Light

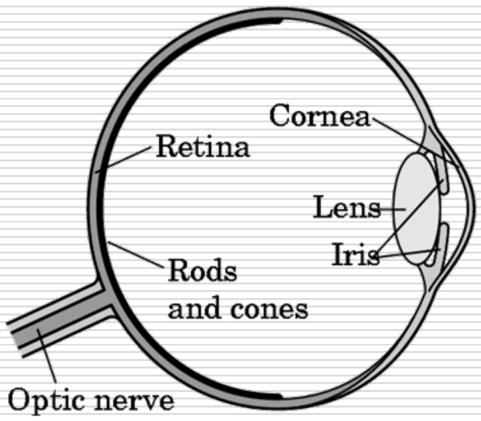
- *Light* is the part of the electromagnetic spectrum that causes a reaction in our visual systems
- Generally these are wavelengths in the range of about 350-750 nm (nanometers)
- Long wavelengths appear as reds and short wavelengths as blues

Luminance and Color Images

- Luminance
  - Monochromatic
  - Values are gray levels
  - Analogous to working with black and white film or television
- Color
  - Has perceptional attributes of hue, saturation, and lightness
  - Do we have to match every frequency in visible spectrum? No!

Three-Color Theory

- Human visual system has two types of sensors
  - Rods: monochromatic, night vision
  - Cones
    - Color sensitive
    - Three types of cone
    - Only three values (the *tristimulus* values) are sent to the brain

