Introduction to Digital Image Processing

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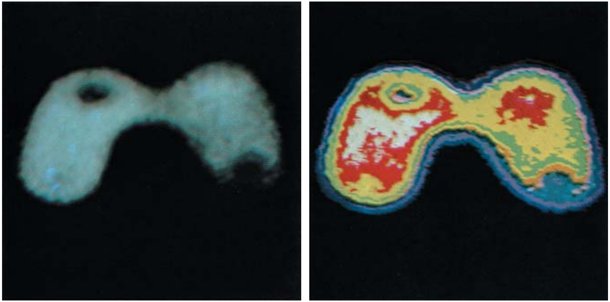
Color Image Processing

Introduction

- Full-color processing
  - Color is acquired with a full-color sensor.
- Pseudo-color processing
  - Assigning colors to monochrome images.

Color Importance

- Color is an excellent Descriptor.
    - Suitable for object identification and extraction
- Discrimination:
    - Humans can distinguish thousands of color shades and intensities but few shades of gray levels.

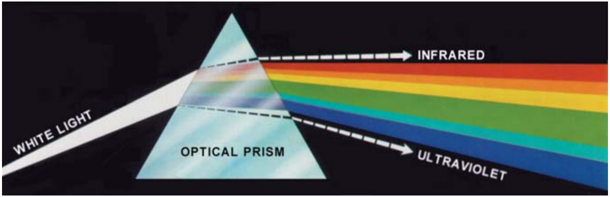


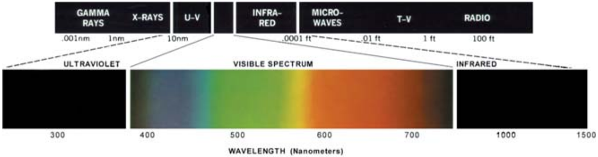
What is Color?

- An attribute of objects.
- Color depends on:
  - Spectral characterizations of light source (sun) which illuminates object, PSD (power spectral density)
  - Spectral characteristics of objects (Reflectance)
  - Spectral characteristics of sensors of imaging systems (ex. Eye)
- Color Fundamentals:
  - Physiopsychological phenomenon: How human brain perceive and interpret color is not fully understood
- Physical Phenomenon: Physical Nature of color is clear.

Color Spectrum

- Color spectrum seen by passing white light through a prism.





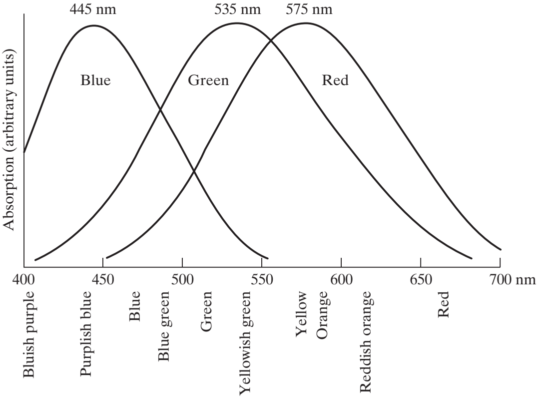
- Six broad region: violet, blue, green, yellow, orange, and red.

Chromatic Light

- Span the electromagnetic spectrum from 400 to 700 nm.
- Three basic quantities to describe the quality of a chromatic light source;
  - Radiance
  - Luminance
  - Brightness
- *Radiance:* Total amount of energy that flows from light source (W).
- *Luminance:* The amount of energy that an observer perceives from light source. (IR case: R may be high while L is zero).
- *Brightness:* Subjective description, practically impossible to measure.

Relative absorption by Human Eye

- Approximately 65% of all cones are sensitive to red light, 33% are sensitive to green light, and only about 2% are sensitive to blue (blue cones are the most sensitive)



Primary Colors

- Colors are seen as variable combination of primary colors:
    - Red
    - Green
    - Blue
- Secondary Colors:
    - Addition of primary colors

$$\begin{aligned} Magenta &= Red + Blue \\ Cyan &= Green + Blue \\ Yellow &= Red + Green \end{aligned}$$

- Mixing three primary and secondary with its opposite primary produce white color.

