Color Concepts

CS 355: Introduction to Graphics and Image Processing

Light and Wavelengths

- Visible light is in the range 400 nm (blue) to 700 nm (red)

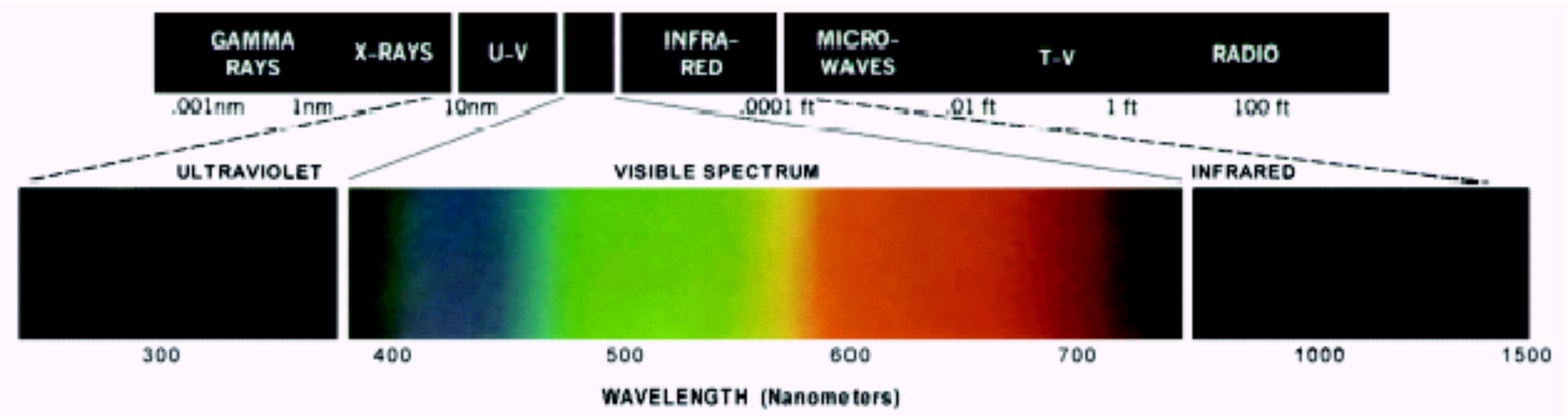


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Perception of Light

- Cones have three different kinds of color-sensitive pigments, each responding to a different range of wavelengths
- These are roughly "red", "green", and "blue" in their peak response *but each responds to a wide range of wavelengths*
- The *combination* of the responses of these different receptors gives us our color perception
- *Multiple combinations of wavelengths can produce the same response*
- This is called the *tristimulus model* of color

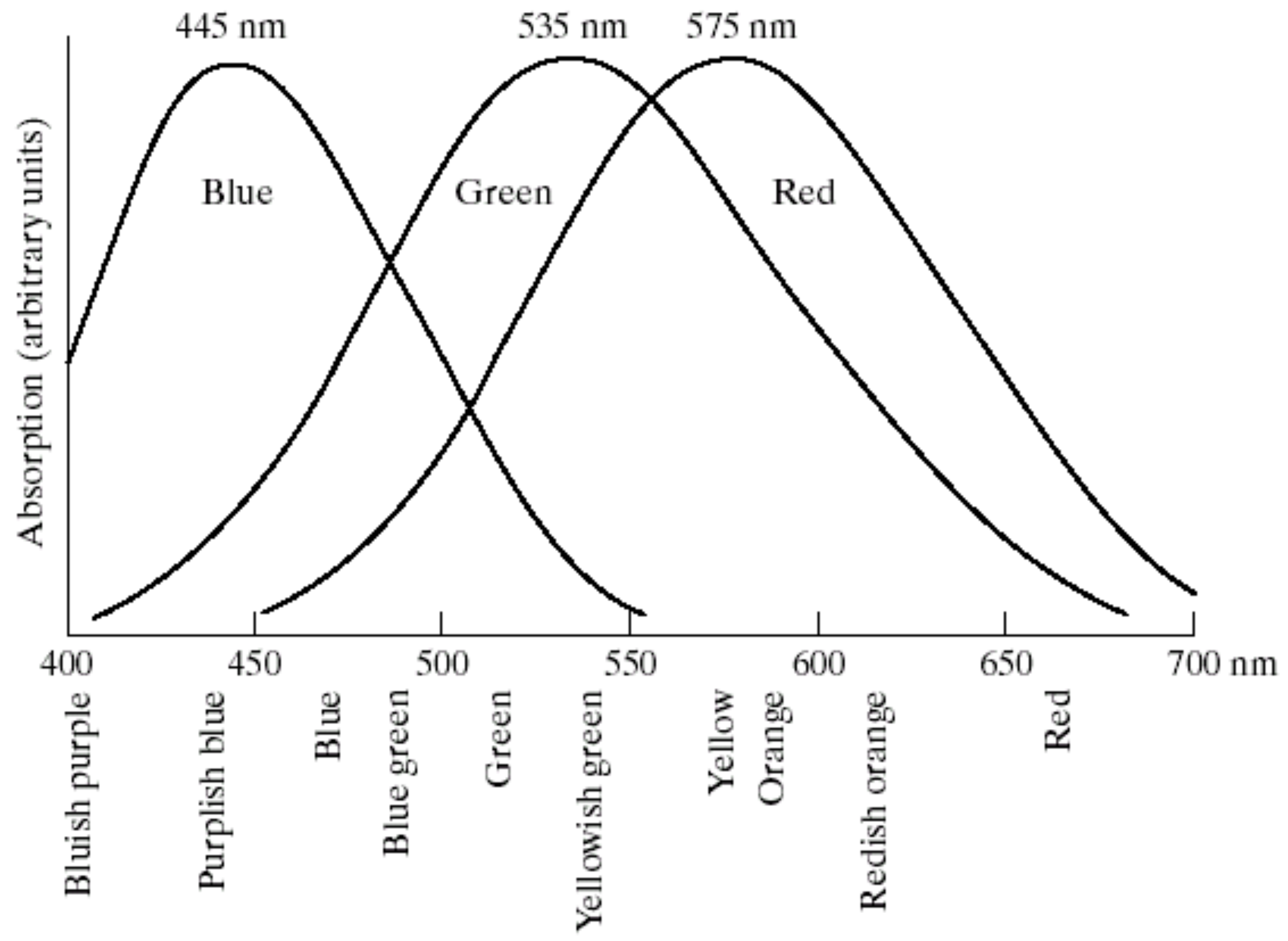
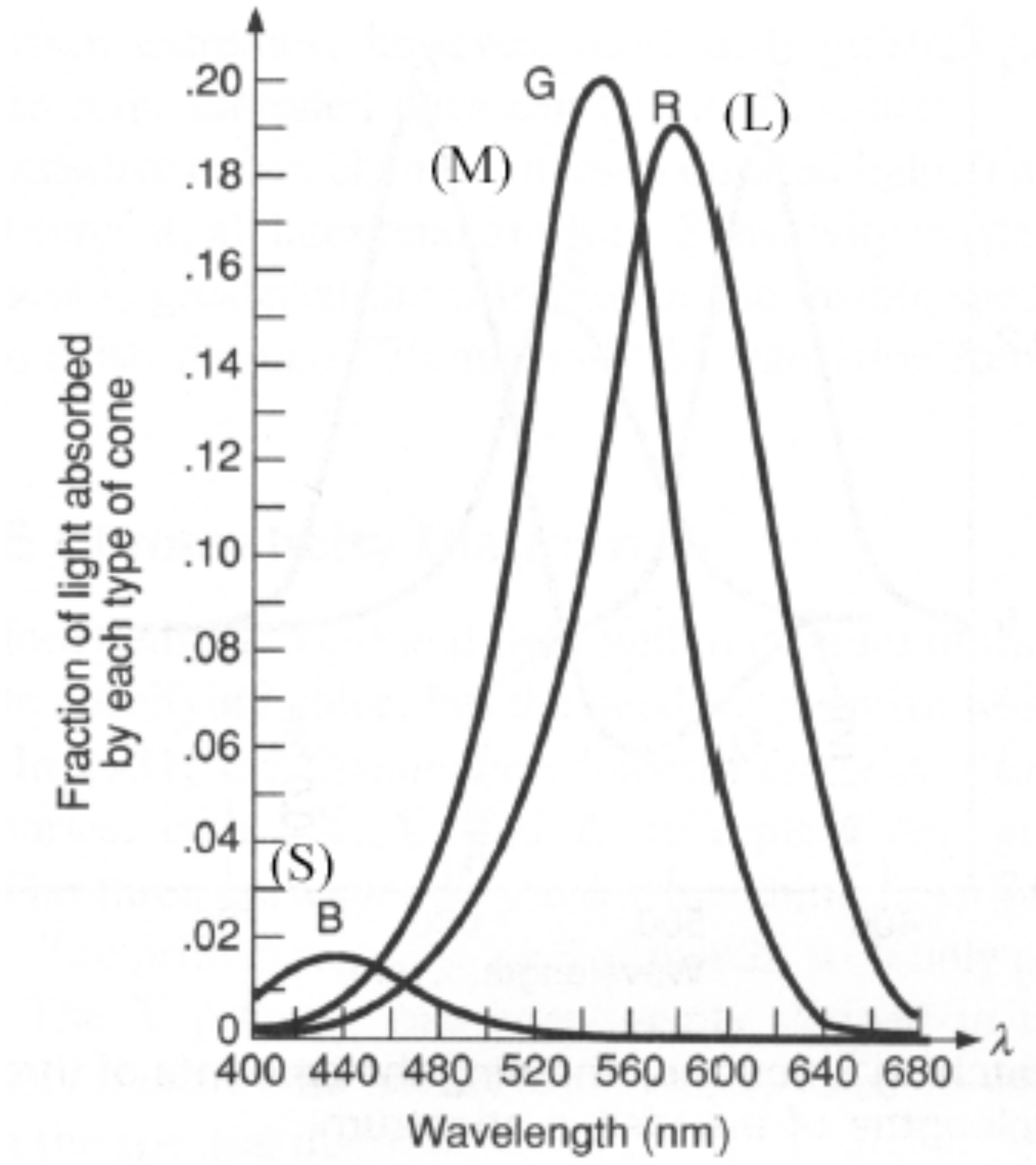


