Color Image Processing

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1. Color fundamentals

2. Color models

3. Pseudocolor image processing

4. Color Transformation

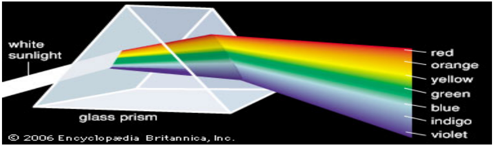
Color Image Processing

Why color?

- Color is a powerful descriptor for object identification and extraction
- Human capability for perceiving of thousands of color shades and intensities

Color fundamentals

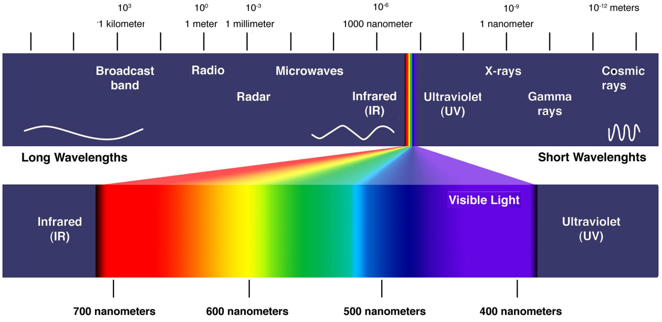
- Splitting of white light, while passes through glass prism



Visible range

Color fundamentals

Visible light



Color fundamentals

Color perception

- The perceive colors from an object are determined by the nature of light reflected from the object
  - If an object reflects light that balanced from all visible wavelengths, object is perceived as white
  - If an object reflects light mainly in the range of 575 to 625 nm, the object is perceived as red

Color fundamentals

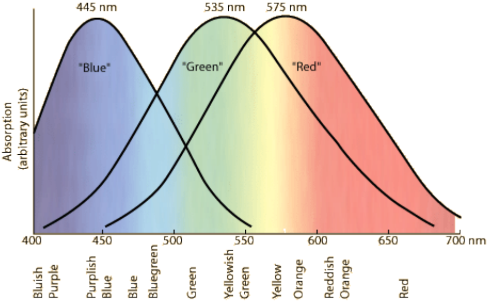
Chromatic light

- Achromatic light(free of color), its only attribute is its intensity
- Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm
- The quality of chromatic light is described by radiance, luminance, and brightness
  - Radiance is the total amount of energy that flows from the light source, measured in W
  - Luminance is the measure of the energy that observer receives from the light, lm (lumens)
  - Brightness is a subjective descriptor that is impossible to measure

Color fundamentals

Primary colors

- Why so called primary colors, Red (R), Green (G), and Blue (B) ?
  - Average absorption of light by human eyes cones



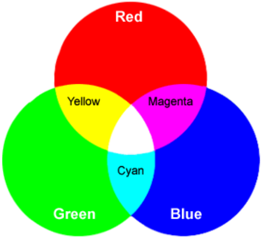
- Colors are seen as variable combination of primary R, G and B

Color fundamentals

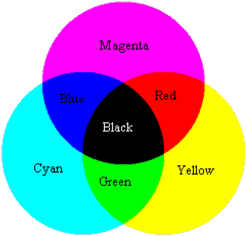
Primary colors

- Specific wavelength to the three colors by CIE (International Commission on Illumination)designated: B (435.8 nm), G (546.1 nm) and R (700 nm)
- Secondary colors : adding the primary colors
  - magenta (R+B), cyan (G+B), yellow (R+G)

Mixture of light



Mixture of pigments



Color fundamentals

Color characteristics

- *Brightness* - embodies the achromatic notation of intensity
- *Hue* - associate with the dominant wavelength in a mixture of waves, represent the dominant color
- *Saturation* - relative purity or the amount of white light mixed with hue.
    - Pure spectrum colors are fully saturated
    - Degree of saturation and amount of added white light $\rightarrow$ inversely proportional
- *Chromaticity* - Hue and Saturation together
- *Tristimulus value* - amount of R,G and B to form any particular color (X, Y, Z)
- *Trichromatic color coefficients* - $x = \frac{X}{X+Y+Z}$, $y = \frac{Y}{X+Y+Z}$, $z = \frac{Z}{X+Y+Z}$, $x + y + z = 1$