Primary Colors

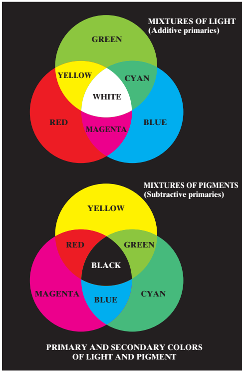
- Primary colors of light and primary colors of pigments (colorant):
  - Primary color of pigments: Subtract or absorbs a primary color of light and reflect the other two!
  - Primary colors of light are: R-G-B
  - Primary color of pigments are: C-M-Y.
  - Secondary color of light are: C-M-Y.
  - Secondary color of pigments are: R-G-B

Color of light:	R	G	B
	↓	↓	↓
Color of pigments:	absorb R Cyan	absorb G Magenta	absorb B Yellow

- Problem is application dependent:
  - R-G-B: Primary for Color TV.
  - C-M-Y: Primary for Color Printer.

Mixing of Lights

- A pigment is a material that changes the color of reflected or transmitted light as the result of wavelength-selective absorption.



a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Characteristics of Color

- To distinguish a color from another
- Characteristics of colors are *Hue*, *Saturation*, and *Brightness*
    - **Hue**: Dominant color (wavelength) perceived by an observer. (Red, Orange, Yellow, etc.)
    - **Saturation**: Relative purity of color or the amount of white light mixed with a hue. Pure colors are fully saturated. For example, pink is less saturated.
    - **Brightness**: chromatic notion of intensity.
- Hue and saturation taken together are called *chromaticity*.
- Therefore, a color may be characterized by its brightness and chromaticity.

Characteristics of Color

- The amounts of red, green, and blue needed to form any particular color are called the *Tristimulus* values, and are denoted as X, Y, and Z, respectively.
- The color is then specified by its trichromatic coefficients, defined as

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

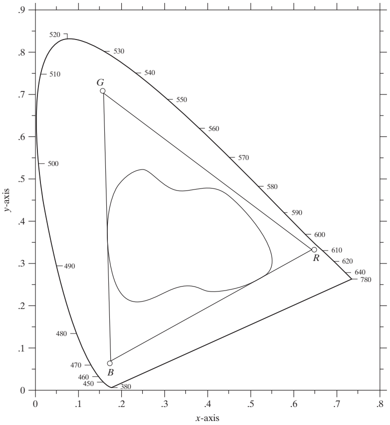
- It is noted that

$$x + y + z = 1$$

Chromaticity Diagram

- Another approach for specifying colors which shows color composition as a function of x (red) and y (green) is **Chromaticity Diagram**. From x and y, the corresponding value of z (blue) is obtained.
- Not all color in chromaticity diagram are enclosed by a triangle!
- With three single primary color we can NOT have all possible color!

Chromaticity Diagram



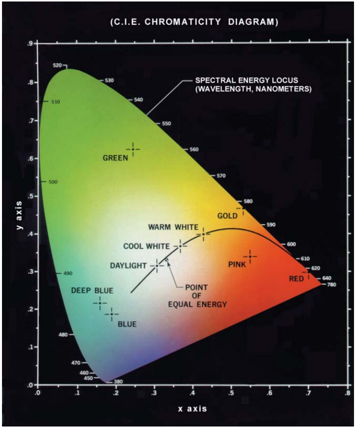


Figure: (a) Chromaticity diagram, (b) Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Models

- Color Model (also called Color Space, Color System)
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point.
- Most used models:
  - RGB model (Monitor/TV)
  - CMY model (3-color Printers)
  - CMYK model (4-color Printers)
  - HSI model (Color Image Processing and Description)

