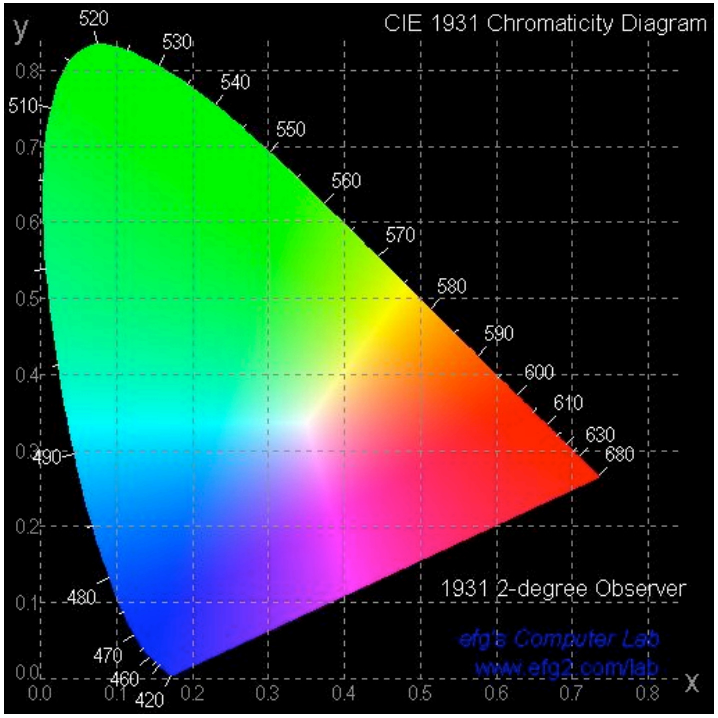
# Qualitative features of CIE x, y

- 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

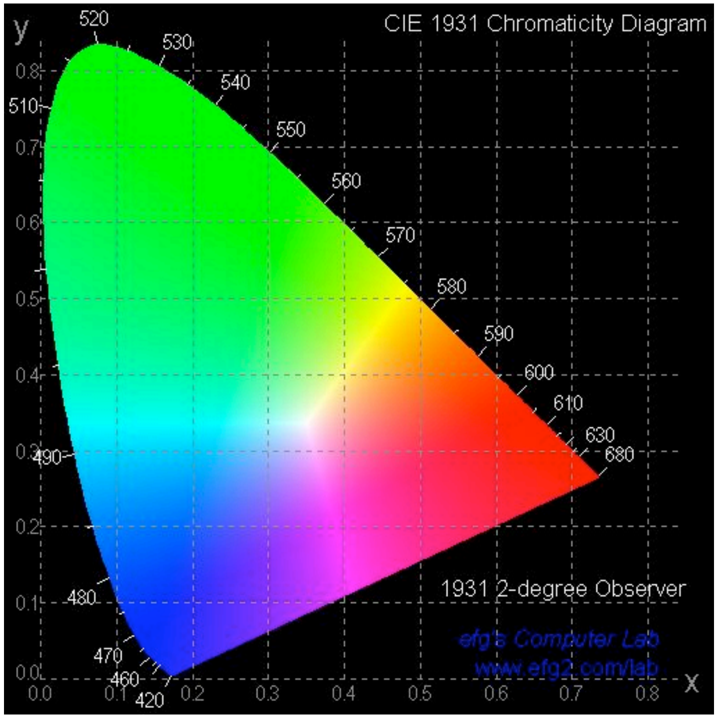
Optional



Optional

# 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 "aperture" 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 aberration in the eye and different spatial resolution for different colors (these are linked)

# Colour Reproduction

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

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.