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

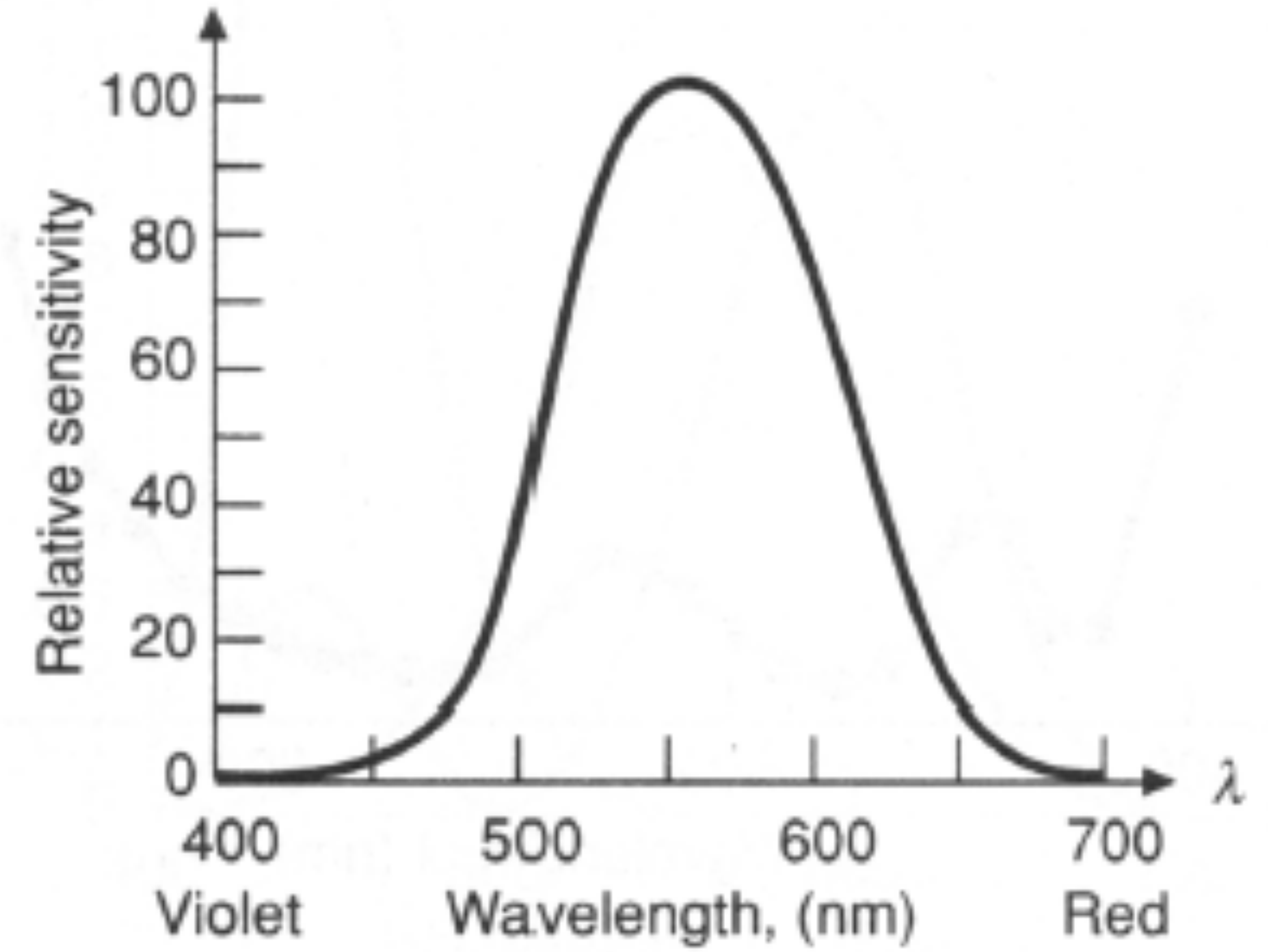
Perception of Light

- The sensitivity and number of the three types of cones are different
- More sensitive overall to green and red than to blue



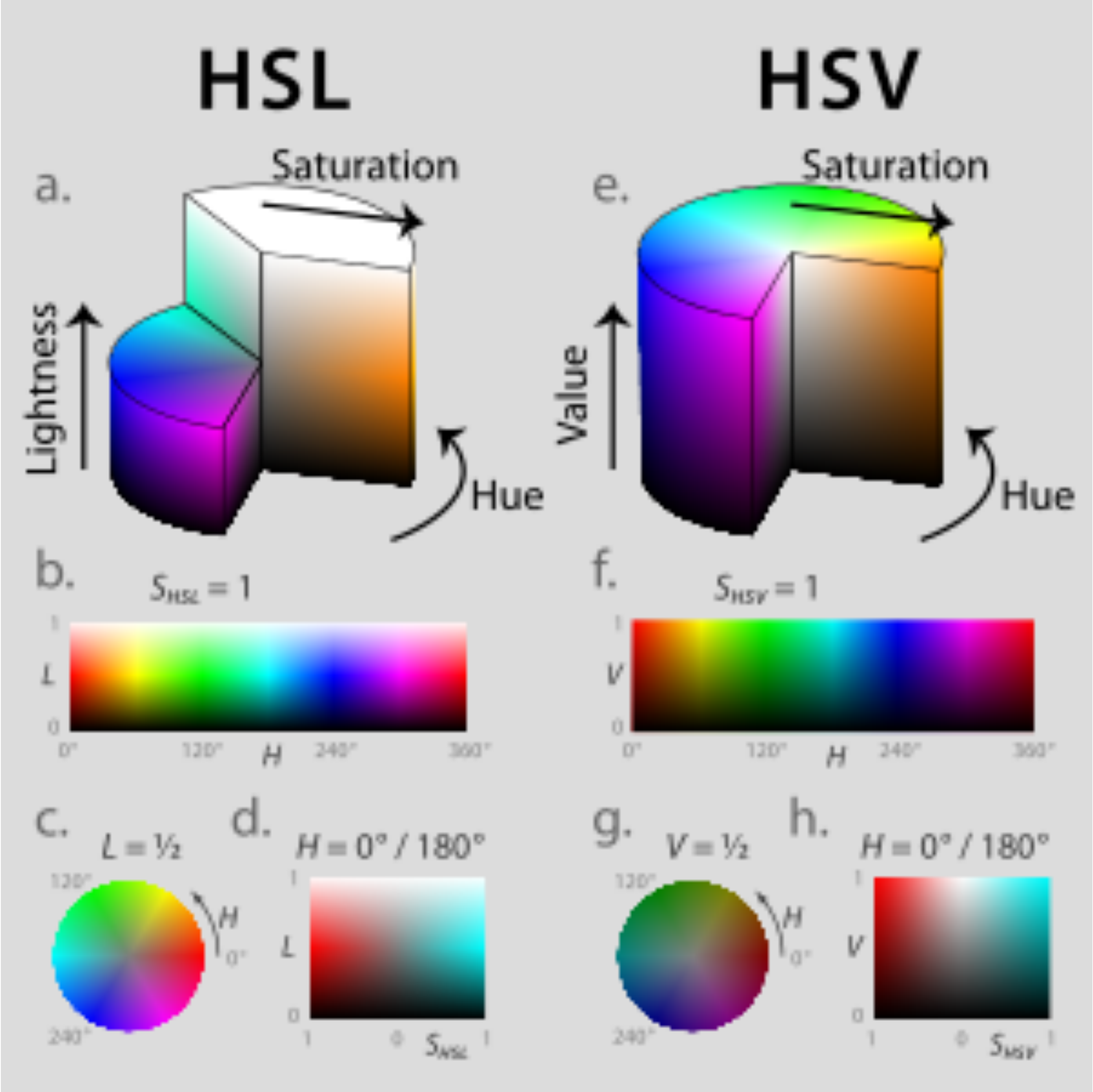
Intensity vs. Brightness

- Technically, there is a difference between
  - physical intensity
  - perceptual brightness
- Caused by differences in sensitivity of our eyes to different wavelengths
- *Luminous efficiency function*