RGB Color Model

- Three Primary colors

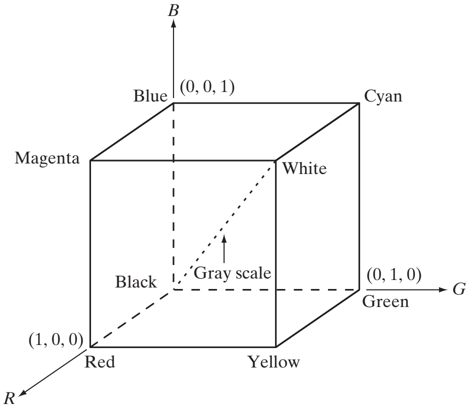


Figure: RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

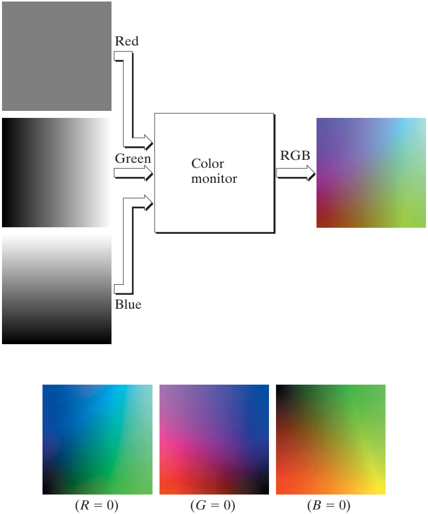
RGB Color Model

- Pixel Depth: The number of bits used to represent each pixel in RGB space.
- Full-color Image: 24-bit RGB color image.
    - (R,G,B)=(8 bits, 8 bits, 8 bits)
    - Number of colors: $(2^8)^3 = 16,777,216$

RGB Color Model

a
b

FIGURE 6.9 (a) Generating the RGB image of the cross-sectional color plane (127, G, B). (b) The three hidden surface planes in the color cube of Fig. 6.8.



RGB Color Model

- Safe RGB Colors:
  - Subset of colors is enough for some application
  - Safe RGB colors (safe web colors, safe browser colors)
  - Only 6 levels of each primary colors are used.
  - Each level value can only be $0, 51, 102, 153, 204$, or 255
  - Thus, RGB triplets of these value give us $6^3 = 216$.

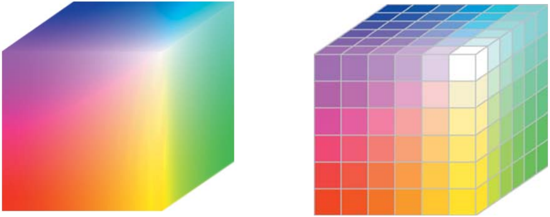


Figure: (a) RGB 24-bit color cube, (b) RGB safe color cube

The CMY and CMYK Color Models

- CMY: Secondary colors of light, or primary colors of pigments are used.
- Used to generate hardcopy output (Printer and Copier).
- Some facts:
  - Printer papers are white (reflect all colors)
  - Printers use ink (Transparent)
  - Cyan-Magenta-Yellow Pigments (ink) absorb Red-Green-Blue
- White Paper reflect 100% of incoming light.
- K (Black) is practical problem of $C + M + Y \neq Black$ (Muddy Brown). Add a fraction of Black color

The CMY and CMYK Color Models

- CMY to RGB

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

- RGB to CMYK

$$\left.\begin{array}{c} \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix} \\ K = \min(C, M, Y) \end{array}\right\} \Rightarrow \begin{cases} C = 255 \times \frac{C-K}{255-K} \\ M = 255 \times \frac{M-K}{255-K} \\ Y = 255 \times \frac{Y-K}{255-K} \end{cases}$$

HSI Color Model

- Human description of color is not RGB or CMYK
- Human description of color is Hue, Saturation and Brightness:
  - **Hue**: color attribute
  - **Saturation**: purity of color
  - **Brightness**: achromatic notion of intensity

