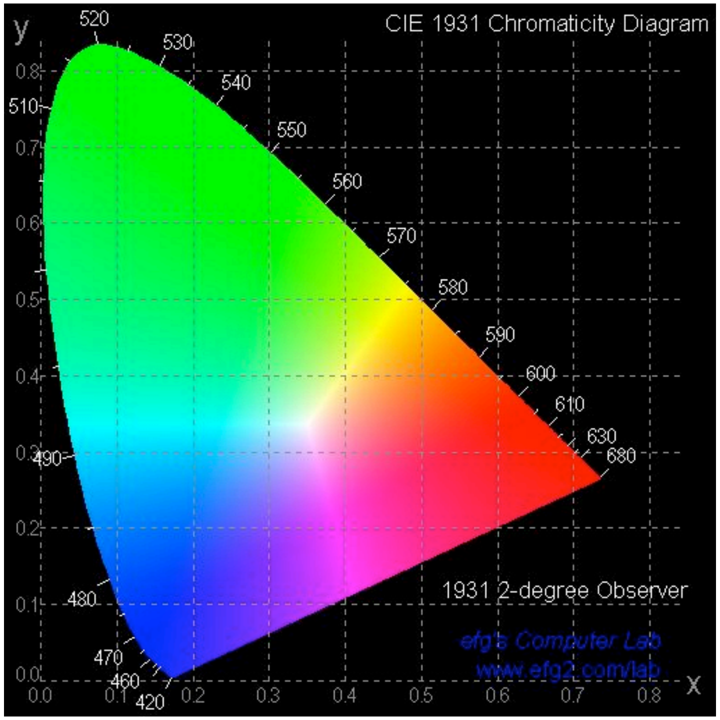




Available from efg2.com

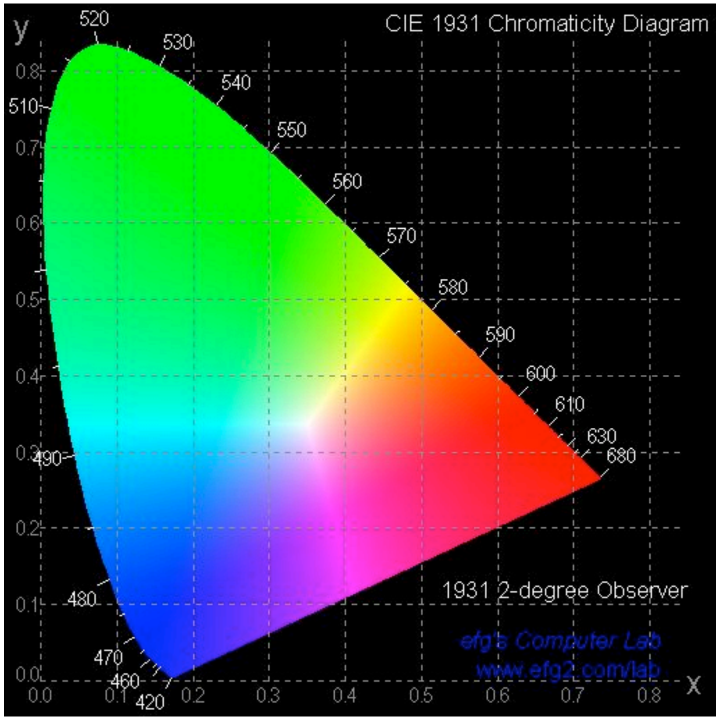
Qualitative features of CIE x, y

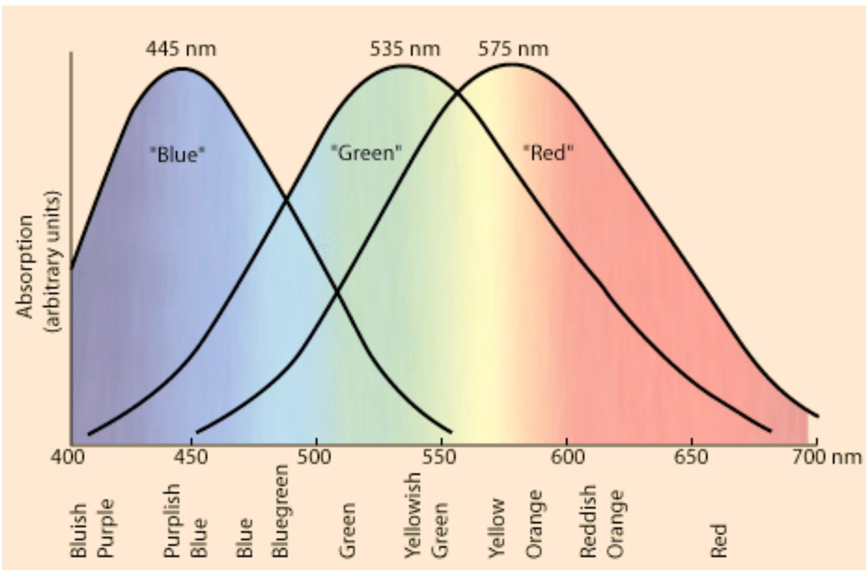
- Linearity implies that colors obtainable by mixing lights with colors A, B lie on line segment with endpoints at A and B
