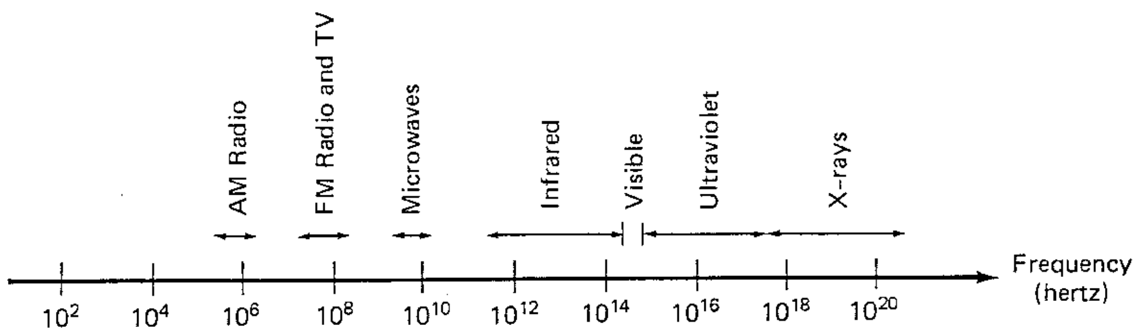
COLOR MODELS
(Section 14-4 in *Computer Graphics*)

A Color Model is a Method of Modeling the Properties or Behavior of Light in a Particular Context

- Properties Of Light
- Standard Primaries
- The Chromaticity Diagram
- Intuitive Color Concepts
- RGB Color Model
- CMY Color Model
- Conversion Between RGB and CMY Models
- HSV Color Model
- Conversion Between HSV and RGB Models
- HLS Color Model
- Color Selection

Properties of Light

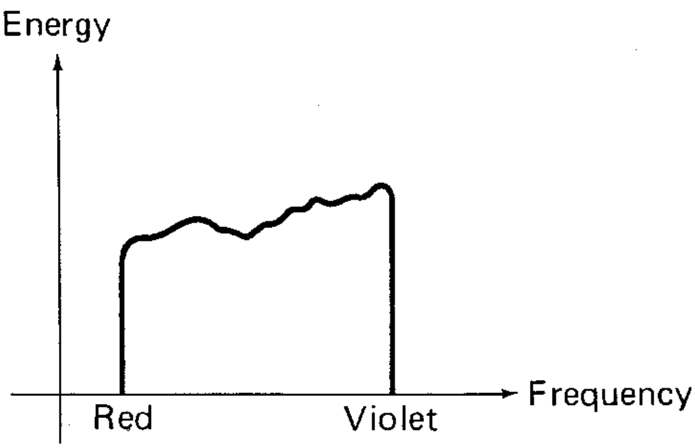
- perceived light is a narrow frequency band within the electromagnetic spectrum



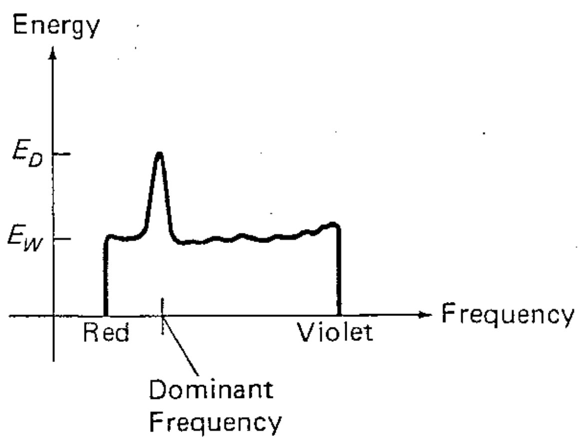
- each frequency in the visible band corresponds to a distinct color
- the eye can perceive 400,000 distinct frequencies
- colors can be described in terms of frequency or wavelength, which are inverses with a proportionality constant

