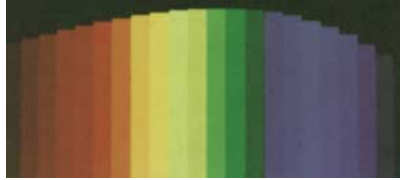
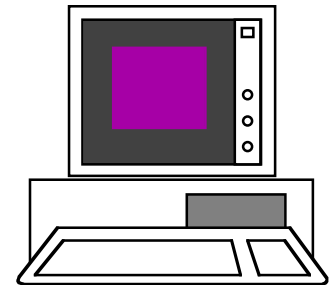
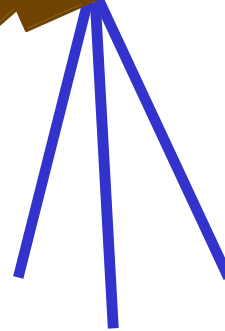
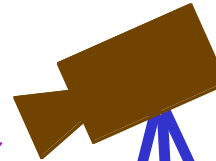
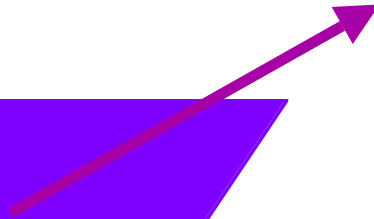
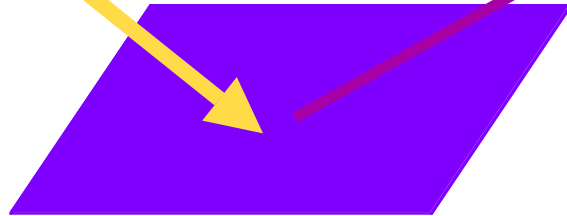
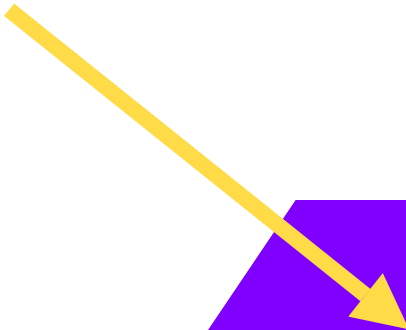
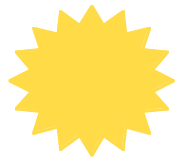
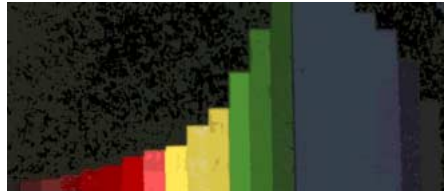


Administrative

- Homework 3 due on Nov 12

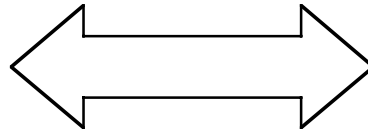
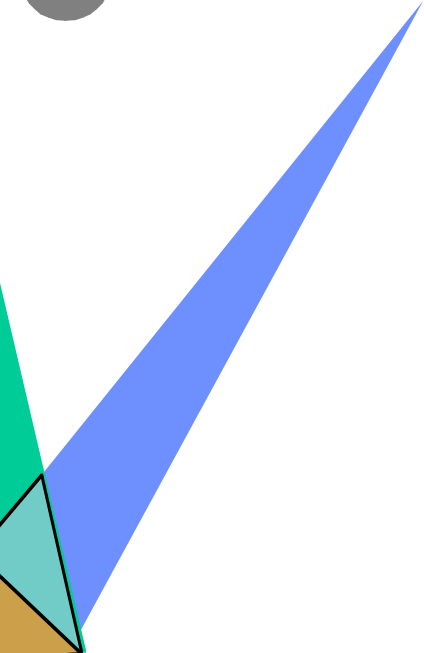
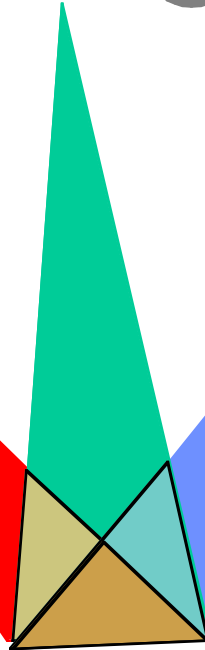
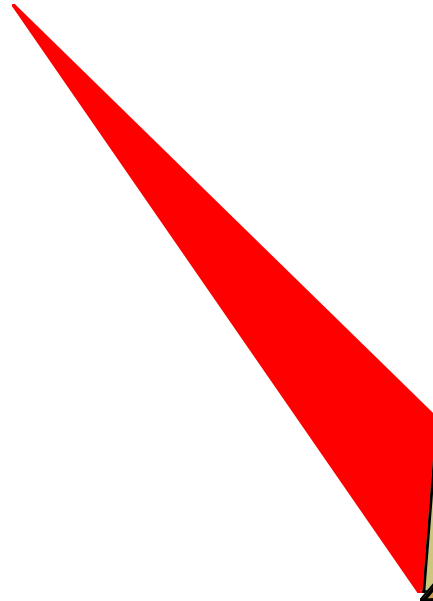
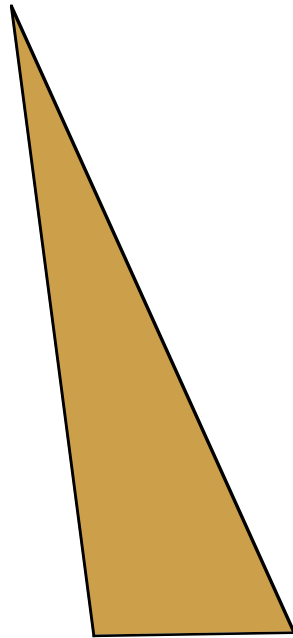