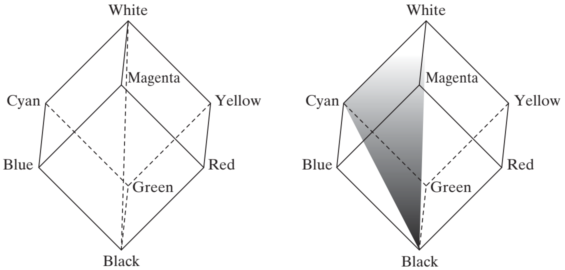


Figure: Conceptual relationship between the RGB and HSI color models

HSI Color Model

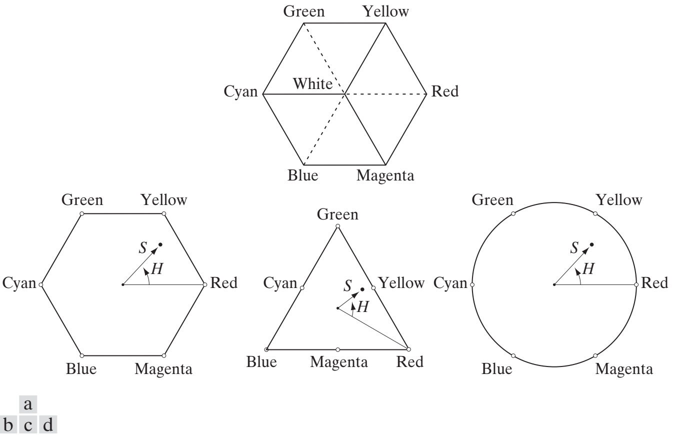


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

HSI Color Model

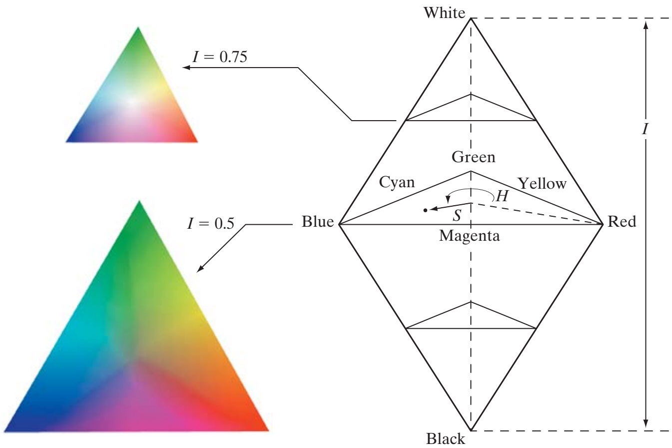


Figure: The HSI color model based on triangle color planes

HSI Color Model

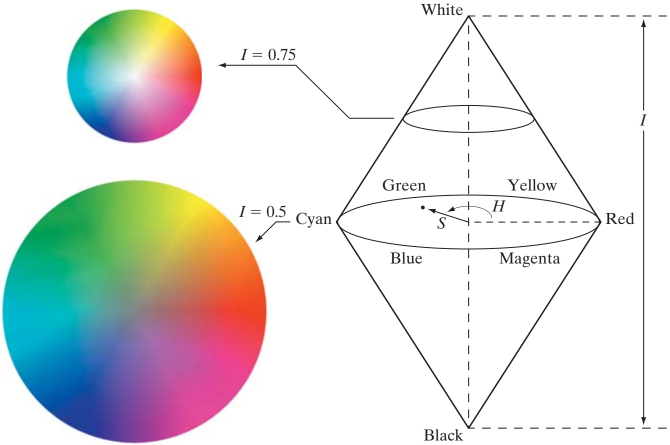


Figure: The HSI color model based on circular color planes

Converting color from RGB to HSI

- Given an image in RGB

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

with

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

- The saturation components is given by

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

- Intensity component is given by

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

Converting color from HSI to RGB

- Given values of HSI in the interval $[0, 1]$.
- The different equation for different values of H.
- There are three sectors of interest, corresponding to the 120^o intervals in the separation of primaries.
- **RG Sector** $(0^o \leq H < 120^o)$

$$B = I(1 - S)$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

and

$$G = 3I - (R + B)$$

Converting color from HSI to RGB

- **GB Sector** $(120^o \leq H < 240^o)$: First subtract 120^o from H as

$$H = H - 120$$

Then the RGB components are

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S \cos H}{\cos(60^\circ - H)}\right]$$

and

$$B = 3I - (R + G)$$

Converting color from HSI to RGB

- **BR Sector** $(240^o \leq H < 3^o)$: First subtract 240^o from H as

$$H = H - 240$$

Then the RGB components are

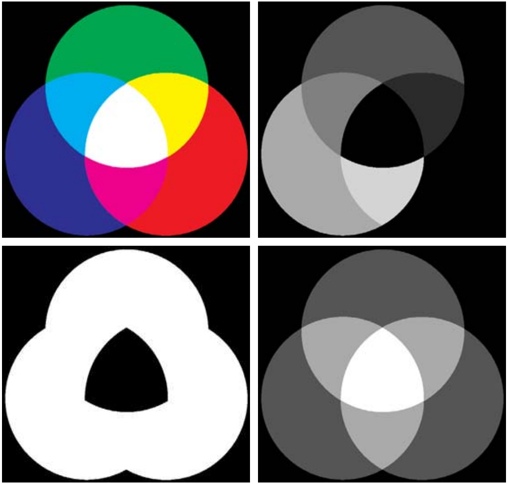
$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

