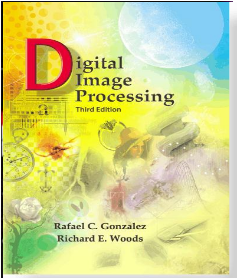


Color Image Processing

- Newton Experiments (Spectral Analyzer)

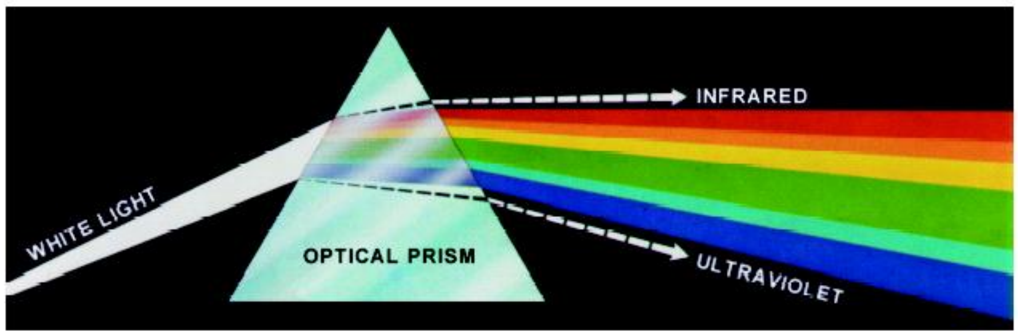
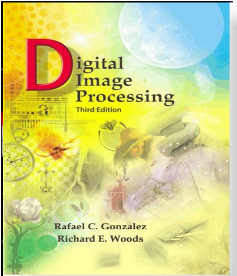


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

  - Emerging light is not longer white but a continuous spectrum of color from violet to red
  - Six broad region: violet, blue, green, yellow, orange, and red



Color Image Processing

- Chromatic Light:
  - Span the electromagnetic spectrum from 400 to 700 nm

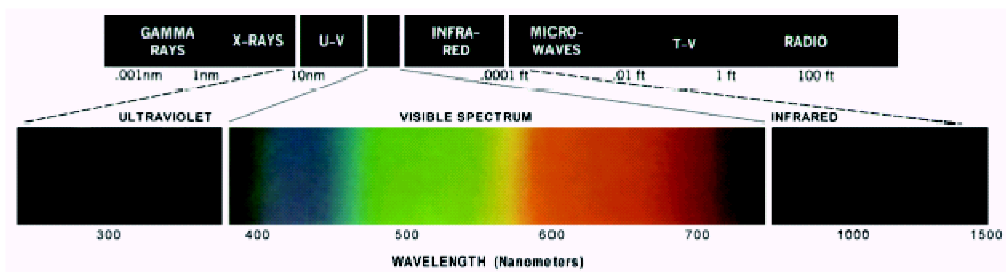
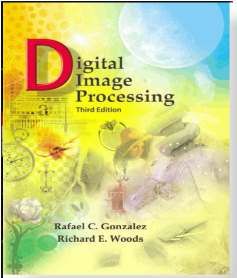


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Image Processing

- Eye as light sensor:
  - (6-7) millions cons cell categorized in 3 group sensors:
    - **Red** (67%)
    - **Green** (33%)
    - **Blue** (2%)
      - Blue is most sensitive
  - Standard Definition of R-G-B (CIE):
    - **Red: 700nm**
    - **Green: 546.1 nm**
    - **Blue: 435.8nm**
  - No single color may be called R,G, or B.



Color Image Processing

- Relative Absorption of R/G/B cones:

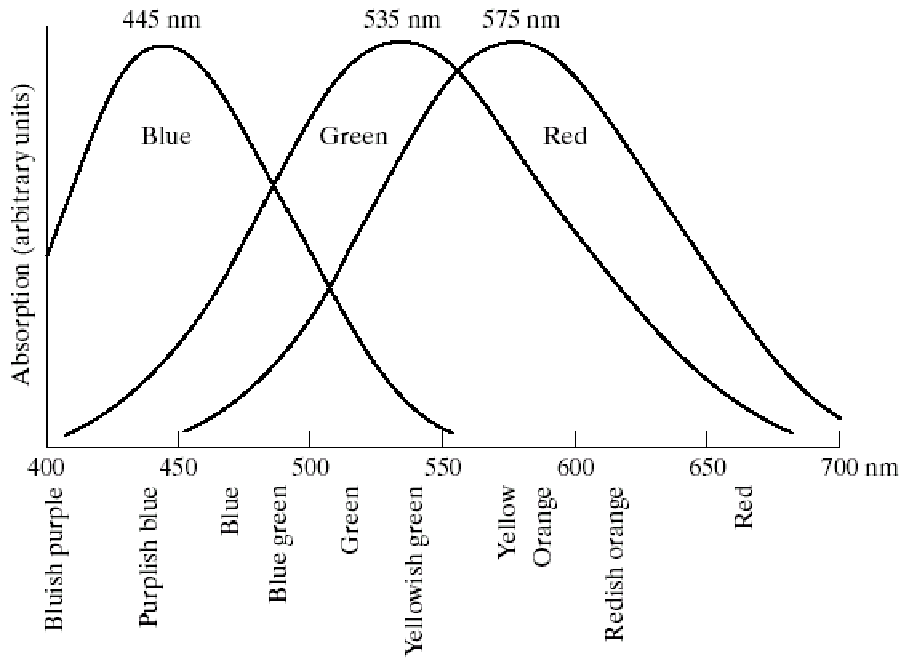
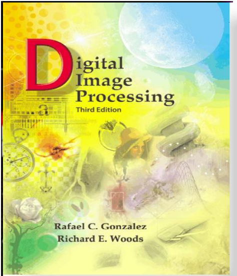


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color Image Processing

- Absorption characteristic of eye and Primary colors:
  - Curves are experimental
  - Colors are seen as variable combination of *primary colors* (R-G-B)
  - With three specific primary colors (fixed wavelength) it is **NOT** possible to generate all spectrum colors.



