Recursive ray tracing (chapter 14)

- Pixel brightness =

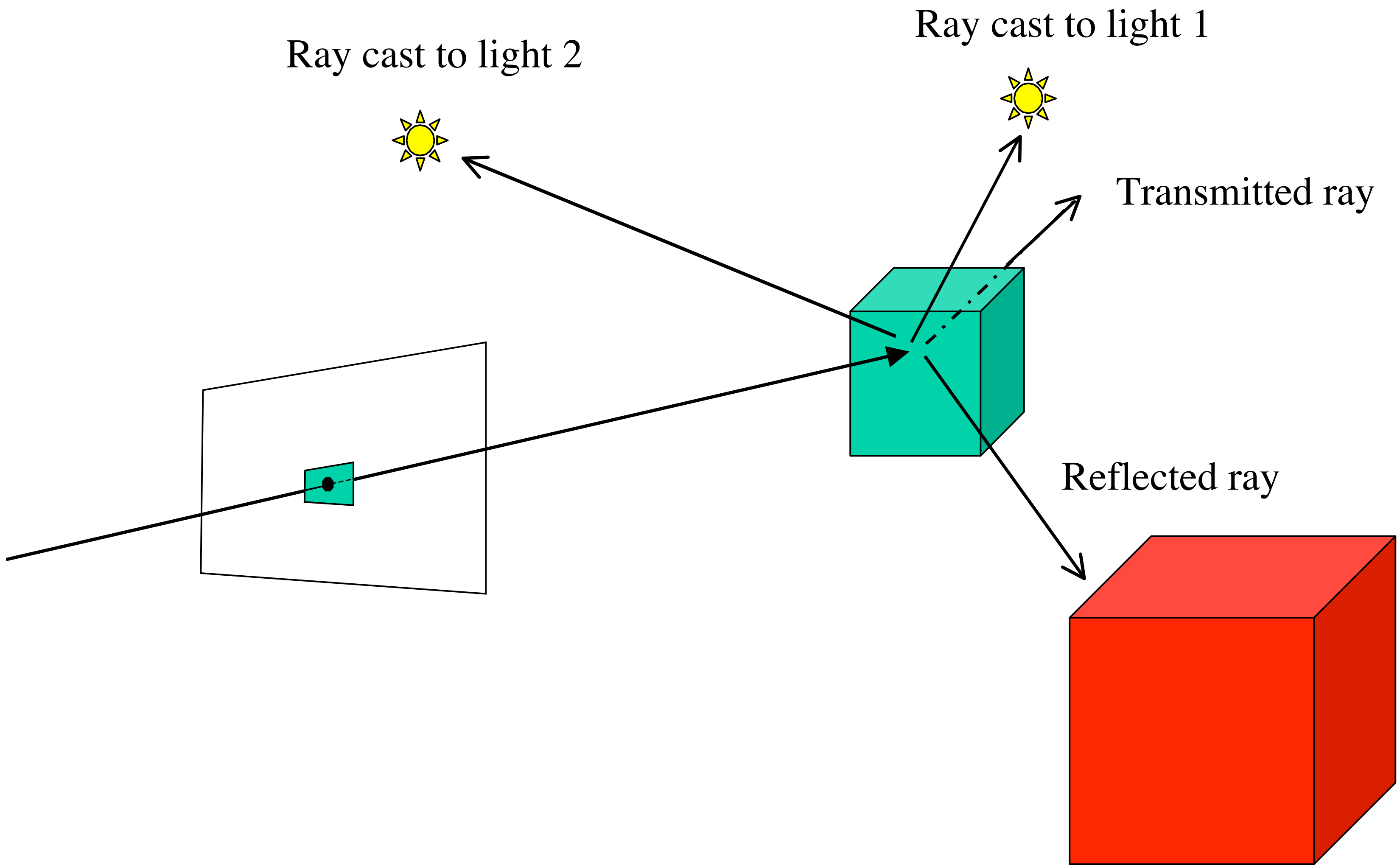
  radiance along ray to pinhole =

  $\square_d$(diffuse) +
  $\square_s$(reflected) +
  $\square_t$(transmitted)

- Diffuse component:
  - from sources alone (local shading model) typically Lambertian but could add a Phong type specular model
  - from global illumination model (usually just “ambient”)

- Reflected component is due to radiance along ray from intersection along mirror direction (often referred to as specular ray, but this is not to be confused with the specular lobe which might be added in as part of the diffuse component if it contributions from non-sources would be ignored--the usual case)

- Transmitted component is due to radiance along ray from intersection along transmitted direction