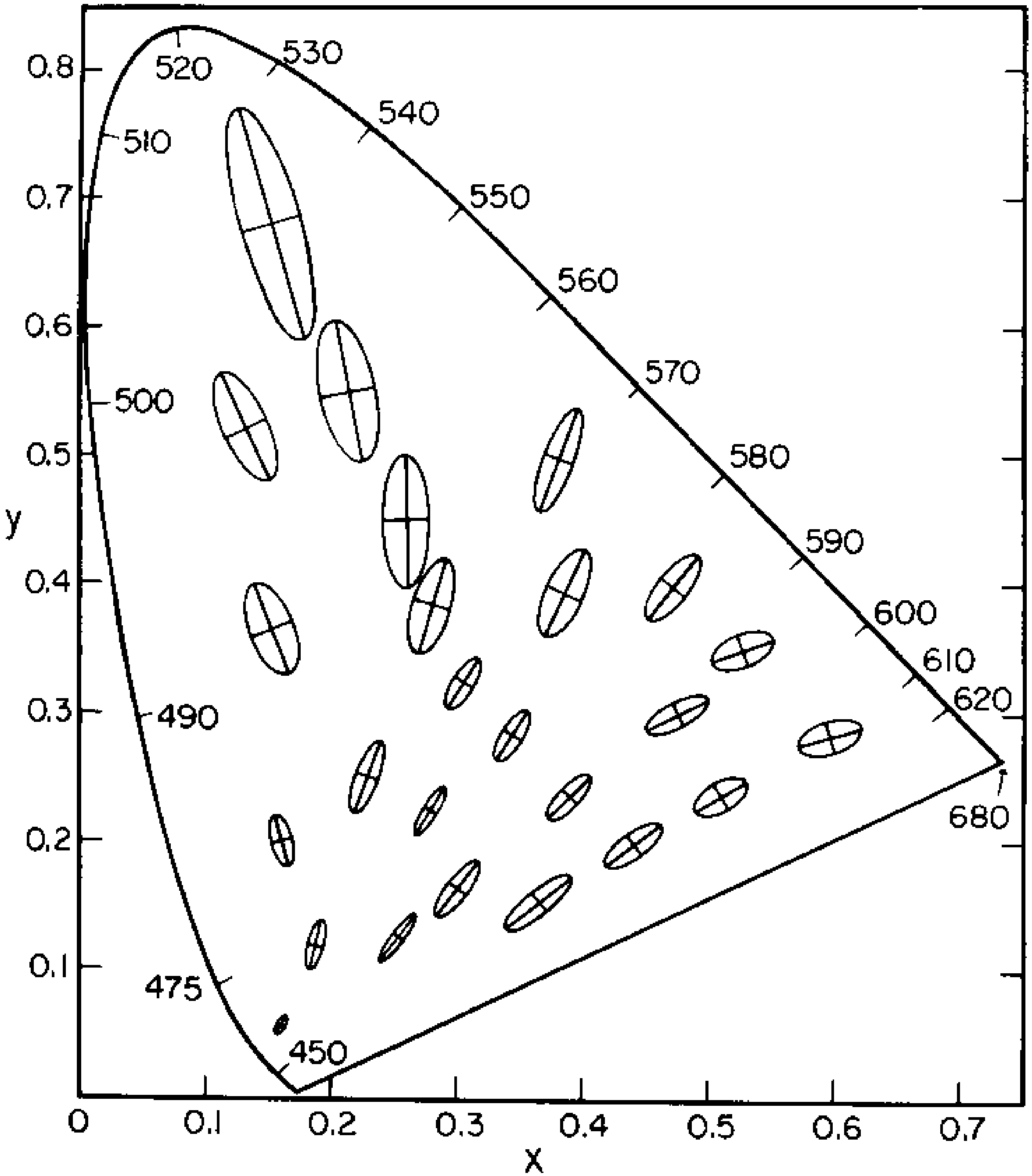
Optional

# 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<-->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.

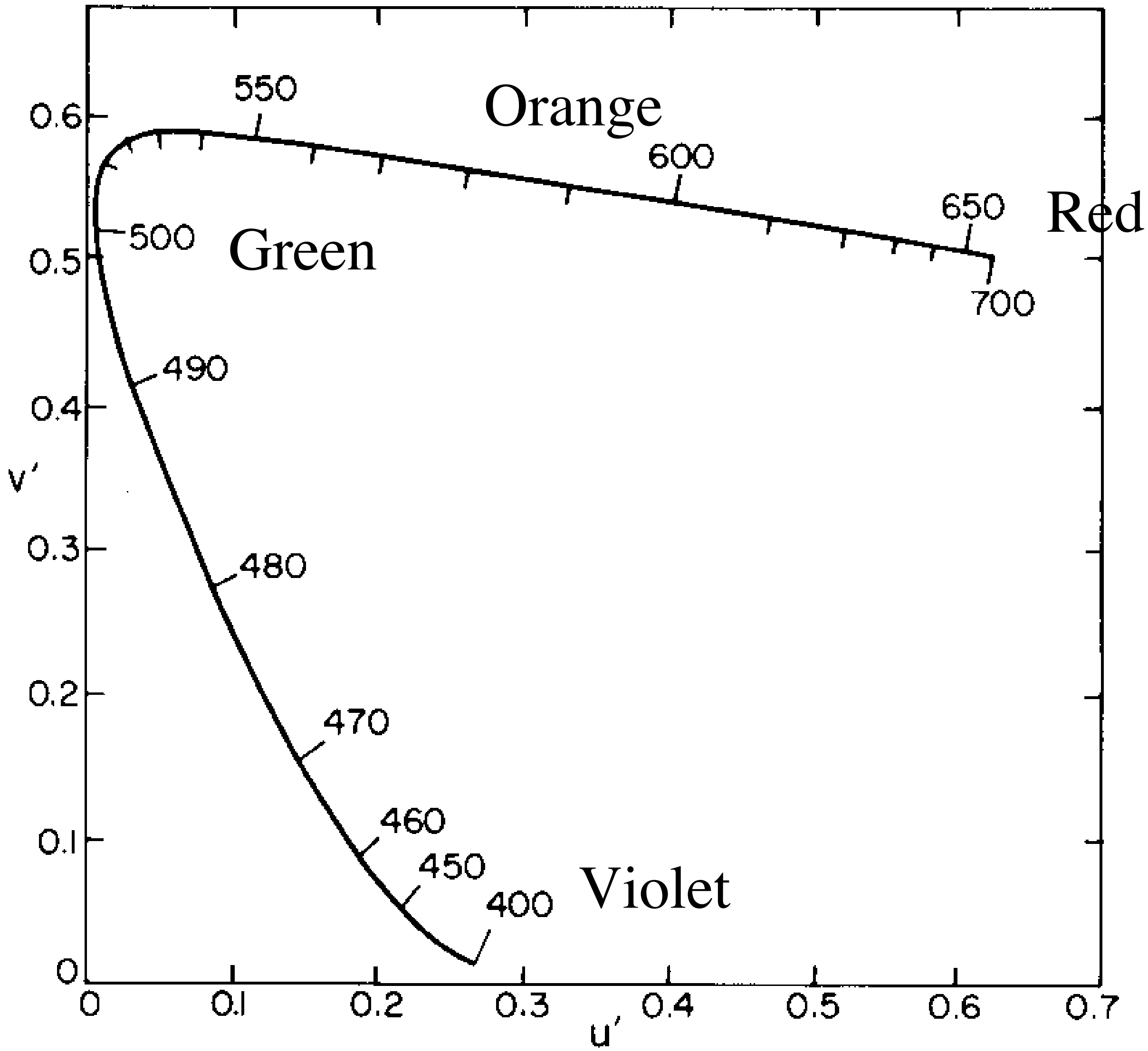
# The quest for uniform colour spaces

- 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