X



Test Light

Three standard lights



Match?

Matching is Linear (formal)

$$C = a * C1 + b * C2$$

C1 is matched with (X1,Y1,Z1)

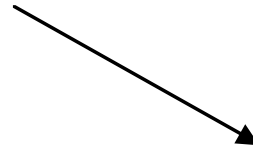
C2 is matched with (X2,Y2,Z2)

C is matched by

$$a * (X1, Y1, Z1) + b * (X2, Y2, Z2)$$

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

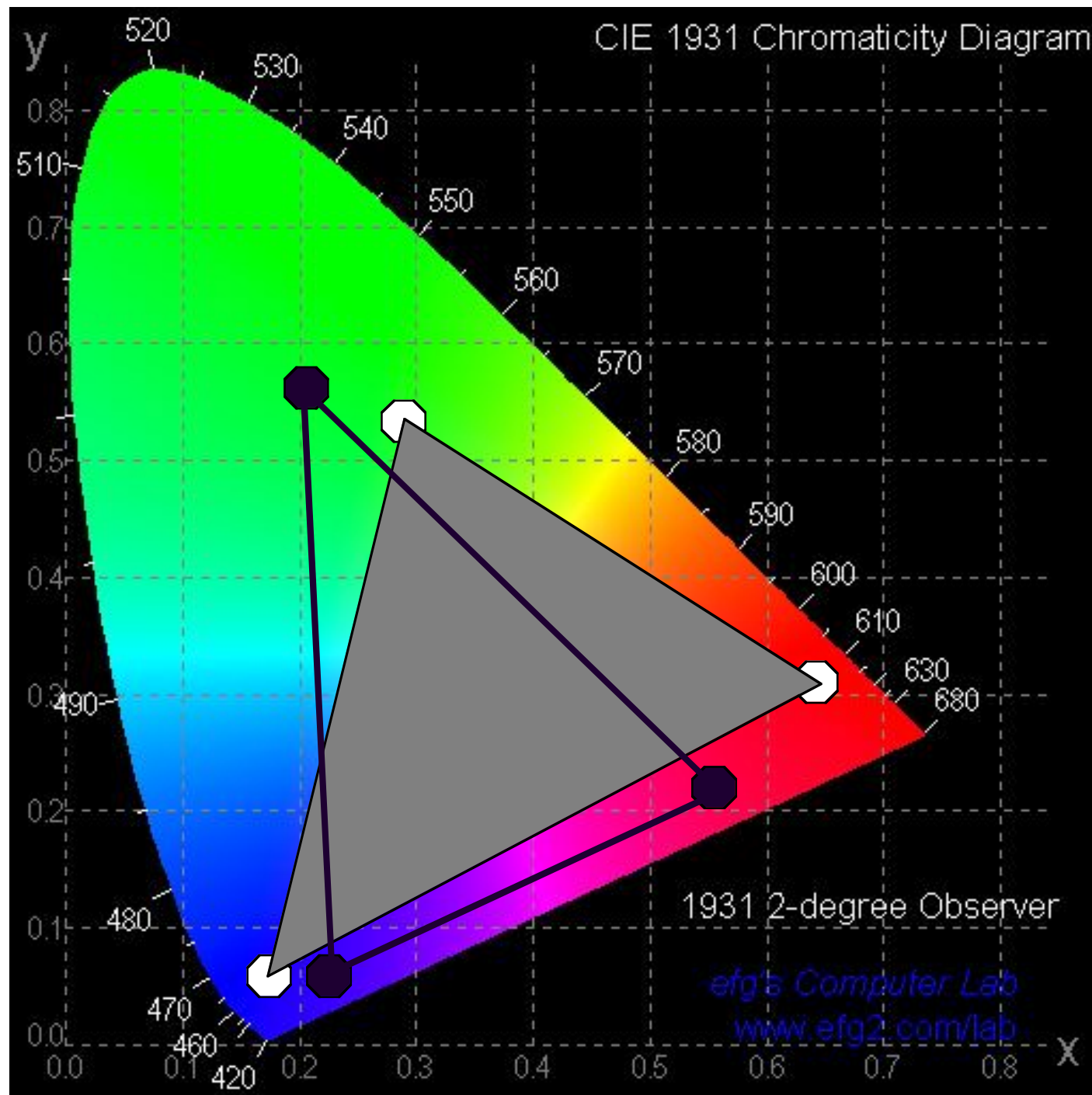
Colour Reproduction (Monitors & Projectors)