Color Image Processing

- Secondary Colors:
  - Addition of primary colors:
    - Magenta = Red + Blue
    - Cyan = Green + Blue
    - Yellow = Red + Green
  - Mixing three primary and secondary with its opposite primary produce white color.

Color Image Processing

- Primary Colors of light and primary colors of pigments (colorant): Pigment colors are those which physically exist like paint
  - 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 Image Processing

- Primary Colors of light and primary colors of pigments (colorant):

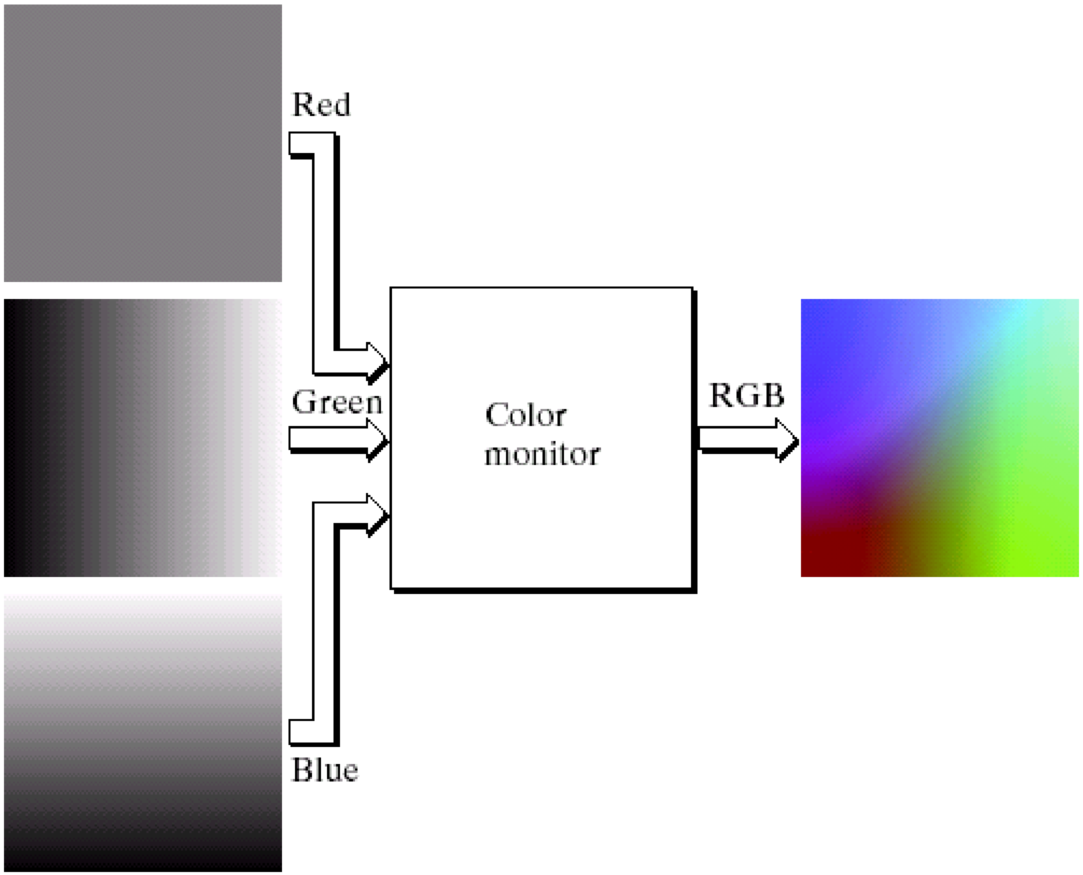
Color of light:	R	G	B
	↓	↓	↓
Color of pigments:	absorb R Cyan	absorb G Magenta	absorb B Yellow

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

Every color absorbs its opposite/complement color and reflects other.

Color Image Processing

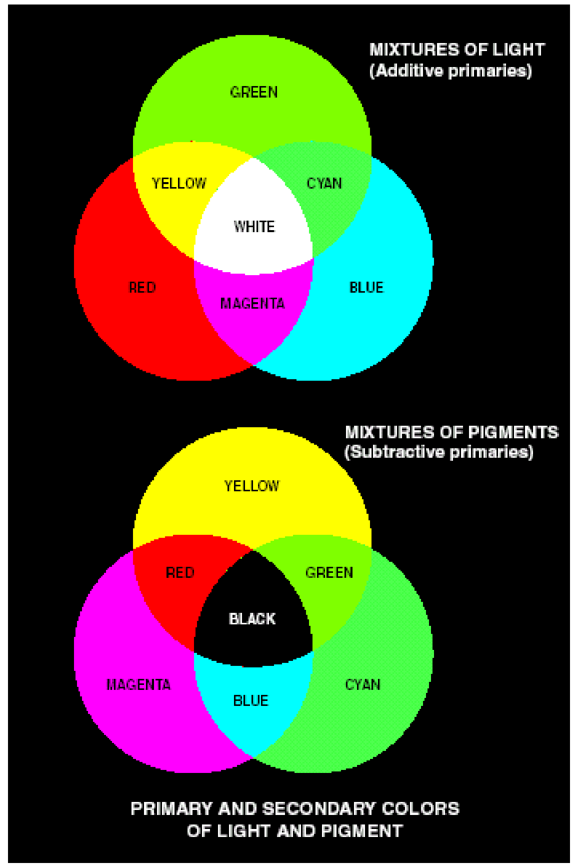
- Color TV:



Color Image Processing

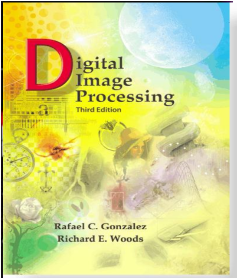
Light

Pigments



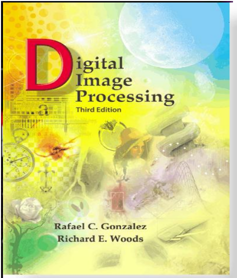
a
b

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



Color Image Processing

- Characteristics of color
  - To distinguish a color from another
  - Hue, Saturation, and Brightness
    - Hue: Dominant color (wavelength) perceived by an observer. (Red, Orange, Yellow, ant etc.)
    - Saturation: relative purity of color or the amount of white light mixed with a hue.
      - Pure colors (**$\delta(\lambda-\lambda_0)$**) are fully saturated.
      - Pink is less saturated.
    - Brightness: chromatic notion of intensity.



Color Image Processing

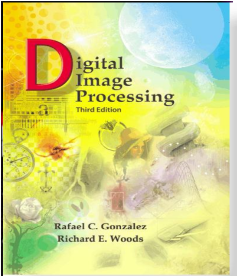
- Characteristics of color:
  - Chromaticity:
    - Hue+Saturation.
  - Tri-stimulus:
    - The amounts of R/G/B needed to form any particular color (X,Y, and Z)

Red color is the probability of red color divided by sum of probabilities of red, green and blue because RGB is composed of only these colors.
'Hue' is the color which is super-saturated.

$$r = \frac{R}{R+G+B} \qquad g = \frac{G}{R+G+B} \qquad b = \frac{B}{R+G+B}$$

$r+g+b=1$ r, g, b $\Leftrightarrow$ wavelength of light for that color

Sum of probabilities of total event is always equal to one.



Color Image Processing

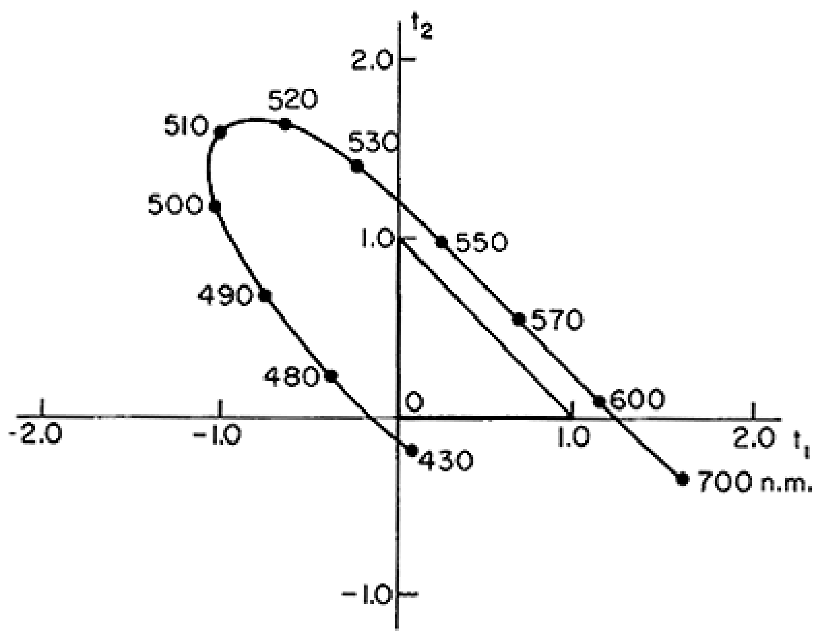
- Chromaticity Diagram:
  - Color composition as a function of red (x-axis) and green (y-axis).
  - Blue = 1-Red-Green (Negation of blue color)

-- Word chromatic means combination of different color and opposite is monochrome which can be zero or one.