Optional




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

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

Optional

# Non-linear colour spaces

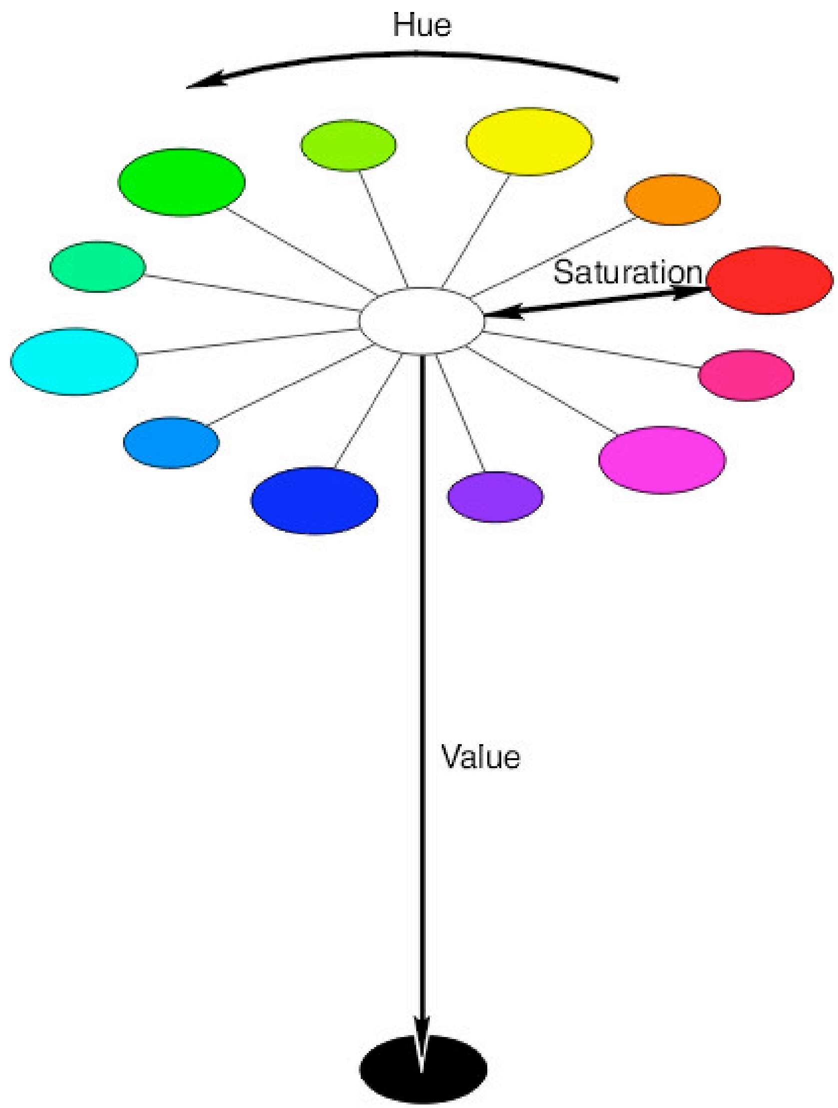
- HSV: Hue, Saturation, Value are non-linear functions of XYZ.