Properties of Light, continued

- white light emits all frequencies within the visible range

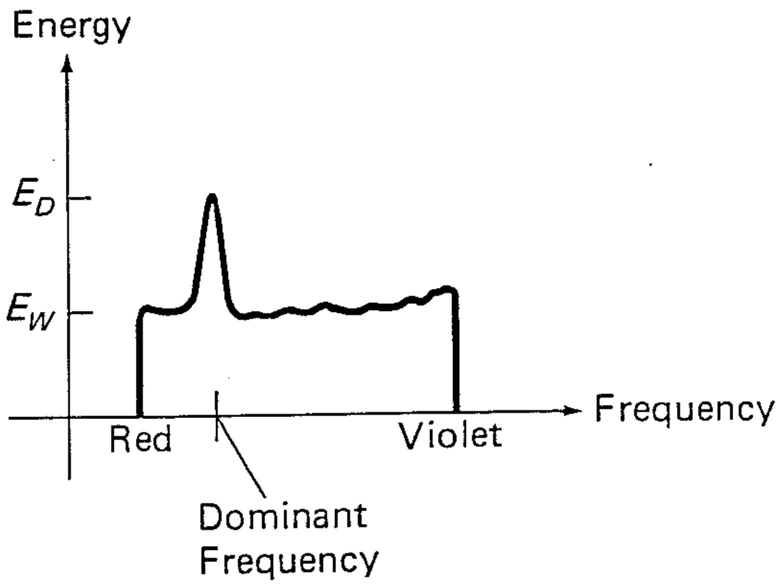


- objects absorb some frequencies and reflect others
- the combination of reflected frequencies determines the perceived color
- the frequency range which predominates is called the dominant frequency, the dominant wavelength, the color or hue.



Properties of Light, continued

- luminance or brightness is related to intensity or energy
- purity or saturation describes how pure the color appears
  - pastels are less pure
- chromaticity refers to purity and dominant frequency together
- light can have a color corresponding to a dominant frequency



- purity depends on the difference between ED and EW
- brightness (emitted energy) is the area under the curve

Properties of Light, continued

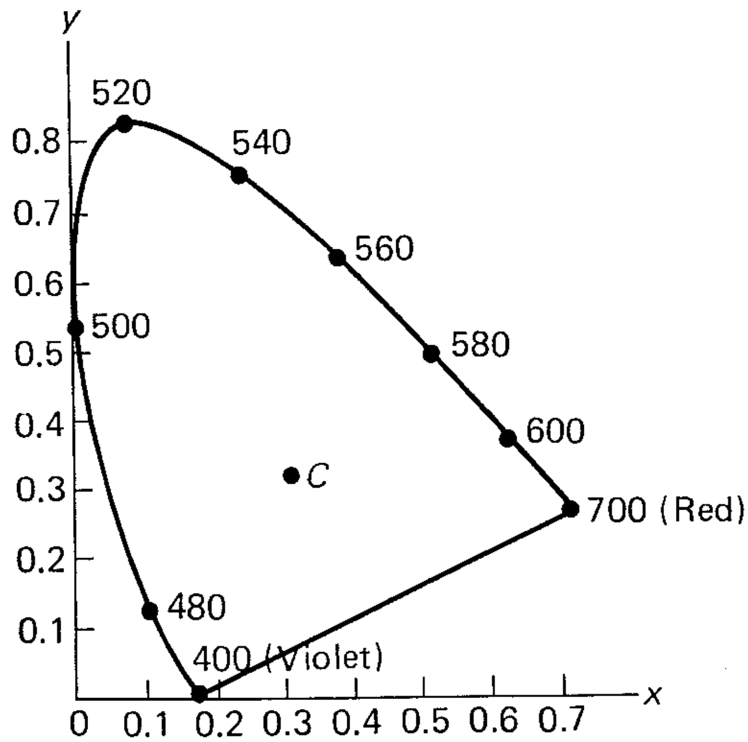
- two color sources which combine to produce white light are called complementary colors
  - red and cyan
  - green and magenta
  - blue and yellow
- a wide range of colors (color gamut) can be produced from a small, judiciously chosen set of colors (primary colors)
  - three primaries generally are sufficient

Standard Primaries

- in 1931, the International Commission on Illumination established an international standard for primary colors
  - all other colors can be described as weighted sums of the three primaries
  - each primary represents an imaginary color described by an energy distribution curve
- let A, B, and C represent the amounts of the standard primaries needed to match a given color
  - components of the color are represented as
    $x = A/(A + B + C)$
    $y = B/(A + B + C)$
    $z = C/(A + B + C)$
  - note that $z = 1 - (x + y)$

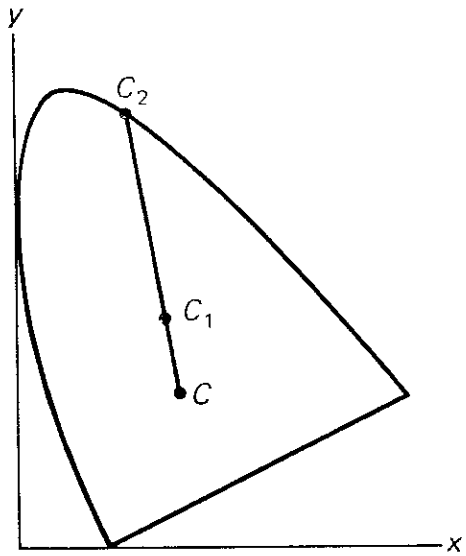
The Chromaticity Diagram

- plotting x and y for all visible colors produces a chromaticity diagram based on wavelengths in nanometers