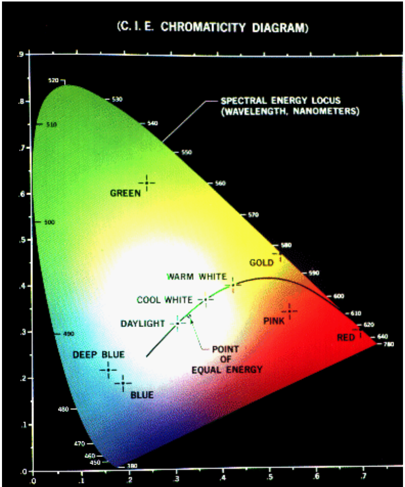
Color fundamentals

CIE Chromaticity diagram

- A method for specifying colors
- Specific color composition as function of x(red) and y(green)
- For any value of x and $y \rightarrow z$ (blue) $= 1 - x - y$

Color fundamentals

CIE Chromaticity diagram



Color fundamentals

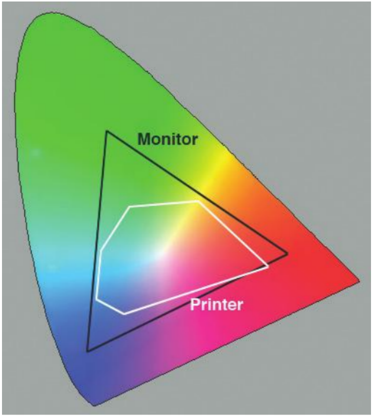
CIE Chromaticity diagram

- Pure spectrum colors located around boundary
- Non-boundary colors are mixture of spectrum colors
- The equal energy point represent the CIE standard for white light
- A straight line joining any two point on the border, represent all the colors that can be created by mixing these two colors

Color fundamentals

CIE Chromaticity diagram

Typical color gamut of color monitors and color printers

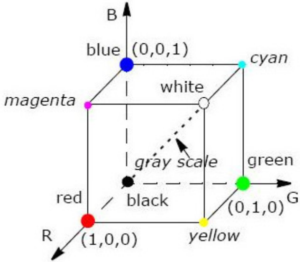


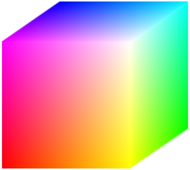
Color models

- Oriented towards hardware or application
- RGB (red, green, blue) model for color monitors and color video cameras
- CMY (cyan, magenta, yellow) and CMYK (cyan, magenta, yellow, black) for color printing
- HSI (hue, saturation, intensity), closer to human eyes,

RGB model

- Based on Cartesian coordinates
- Three axis, representing, red, green and blue
- *Bit depth* - number of bits representing each pixel in RGB
- 24 RGB bit depth - Total number of colors = $(2^8)^3 = 16,777,216$





Color models
RGB model

RGB model

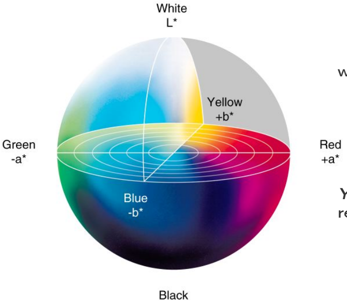
XYZ $\rightarrow$ RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.41847 & -0.15866 & -0.082835 \\ -0.091169 & 0.25243 & 0.015708 \\ 0.00092090 & -0.0025498 & 0.17860 \end{bmatrix} . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Color models
Lab model

Lab color space

- Three components:
- Luminance, brightness (L) and two chromatic components, one ranges from green to red, the other from blue to yellow



$$L^* = 116 f(Y/Y_n)$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)]$$

where

$$f(t) = \begin{cases} t^{1/3} & \text{if } t > (\frac{6}{29})^3 \\ \frac{1}{3}(\frac{29}{3})^2 t + \frac{4}{29} & \text{otherwise} \end{cases}$$