Shade: Amount of darkness present in an image. More black color, more shaded image.
Tint: Amount of brightness present in an image. More white color involved, more tinted image

Color Image Processing

- Real and Imaginary Color
  - Negative Color



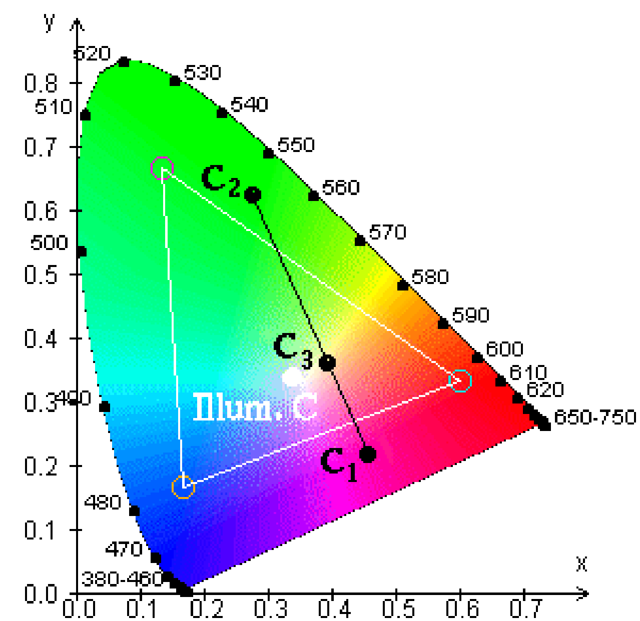
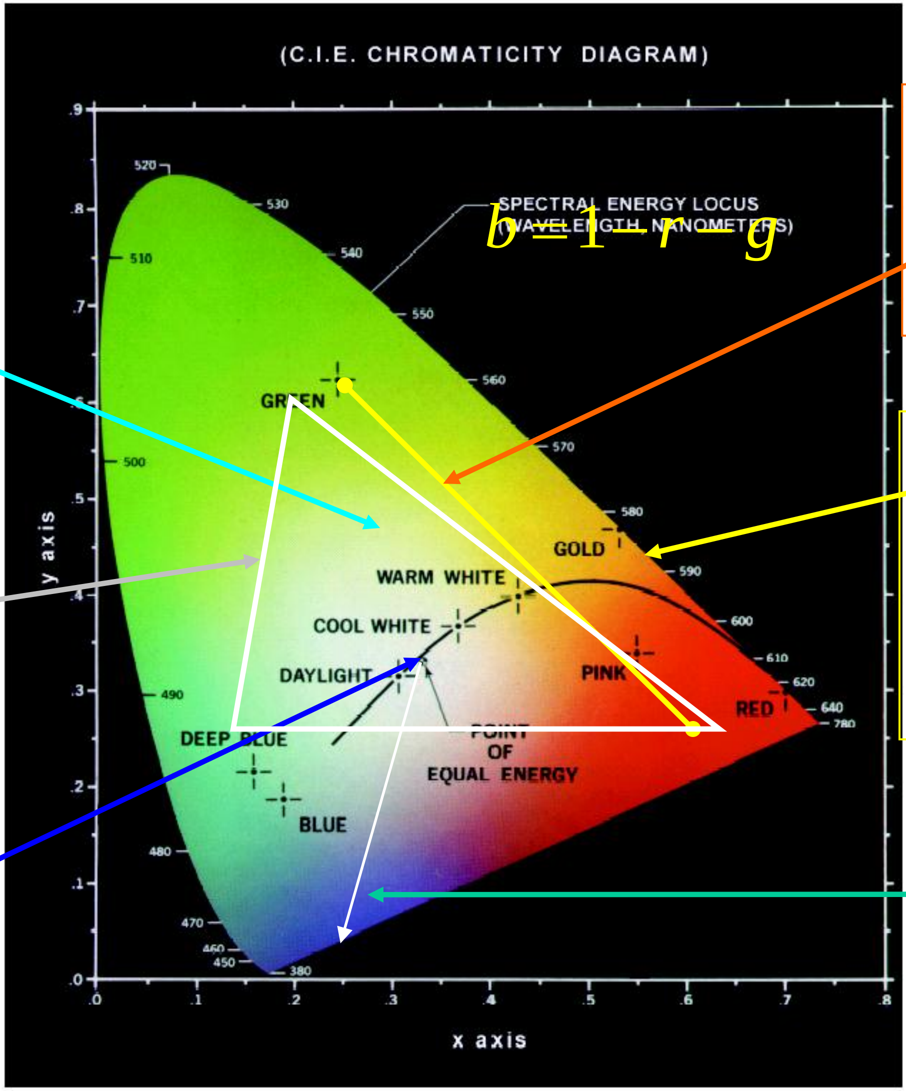


FIGURE 3.3-3. Chromaticity diagram for typical red, green, and blue primaries.

Color Image Processing

FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



2. Mixed Color

6. Color Mixing With various Value of 3 color

3. CIR White (1/3,1/3,1/3) -zero saturation

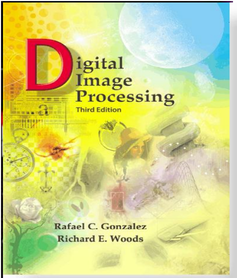
5. Color Mixing With various Value of 2 color

1. Boundary are full saturated (Pure Color)

4. All shade Of Pure color

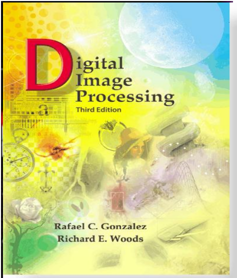
Color Image Processing

- Chromaticity Diagram:
  - Color composition as a function of red (x-axis) and green (y-axis).
  - Blue = 1-Red-Green



Color Image Processing

- Chromaticity Diagram:
  - Not all color in chromaticity diagram are enclosed by a triangle!
    - With three single primary color we can NOT have all possible color!