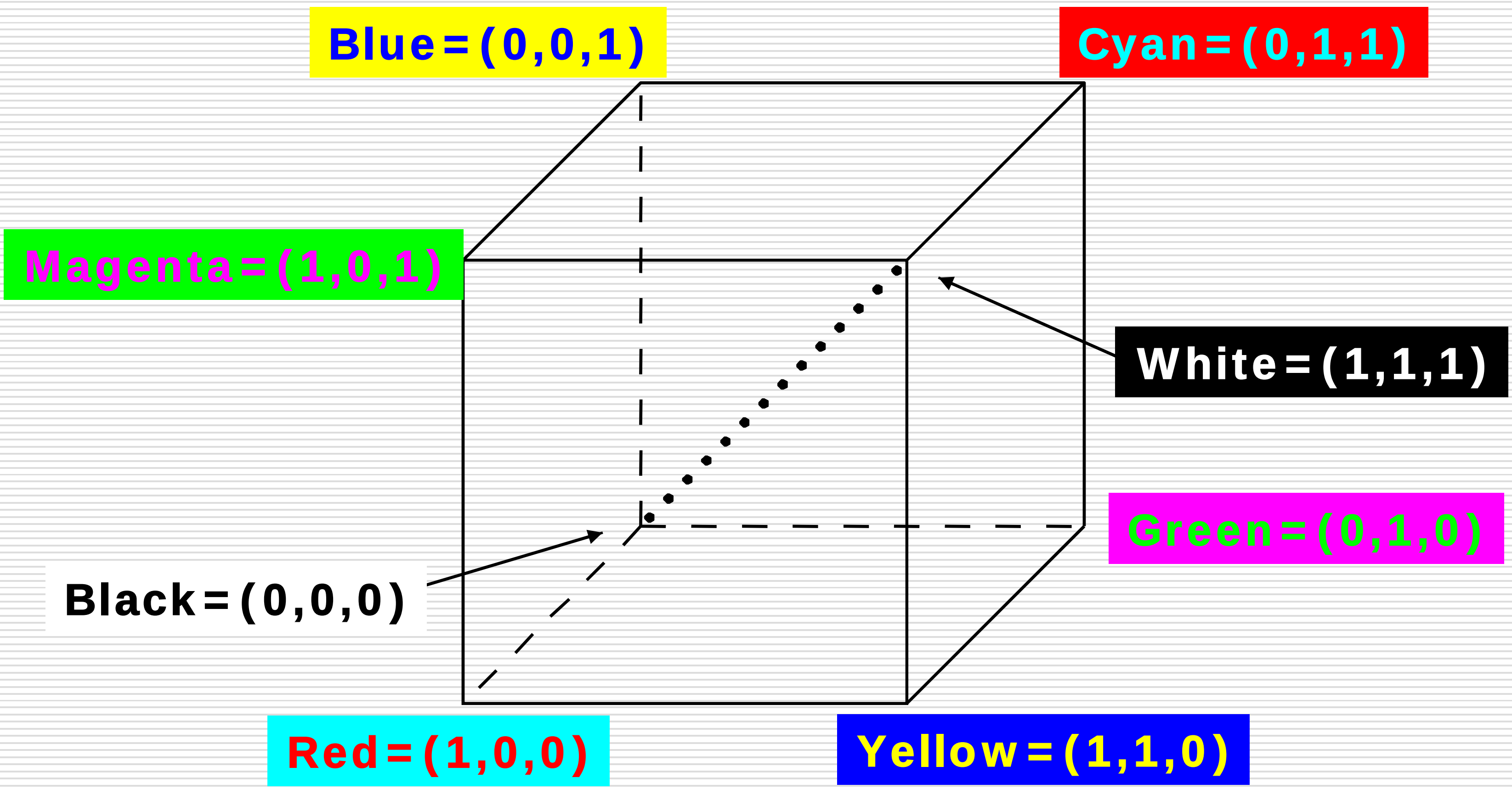


- Need only match these three values
  - Need only three *primary* colors

Additive and Subtractive Color

- Additive color
  - Form a color by adding amounts of three primaries
    - CRTs, projection systems, positive film
  - Primaries are Red (R), Green (G), Blue (B)
- Subtractive color
  - Form a color by filtering white light with Cyan (C), Magenta (M), and Yellow (Y) filters
    - Light-material interactions
    - Printing
    - Negative film