Y_n, X_n and Z_n, CIEXYZ tristimulus values of white reference point under illumination of D65

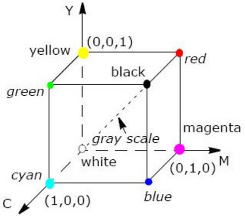
$$X_n = 0.95047,\ Y_n = 1.0000,\ Z_n = 1.08883$$

Color models
CMY model

CMY / CMYK model

- Color printers and copies
- CMYK (four-color printing)
- For normalized colors $\in [0, 1]$

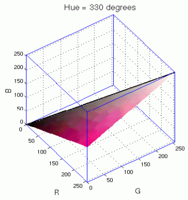
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

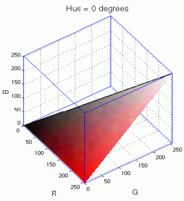


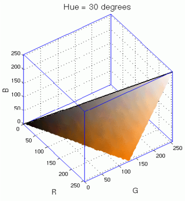
Color models
HSI model

HSI model

- Closest to human color interpretation
- **Hue** - Pure/dominant color
- All colors on the plain defined by black/white line and one pure color have the same hue



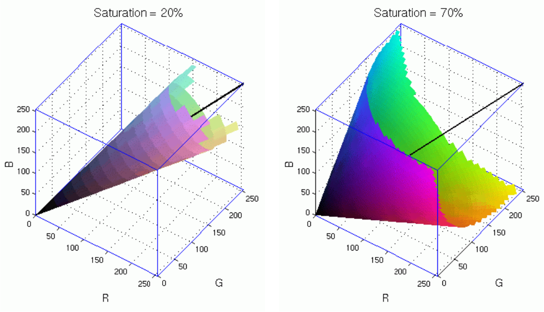




Color models
HSI model

HSI model

- **Saturation** - Purity, amount of white light mixed with hue
- Distance form associated pure color (perpendicular distance to the black/white line)
- points further away from this line are more saturated, then the one closer

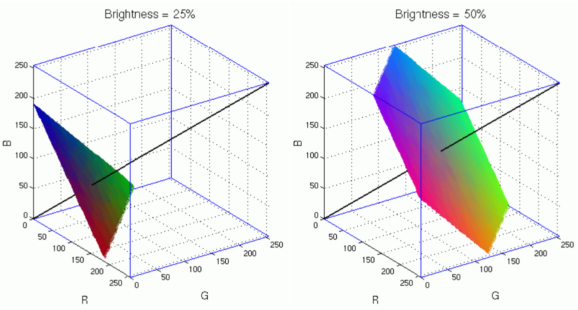


(a) (b)

Color models
HSI model

HSI model

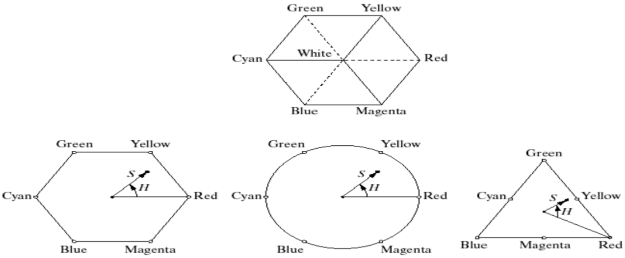
- **Intensity** - Brightness
- How much light an object is emitting
- Colors on the plane perpendicular on black/white line, where $R + G + G = k$ have the same brightness