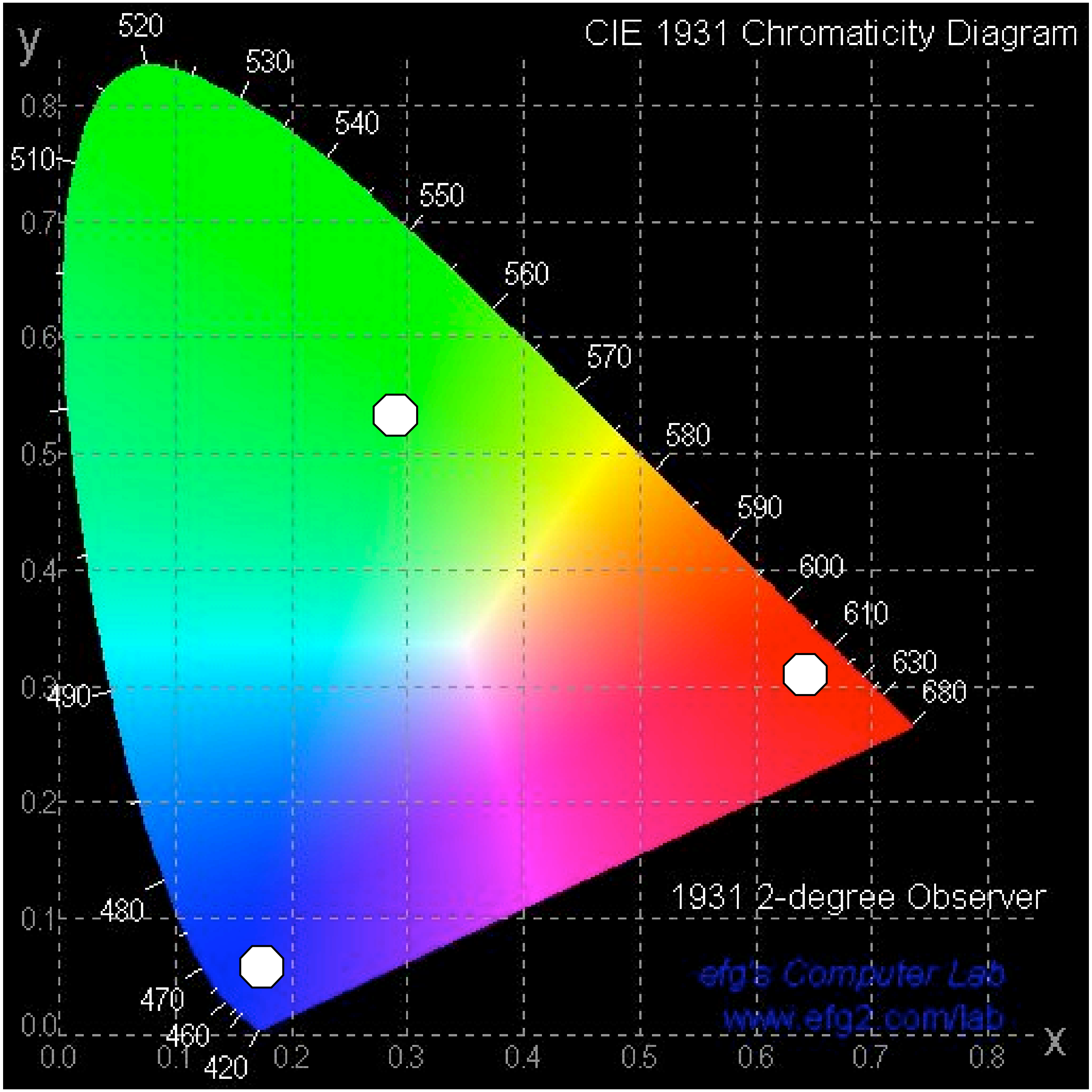

Ray cast to light 2
Ray cast to light 1
Transmitted ray
Reflected ray

Recursive ray tracing rendering algorithm

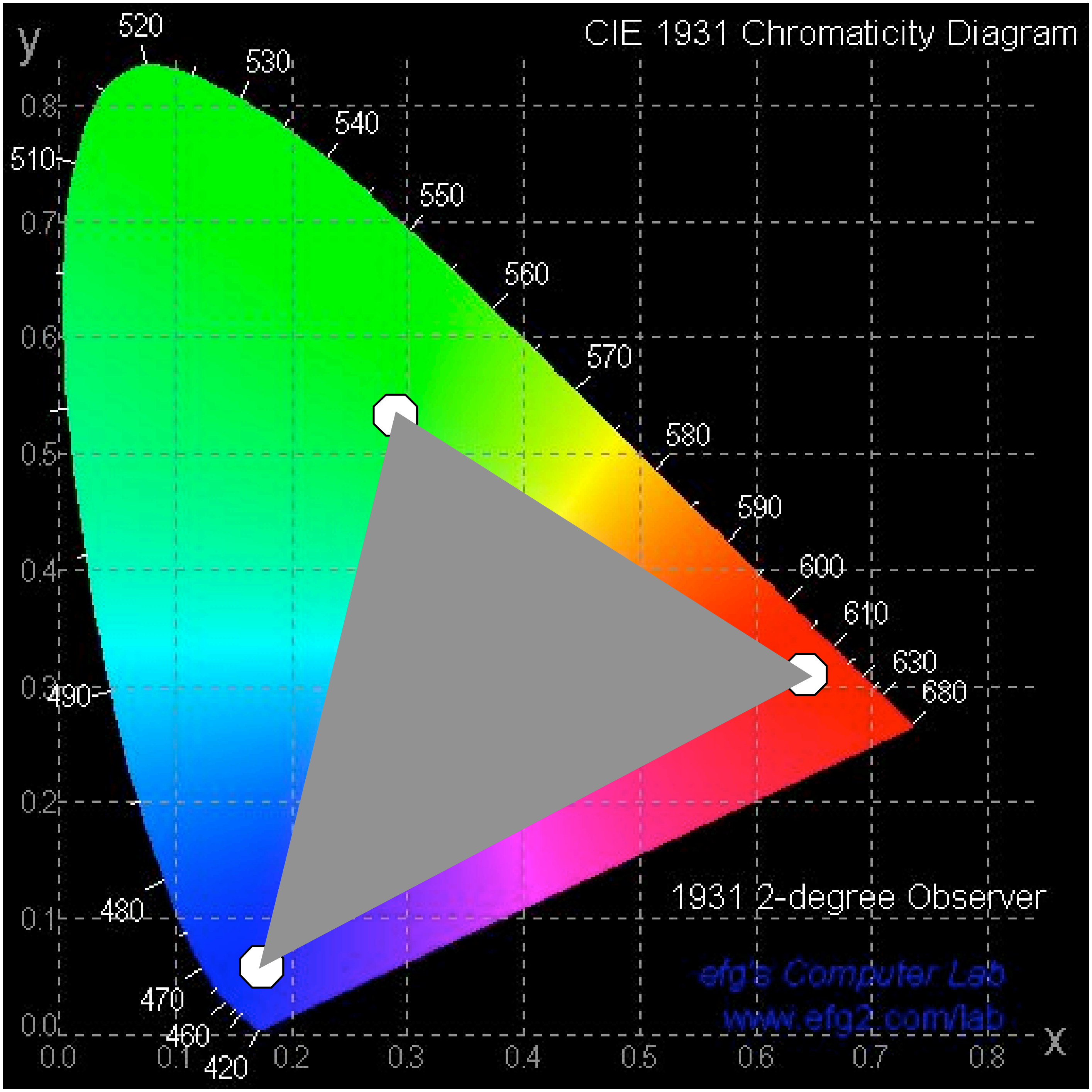
- Cast ray from pinhole (projection center) through pixel, determine nearest intersection
- Compute components by casting rays
  - to sources = shadow ray (and for specular lobe)
  - along reflected direction = reflected ray
  - along transmitted dir = refracted ray
- Each of the components has a weight
  - The main processes do not affect color much but a vector of weights for may be more convenient, or accurate depending on a color model
- Determine each component and add them up
- To determine some of the components, the ray tracer must be called **recursively**.

Recursive ray tracing rendering (cont)