The Chromaticity Diagram, continued

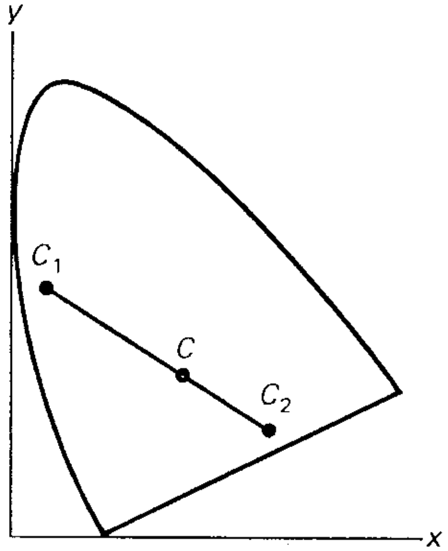
- "C" is the white-light position
- purity is the relative distance of a color point from the white-light position along a line to the border
- dominant wavelength is the point of intersection from the white-light point through the color point at the spectral curve



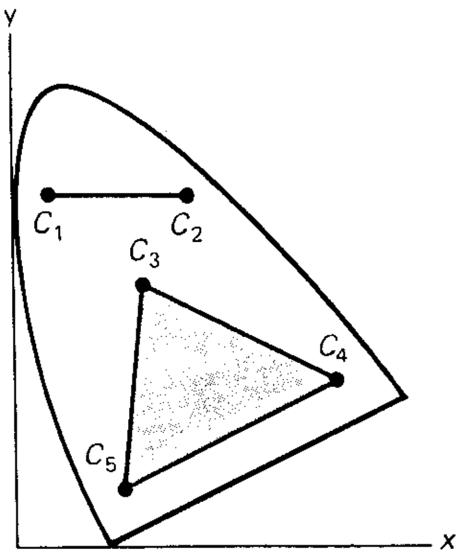
- C1 is 25% pure
- C2 shows the dominant wavelength

The Chromaticity Diagram, continued

- complimentary colors are found by reflecting across the white light position



- color gamuts are represented by regions between the color points defining the gamut

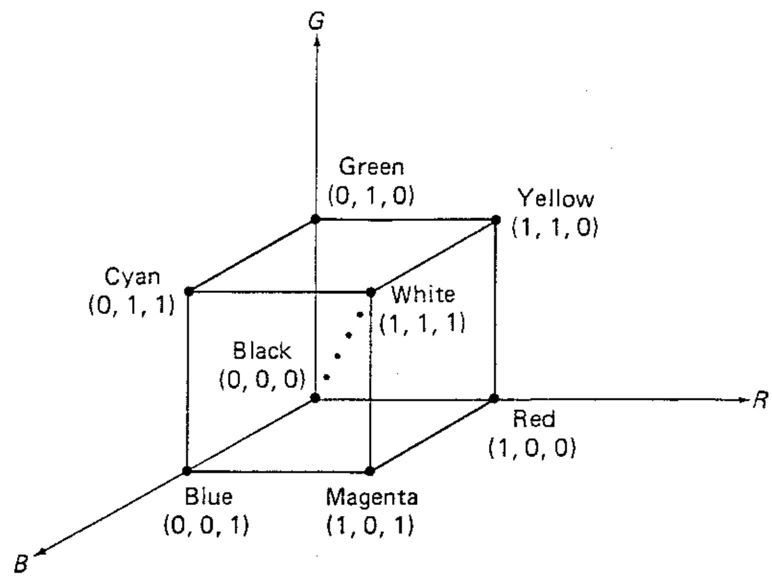


Intuitive Color Concepts

- artists create shades by starting with a pure color and adding black pigment
- tints are obtained by adding white pigment
- tones are produced by adding black and white pigments
- graphics packages often provide an intuitive color model for the user and different model suited to the output device