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

apple

Find (R,G,B)

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



Available
from
efg2.com

Colour Reproduction

Key point--color reproduction is based on “metamersism”

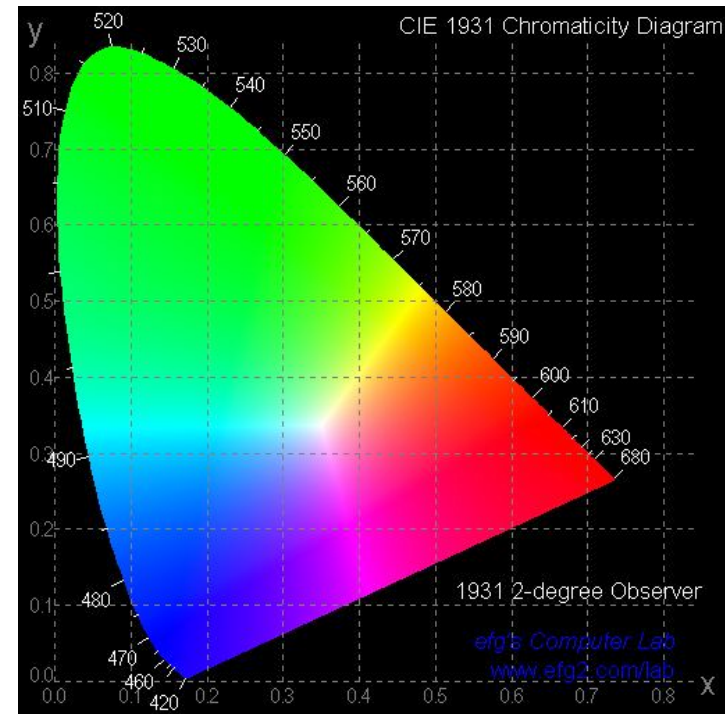
Metameric match--colors which match, despite different spectra.

Duplicating spectra would work, but for practical reasons, we duplicate the match.

For reflective surfaces, e.g prints, this means that the match can change if the illumination changes.

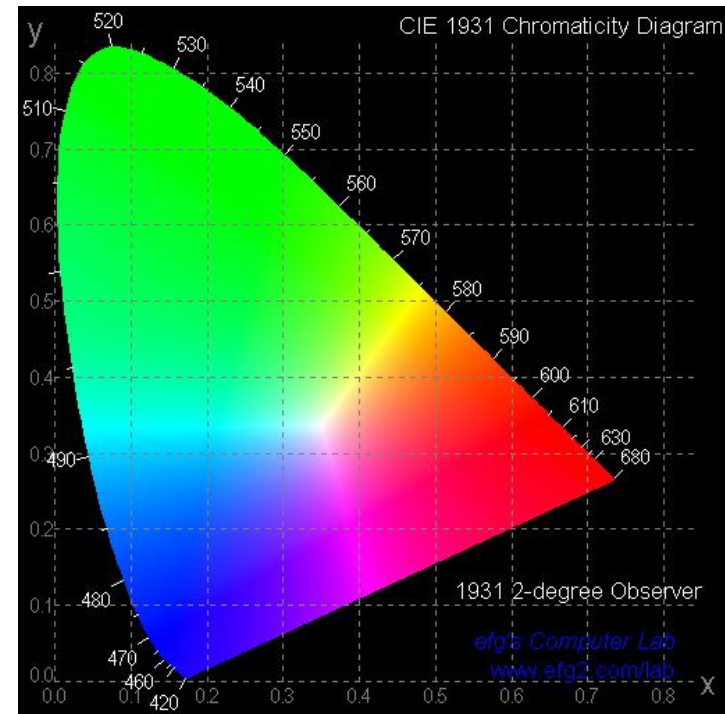
Qualitative features of CIE x, y

- 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”
- Dominant wavelength = Spectral color that can be mixed with white to match



Qualitative features of CIE x, y

- Purity = (distance from C to spectral locus)/(distance from white to spectral locus)
- Wavelength and purity can be used to specify color.
- Complementary colors=colors that can be mixed to get white