Color models
HSI model

HSI model

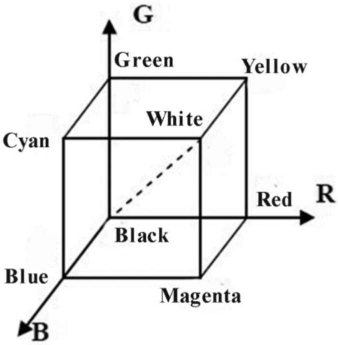
- Relations between RGB cube and HSI

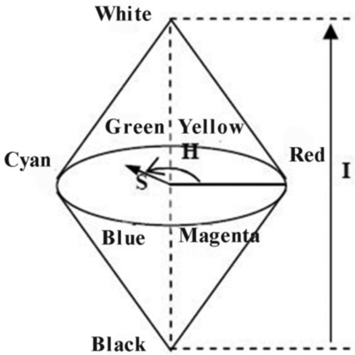


Color models
HSI model

HSI model

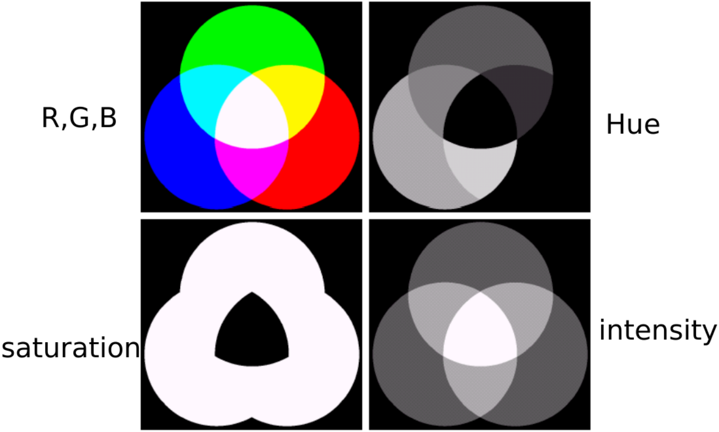
- Relations between RGB cube and HSI





Color models
HSI model

RGB $\rightarrow$ HSI



Color models
HSI model

Conversion from RGB to HSI

$$H = \begin{cases} 0 & \text{if } B \geq G \\ 360 - \theta & \text{if } B > G \end{cases}$$

$$\theta = \cos^{-1}\{\frac{\frac{1}{2}(R-G)+(R-B)}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\}$$

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

$$I = \frac{R+G+B}{3}$$

Color models
HSI model

Conversion from HSI to RGB

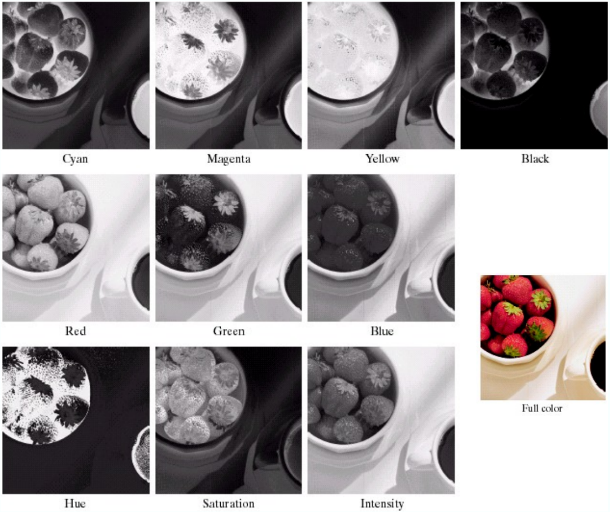
- re-arrange H $\in [0, 360°]$

$$\text{RG sector}\ ,\ 0° \leq H < 120° \rightarrow \begin{cases} B = I(1-S) \\ R = I[1 + \frac{S\cos H}{\cos(60° - H)}] \\ G = 3I - (R+B) \end{cases}$$

$$\text{GB sector}\ ,\ 120° \leq H < 240° \rightarrow \begin{cases} H = H - 120° \\ R = I(1-S) \\ G = I[1 + \frac{S\cos H}{\cos(60° - H)}] \\ B = 3I - (R+G) \end{cases}$$