RGB Color Model

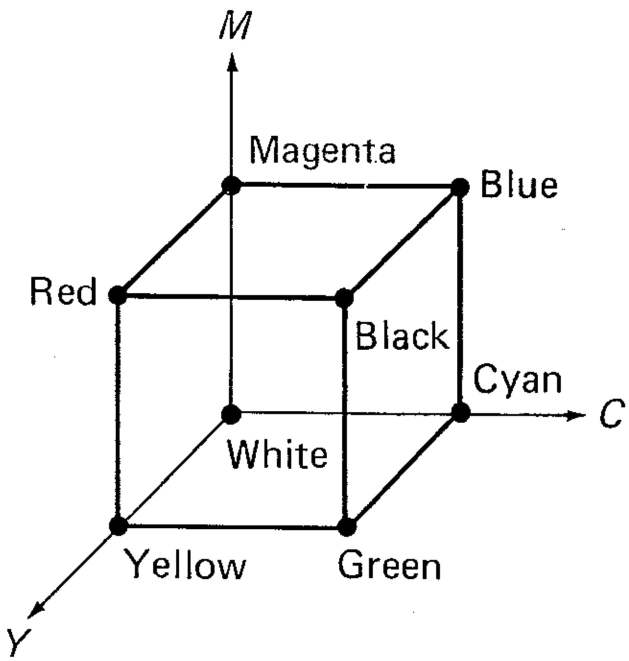
- the eye perceives color when the (three) visual pigments in the cones of the retina are stimulated
- visual pigments have peak sensitivities at
  - 630 nm (red)
  - 530 nm (green)
  - 450 nm (blue)
- the RGB color model for a video monitor combines light from red, green and blue screen phosphors



  - an additive model
- halftoning techniques can increase the number of combinations in an on-or-off system from 8 to 125 using 2-by-2 pixels

CMY Color Model

- uses primary colors cyan, magenta and yellow
- used for color output to hard-copy devices
  - coats paper with color pigments
  - a subtractive model in which colors are seen by reflected light



- the point (1, 1, 1) represents black because all components of incident light are subtracted

Conversion Between RGB and CMY Models

- RGB to CMY

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} W \\ W \\ W \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where (1, 1, 1) represents white light

- CMY to RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} B \\ B \\ B \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

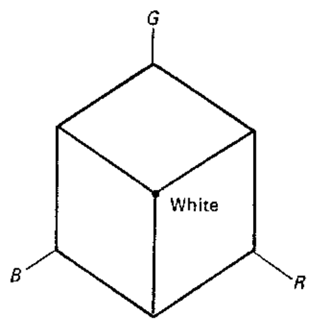
where (1, 1, 1) represents black

HSV Color Model

- a more intuitive model
- the user specifies
  - a color
  - the amount of black and white to achieve the desired shade, tint and tone
  - components presented to the user
    - hue
    - saturation (ratio of purity to maximum purity)
    - value (intensity)