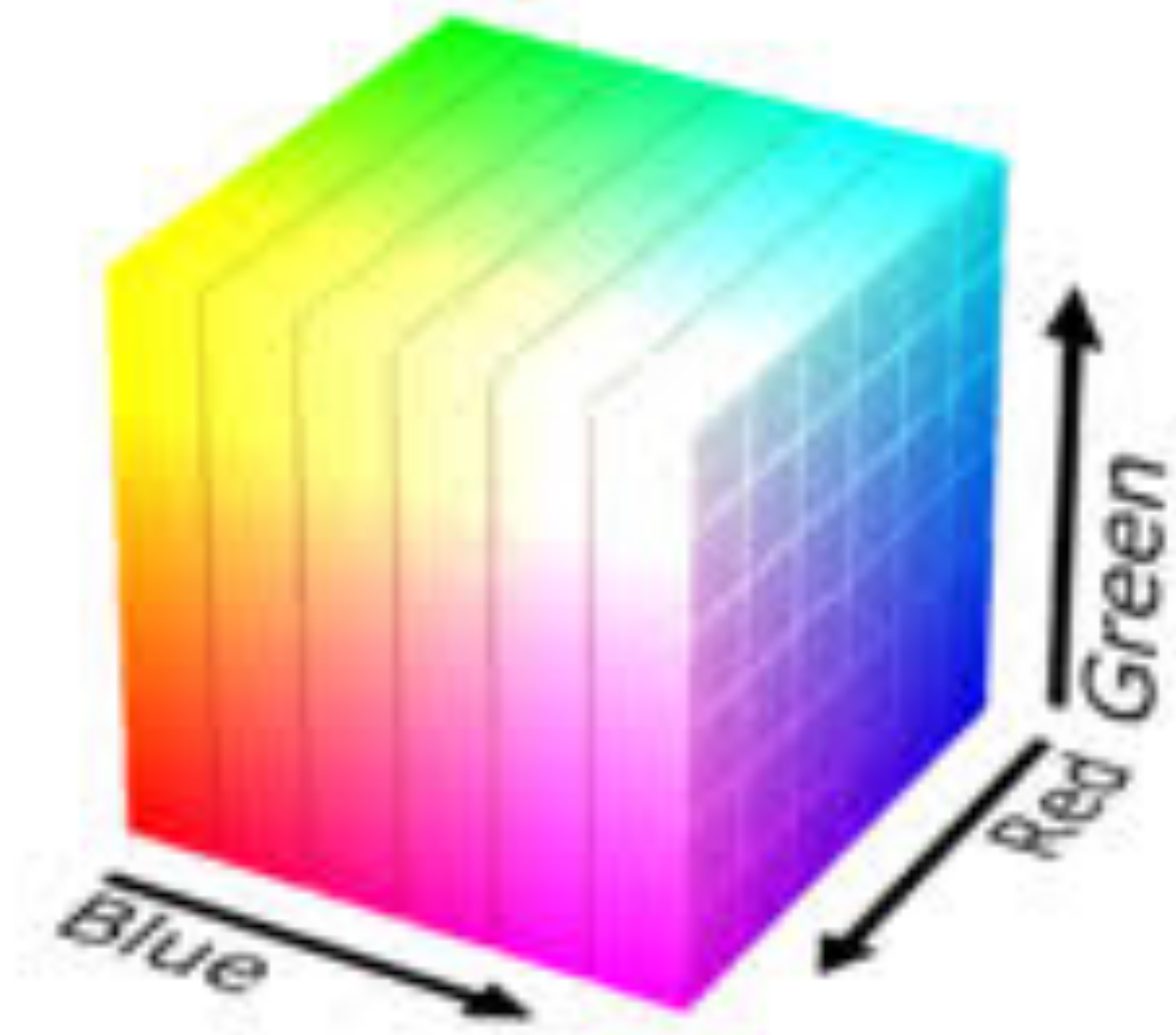
Color Models

- Color is a natural phenomenon, but for graphics and imaging we need to represent colors numerically
- There are many ways to do this
- Numerical representations of color are called *color models*