Color Image Processing

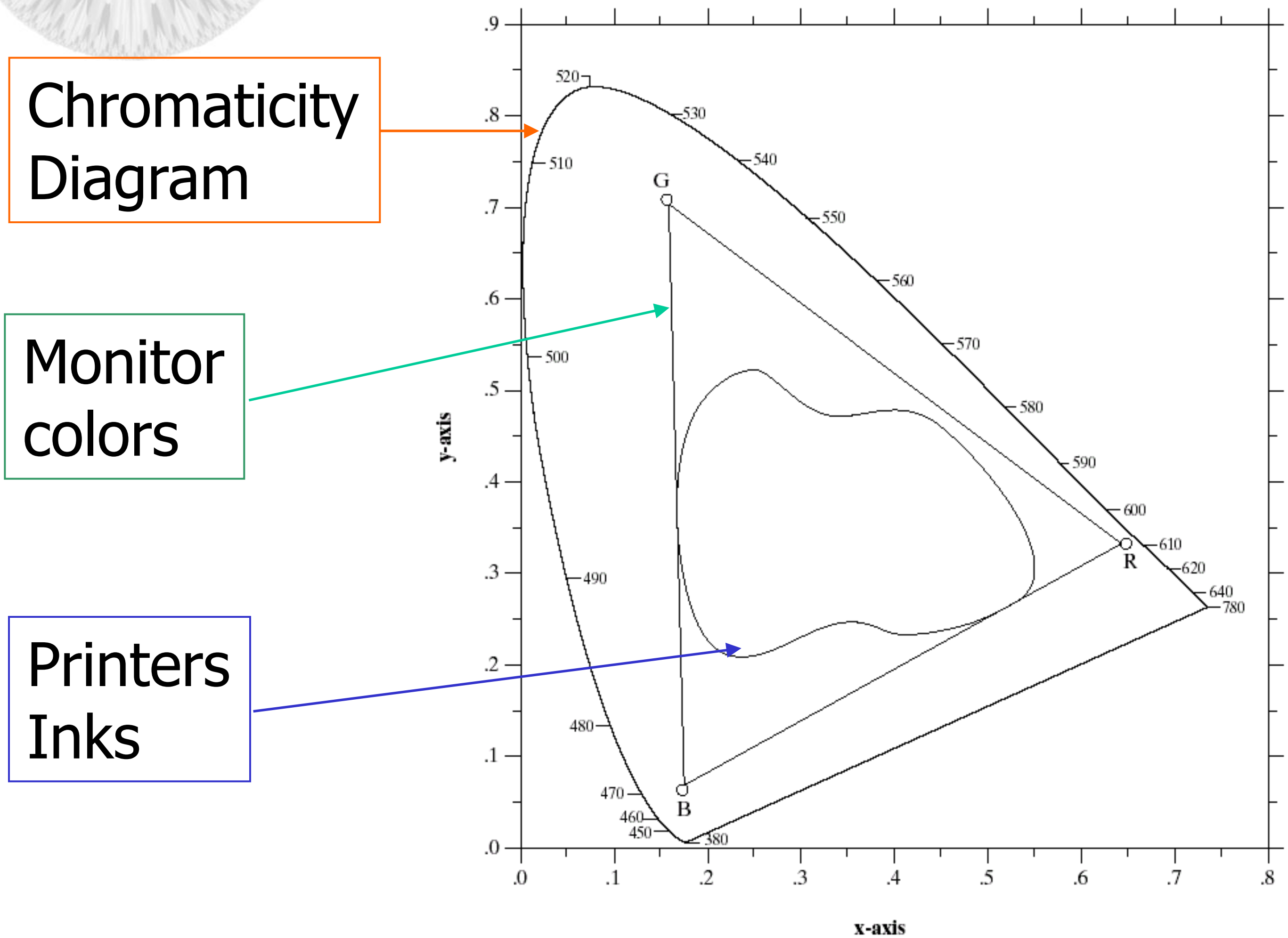


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

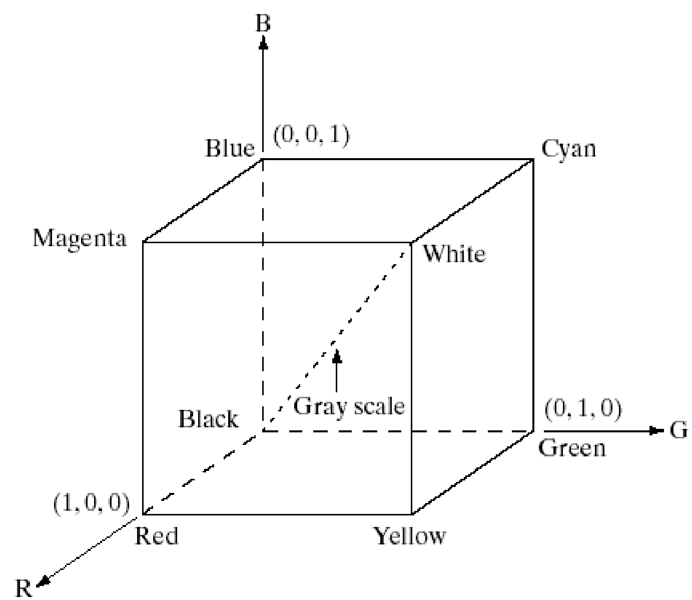
Color Image Processing

- Color Model (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)

Color Image Processing

- RGB Color Model:
  - Three Primary colors

FIGURE 6.7
Schematic of the 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: $\left(2^8\right)^3 = 16,777,216$

