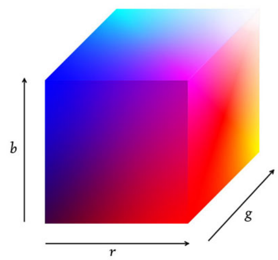
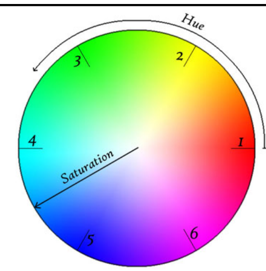


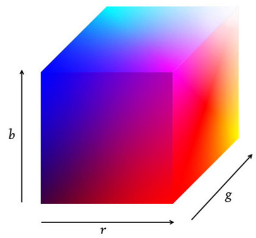
Color



- Color perception usually involves three quantities:
  - *Hue*: Distinguishes between colors like red, green, blue, etc
  - *Saturation*: How far the color is from a gray of equal intensity
  - *Lightness*: The perceived intensity of a reflecting object
- Sometimes lightness is called *brightness* if the object is emitting light instead of reflecting it.
- In order to use color precisely in computer graphics, we need to be able to specify and measure colors.

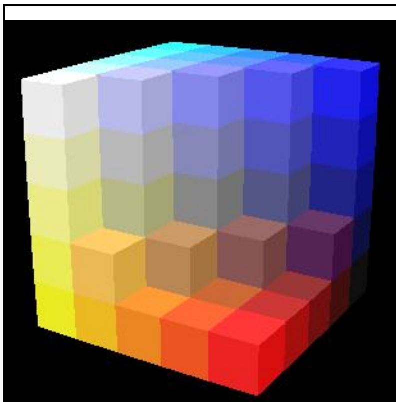
Numerous Color Spaces

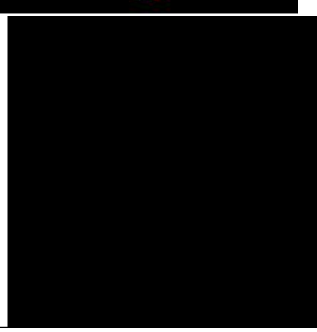
- RGB, CMY, XYZ; HSV, HLS; Lab, UVW, YUV, YCrCb, Luv, $L^* u^* v^*$, ..
- Different Purposes: display, editing, computation, compression, ..
- Equally distant colors may not be equally perceivable
- Separation of luminance and chromaticity (YIQ)



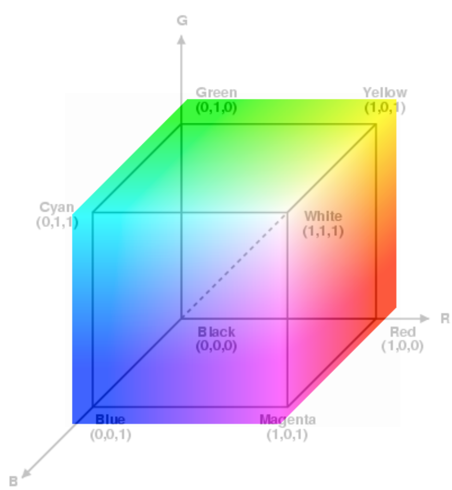
Additive Model: (RGB System)

- R, G, B normalized on orthogonal axes
- All representable colors inside the unit cube
- Color Monitors mix R, G and B
- Video cameras pick up R, G and B
- CIE (Commission Internationale de l'Eclairage) standardized in 1931: B: 435.8 nm, G: 546.1 nm, R: 700 nm.
- 3 fixed components acting alone can't generate all spectrum colors.





RGB Color space



Problems with RGB

- Only a small range of potential perceivable colors (particularly for monitor RGB)
- It isn't easy for humans to say how much of RGB to use to get a given color
  - How much R, G and B is there in "brown"?
- Perceptually non-linear
  - Two points, a certain distance apart, may be perceptually different in one part of the space, but could be same in another part of the space.