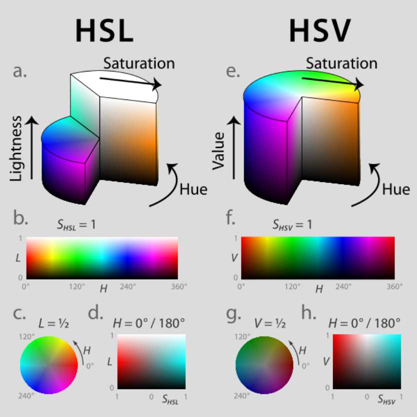
$$\text{BR sector}\ ,\ 240° \leq H < 360° \rightarrow \begin{cases} H = H - 240° \\ G = I(1-S) \\ B = I[1 + \frac{S\cos H}{\cos(60° - H)}] \\ R = 3I - (G+B) \end{cases}$$

Color models
Example of RGB, HSI and CMYK



Color models
HSL and HSV

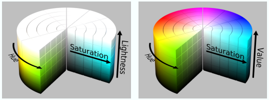
- *HSL* stands for hue, saturation and lightness
- *HSV* stands for hue, saturation and value



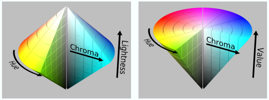
Color models
HSL and HSV

In both colorspace:

- Hue is the angle around the central vertical axis
- Saturation is the distance from the axis
- Lightness or value are the distance along the axis
- Hue is the same, while **saturation** differs dramatically

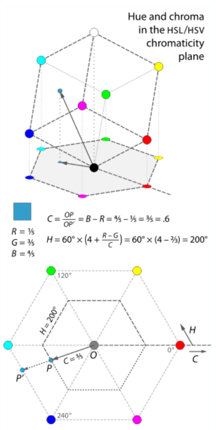


- Plotting the hue and lightness and value against chroma rather than saturation



Color models
HSL and HSV

- Chroma: The "colorfulness relative to the brightness of a similarly illuminated white"
- $C = \frac{OP}{OP'}$



Color models
HSI vs. HSL vs. HSV

$$I = \frac{R+G+B}{3}$$

$$V = \max(R, G, B)$$

$$L = \frac{\min(R, G, B) + \max(R, G, B)}{2}$$

$$S_{HSI} = \begin{cases} 0 & \text{if } C = 0 \\ 1 - \frac{m}{I} & \text{otherwise} \end{cases}$$

$$S_{HSV} = \begin{cases} 0 & \text{if } C = 0 \\ \frac{C}{V} & \text{otherwise} \end{cases}$$

$$S_{HSL} = \begin{cases} 0 & \text{if } C = 0 \\ \frac{C}{1-|2L-1|} & \text{otherwise} \end{cases}$$

Pseudocolor image processing

- Pseudocolor (false color) is assigning color to gray values based on a specified criteria
- $\rightarrow$ Converting gray images to color
- **Why ?** improve the visualization and since human can discern thousands of color shades but only two dozen gray shades

Techniques

- Intensity slicing
- Intensity to color transformation

Pseudocolor image processing

Intensity slicing

- Assume $[0, L-1]$ represent the gray scale of gray image I
- Let l_0 represent black level $[f(x,y) = 0]$ and l_{L-1} represent white level $[f(x,y) = L-1]$
- Suppose that P planes perpendicular to the intensity axis are defined at levels $l_1, l_2, ..., l_p$
- Assuming that $0 < P < L-1$, the P planes partition the gray scale into $P+1$ intervals $V_1, V_2, ..., V_{P+1}$
- Intensity to color are made based on :

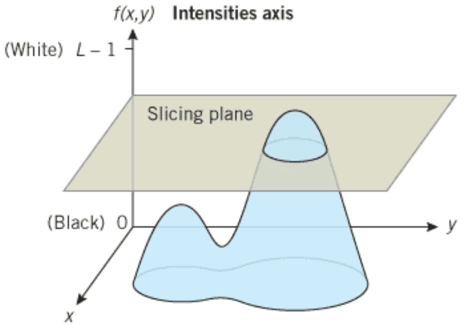
$$f(x,y) = c_k, \text{ if } f(x,y) \in V_k$$