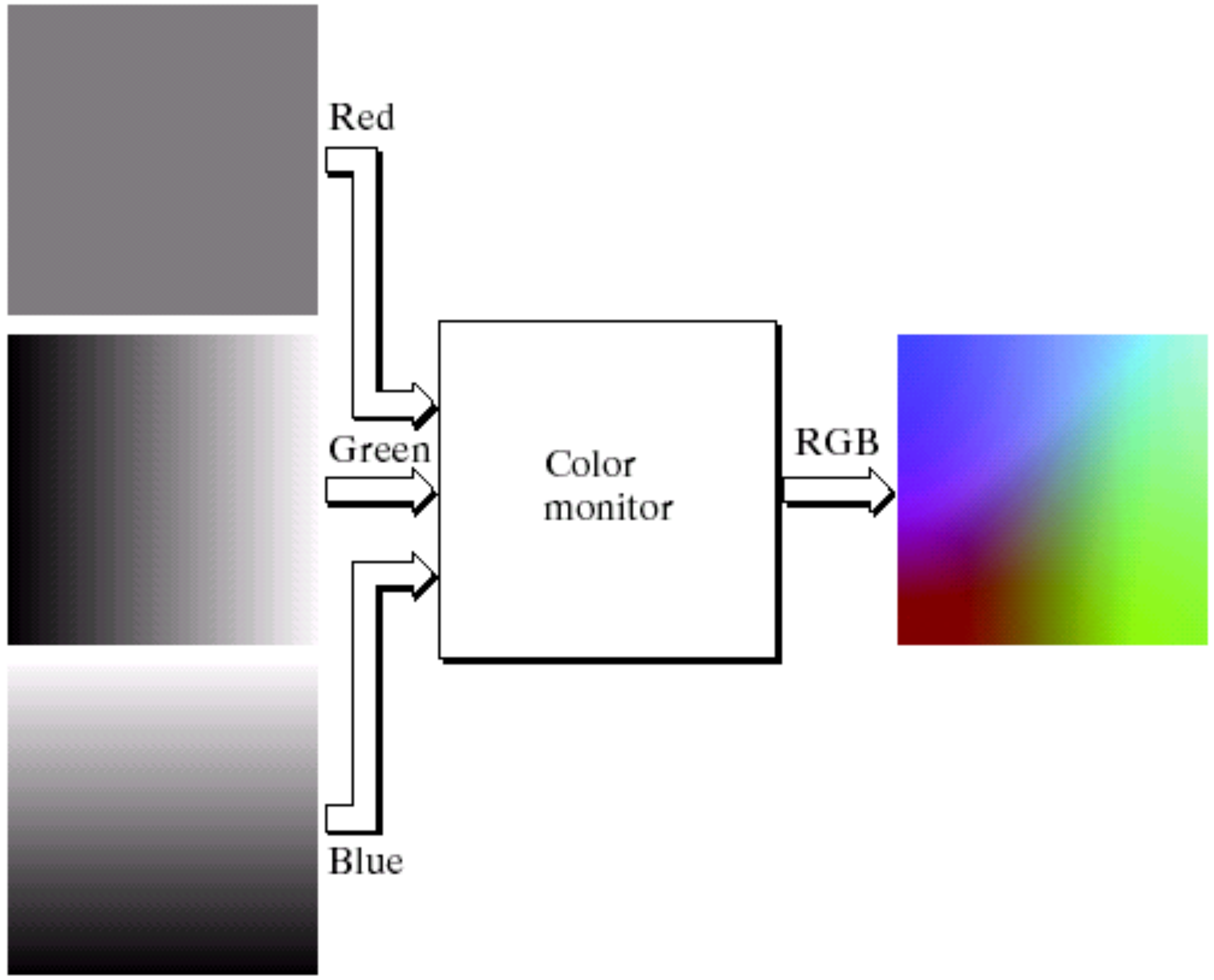
RGB Color Model

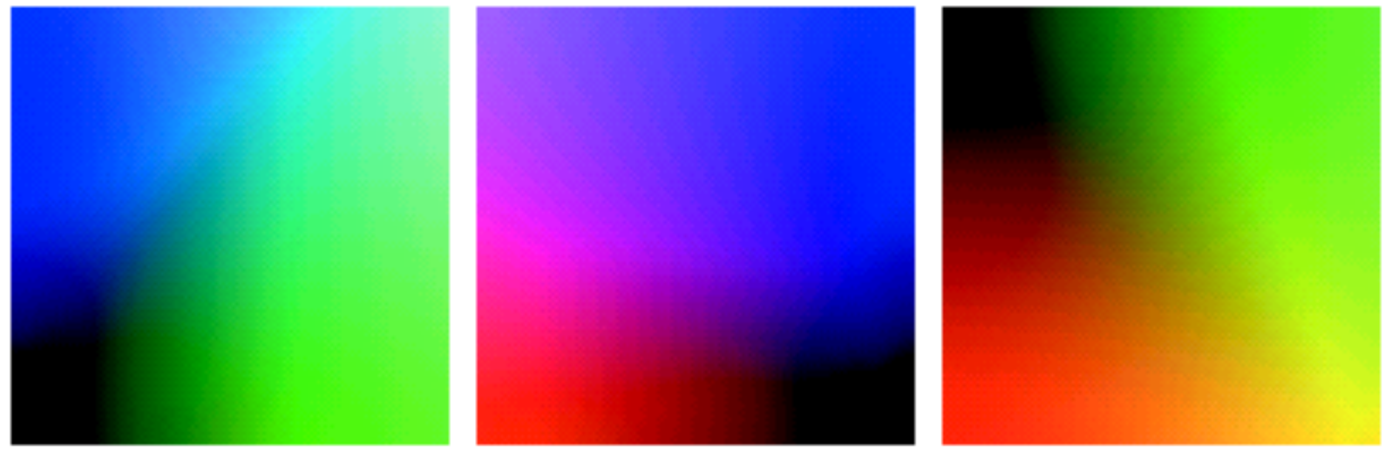
- Simplest model is just to store red, green, and blue values
- Colors can be thought of as points in a RGB cube



Color Channels

- Can think of an RGB image as distinct *color channels* or *color planes*
- Doesn't matter how you store it:
  - An RGB triplet for each pixel
  - Three separate images





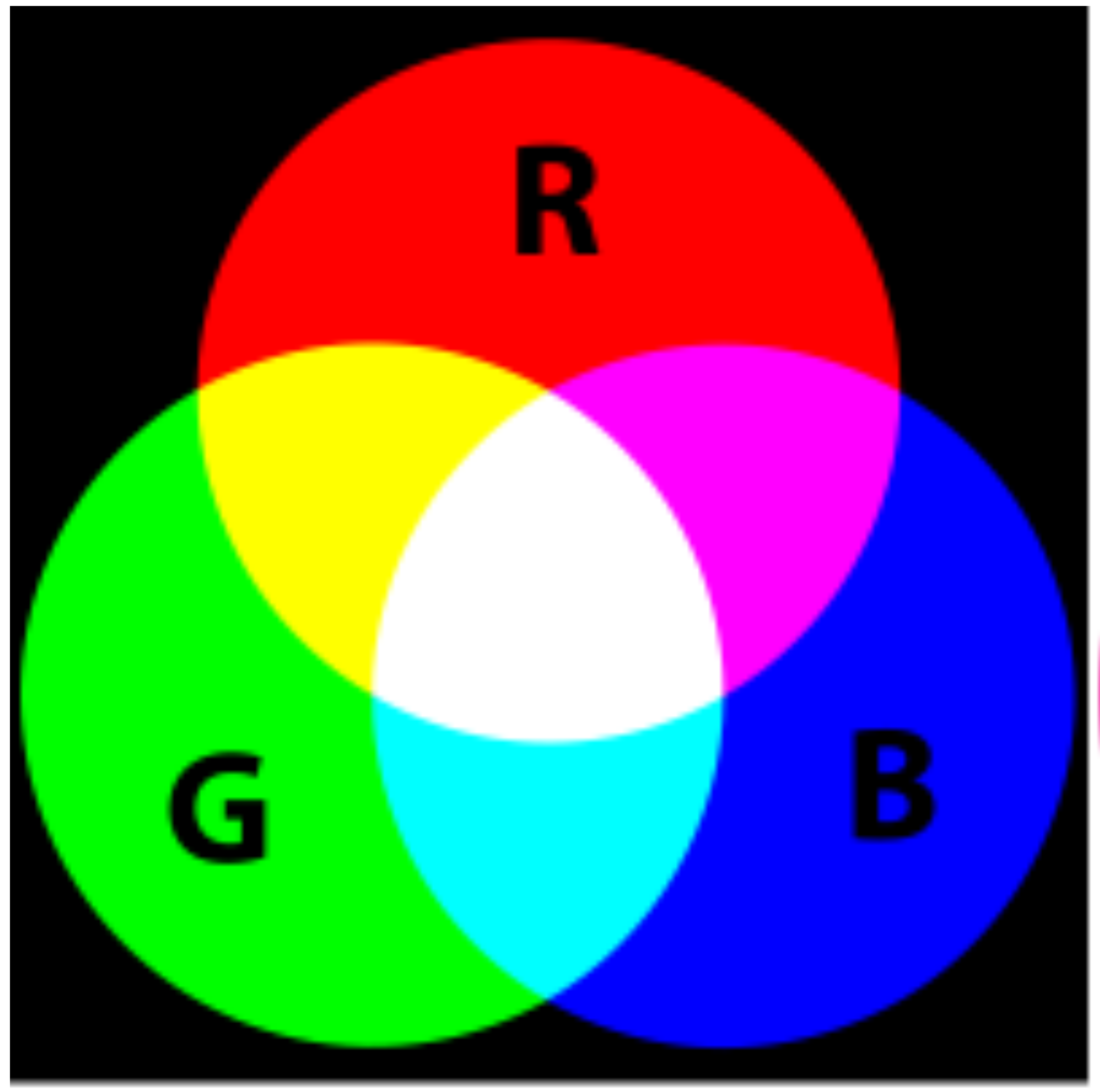
$(R = 0)$ $(G = 0)$ $(B = 0)$

Primaries and Secondaries

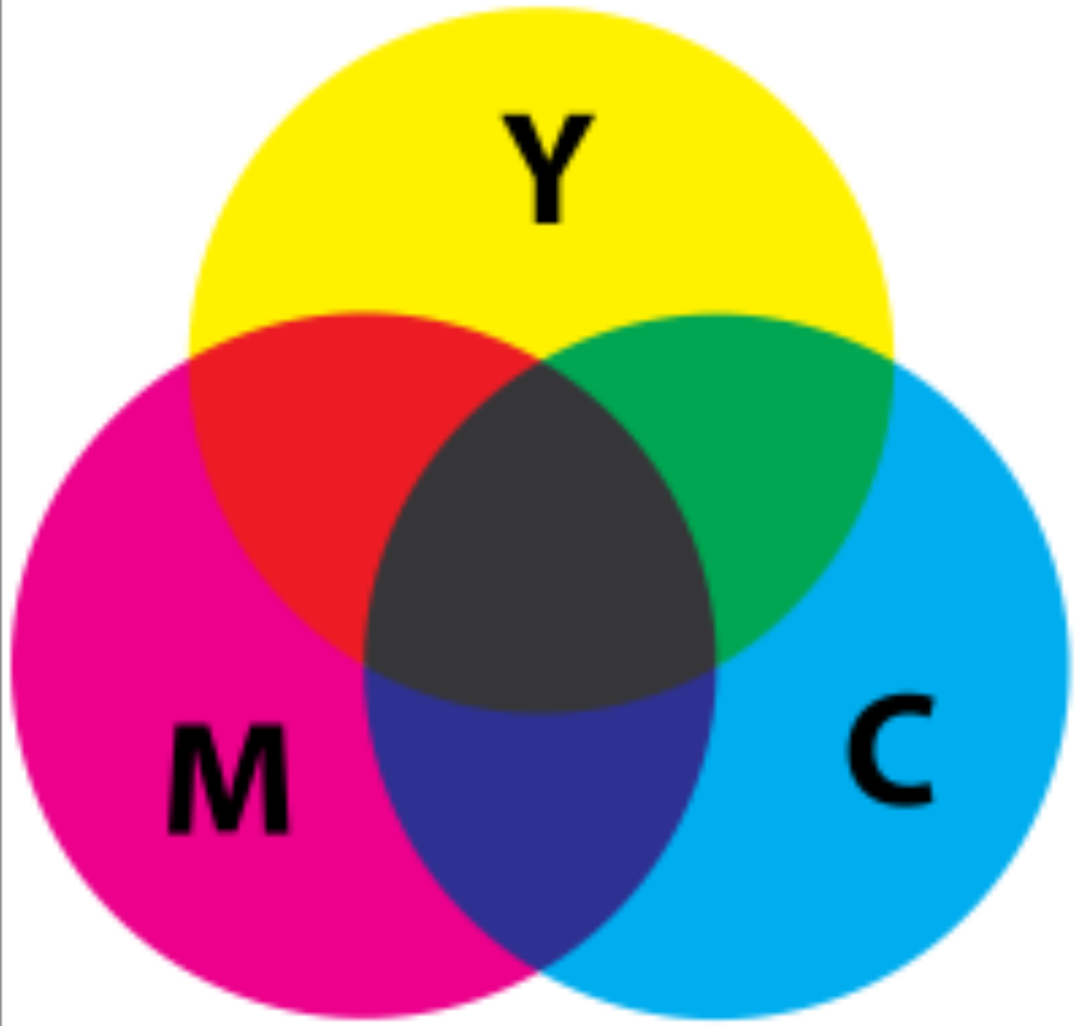
- Primary colors:
  ones mixed to make other colors
- Secondary colors:
  pairwise combinations of primaries
- Primaries and secondaries are *complementary*
- Can be *additive* or *subtractive*

