EE 576 - Color

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Color

- Perception
- Dominant Wavelength
- Tristimulus Theory of Color Perception
- Color Models
- Light Sources

Electromagnetic Waves

Electromagnetic waves – Varying frequency

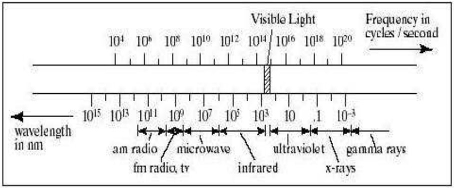


Figure: Electromagnetic Frequency Spectrum

Visible Spectrum

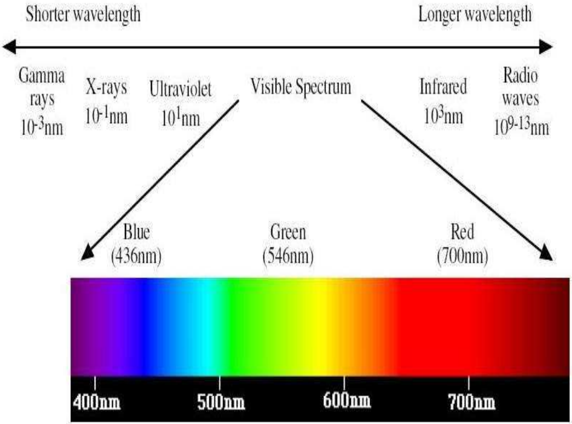


Figure: Visible spectrum

Pure Colors

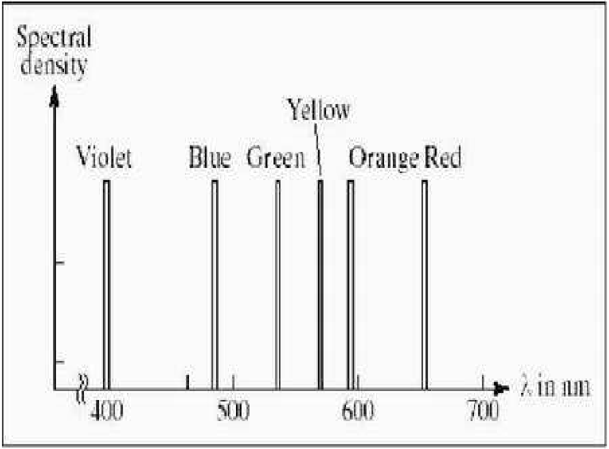
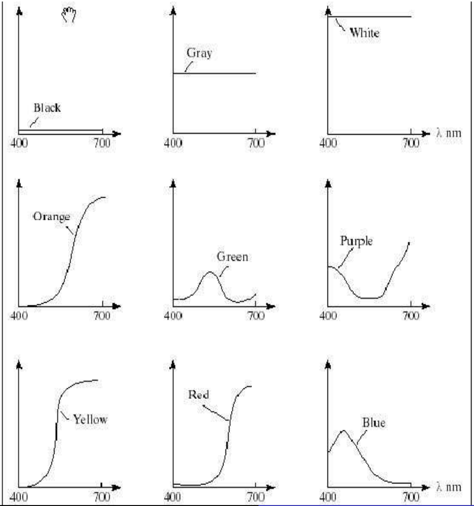


Figure: Pure colors

Mixed Colors



Human Color Perception

- The human visual system - Distinguish 100 shades of gray, however it has much more discriminating power wrt to color shades.
- Color – Provides a lot of information about the current scene which can then be used in image analysis and understanding – in particular segmentation.
- Brightness or luminance – Perception of the color, and is therefore psychological.
- Given equally intense blue and green, the blue is perceived as much darker than the green.
- our perception of intensity – nonlinear
    1. $0.1 \rightarrow 0.11$ and $0.5 \rightarrow 0.55$ – perceived as equal changes in brightness.

Color Perception Factors

Our perception of color is determined by the following factors:

1. Color of the light source
2. Reflectance properties of an object – we see those rays that are reflected, while others are absorbed.
3. The nature of the visual system (human or robot)
   - The human retina - 3 kinds of cones.
   - The response of each type of cone as a function of the wavelength of the incident light
   - The peaks for each curve – 440nm (blue), 545nm (green) and 580nm (red).