Matching is only for “aperature” color

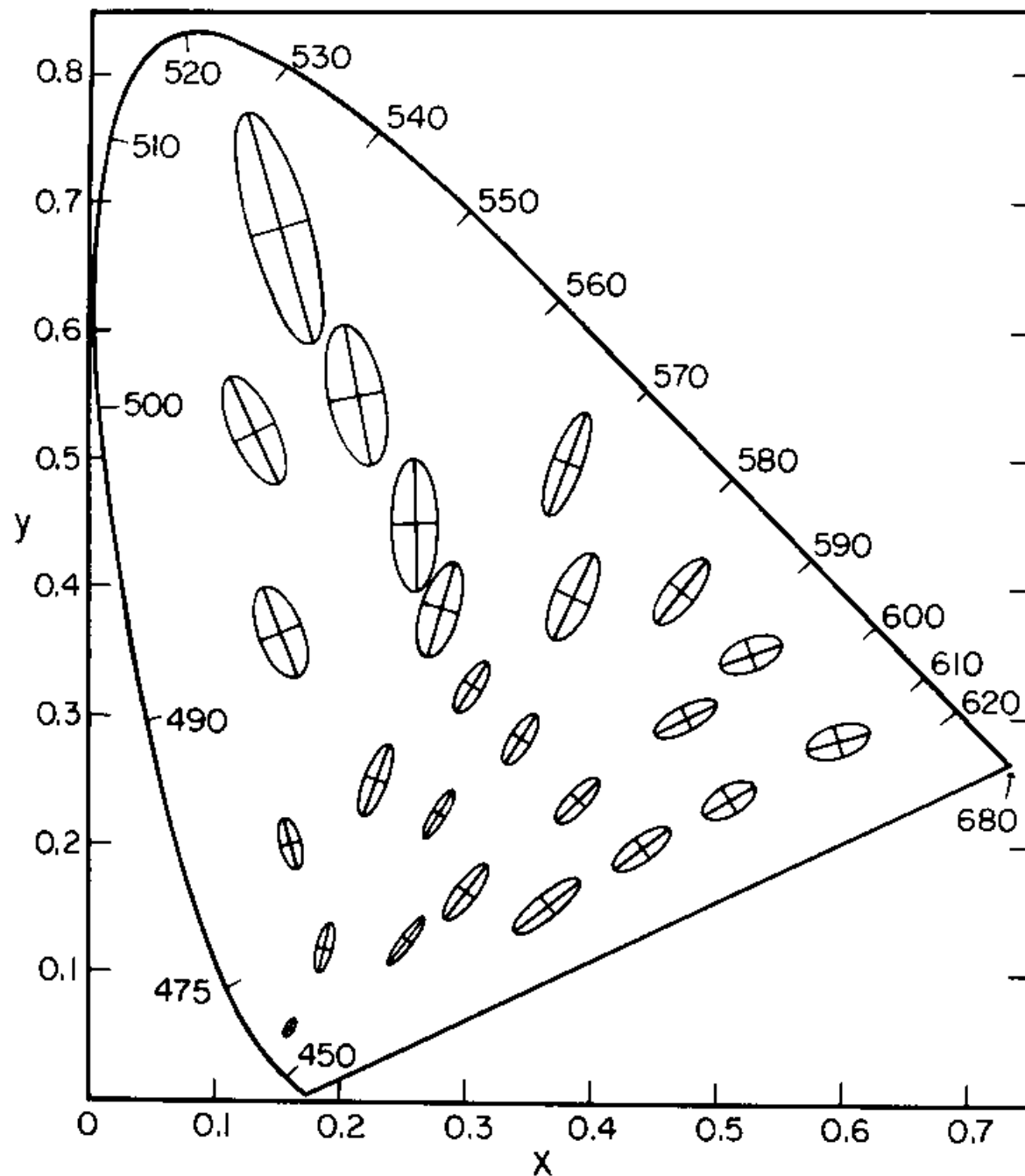
- When color is viewed in the context of other colors numerous effects occur which complicate the characterization of color (simultaneous contrast, color constancy, etc)
- Other complications include chromatic aberation in the eye and different spatial resolution for different colors (these are linked)