CMY Model

- *Subtractive* media absorb light
  - Real-world objects
  - Paint
  - Printing ink
- The perceived color is what is *not* absorbed
- CMY uses subtractive primaries: cyan, magenta, yellow



Additive RGB Color



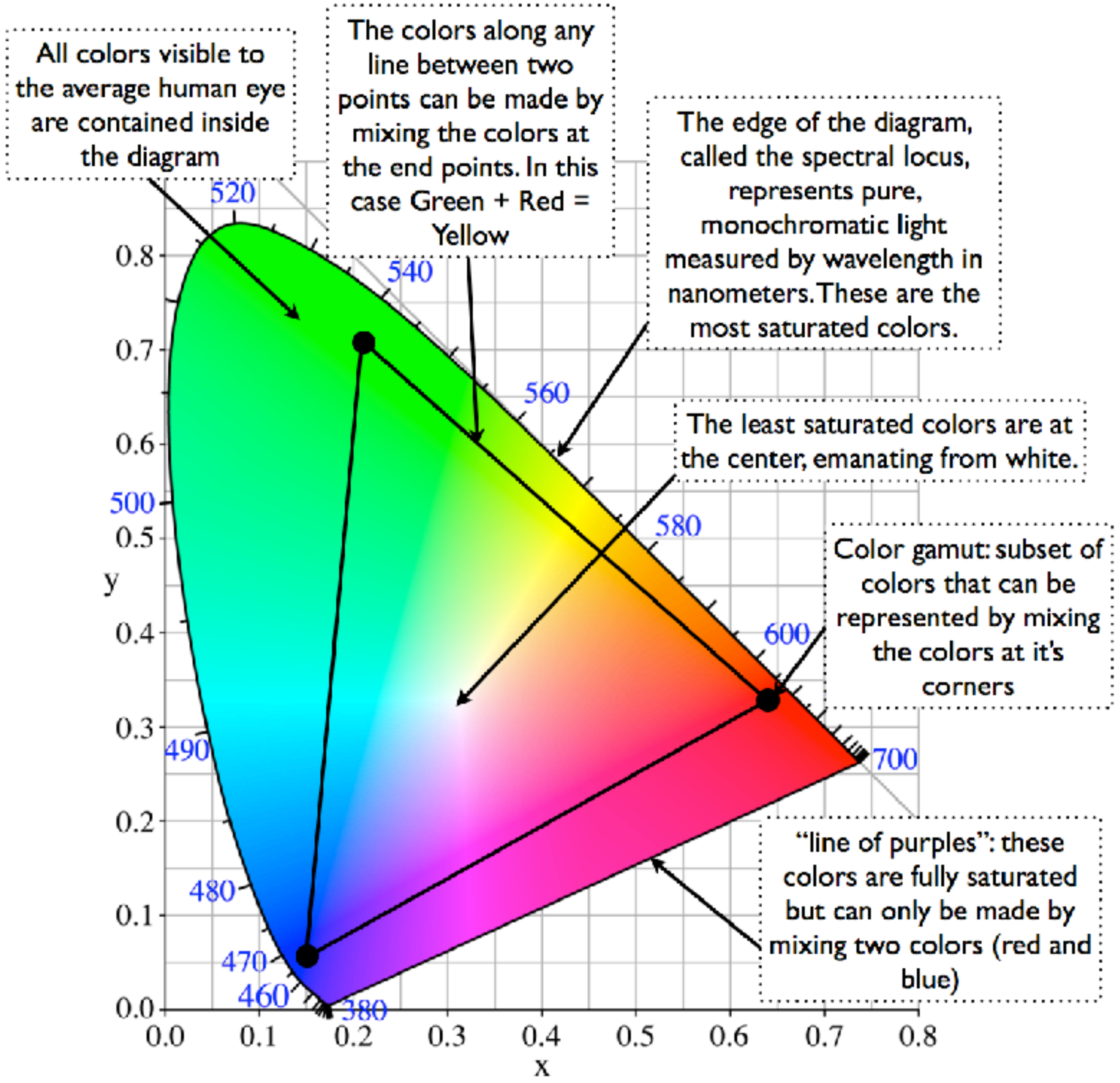
Subtractive CMY(K) Color

CMYK Model

- It’s difficult and expensive to make pure subtractive primaries
- Many systems introduce pure black as a fourth primary (K)

Color Gamuts

- Can visualize the space of all visible colors using a *chromaticity diagram*
- Important points:
  - No three primaries can span the space of visible colors
  - Different primaries will cover different parts of the space
  - *Colors produceable on one device may not be produceable on another*
  - *Even if they can be reproduced, the mix of primaries might be different—requires calibration*

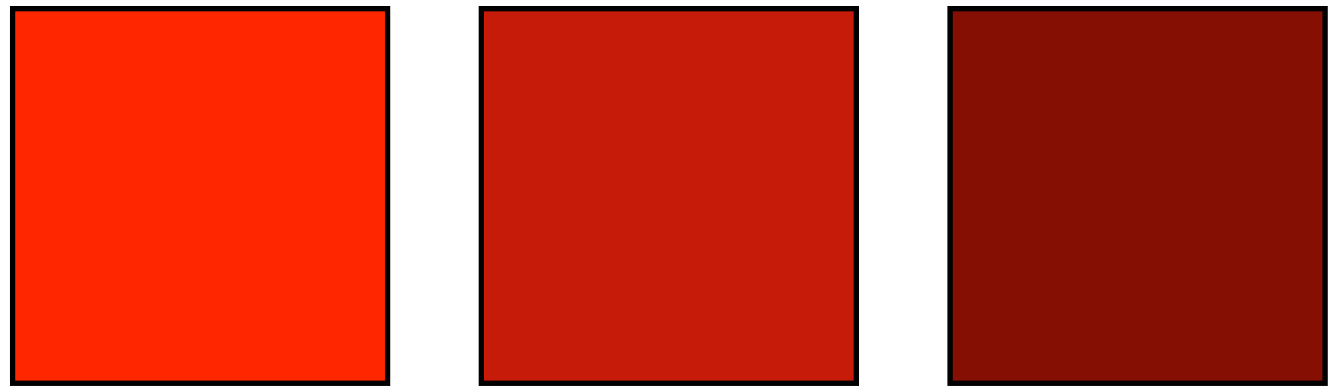


Anatomy of a CIE Chromaticity Diagram

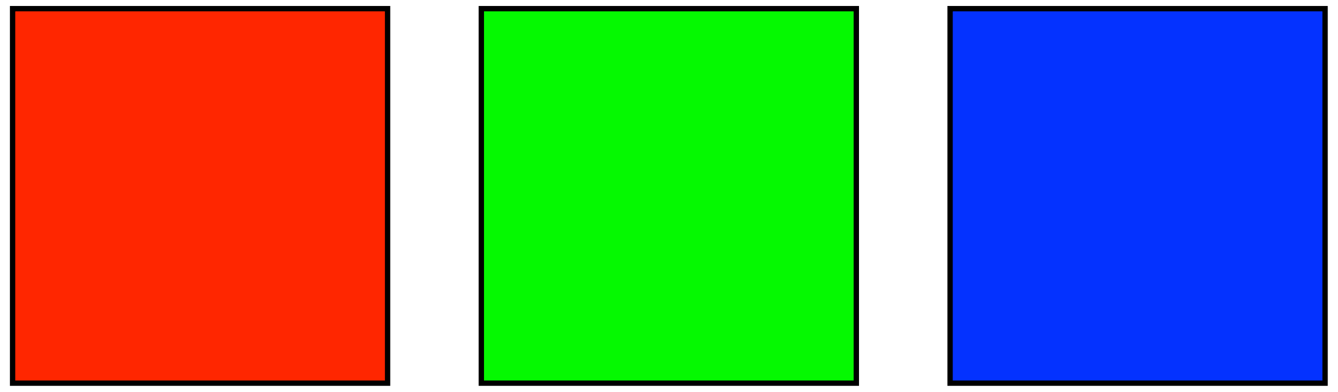
Luminance and Chromaticity

- RGB model is common but not all that intuitive to use
- Artists tend to think more in terms of luminance separate from chromaticity
- Much more intuitive:
  - Luminance - how bright
  - Hue - the “color” (wavelength)
  - Saturation - how pure