and

$$R = 3I - (G + B)$$

Channel Split



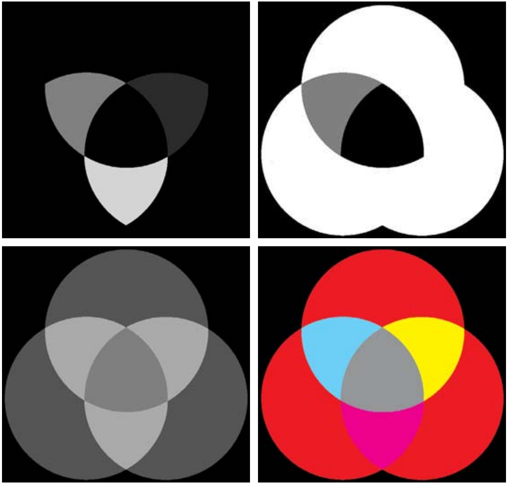
a b
c d

FIGURE 6.16
(a) RGB image and the components of its corresponding HSI image:
(b) hue,
(c) saturation, and
(d) intensity.

Modifying Channel

a b
c d

FIGURE 6.17
(a)–(c) Modified HSI component images.
(d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)



Split Channel (RGB Model)

RGB **R** **G** **B**

Split Channel (CMYK Model)

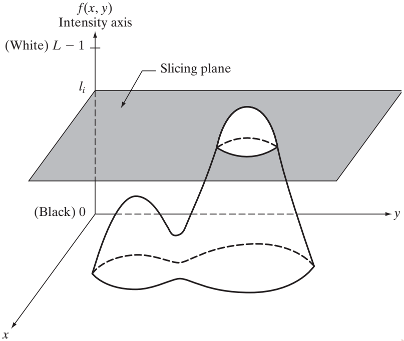
CMYK C M Y K

Pseudocolor Image Processing

- Also called false coloring
- Assign colors to gray values based on a specified criterion
- For human visualization and interpretation of gray-scale events
- Methods:
    - Intensity slicing
    - Gray level to color transformations

Intensity Slicing

- $f(x, y) = c_k$ if $f(x, y) \in V_k$
  where $V_1, V_2, \ldots, V_{P+1}$ and Plane P partition the gray scale into $P + 1$ intervals.
- where c_k is the color associated with the k^{th} intensity interval defined by the partitioning planes at $l = k - 1$ and $l = k$.



Intensity Slicing : Two Levels

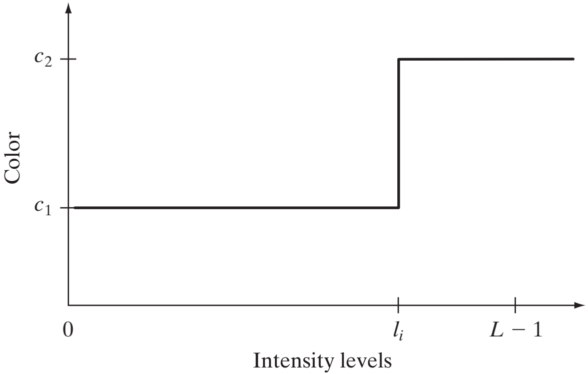


Figure: An alternative representation of the intensity-slicing technique

Intensity Slicing : Example

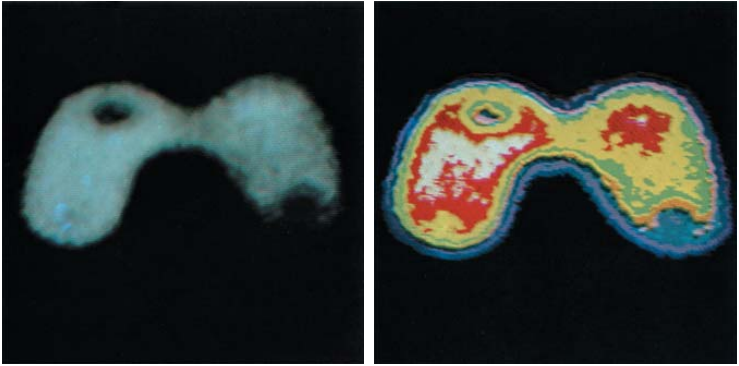


Figure: (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors.