- Monochromatic colors (spectral colors) run along the "Spectral Locus"



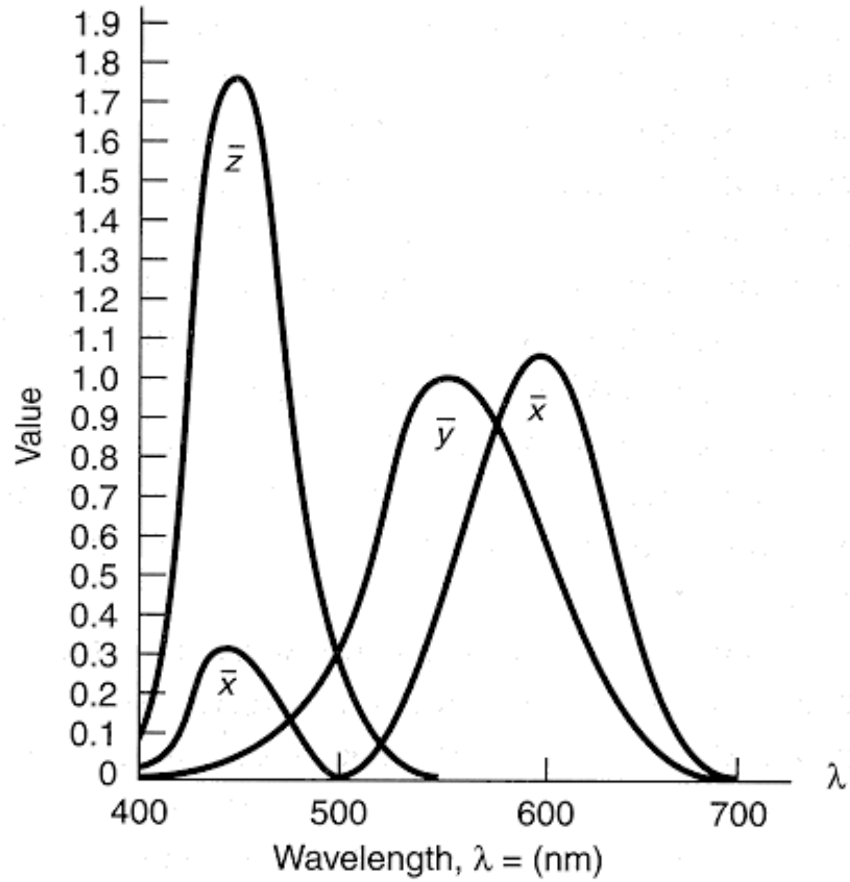
Qualitative features of CIE x, y

- Why the funny shape?





One measurement of human cone absorption



XYZ response curves