(lots of variations on this idea)



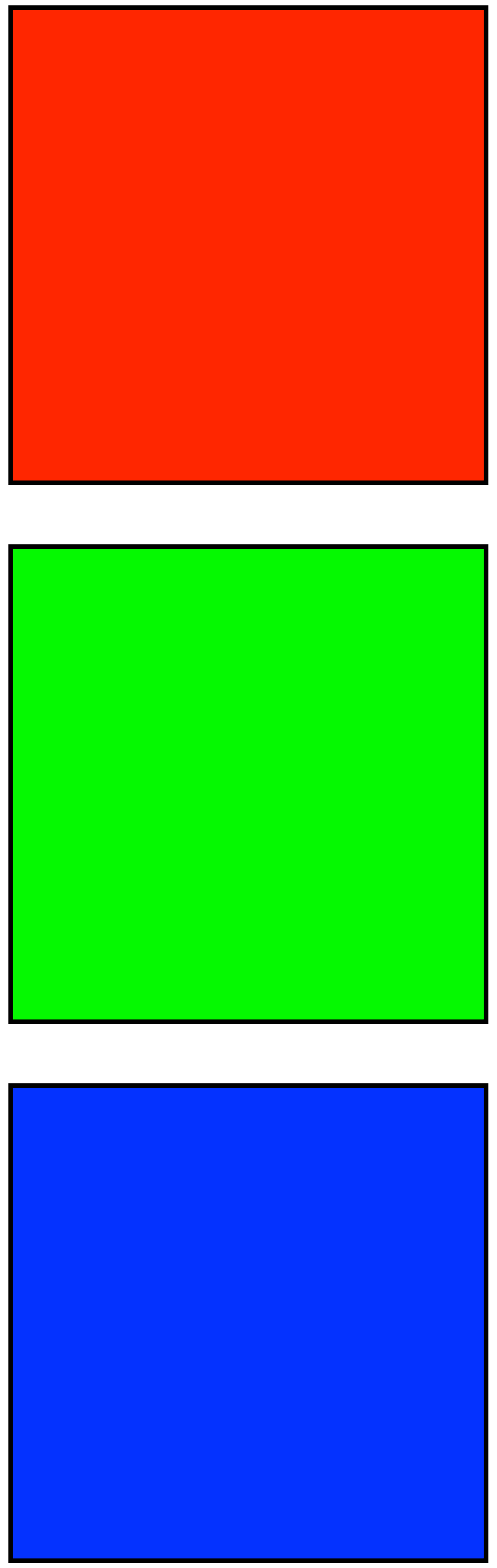
Different brightnesses



Different hues

Hue

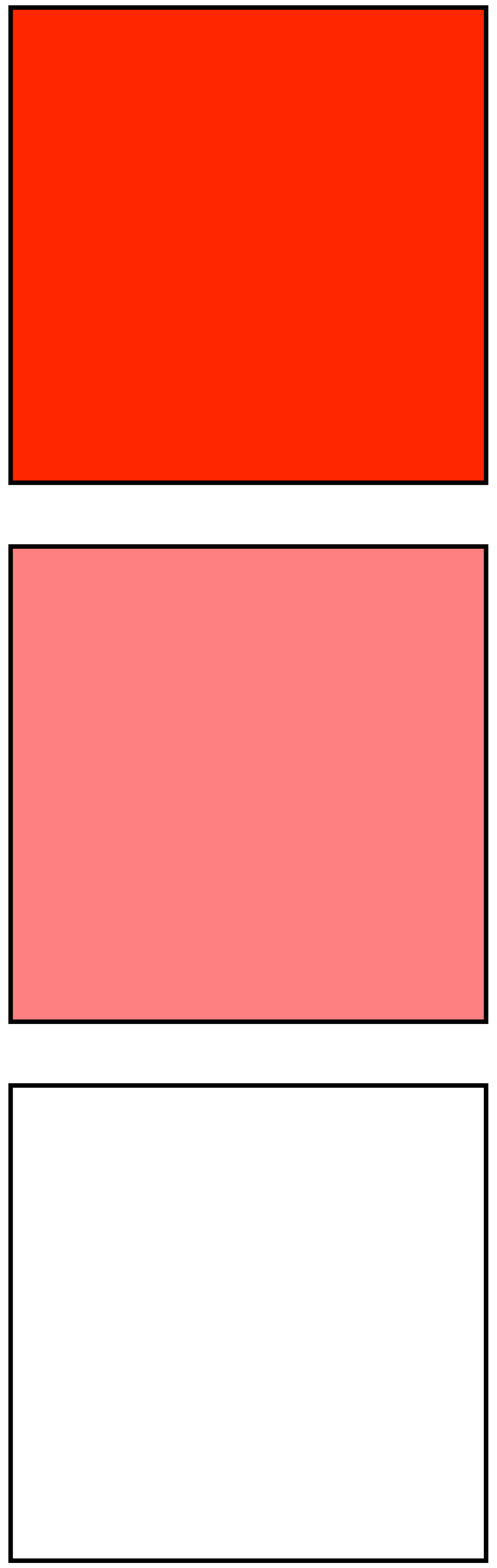
- What we first think of as “color”
- Pure wavelength of light
- Artistically most important
- Example:
  red vs. green vs. blue




OH THE
HUE-MANATEE

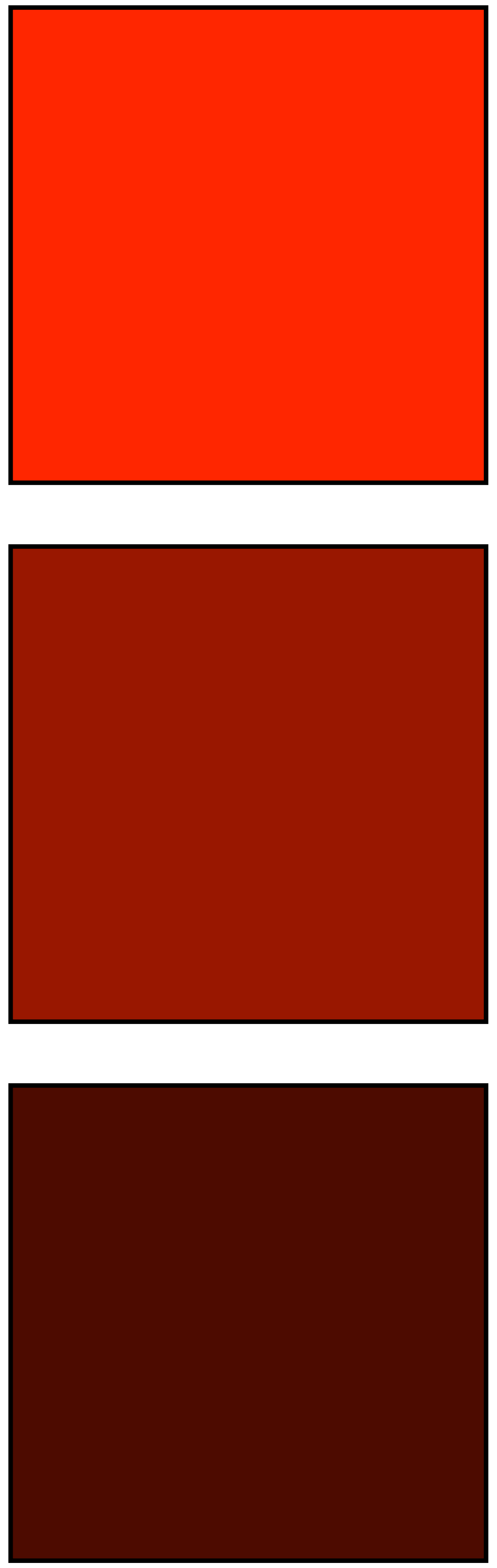
Saturation

- How pure a color is
- A single pure color is 100% saturated
- White, black, and gray are 0% saturated
- Examples:
  - red vs. pink
  - strong vibrant colors - high saturation
  - pastels - low saturation