Subtractive model (CMY System)

- Color results from removal of light from the illumination source
- Pigments absorb R, G or B and so give C, M or Y
- Used in deskjet/ inkjet printers.
- No ink (pigment) = white

CMY Color space

CMY Color Cube

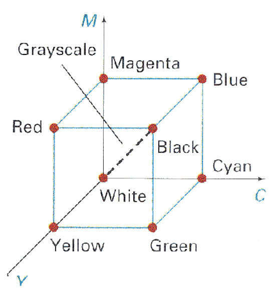
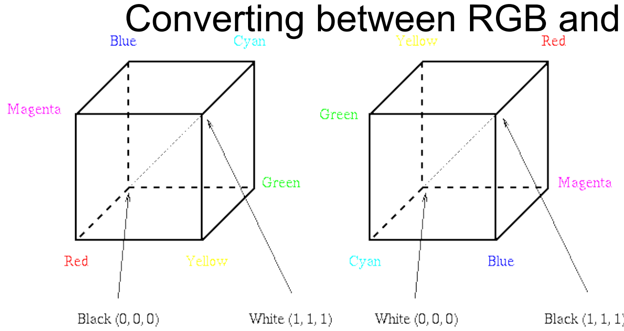


Figure 15.14 from H&B

Converting between RGB and CMY

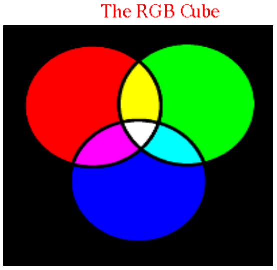


$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

The RGB Cube

The CMY Cube

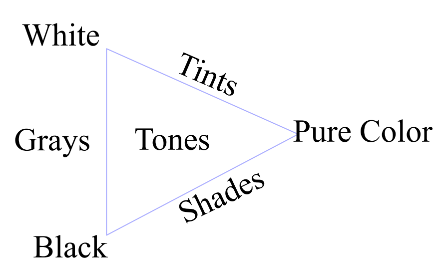


Specifying Color

- Color perception usually involves three quantities:
  - *Hue*: Distinguishes between colors like red, green, blue, etc
  - *Saturation*: How far the color is from a gray of equal intensity
  - *Lightness*: The perceived intensity of a reflecting object
- Sometimes lightness is called *brightness* if the object is emitting light instead of reflecting it.

How Do Artists Do It?

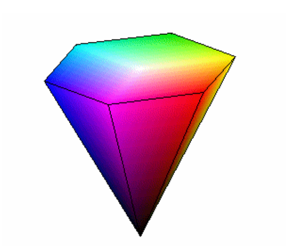
- Artists often specify color as tints, shades, and tones of saturated (pure) pigments
- *Tint*: Gotten by adding white to a pure pigment, decreasing saturation
- *Shade*: Gotten by adding black to a pure pigment, decreasing lightness
- *Tone*: Gotten by adding white and black to a pure pigment

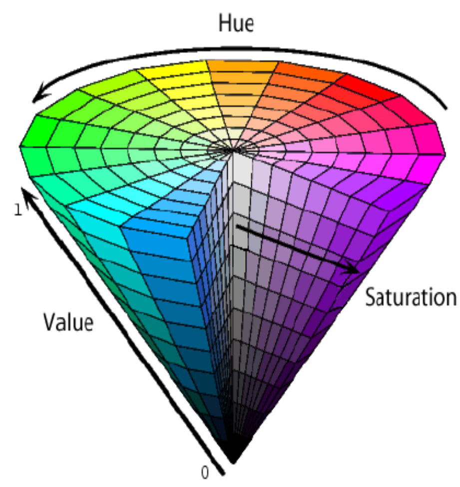


HSV Color Space

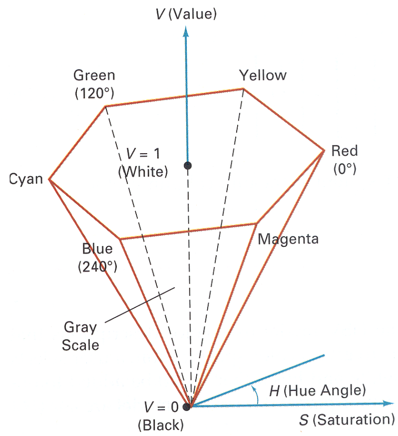
- Computer scientists frequently use an intuitive color space that corresponds to tint, shade, and tone:
  - Hue - The color we see (red, green, purple)
  - Saturation - How far is the color from gray (pink is less saturated than red, sky blue is less saturated than royal blue)
  - Brightness (Luminance) - How bright is the color (how bright are the lights illuminating the object?)