Intensity Slicing : Example

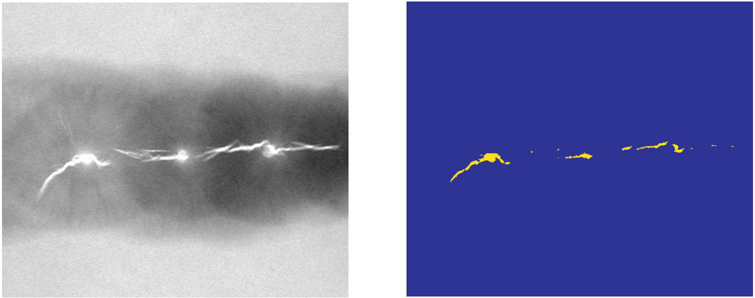


Figure: (a) Monochrome X-ray image of a weld. (b) Result of color coding.

Intensity Slicing: Example

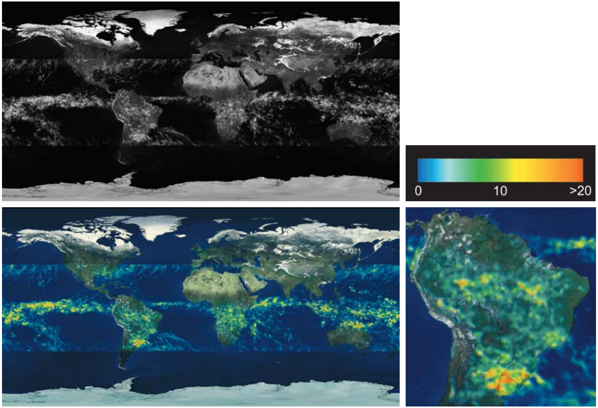


Figure: (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region

Intensity to Color Transformations

- More general and thus capable of achieving a wider range of pseudocolor compare to simple to slicing technique.

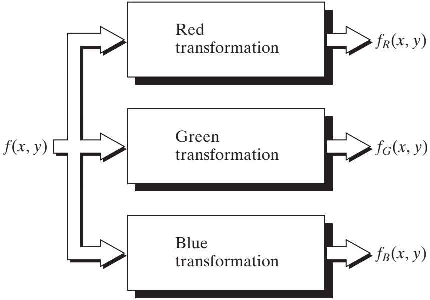


Figure: Functional block diagram for pseudocolor image processing. f_R, f_G and G_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Intensity to Color Transformations: Example

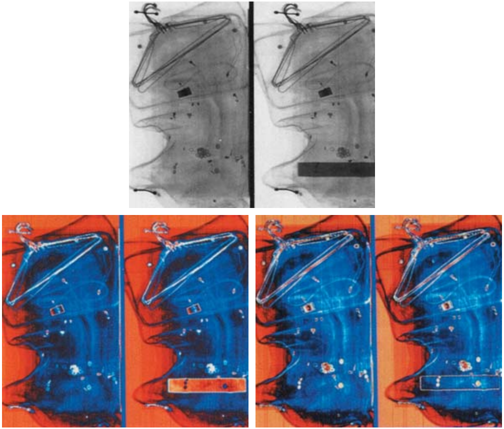
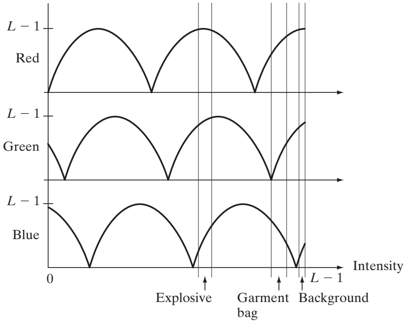


Figure: Pseudocolor enhancement by using the gray level to color transformations

Intensity to Color Transformations: Transformation functions



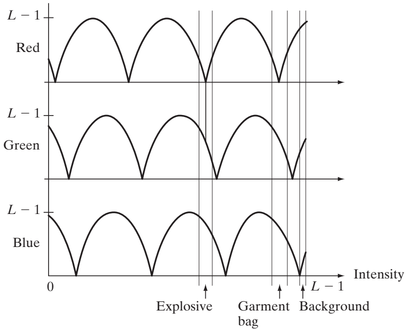


Figure: Transformation functions used to obtain the images on previous slide

Color Complements

- Analogy of Gray-Level Negative
- Color Complement: Hue directly opposite one another on color circle.