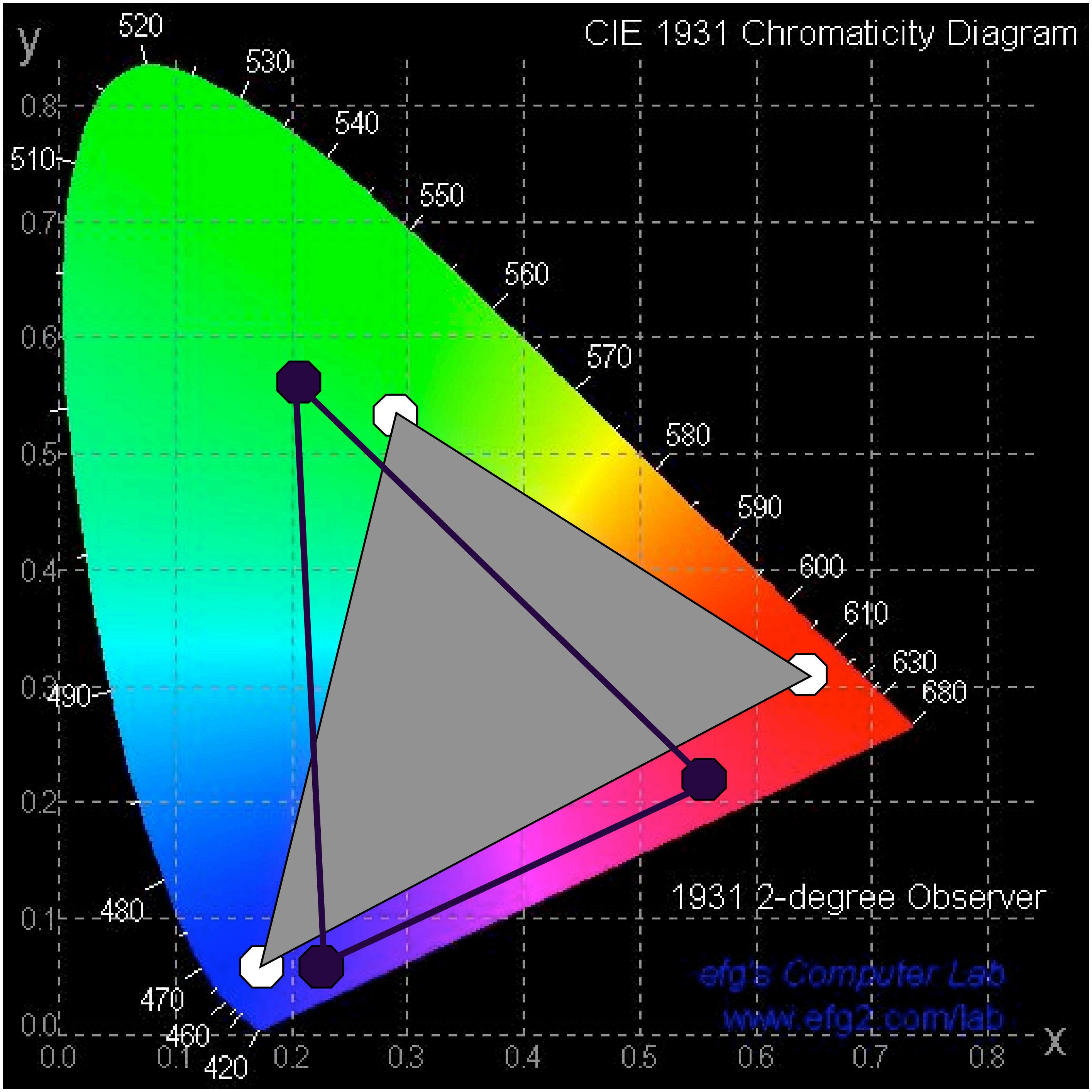
- Reflections (at least need to be attenuated)--no perfect reflectors
- We must stop the recursion at some point
  - when contributions are too small
    - need to track the cumulative effect
  - typically also limit the depth explicitly