More linear color spaces

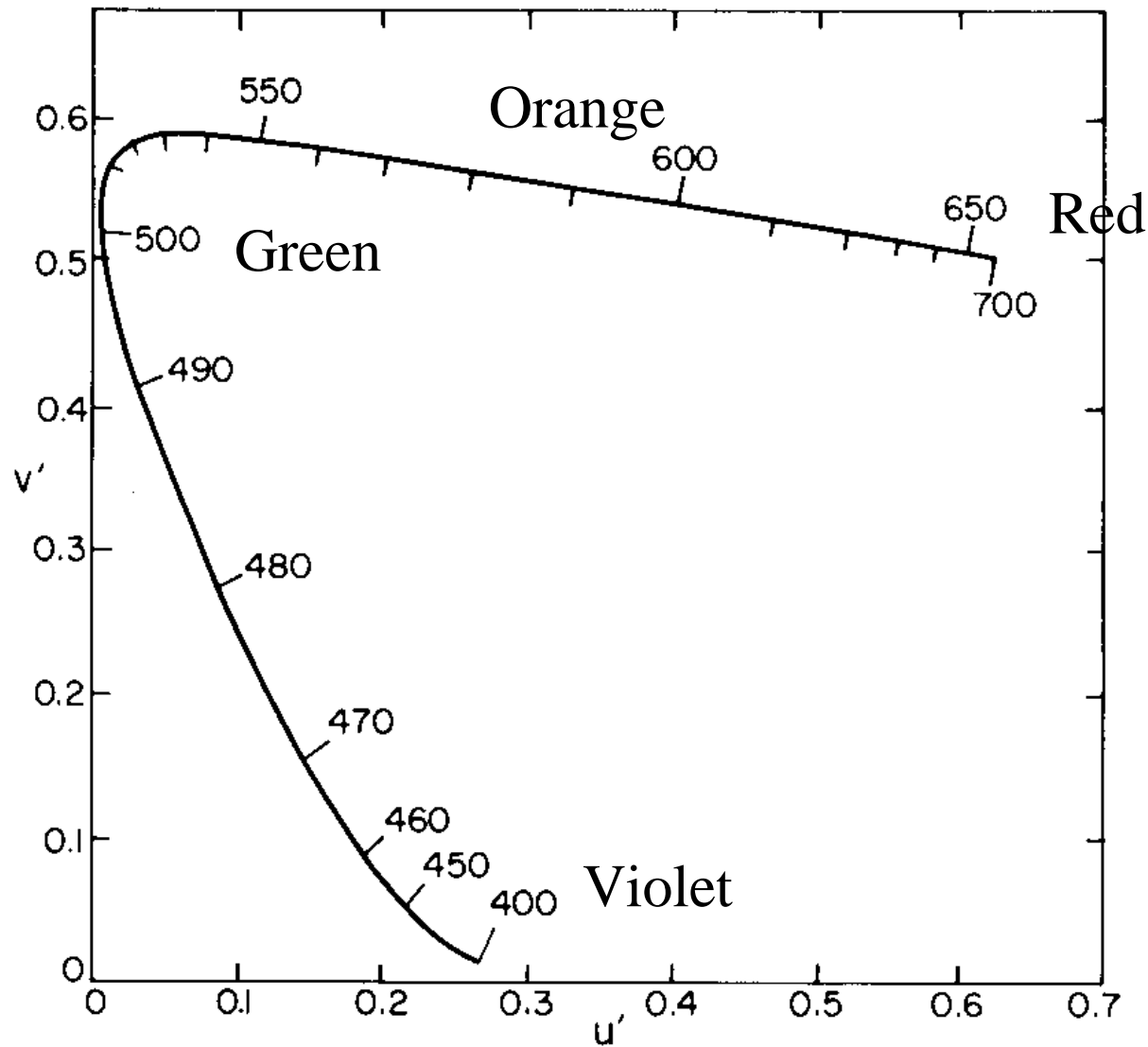
- Monitor RGB: primaries are monitor phosphor colors, primaries and color matching functions vary from monitor to monitor - careful!
- However--RGB without qualification usually means sRGB which is a standard definition adopted recently where the matrix transform $XYZ \leftrightarrow RGB$ is agreed upon based on “standard” monitor primaries.
- YIQ: mainly used in television, Y is (approximately) intensity, I, Q are chromatic properties. Linear color space; hence there is a matrix M that transforms XYZ coords to YIQ coords. I and Q can be transmitted with low bandwidth.

The quest for uniform colour spaces

- Uniform: equal (small!) steps give the same perceived color changes.
- XYZ is not uniform!
- Uniformity only applied to small differences. There is no theory for numerically deciding if yellow is perceptually closer to green or red.