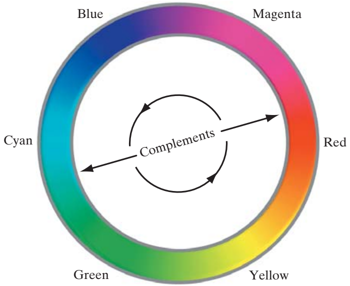
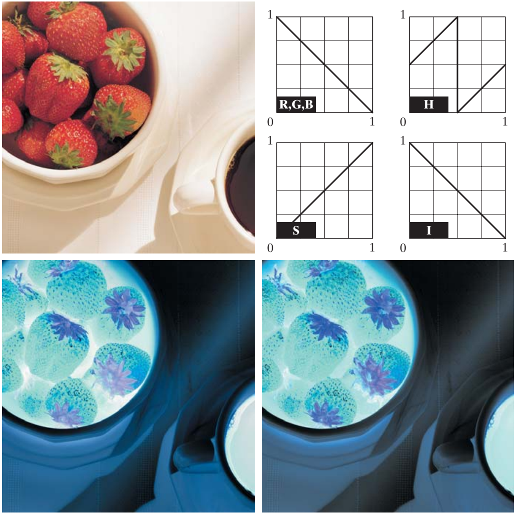


Figure: Complements on the color circle

Color Complements



a b
c d

FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

Color Slicing

- One of the simplest way to "slice" a color image is to map the colors outside some range of interest to a nonprominent neutral color.
- If the colors of interest are enclosed by a cube of width W and centered at (a_1, a_2, a_3), the set of transformation is

$$s_i = \begin{cases} 0.5 & \text{if } \left[|r_j - a_j| > \dfrac{W}{2} \right]_{\text{any } 1 \leq j \leq n} \\ r_i & \text{otherwise} \end{cases} \qquad i = 1, 2, \ldots, n$$

- If a sphere is used to specify the colors of interest

$$s_i = \begin{cases} 0.5 & \text{if } \sum_{j=1}^{n} (r_j - a_j)^2 > R_0^2 \\ r_i & \text{otherwise} \end{cases} \qquad i = 1, 2, \ldots, n$$

Color Slicing: Example

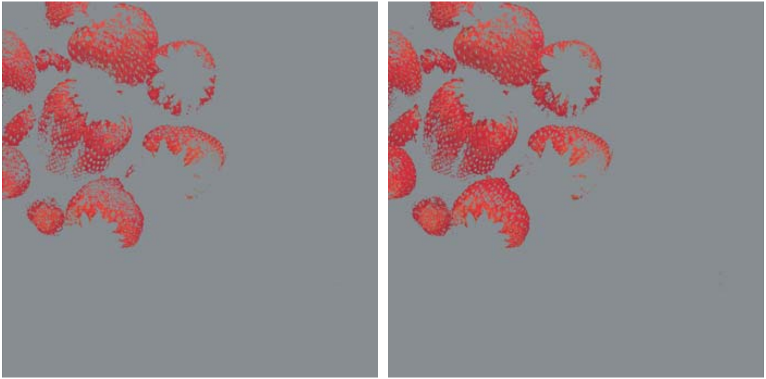


Figure: Color-slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at $(0.6863, 0.1608, 0.1922)$, and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color $(0.5, 0.5, 0.5)$.