HSV Color space





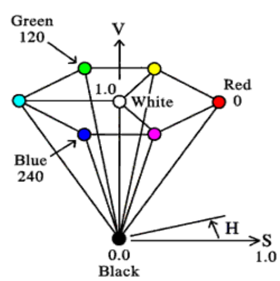
HSV Color Model

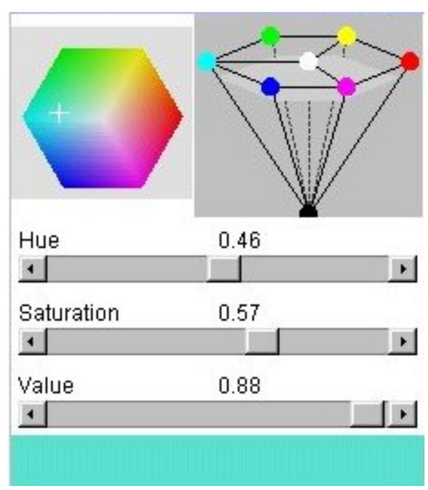


- Hue (H) is the angle around the vertical axis
- Saturation (S) is a value from 0 to 1 indicating how far from the vertical axis the color lies
- Value (V) is the height of the hexcone"

HSV Color Space

- A more intuitive color space
  - H = Hue
  - S = Saturation
  - V = Value (or brightness)



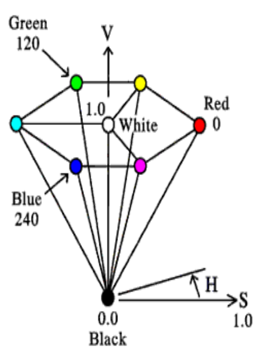


http://www.cs.rit.edu/~ncs/color/a_spaces.html

HSV System

- Normally represented as a cone or *hexcone*
- Hue is the angle around the circle or the regular hexagon; $0 \le H \le 360$
- Saturation is the distance from the center; $0 \le S \le 1$
- Value is the position along the axis of the cone or hexcone; $0 \le V \le 1$
- Value is not perceptually-based, so colors of the same value may have slightly different brightness
- Main axis is grey scale

HSV to RGB Conversion




```
if ( S == 0 )                       //HSV values = From 0 to 1
{
   R = V * 255                      //RGB results = From 0 to 255
   G = V * 255
   B = V * 255
}
else
{
   var_h = H * 6
   var_i = int( var_h )             //Or ... var_i = floor( var_h )
   var_1 = V * ( 1 - S )
   var_2 = V * ( 1 - S * ( var_h - var_i ) )
   var_3 = V * ( 1 - S * ( 1 - ( var_h - var_i ) ) )

   if      ( var_i == 0 ) { var_r = V     ; var_g = var_3 ; var_b = var_1 }
   else if ( var_i == 1 ) { var_r = var_2 ; var_g = V     ; var_b = var_1 }
   else if ( var_i == 2 ) { var_r = var_1 ; var_g = V     ; var_b = var_3 }
   else if ( var_i == 3 ) { var_r = var_1 ; var_g = var_2 ; var_b = V     }
   else if ( var_i == 4 ) { var_r = var_3 ; var_g = var_1 ; var_b = V     }
   else                   { var_r = V     ; var_g = var_1 ; var_b = var_2 }

   R = var_r * 255                  //RGB results = From 0 to 255
   G = var_g * 255
   B = var_b * 255
   }
}
```

Lab 4 Objectives

- The goal of this lab is to implement a virtual knob in HSV color space to generate the majority of colors using a tri-color LED in RGB color space.
- You will determine the movement of the virtual knob by utilizing the Chronos accelerometer.
- In addition, you will also use pulse width modulation to control the brightness of the LEDs on your Amber radio module.