  - because hue relations are naturally expressed in a circle
  - popular in graphics
  - a variety of similar but different hacks are available for converting between RGB TO HSV

- 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 in colour science

Optional

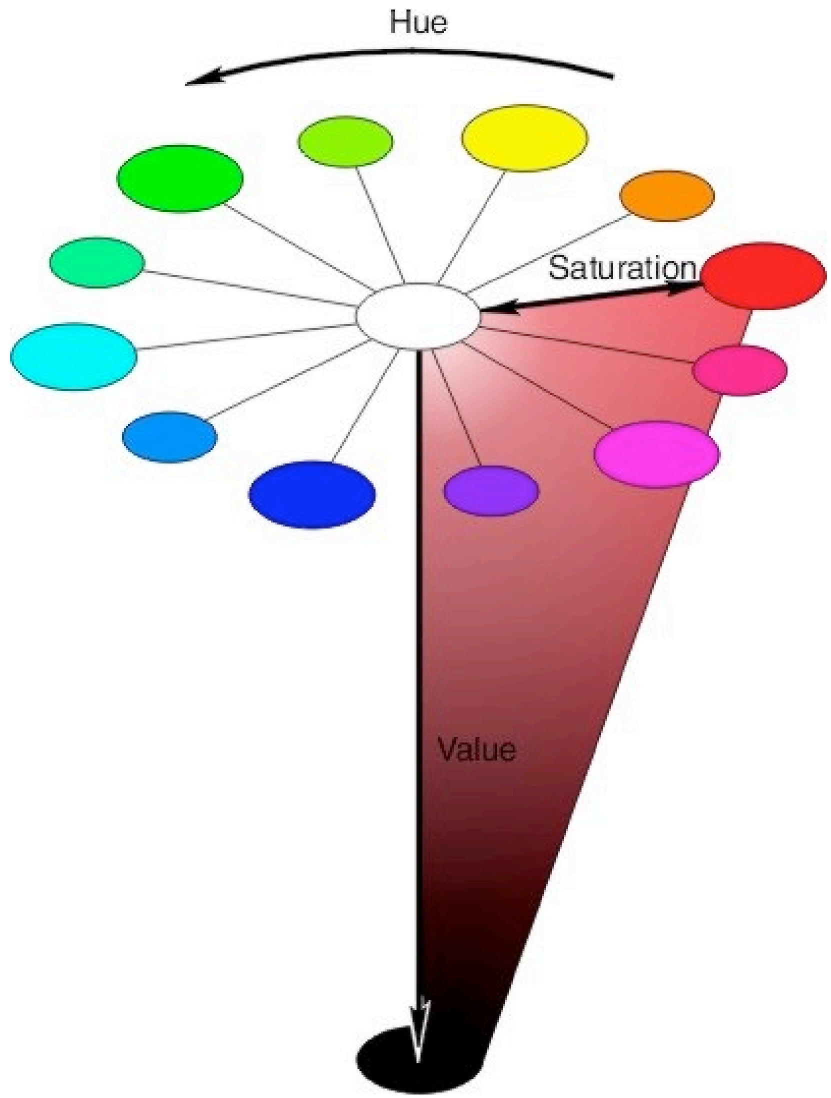
# HSV (cont)