Avalable from efg2.com



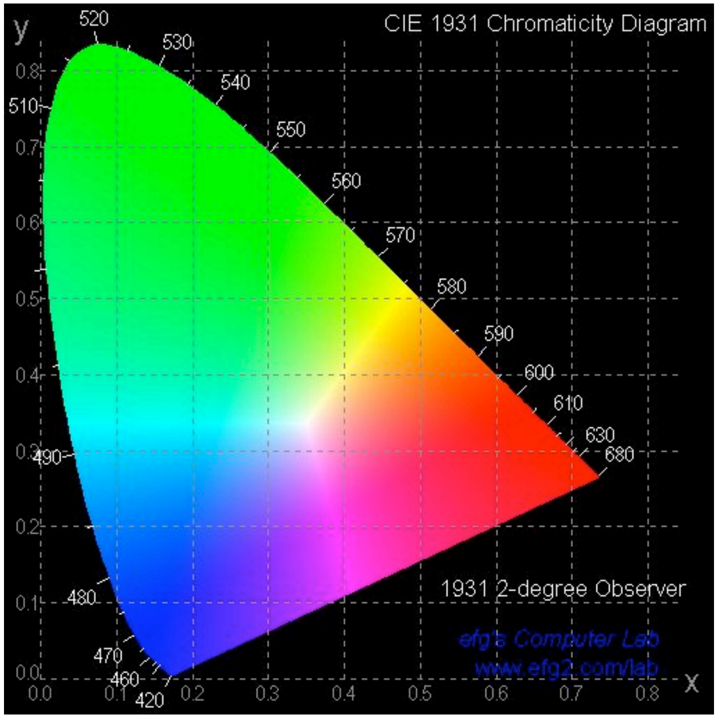
Avalable from efg2.com



Avalable from efg2.com

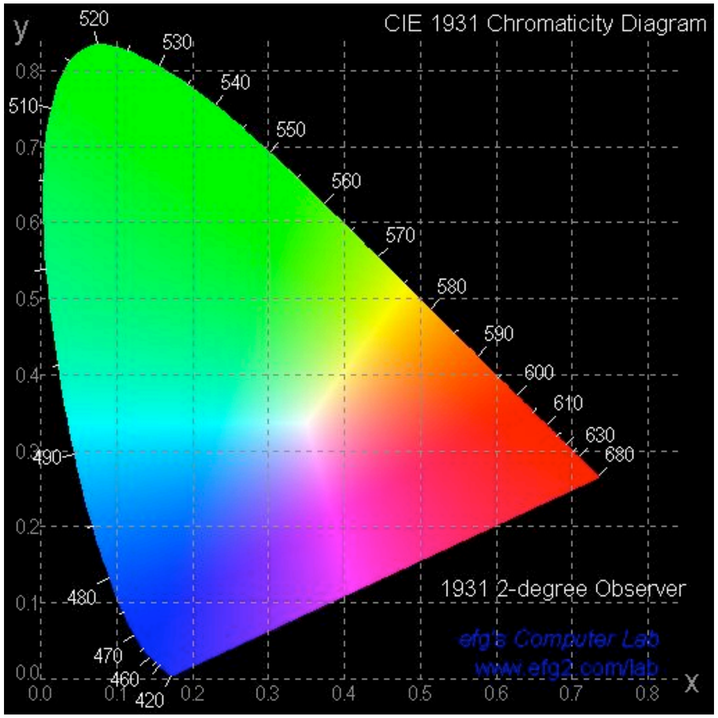
Qualitative features of CIE x, y

- 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”
- 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 “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.

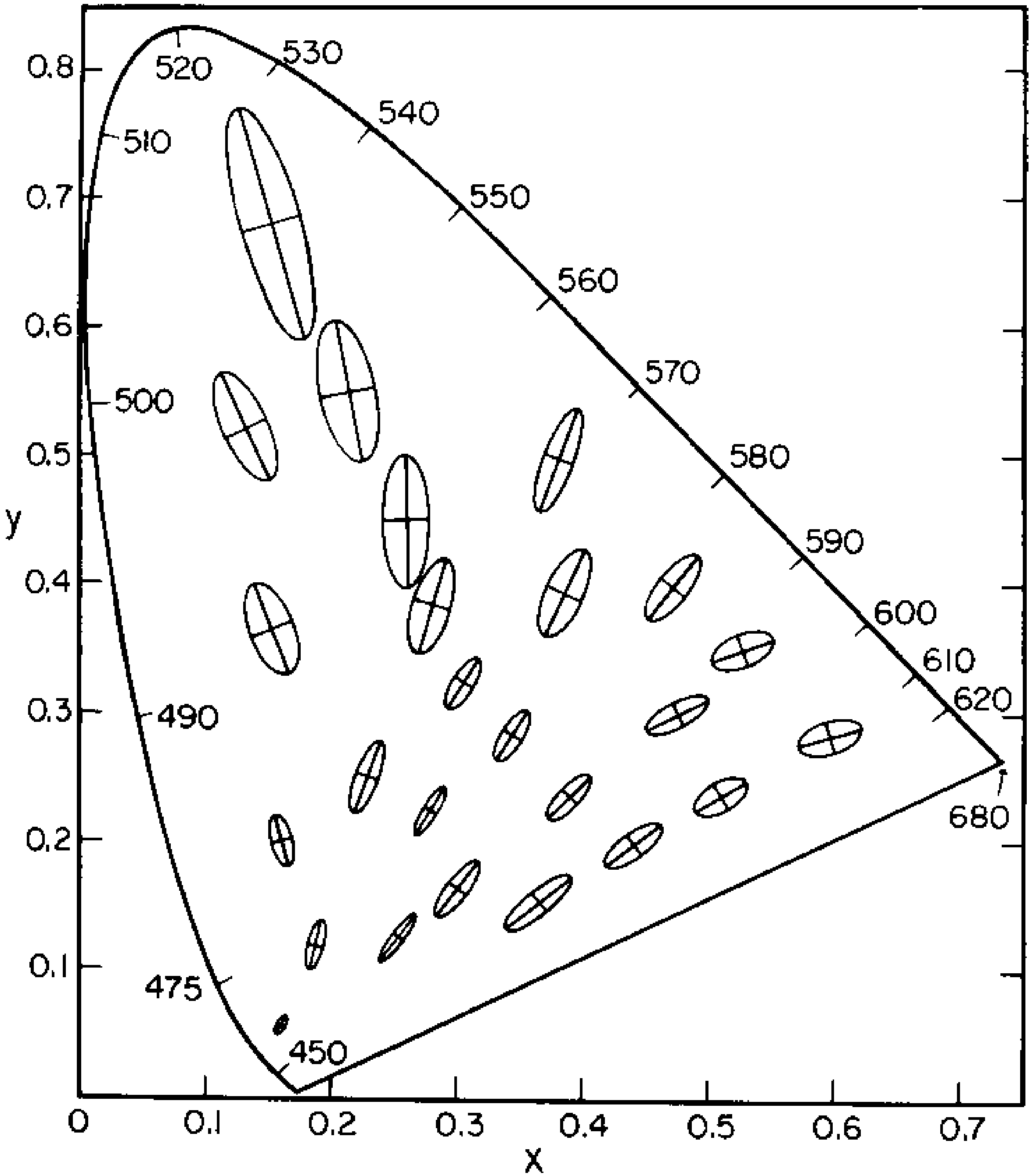
For reflective surfaces, e.g prints, this means that the match can change if the illumination changes.