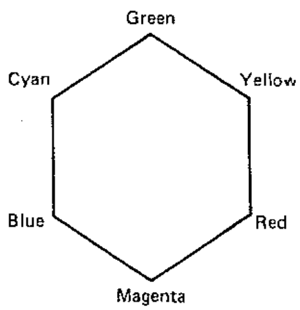
HSV Color Model, continued

- derivation
  - view the RGB cube along the black-white diagonal

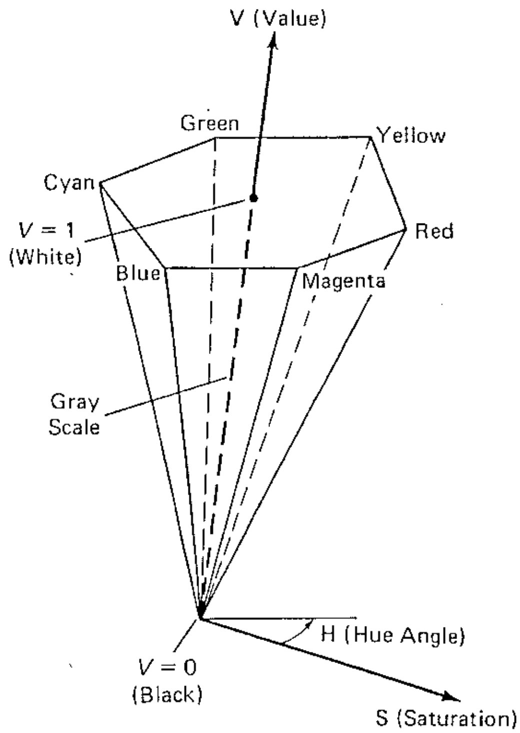


RGB Color Cube

  - use the boundary of this hexagon as the top of the HSV hexacone

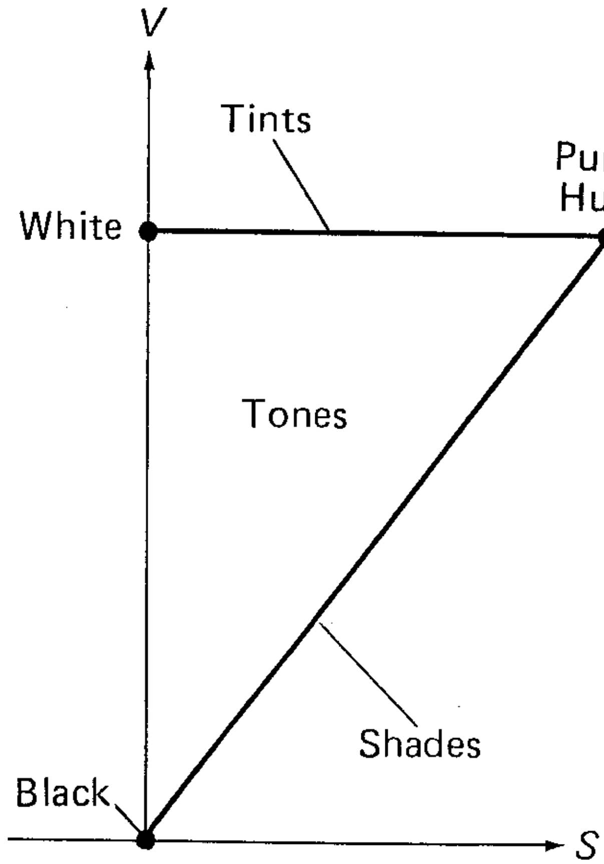


Color Hexagon



- saturation is measured horizontally
- value is measured vertically

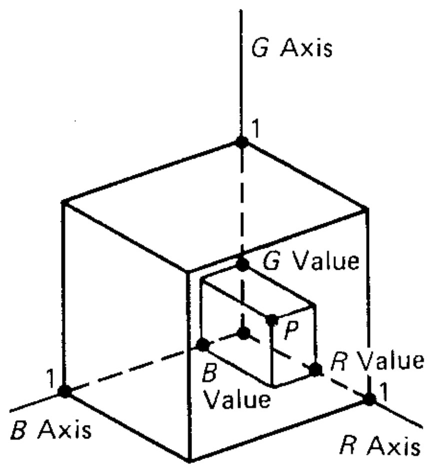
HSV Color Model, continued



- the user starts with a pure hue
- adding black decreases V
- adding white decreases S
- the eye can distinguish
  - 128 different hues (colors)
  - 130 different tints (saturations)
  - 23 shades (values) of yellows
  - 16 shades of blues

Conversion Between HSV and RGB Models

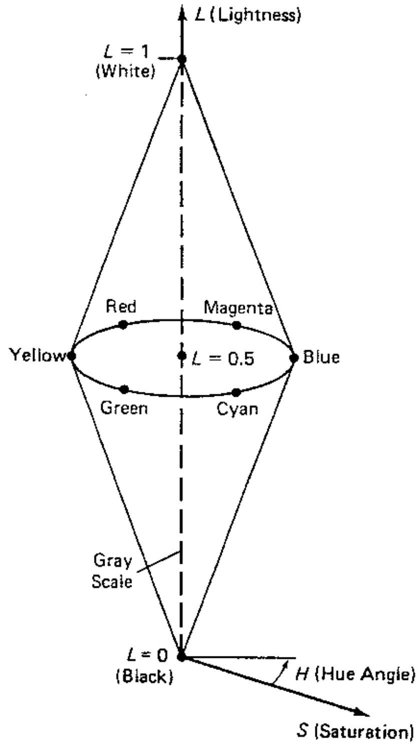
- the user may prefer the HSV model and the color monitor may require the RGB model
  - the diagonal of the RGB cube from black at the origin to white at (1, 1, 1) corresponds to the V axis of the hexacone
  - each subcube of the RGB cube corresponds to a hexagonal cross section of the hexacone
  - a procedure for mapping between hue, saturation and value (HSV) and red, green and blue (RGB) is given on pages 304 and 305 of the course text



(a)

HLS Color Model

- another intuitive model
- three parameters
  - hue (identical to HSV hue)
  - lightness (pure hues lie on the L = 0.5 plane)
  - saturation (identical to HSV saturation)



  - shade, tint and tone are achieved by adjusting L and S

Color Selection

- obtaining a set of coordinating colors
  - generate the set from a subspace of the color model
  - select colors at regular intervals along straight lines in the RGB or CMY cube
  - restrict colors to one half (or less) of the HSV hexacone
    - the eyes focus on colors according to their frequencies, causing them to appear at different depths
  - tints and shades blend better than pure hues
- use a small number of colors
- for background
  - gray or
  - a complement of a foreground color

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