- c_k is the color associated with the k^{th} intensity interval V_k

Pseudocolor image processing

Intensity slicing

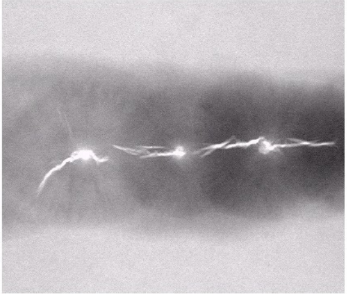
- Assuming 3D representation of image, considering the intensity as z axis

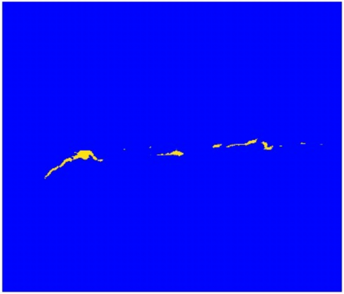


Pseudocolor image processing

Intensity slicing

- Monochrome Xray image and result of color coding

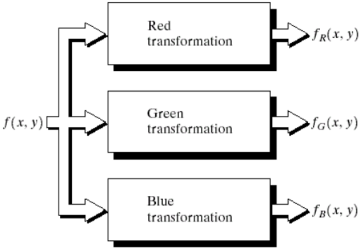




Pseudocolor image processing

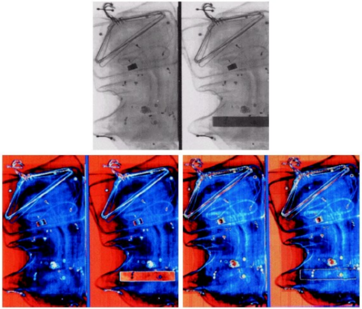
Intensity to color transformation

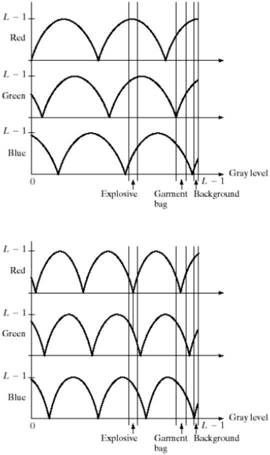
- Intensity slicing, limits range of pseudocolor enhancement result
- To have a wider range of pseudocolor enhancement $\rightarrow$ process gray image using independent transformation (R, G, B) and combine the results to create one color image



Pseudocolor image processing

Intensity to color transformation





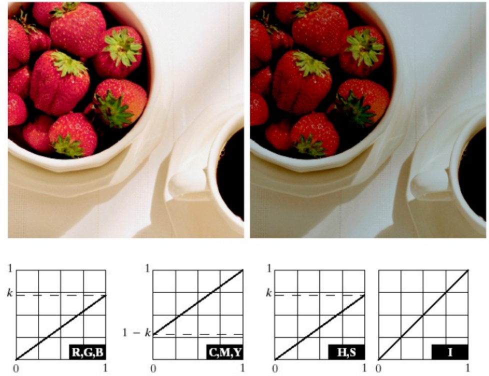
Color transformation

$$g(x, y) = T[f(x, y)]$$

- $f(x, y)$ is the color input, $g(x, y)$ is the transformed color output, and T is an operator on f over a spatial neighborhood of (x, y)
- In theory, any transformation can be applied in any color model, however in practice some operation are suited to some models than others
- E.g. Modifying the intensity of the image using $g(x, y) = kf(x, y)$, for $0 < k < 1$
  - *HSI* - $s_3 = kr_3$, and $s_2 = r_2$, $s_1 = r_1$
  - Only HSI intensity r_3 is modified
  - *RGB* - $s_i = kr_i$, $i = 1, 2, 3$
  - *CMY* - $s_i = kr_i + (1 - k)$, $i = 1, 2, 3$

Color transformation

Adjusting the intensity of color image and the required RGB, HSI and CMY transfer function



The H,S and I caption should be switch

Colro transformation
Histogram equalization

- Adapting the mono-channel histogram equalization to color-channels are not wise and cause erroneous colors
- More suitable approach : spreading the color intensities uniformly and leaving the color themselves (e.g, hue) unchanged