More linear color spaces

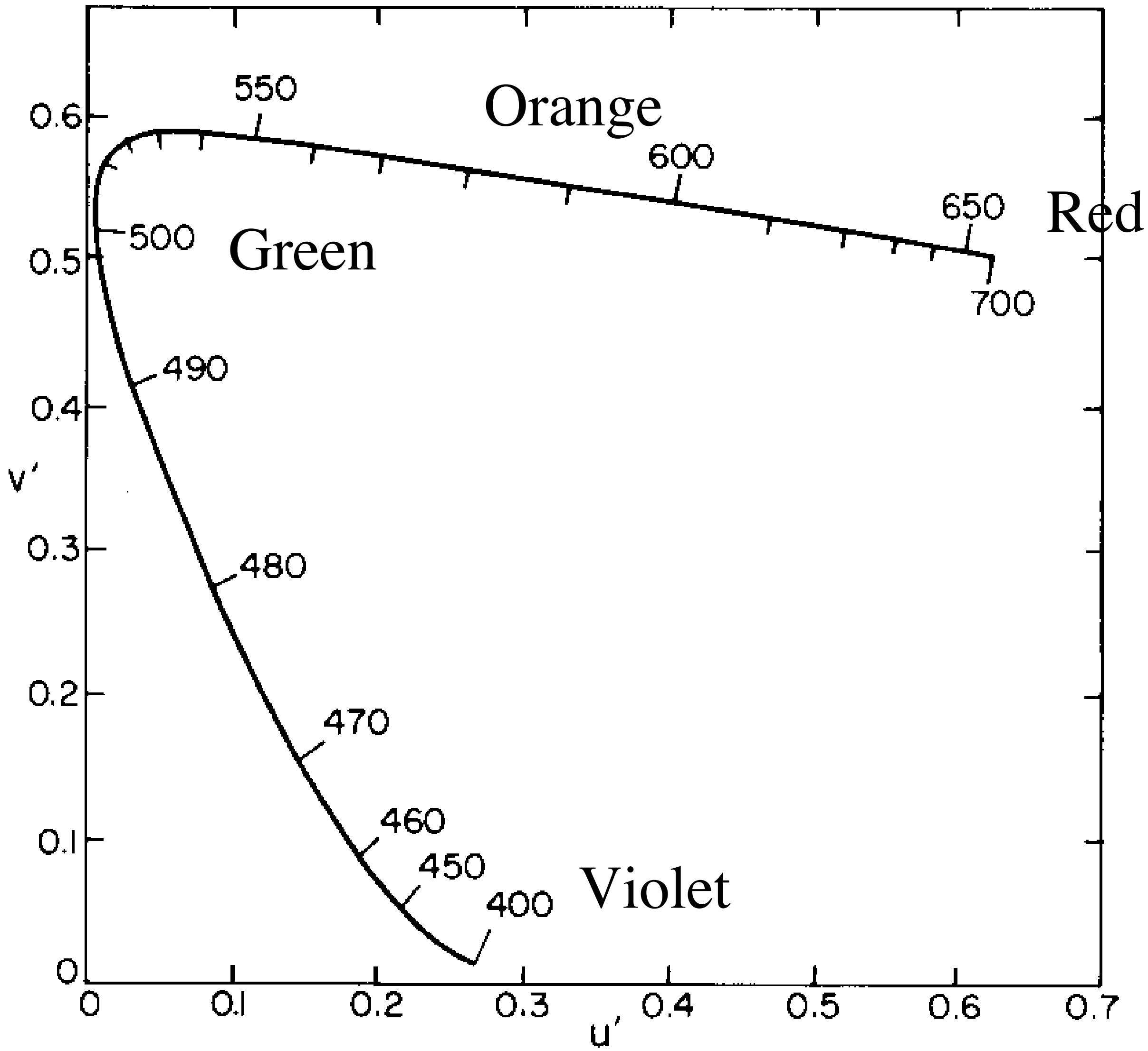
- Monitor RGB: primaries are monitor phosphor colors, primaries and color matching functions vary from monitor to monitor - careful!
- However--RGB without qualification usually means sRGB which is a standard definition adopted recently where the matrix transform XYZ<-->RGB is agreed upon based on "standard" 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