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

Optional

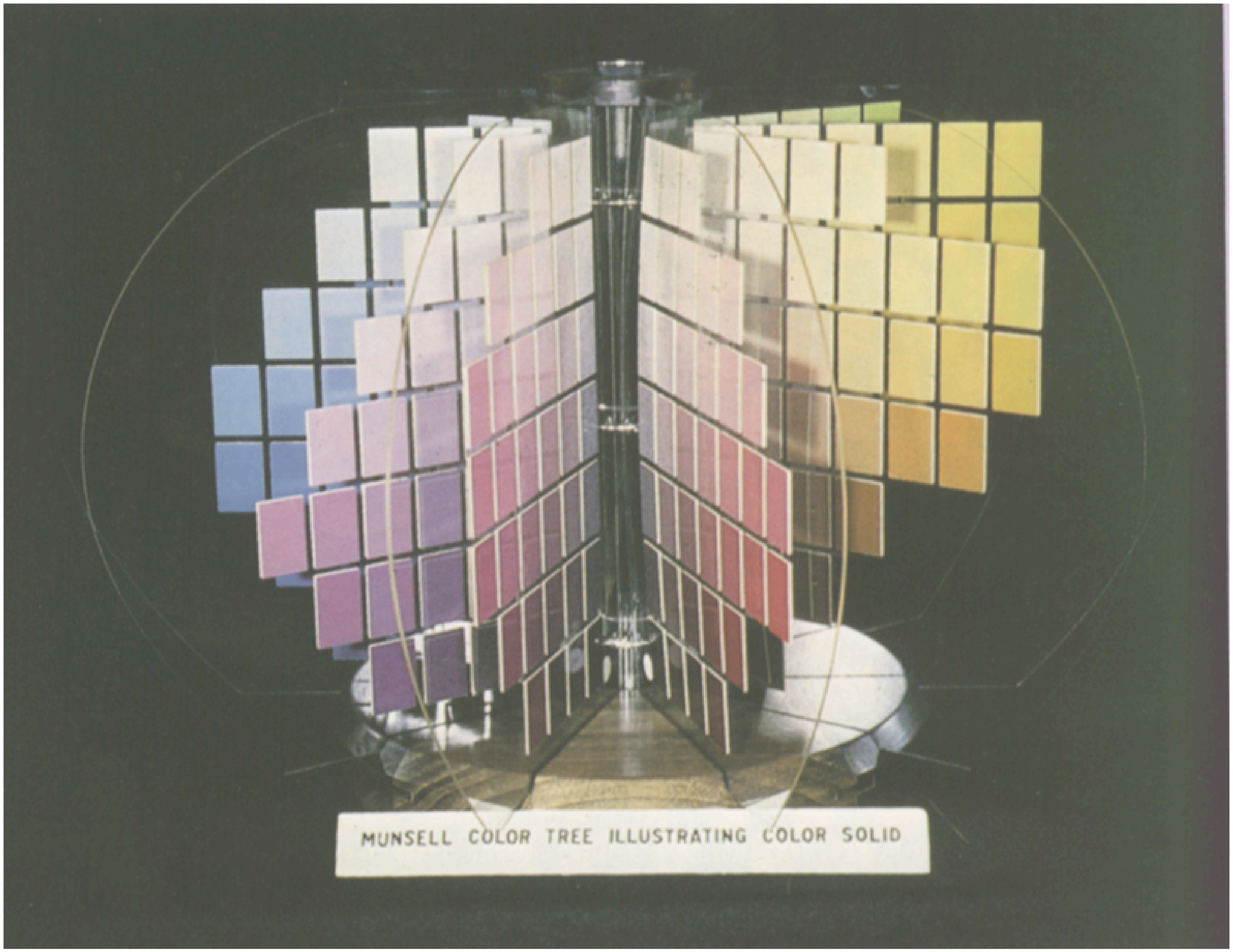
# HSV (cont)




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

Optional

# Munsell color space



Optional

# Lab Color Space

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

Optional

# 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.

Optional

# Monitor Gamma

Due to the physics involved, CRT monitor brightness is proportional to 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 pow(1/2.2)

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

Confusing? Yes!