Human Spectral Response

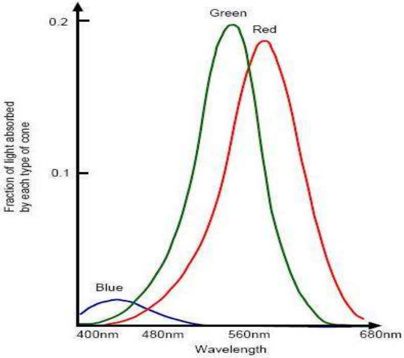


Figure: Human spectral response.

Color Perception of Objects

Consider an object that reflects both red and green.

- Will appear green when there is green but no red light illuminating it.
- Conversely, if the light is only red (no green light), it will appear red.
- In white light, it will appear yellow which is combination of red and green.

Hence, the perception of color – entirely due to our vision system.

Dominant Wavelength (cont.)

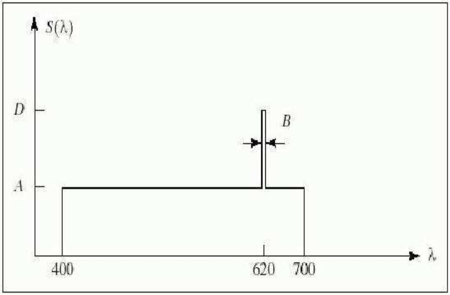


Figure: Dominant wavelength.

RGB Colors

- Any color – from a mix of the three primaries – red, green and blue.
- However, although nearly all visible colors can be matched in this way, some cannot.
- One of the primaries – Added to one of these unmatchable colors, it can be matched by a mixture of the other two,
- The color may be considered to have a negative weighting of that particular primary

RGB Colors

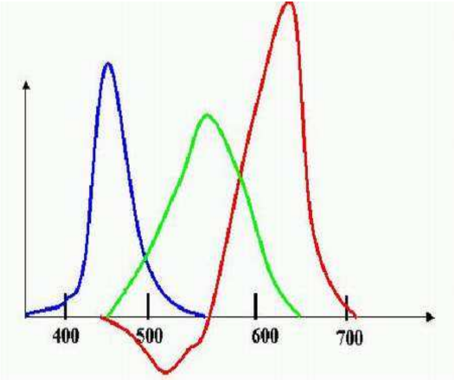


Figure: RGB Colors.

Models

There are several different color models:

- RGB Model
- CMY Model
- HSI Model
- YIQ Model

RGB

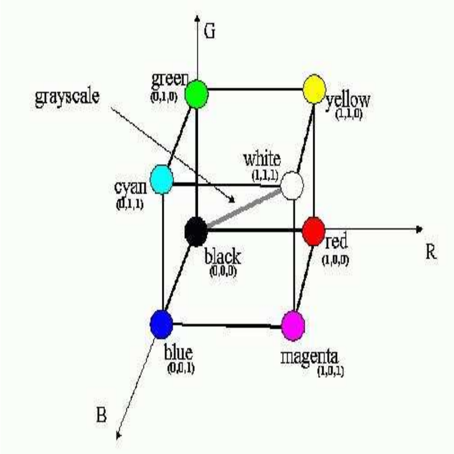


Figure: RGB Cube Model

RGB Model

An image –consists of three independent image planes: red, green and blue.

Color - Specified by the amount of each primary color.

This is an additive model, i.e. the colors present in the light add to form new colors,

- Yellow (red + green)
- Cyan (blue + green)
- Magenta (red + blue)
- White ((red + green + blue)

Note that the gray scale spectrum – namely those colors made from equal amounts of each primary – On the line joining the black and white vertices.

The RGB model – used for color monitors and most video cameras.

CMY Model

The CMY (cyan-magenta-yellow) model - A subtractive model – with three primaries: Cyan (C), magenta (M) and yellow (Y).

Used where absorption of colors is valid.

In contrast to RGB model's black base, CMY model defines what is subtracted from white.

If a surface coated with cyan pigment – illuminated by white light $\rightarrow$ no red light reflected

Similarly for magenta and green, and yellow and blue.

RGB vs CMY

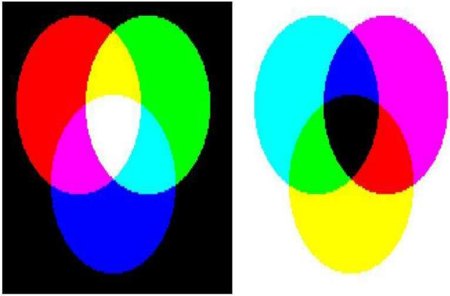


Figure: Left: Color addition with RGB model; Right: Color subtraction with CMY model.