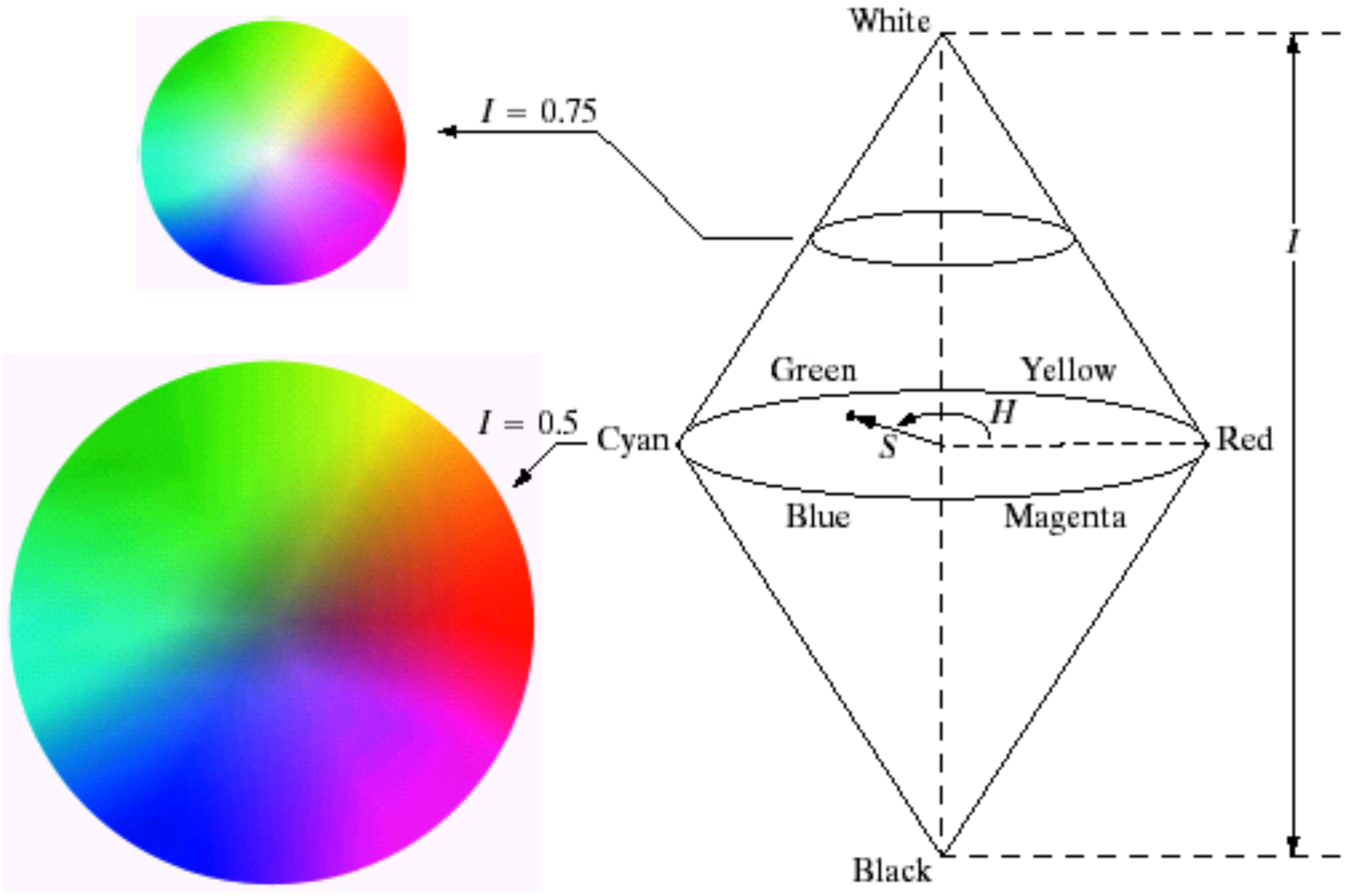
Luminance

- How bright /strong a color is
- Equivalent to measuring quantity of light independent of wavelength
- Most contributes to human perception of shape and form
- Lots of synonyms
  - Luminance
  - Intensity
  - Brightness (remember the difference)
  - Lightness
  - Luma
  - Value



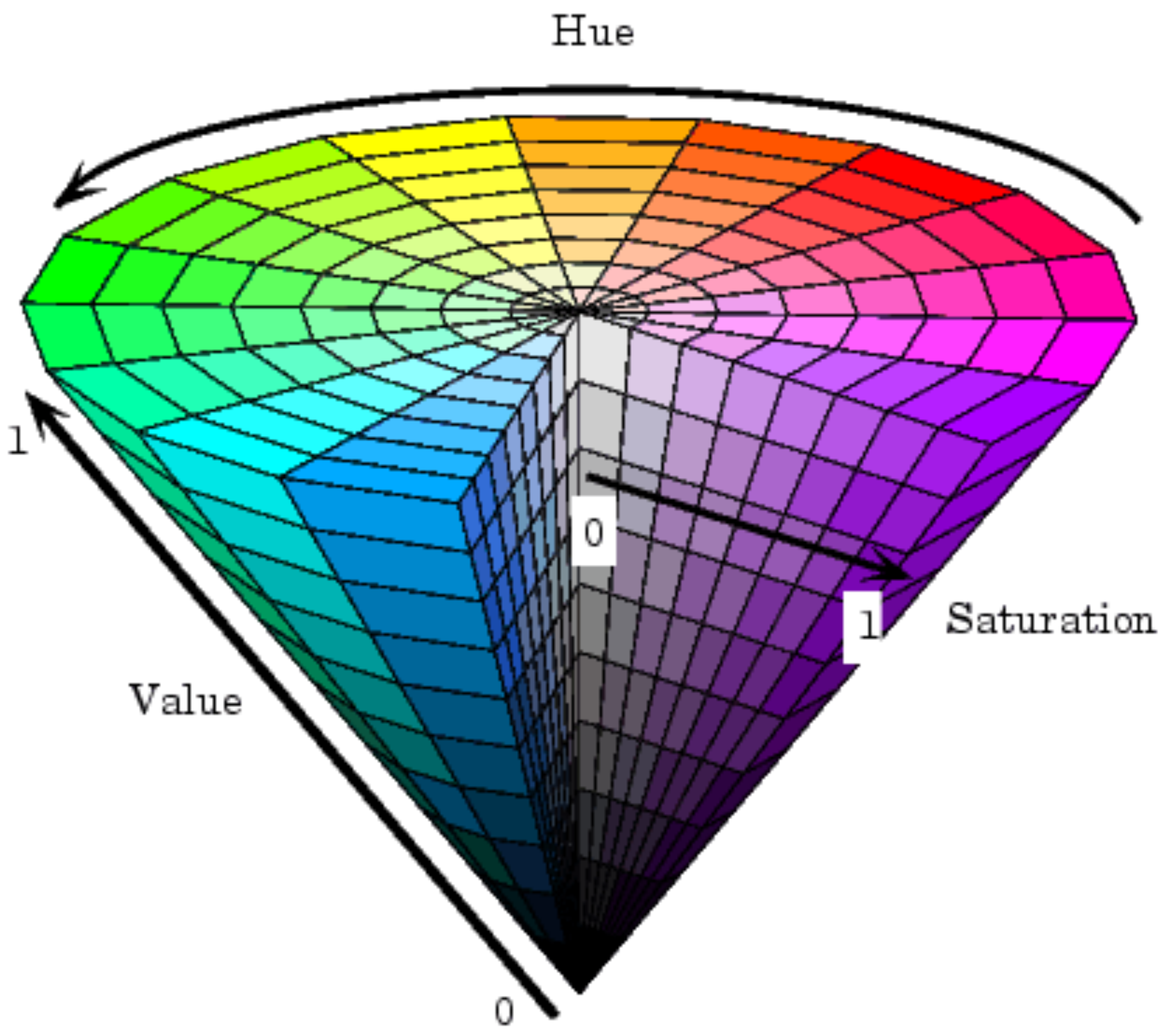
HSI Color Model

- One axis is intensity (luminance)
- The plane perpendicular to this axis represents chromaticity
    - Angle = hue
    - Distance from center = saturation
- Can map this plane using a triangle, hexagon, or circle
- The axis down the middle is the "line of grays"



Variations

- Hue-Saturation-Value (HSV)
  - Like HSI but with only one cone
- Hue-Lightness-Saturation (HLS)
- Hue-Value-Chroma (HVC)



NTSC YIQ Model

- Chromaticity requires two parameters, *but these don't have to be hue and saturation*
- Lots of other variations
- The NTSC model was used in analog broadcast television
  - Y = luminance
  - I and Q = chromaticity