MacAdam Ellipses
(scaled by a factor
of 10) on CIE x, y



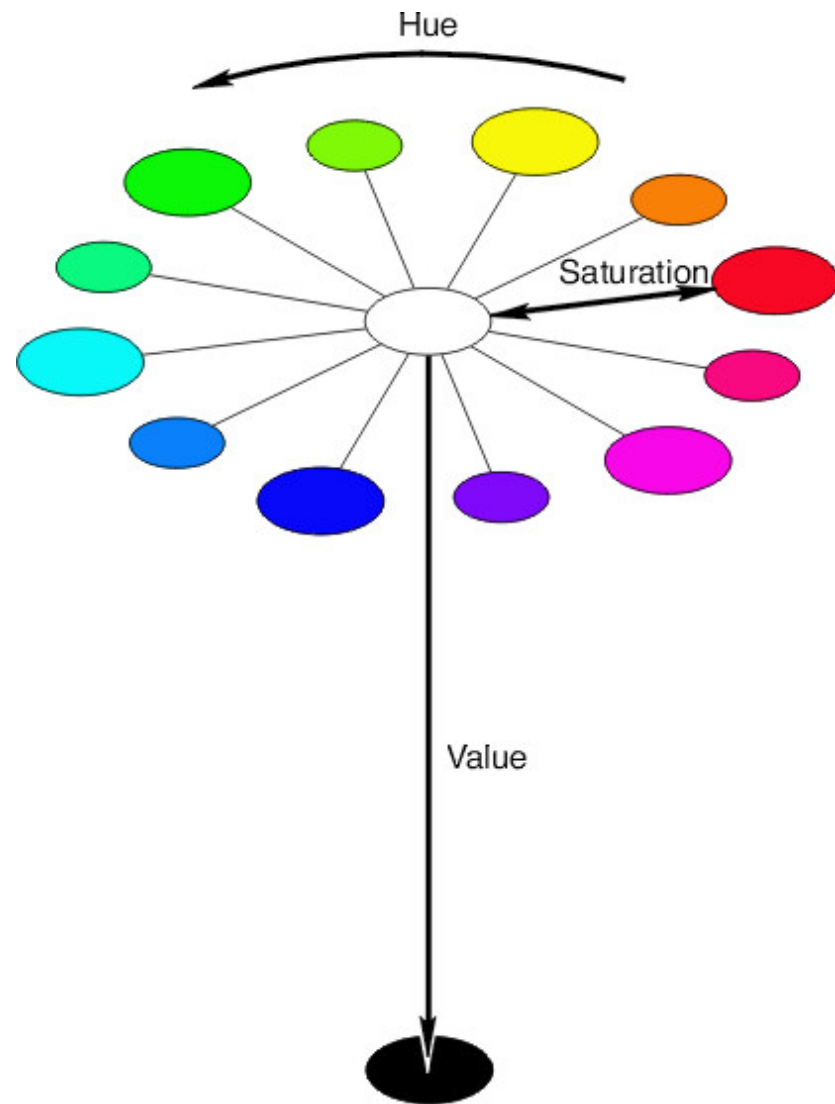
CIE $u'v'$
is a non-linear
colour space
where colour
differences are
more uniform

$$(u', v') = (4 X / (X + 15 Y + 3 Z), 9 Y / (X + 15 Y + 3 Z))$$

Non-linear colour spaces

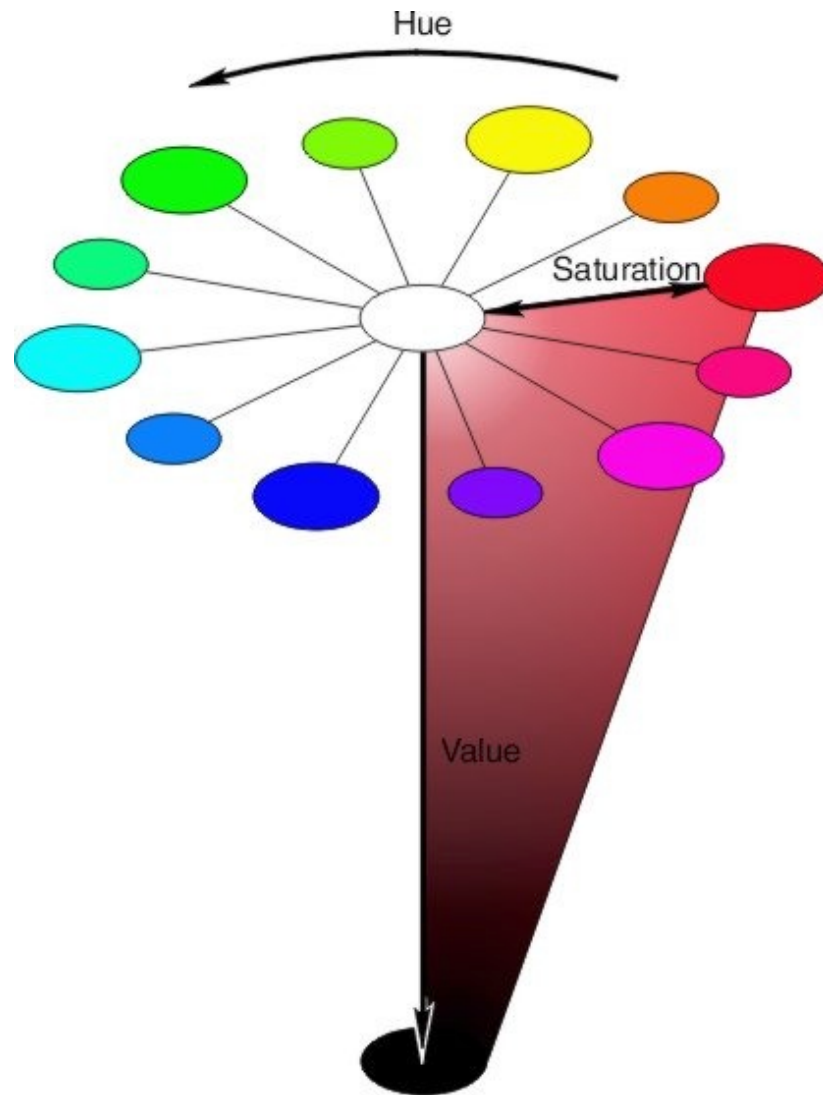
- HSV: Hue, Saturation, Value are non-linear functions of XYZ.
 - because hue relations are naturally expressed in a circle
 - popular in graphics
 - a variety of similar but different hacks are available for converting between RGB TO HSV
- Munsell: describes surfaces, rather than lights - less relevant for graphics. Surfaces must be viewed under fixed comparison light
- L^*a^*b : Another attempt to approximate uniformity
 - popular colour science