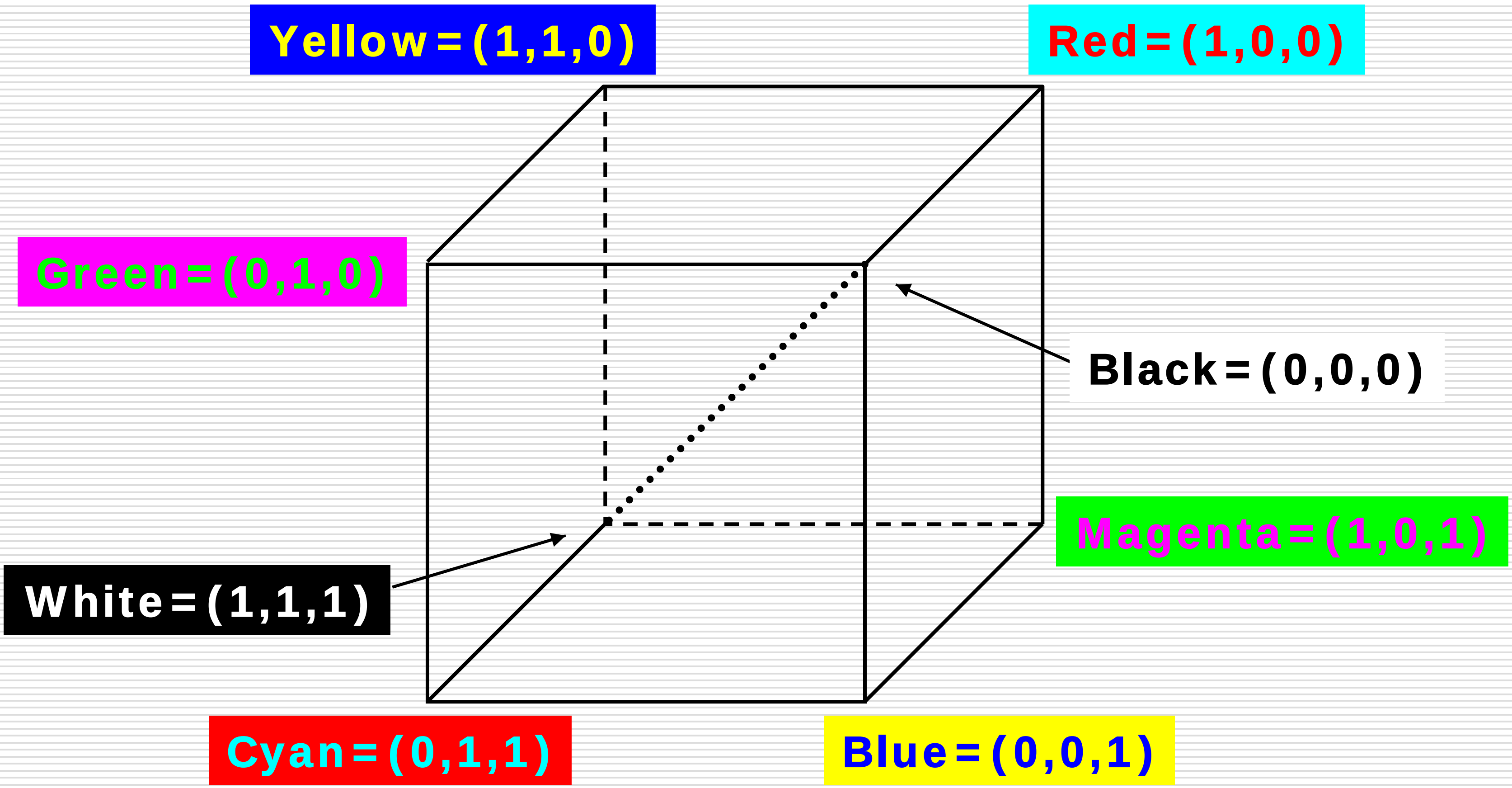
The RGB Color Model – for CRT



Color Depth

- Can choose number of bits for each of *r*, *g* and *b*
  - More bits per component means more colors can be distinguished, but image files will be larger
  - 8 bits (1 byte) per component: *24-bit color*, millions of colors
- If *r* = *g* = *b*, color is a shade of gray, so grayscale can be represented by a single value
  - 8 bits permits 256 grays

The CMY Color Model – for hardcopy



Undercolor Removal: CMYK System

- Real inks do not correspond to ideal subtractive primaries
- Combining three inks for black is undesirable
- Printers use *four process colors*, cyan, magenta, yellow and black
- CMYK gamut is not the same as RGB
  - Implications for using images prepared for print (CMYK) on the Web (RGB)