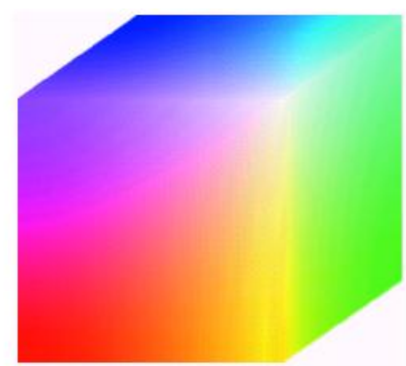
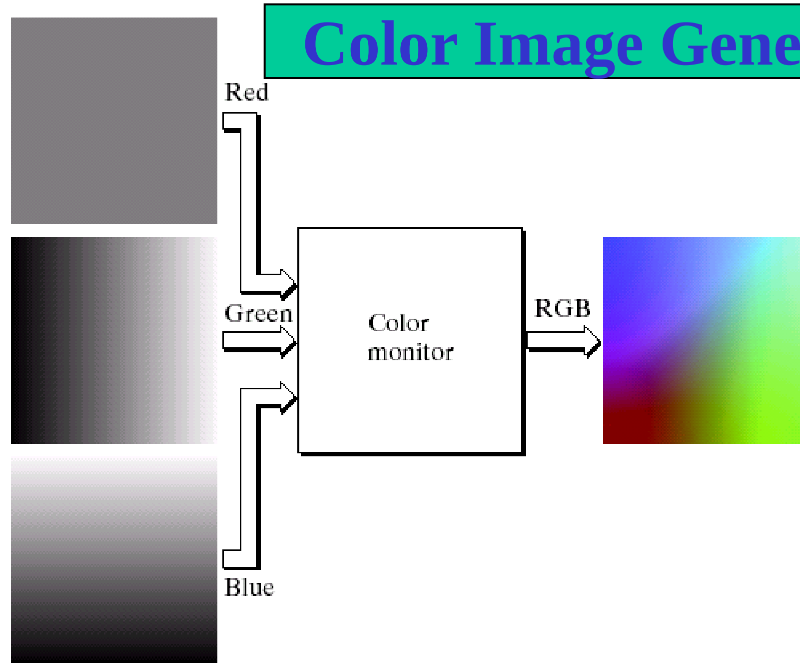


FIGURE 6.8 RGB 24-bit color cube.

Color Image Processing

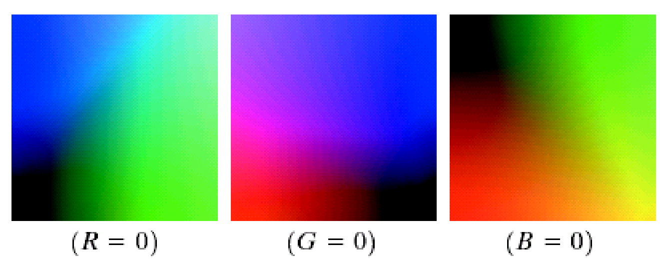
a
b

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.

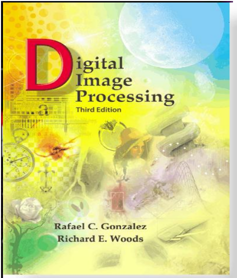


Color Image Generation

Color Image Acquisition



Filter-Sensor



Color Image Processing

- 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.
  - 6^3=216
  - **000000=Black**
  - **111111=White!**
  - **110000=Purest Red**

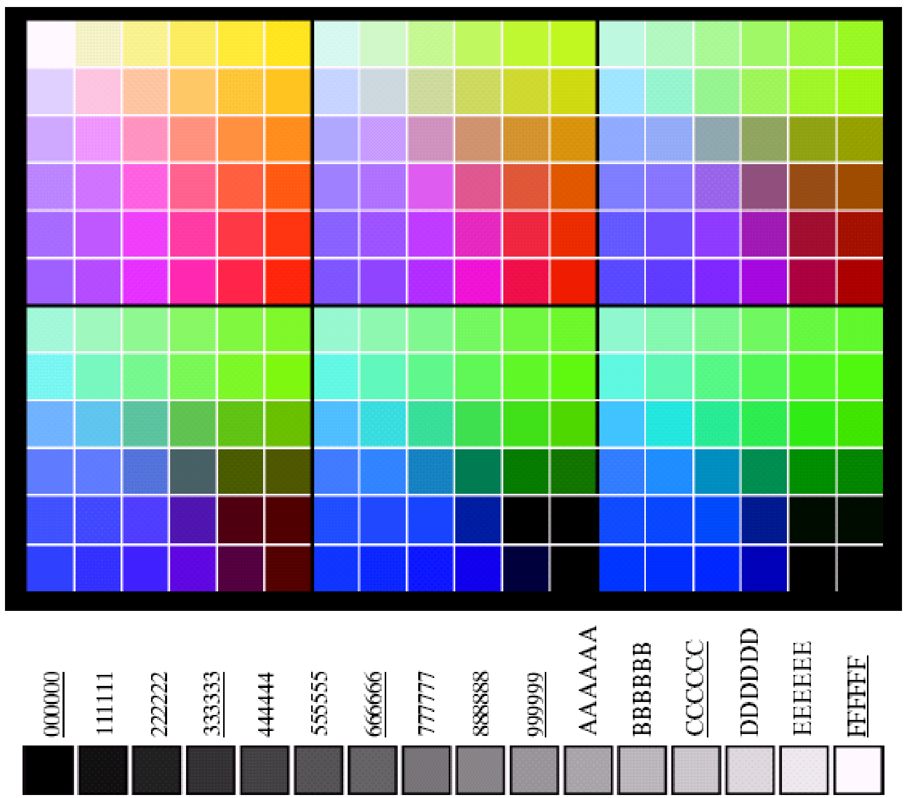
For example, Jhon has shared an dark image to Allan, when Allan opens that image it seems to be white. So, different systems treat different color in a different manner with a different algorithm. So, there only safe color are used so that this conflict from system to system cannot occur.