HSV (cont)



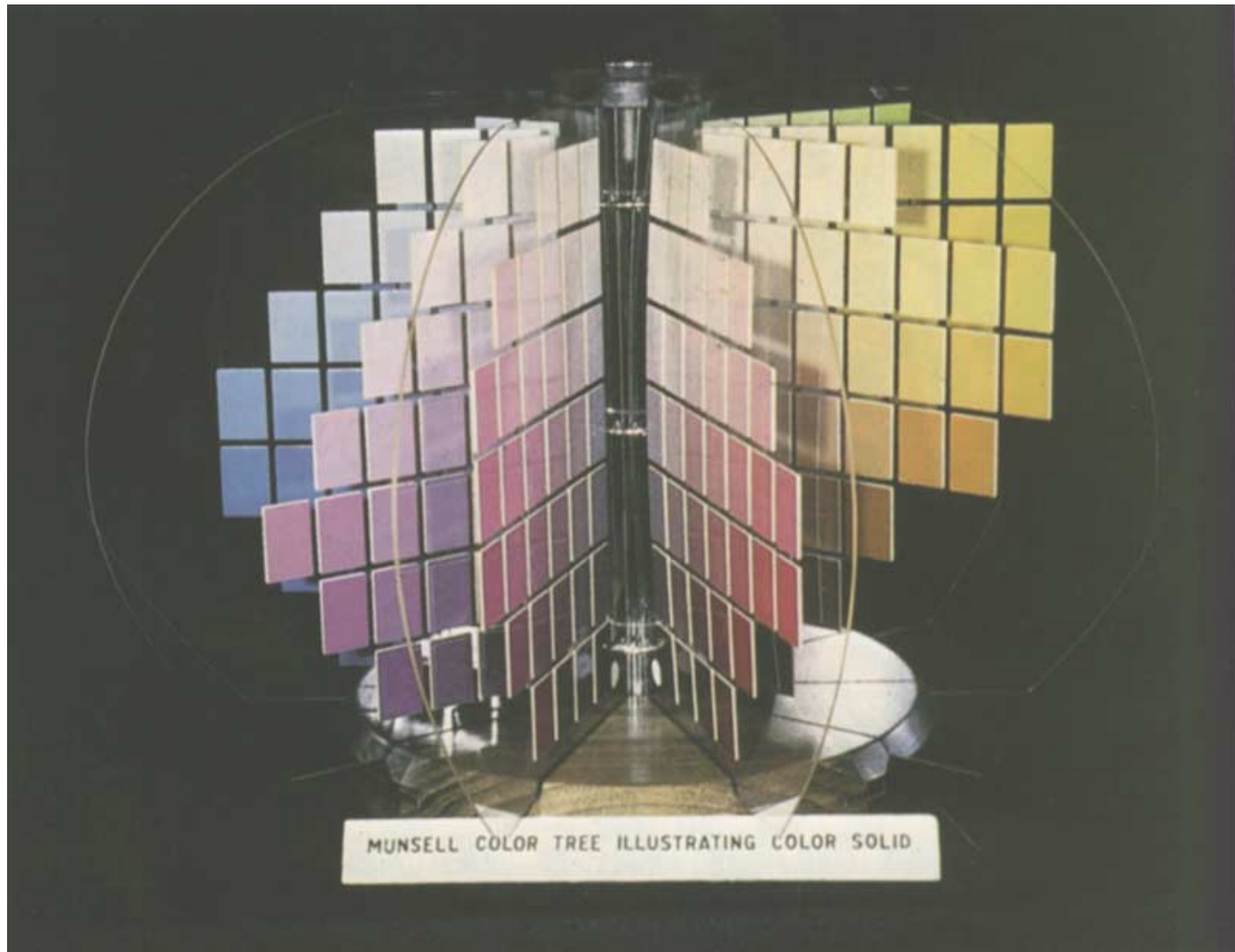
From <http://www2.ncsu.edu:8010/scivis/lessons/colormodels/>

HSV (cont)



From <http://www2.ncsu.edu:8010/scivis/lessons/colormodels/>

Munsell color space



Lab Color Space

Yet another attempt at (approximating) a uniform color space!