The CMYK Color Model – for hardcopy

- $C = G+B = W-R$
- $M = R+B = W-G$
- $Y = R+G = W-B$

$$\Downarrow$$

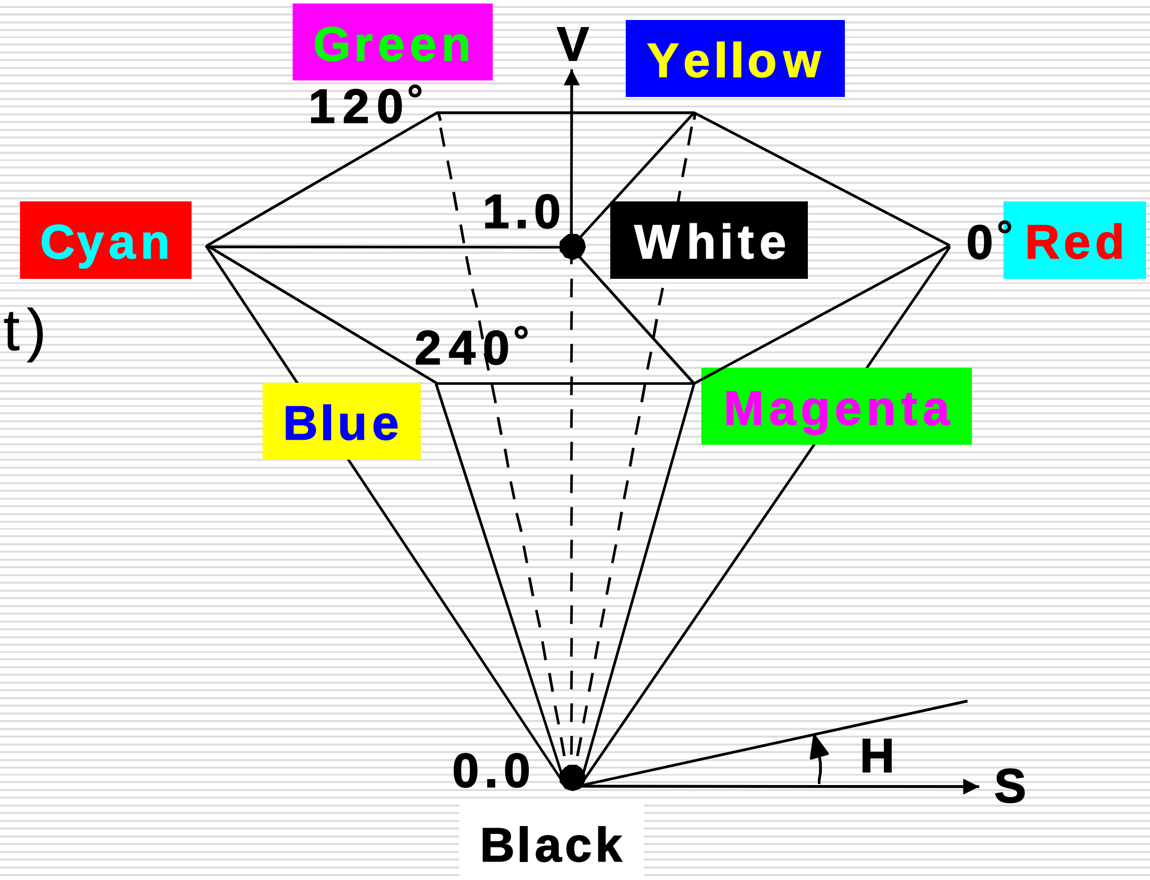
- $K = \min(C,M,Y)$
- $C \leftarrow C-K$
- $M \leftarrow M-K$
- $Y \leftarrow Y-K$

The HSV Color Model – for user-oriented

- Alternative way of specifying color
- *Hue* (roughly, dominant wavelength)
- *Saturation* (purity)
- *Value* (brightness)
- Model HSV as a cylinder: *H* angle, *S* distance from axis, *V* distance along axis
- Basis of popular style of *color picker*

The HSV Color Model – for user-oriented

- H : hue
- S : saturation
- V : value
  - (or B for blight)



Color Models in Video

- Largely derive from older analog methods of coding color for TV. Luminance is separated from color information.
- YIQ is used to transmit TV signals in North America and Japan. This coding also makes its way into VHS video tape coding in these countries since video tape technologies also use YIQ.
- In Europe, video tape uses the PAL or SECAM codings, which are based on TV that uses a matrix transform called YUV.
- Digital video mostly uses a matrix transform called YC_bC_r that is closely related to YUV.

The YUV Color Model – for PAL video

- Can be useful to separate brightness and color information, especially for video.
- *Y* is for **luminance** and *U* and *V* are for **chrominance** which are stored as two *color difference* values *B-Y* and *R-Y*.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The YUV Color Model – for PAL video

- For dealing with composite video, it turns out to be convenient to contain *U* and *V* within the range −1/3 to +4/3. So *U* and *V* are rescaled:

$$U = 0.492111(B - Y)$$

$$V = 0.877283(R - Y)$$

- The chrominance signal = the composite signal *C*:

$$C = U \cdot \cos(\omega t) + V \cdot \sin(\omega t)$$

The YIQ Color Model – for NTSC color-TV

- Y : luminance
- I and Q : chromaticity
  (rotated version of U and V)

$$I = 0.492111(R-Y)\cdot\cos 33^{\circ} - 0.877283(B-Y)\cdot\sin 33^{\circ}$$

$$Q = 0.492111(R-Y)\cdot\sin 33^{\circ} + 0.877283(B-Y)\cdot\cos 33^{\circ}$$

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The YC_bC_r Color Model – for digital video

$$C_b = ((B - Y)/1.772) + 0.5$$

$$C_r = ((R - Y)/1.402) + 0.5$$

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.168 & -0.332 & 0.5 \\ 0.5 & -0.418 & -0.082 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 0.5 \\ 0.5 \end{bmatrix}$$

scaled to [0-255]

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112 \\ 112 & -93.786 & -18.214 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$