CMY Model

The relationship between the RGB and CMY models:

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

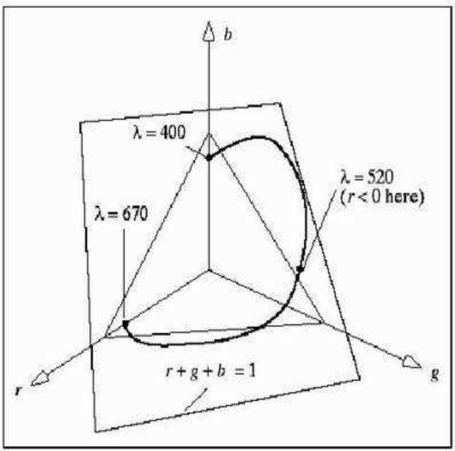
CIE Model

In 1931, the Commission Internationale de l'Eclairage (CIE) defined three standard primaries
X, Y and Z, that can be added to form all visible colors.

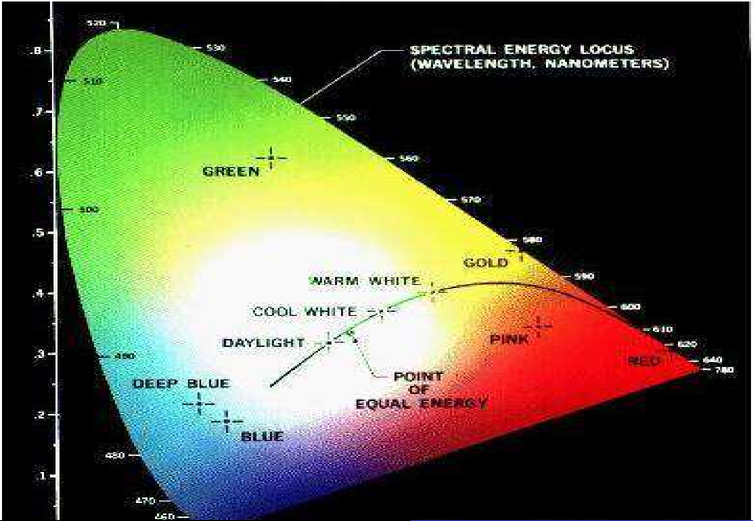
1. X:
2. Y – Chosen so that its color matching function is equal to the luminous-efficiency function for the human eye as given by the sum of the three curves.
3. Z:

The CIE Chromaticity Diagram shows all visible colors where the axes give the normalized amounts of the X and Y primaries for a particular color, and hence $z = 1 - x - y$.

Transition from RGB cube to CIE Chromaticity



CIE Chromacity Diagram



HSI Model

A color – represented by three independent quantities:

1. Hue as determined determined by the dominant wavelength. Visible colors occur between about 400nm (violet) and 700nm (red) on the electromagnetic spectrum.
2. Saturation as determined by the excitation purity or equivalently by the amount of white light mixed with the hue.
3. Intensity as determined by the actual amount of light. Colors with more light correspond to more intense colors.

A pure hue is fully saturated, i.e. no white light mixed in.
Hue and saturation together determine the chromaticity for a given color.

HSI Model

- Achromatic light has no color – that is its only attribute is intensity).
- Gray level is a measure of intensity.
- The intensity is determined by the energy, and is therefore a physical quantity.

RGB – HSI

The intensity -just the average of the red, green and blue

$$I = \frac{1}{3}(R + G + B) \quad (2)$$

R, G and B – the amounts of the red, green and blue components, normalized to the range [0; 1].

Saturation:

$$S = 1 - \frac{min(R, G, B)}{I} = 1 - \frac{3}{R + G + B} min(R, G, B) \quad (3)$$

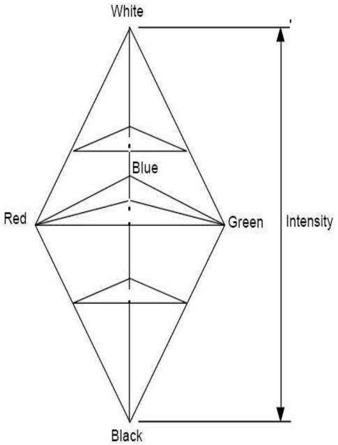
$min(R, G, B)$ term describes the amount of white present.

If any of R, G or B are zero $\rightarrow$ no white $\rightarrow$ pure color.