Monitor Gamma

A typical image is **NOT** linear. Often a gamma correction is included. This leads to no end of confusion.

A “gamma” corrected image is ready to drive a CRT monitor, and has advantages that quantization (8 bits) errors are *roughly* uniformly distributed--that fact that this works is a convenient accident.

Monitor Gamma

Due to the physics involved, CRT monitor brightness is proportional to $\text{voltage}^{2.5}$

This is further hacked to give the “standard” gamma of 2.2

So, if an image looks good on a CRT, it is likely to be non-linear by $\text{pow}(1/2.2)$

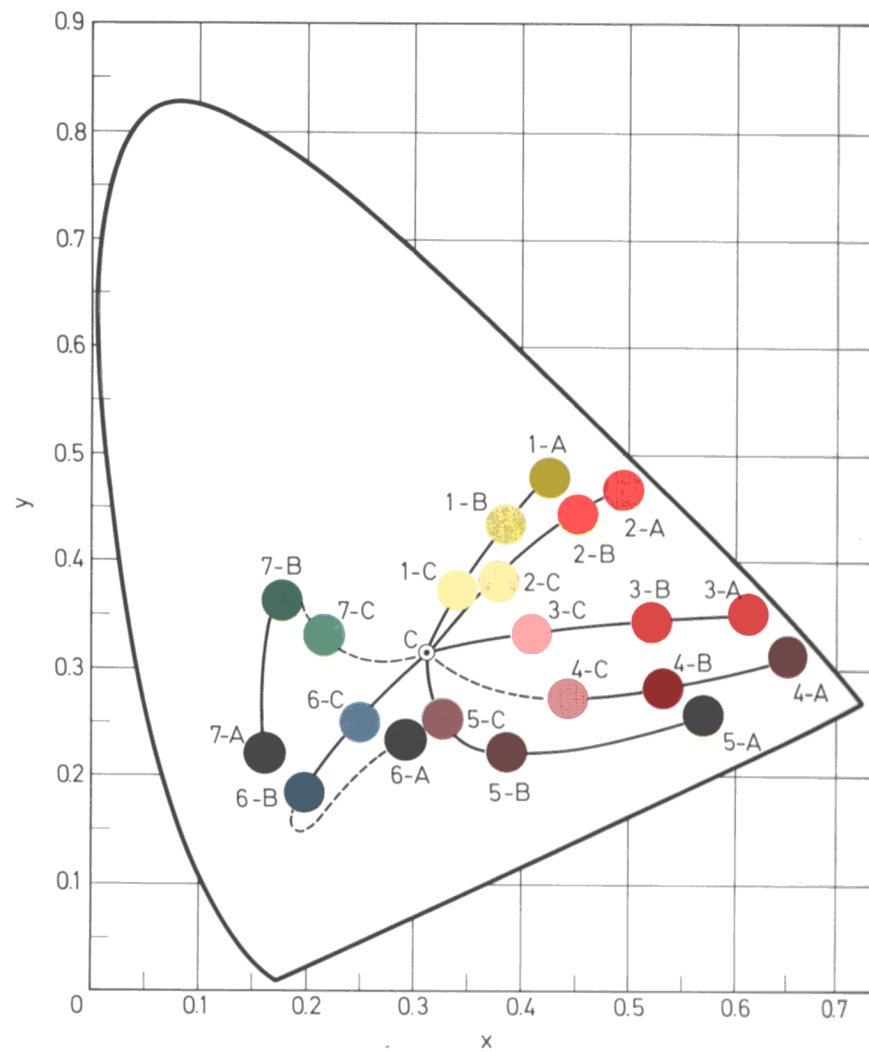
LCD--more linear, but then hardware/software can be hacked to be like CRT

Confusing? Yes!

Subtractive mixing

- Inks subtract light from white, whereas phosphors glow.
- Linearity depends on pigment properties - often hugely non-linear.
- Inks: Cyan=White-Red, Magenta=White-Green, Yellow=White-Blue.
- For a good choice of inks, matching is linear
- eg. $C+M+Y = \text{White} - \text{White} = \text{Black}$
 $C+M = \text{White} - \text{Yellow} = \text{Blue}$
- Usually require CMY and Black, because colored inks are more expensive, and registration is hard
- For good choice of inks, there is a linear transform between XYZ and CMY

Mixing pigments in CIE



Device independent colour imaging

- **Problem:** ensure that colours on a display, printer, etc. give the same experience that a viewer would have seeing relevant light spectra
- **Difficulty:** limited gamuts of most output devices
- **Strategy:** exploit a model of human experience