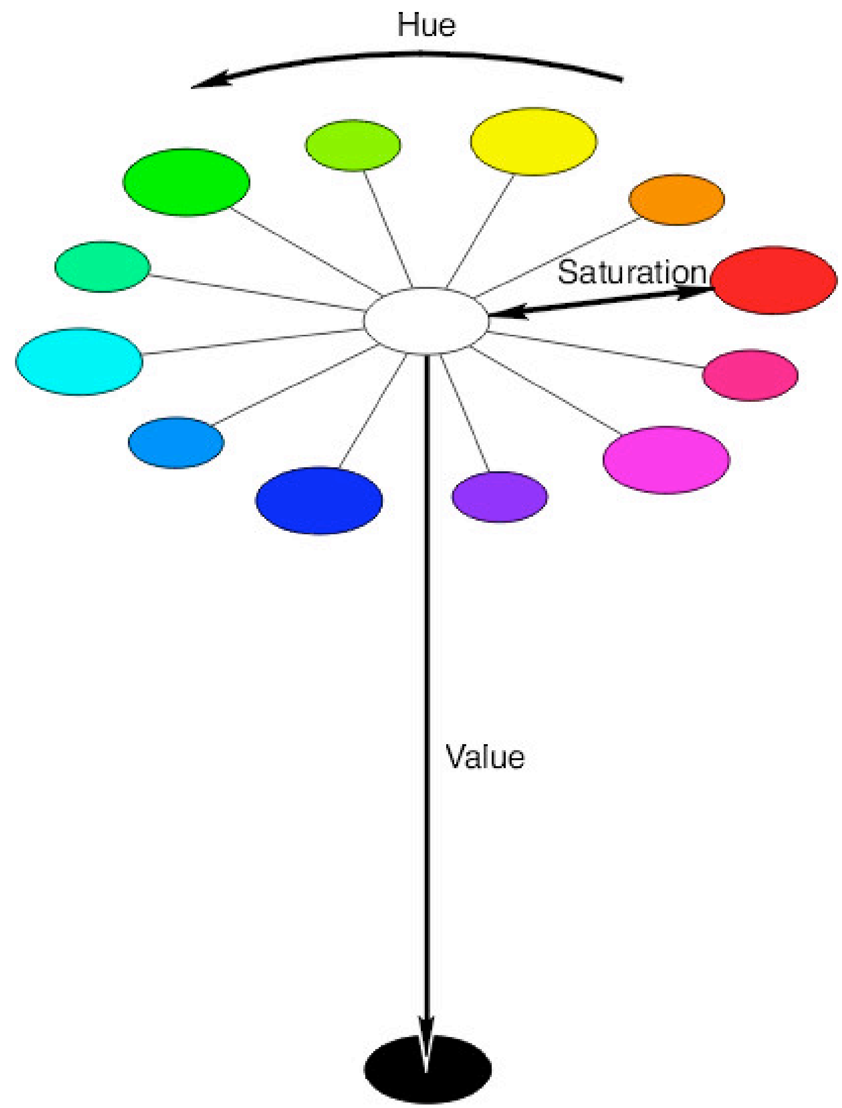
CIE u'v'
is a non-linear
colour space
where colour
differences are
more uniform

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

Non-linear colour spaces

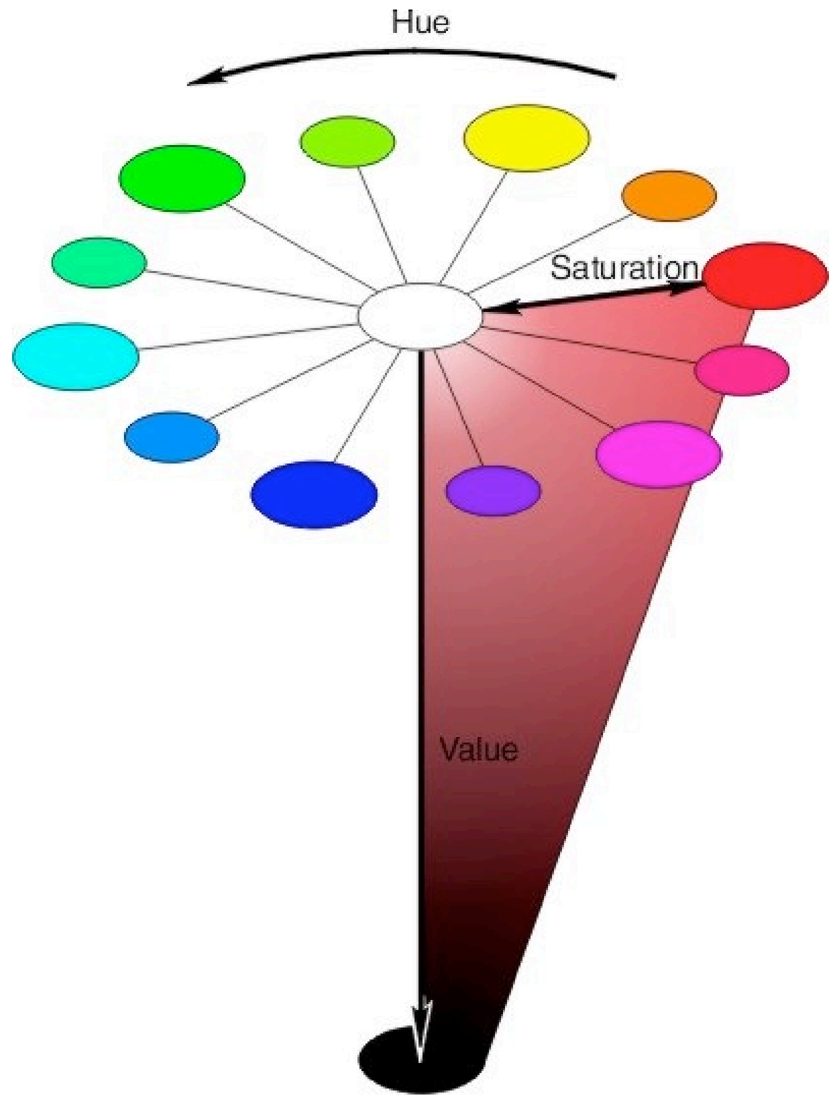
- HSV: Hue, Saturation, Value are non-linear functions of XYZ.
  - because hue relations are naturally expressed in a circle
  - popular in graphics
  - a variety of similar but different hacks are available for converting between RGB TO HSV
- Munsell: describes surfaces, rather than lights - less relevant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