Tone Corrections: Example 01

Figure: Tonal corrections for flat color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Tone Corrections: Example 02

Figure: Tonal corrections for light (high key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Tone Corrections: Example 03

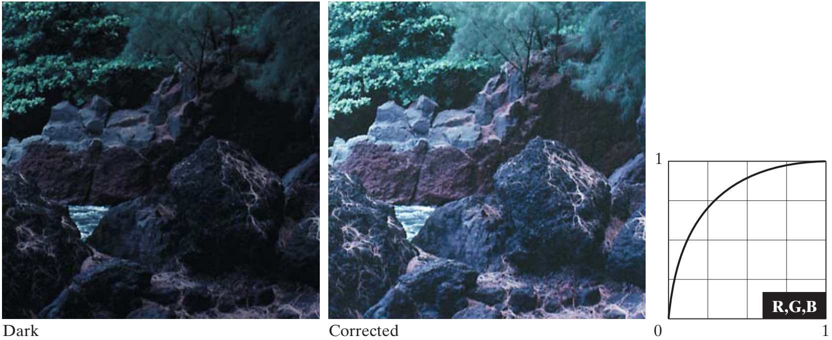


Figure: Tonal corrections for dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Color Balancing Correction for CMYK color images

Histogram Processing

- Histogram Equalization may NOT apply independently!
- Logical approach:
  - Uniform Intensity
  - Hue unchanged
  - Saturation may be changed or not!

Histogram Processing

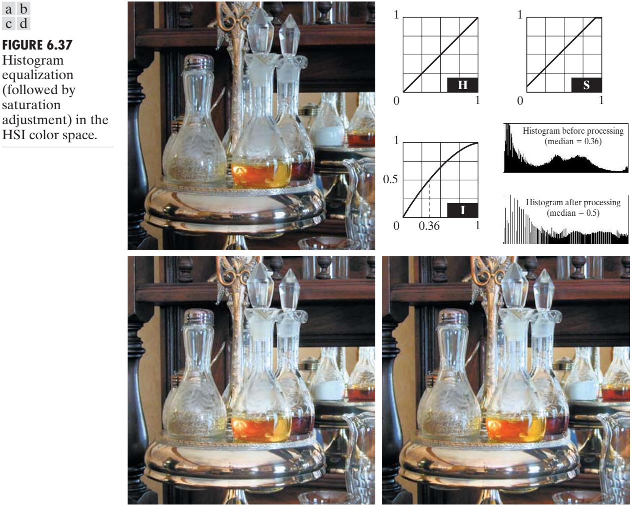


FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Color Image Smoothing

- Like as Gray Level Images.
- Let S_{xy} denote the set of coordinates defining a neighborhood centered at (x, y) in an RGB color image.

$$\bar{\mathbf{c}}(x, y) = \begin{bmatrix} \frac{1}{K} \sum_{(s,t) \in S_{xy}} R(s, t) \\ \frac{1}{K} \sum_{(s,t) \in S_{xy}} G(s, t) \\ \frac{1}{K} \sum_{(s,t) \in S_{xy}} B(s, t) \end{bmatrix}$$

RGB Components

a b
c d

FIGURE 6.38 (a) RGB image. (b) Red component image. (c) Green component. (d) Blue component.

HSI Components

a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

Color Image Smoothing: Example

Figure: Image smoothing with a 5×5 averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.

Color Image Sharpening

- Like as Gray Level Images.

$$\nabla^2[\mathbf{c}(x, y)] = \begin{bmatrix} \nabla^2 R(x, y) \\ \nabla^2 G(x, y) \\ \nabla^2 B(x, y) \end{bmatrix}$$

a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the HSI intensity component and converting to RGB. (c) Difference between the two results.

Solve Problems

Question 01

For the given $[R\ G\ B]$ model

$$[R\ G\ B] = [76\ \ 127\ \ 52]$$

or

$$[R\ G\ B] = [0.3\ \ 0.5\ \ 0.2]$$

compute the corresponding model value

(a) $[C\ \ M\ \ Y]$ model

(b) $[H\ \ S\ \ I]$ model.

Solve Problems

Question 02

For the given $[H \ S \ I]$ model

$$[H \ \ S \ \ I] = [101 \ \ \ 0.4 \ \ \ 0.33]$$

compute the corresponding model value

(a) $[R \ G \ B]$ model value

(b) $[C \ \ M \ \ Y]$ model value.

Solve Problems

Question 03

For the given $[H\ \ S\ \ I]$ model

$$[H\ \ S\ \ I] = [230\ \ \ 0.77\ \ \ 0.35]$$

compute the corresponding model value

(a) $[R\ G\ B]$ model value

(b) $[C\ \ M\ \ Y]$ model value.

Thank You

Queries?