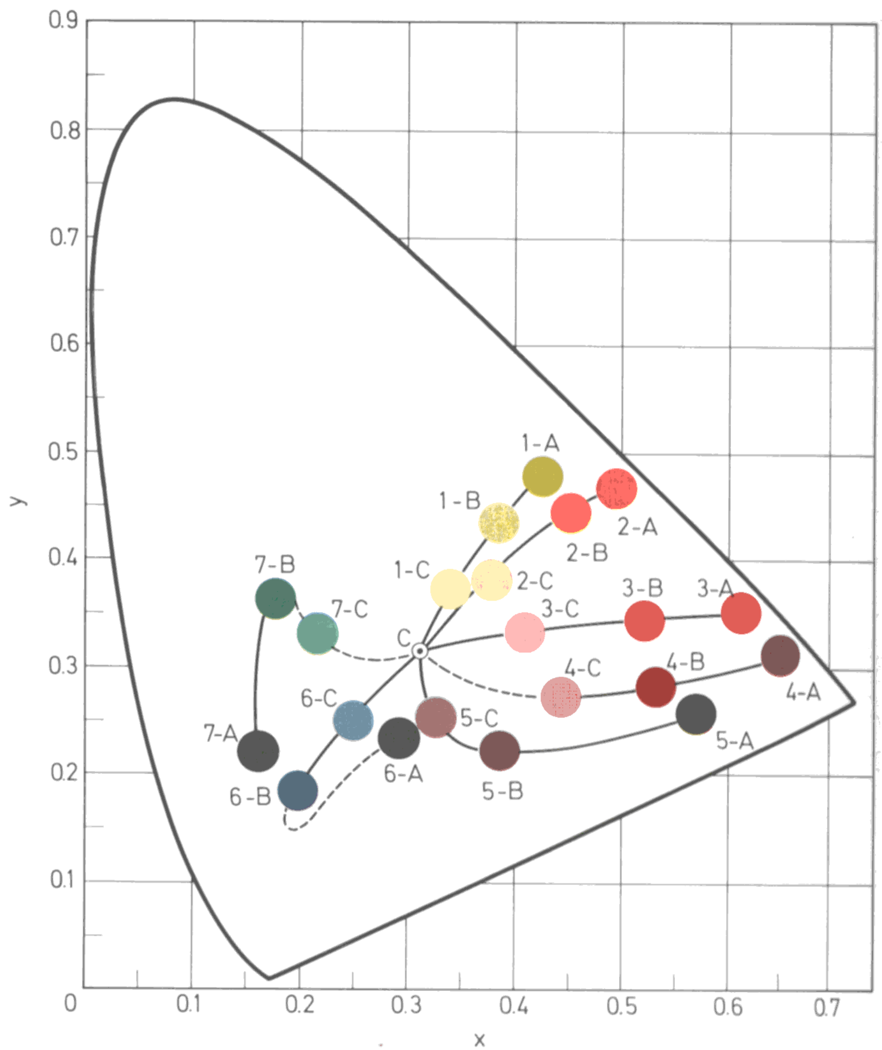
Optional

# 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
- e.g.. C+M+Y=White-White=Black
  C+M=White-Yellow=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

Optional

# Mixing pigments in CIE



Optional

# 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
  - Simple model: The CIE XYZ matching paradigm
  - Being implemented in "Color Management Systems"
  - These try to relieve the user of the different color capabilities of devices
  - Complicated because every device needs to register properly with the CMS
- Deficiencies--as we have seen, the CIE systems does not count for spatial effects, illumination environments, etc., and these are important
- Some progress is being made but the models tend to be complicated

# Shading values for colored surfaces

- Simplest:
  - Use appropriate shading model in 3 channels, instead of one
  - Implies red albedo, green albedo, blue albedo, etc.
  - Works because the shading model is independent of wavelength.
  - Can lead to somewhat inaccurate colour reproduction in some cases - particularly coloured light on coloured surfaces

- Better
  - Use appropriate shading model at many different wavelength samples - 7 is usually enough
  - Estimate receptor response in eye using sum over wavelength
  - Set up pixel value to generate that receptor response