HSV (cont)



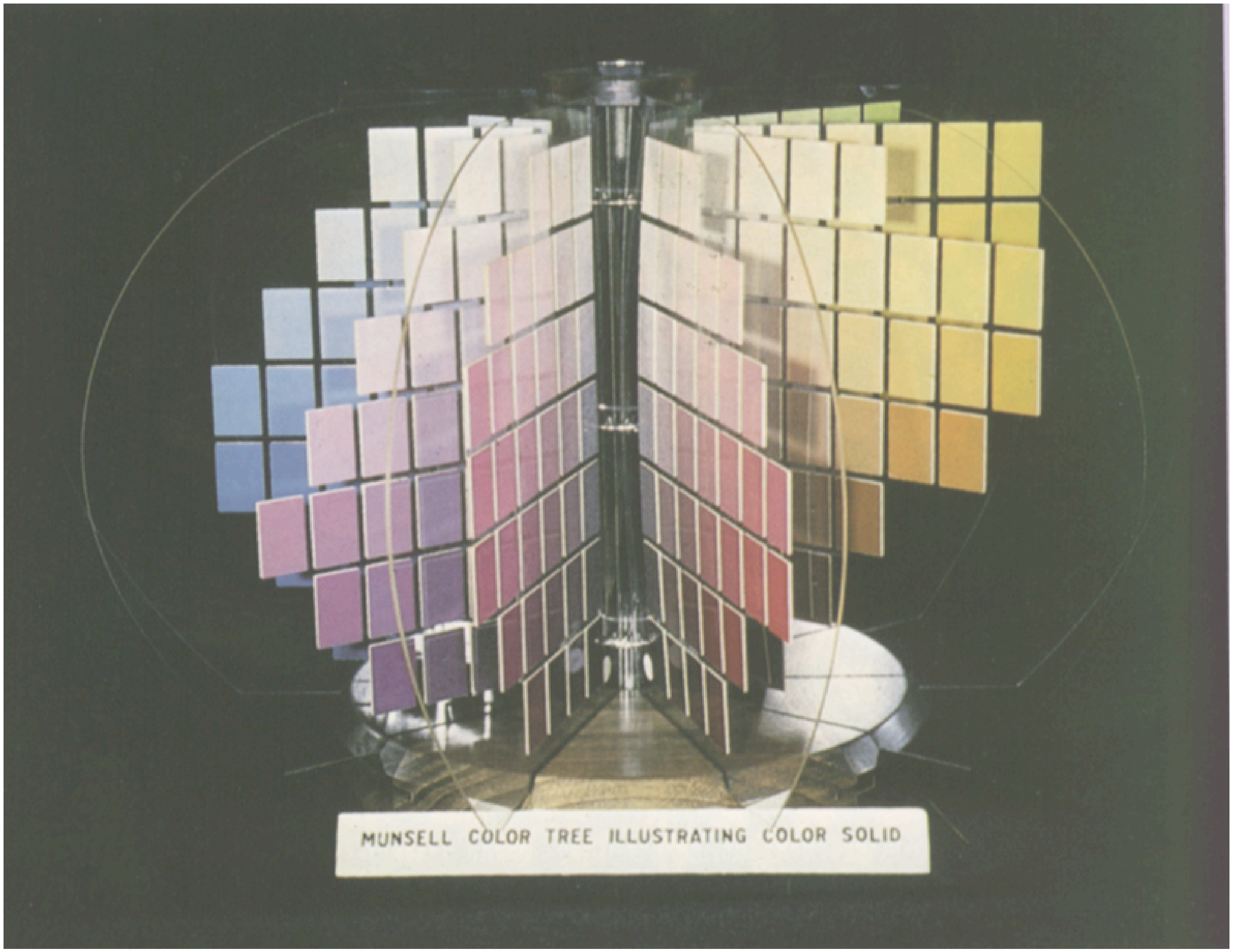
From http://www2.ncsu.edu:8010/scivis/lessons/colormodels/

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 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!