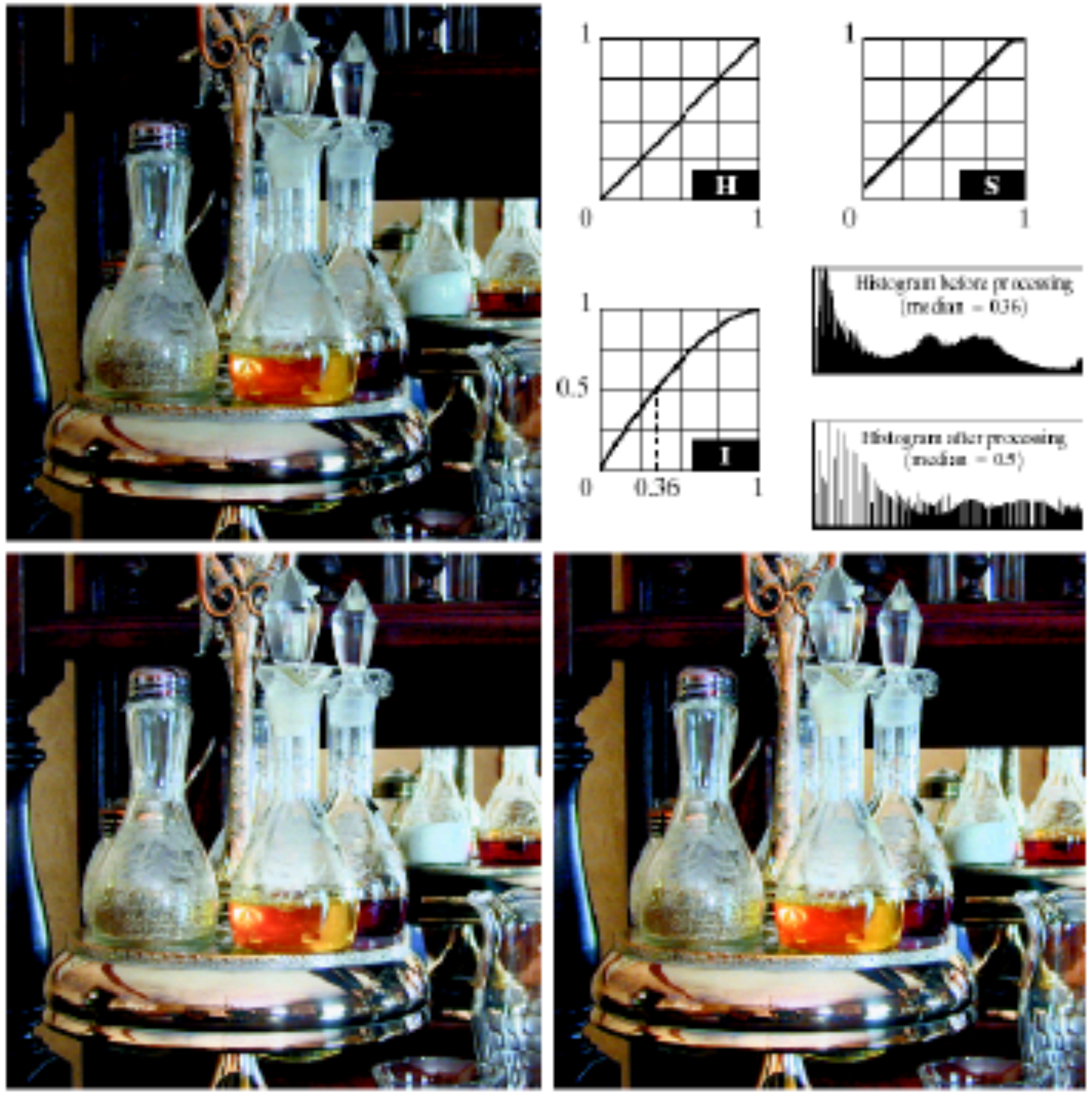
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0532 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Other Chromaticity Representations

- CIE LUV
- CIE La*b* - attempts to be *perceptually linear*
- YCrCb - used in the JPEG standard

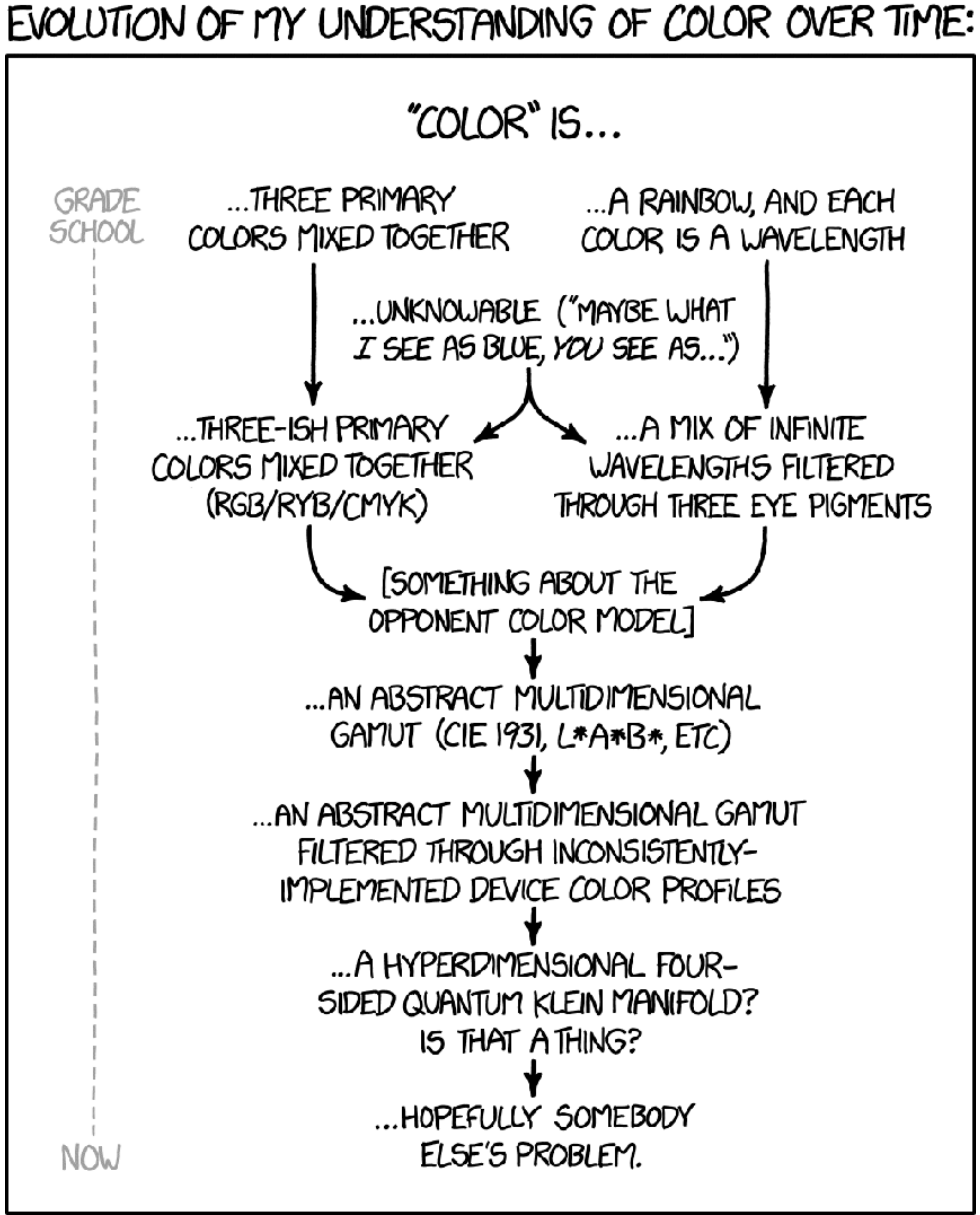
Color Image Processing

- Common approach:
  - Convert to an appropriate model such as HSI, etc.
  - Process
    - Brightness/contrast adjustments
    - Preserving or shifting the hues
    - Adjusting the saturation
  - Convert back to RGB if needed



Summary

- Pick a color space that makes sense for your application:
  - If the application is interactive, consider using HSI or other color space with explicit intensity/chromaticity
  - If you want to process intensities but keep hues the same, work (or at least think) in that kind of color space
- Keep physical limitations in mind:
  - Primaries, different color gamuts, etc.
- There’s a lot more to color than RGB triplets!


EVOLUTION OF MY UNDERSTANDING OF COLOR OVER TIME:
"COLOR" IS...
GRADE SCHOOL
...THREE PRIMARY COLORS MIXED TOGETHER
...A RAINBOW, AND EACH COLOR IS A WAVELENGTH
...UNKNOWABLE ("MAYBE WHAT I SEE AS BLUE, YOU SEE AS...")
...THREE-ISH PRIMARY COLORS MIXED TOGETHER (RGB/RYB/CMYK)
...A MIX OF INFINITE WAVELENGTHS FILTERED THROUGH THREE EYE PIGMENTS
[SOMETHING ABOUT THE OPPONENT COLOR MODEL]
...AN ABSTRACT MULTIDIMENSIONAL GAMUT (CIE 1931, L*A*B*, ETC)
...AN ABSTRACT MULTIDIMENSIONAL GAMUT FILTERED THROUGH INCONSISTENTLY-IMPLEMENTED DEVICE COLOR PROFILES
...A HYPERDIMENSIONAL FOUR-SIDED QUANTUM KLEIN MANIFOLD? IS THAT A THING?
...HOPEFULLY SOMEBODY ELSE'S PROBLEM.
NOW

Coming up...

- Interimage: blending, masking, differencing, compositing
- Neighborhood operations:
  - noise reduction
  - sharpening
  - edge detection