$H \in [0, \pi]$. Otherwise, $H = 2\pi - H$.

$$H = cos^{-1}\left(\frac{\frac{1}{2}((R - G) + (R - B))}{((R - G)^2 + (R - B)(G - B))^{-1}}\right) \quad (4)$$

HSI Color Space



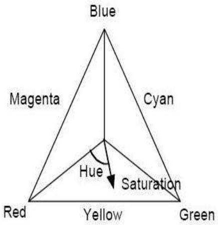


Figure: HSI Color space

Dominant Wavelength (cont.)

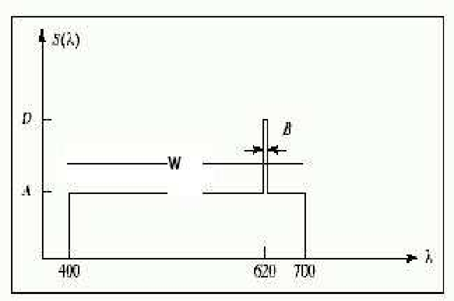


Figure: Dominant wavelength.

HLS

- Luminance $L = (D - A)B + AW$
- Saturation $= (D - A)B/L * 100$
    -
    - White light: $D = A \rightarrow$ Sat. $= 0$

Dominant Wavelength (cont.)

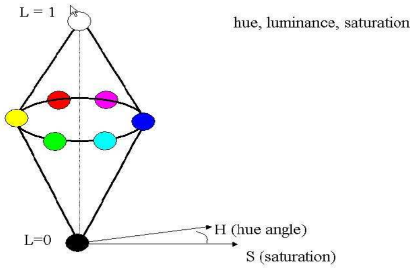


Figure: HLS.

YIQ

YIQ (luminance-in phase-quadrature) model – recoding of RGB for color television.

A very important model for color image processing.

The conversion from RGB to YIQ is given by:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{5}$$

YIQ Interpretation

- The luminance (Y) component – All the information required for B/W television. television, and captures our perception of the relative brightness of particular colors.
- Perceive green as much lighter than red, and red lighter than blue – Indicated by their respective weights of 0.587, 0.299 and 0.114 in the first row
- These weights **should be used** when converting a color image to grayscale if you want the perception of brightness to remain the same.
- Not the case for the intensity component in an HSI image.

Black Body Radiation

Measuring color temperature in Kelvin – Designating a light source's spectral distribution

- Kelvin scale $\rightarrow$ "Black Body Radiator" energy emission.
- At absolute zero - minus 273.3° Centigrade - this theoretical object radiates no energy.
- As the temperature of "Theoretical Black Body" $\uparrow$ $\rightarrow$ Emits energy.
- 700° C, a faint red glow becomes visible to the naked eye.
- At $\uparrow$ 1517° C, it glows with a light similar to candle or firelight (At 1800 K).
- At 2850 K, a typical household incandescent lamp
- At 3200 K, a typical studio incandescent lamp
- At 5600 K, nominal daylight.
- Blue sky of 28,000 K

Kelvin Scale

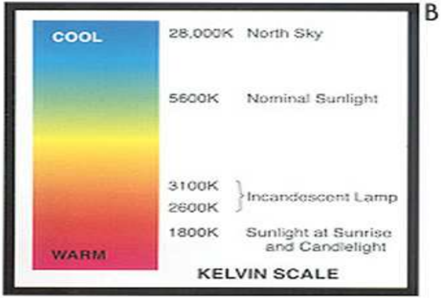


Figure: Kelvin scale.

Spectral Content

- From 1800K to $28,000$K, continuous spectral distribution of the TBB
- from 300 to 700nm – The spectral energy is not "interrupted"
- The balance or ratio of red to blue shifts - Kelvin $\rightarrow$, light's "blueness" $\uparrow$

Kelvin Rating

- Kelvin rating → Light source that emits energy across the entire visible range
- Sunlight and incandescent lamps – "Black Body Simulators"-
  - Similar to spectral distribution of the "Theoretical Black Body Radiator."
  - Measure the energy at two places in the spectrum - red and blue - to determine the Kelvin.
- Light source with "interrupted" spectrum (fluorescent and discharge lamps) – Light source does not have Kelvin temperature.

Light Sources

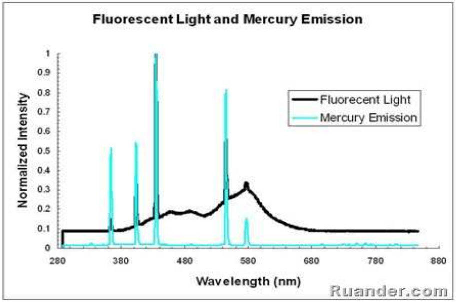


Figure: Spectrum of various type of lights