- Safe RGB Model

Each color has a 51 gap

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

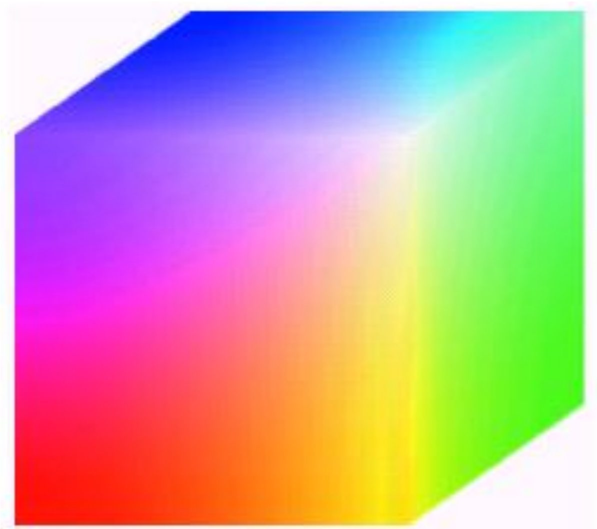
TABLE 6.1 Valid values of each RGB component in a safe color.



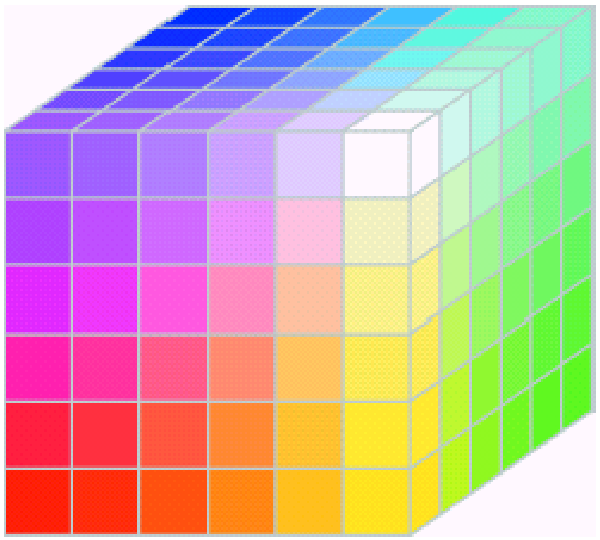
a
b

FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

- Safe RGB Colors



Full Color RGB

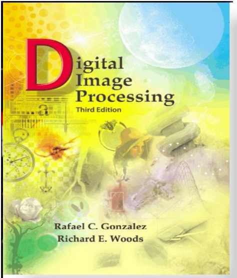


Safe RGB

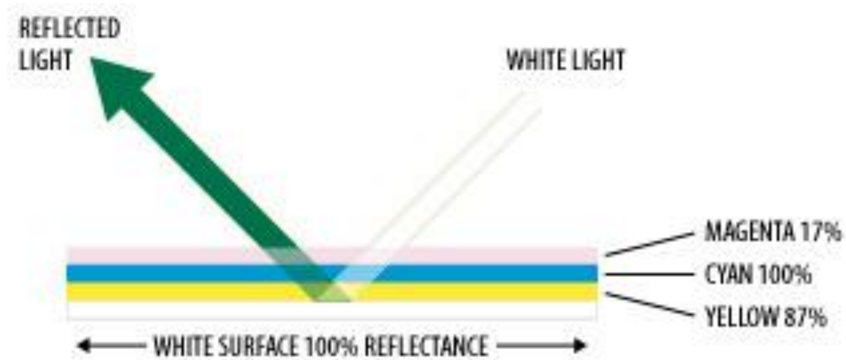
- CMY and CMYK models:
  - **CMY:** Secondary colors of light, or primary colors of pigments are used.
  - Used to generate hardcopy output (Printer and Copier).
  - Some facts:
    - Printer papers are white (reflect all colors)
    - Printers use ink (Transparent)
    - Cyan-Magenta-Yellow Pigments (ink) **absorb Red-Green-Blue**

Color Image Processing

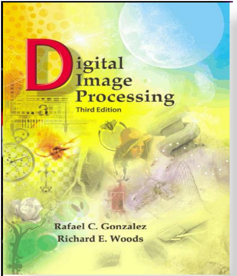
- CMY and CMYK models:
  - Printers: Overlapping layers of varying percentages of transparent cyan, magenta, and yellow inks.
  - Light is transmitted through the inks and reflects off the surface below them.
  - The percentages of CMY ink subtract inverse percentages of RGB from the reflected light so that we see a particular color



- CMY and CMYK models:



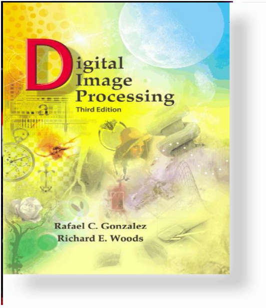
  - White Paper reflect 100% of incoming light.
  - K (Blac**k**) is practical problem of C+M+Y≠Black (Muddy Brown). Add a fraction of Black color



Color Image Processing

- CMY and CMYK models:

Color 1	Color 2	Color 3	Combined
White	White	White	White
Cyan	None	None	Cyan
Magenta	None	None	Magenta
Yellow	None	None	Yellow
Cyan	Magenta	None	Blue
Cyan	Yellow	None	Green
Magenta	Yellow	None	Red
Cyan	Magenta	Yellow	Black



Color Image Processing

- CMY to RGB:

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

Black absorbs all the colors and white reflects all the color and not absorbs any color. So, both are complement of each other.

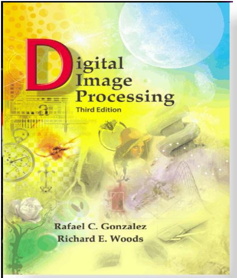
- RGB to CMYK:

$$\left. \begin{array}{l} 1. \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 255 \\ 255 \\ 255 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix} \\ 2. K = \min(C, M, Y) \end{array} \right\} \Rightarrow \begin{cases} C = 255 \dfrac{C-K}{255-K} \\ M = 255 \dfrac{M-K}{255-K} \\ Y = 255 \dfrac{Y-K}{255-K} \end{cases}$$

CMY generates a muddy black color but we need pure black for printing purpose, we have added a separate plane of 'K' for black color.

Color Image Processing

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

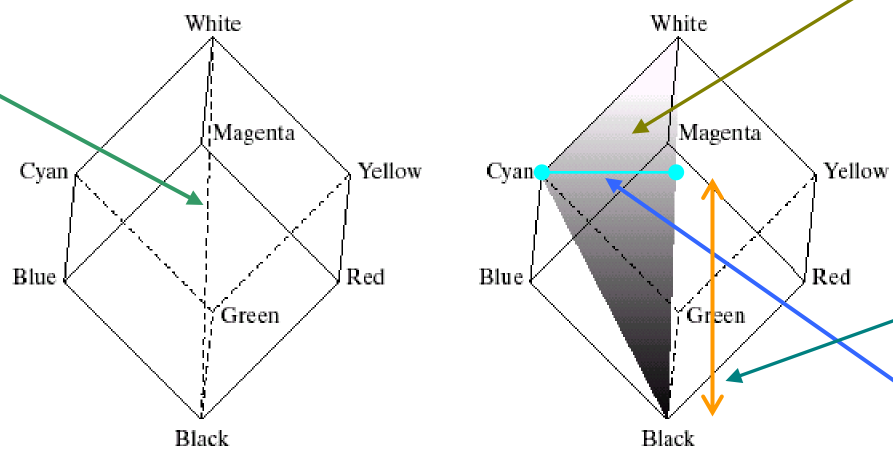


Color Image Processing

- RGB to HIS conversion

Iso-Hue Triangle

Intensity Line (Equal RGB value)



a b

FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

Intensity

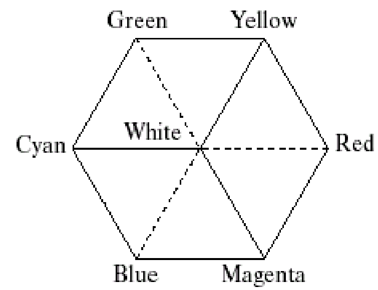
Saturation (Distance)

```
       White
      /    |
Blue /     |
     \     |
      \    |
       Black
```

If H = 240, S = 0, I = 0 ??
Ans: Black
if I = 0.5, then gray

120º and 60º Distance (Pri. & Sec.)

Every color is available at 60 deg in circle. Corner contains more saturation and when we move from boundary towards center, saturation decreases. Hue is changing after every 60 deg.



Different Geometrical Model is possible

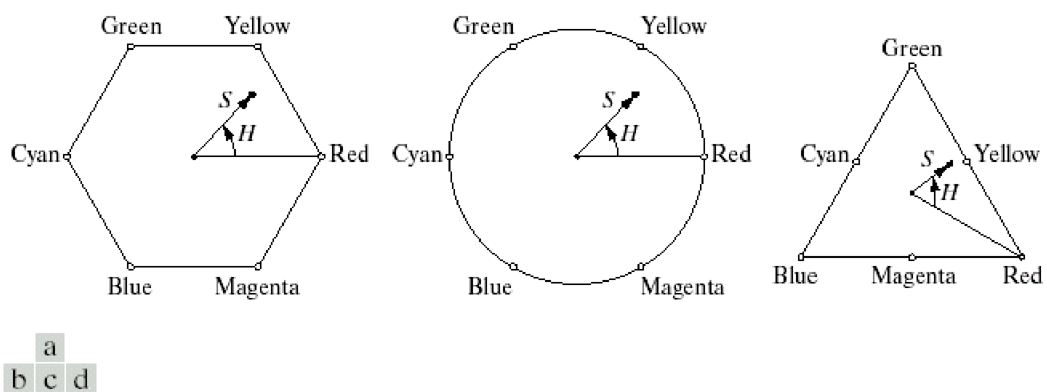
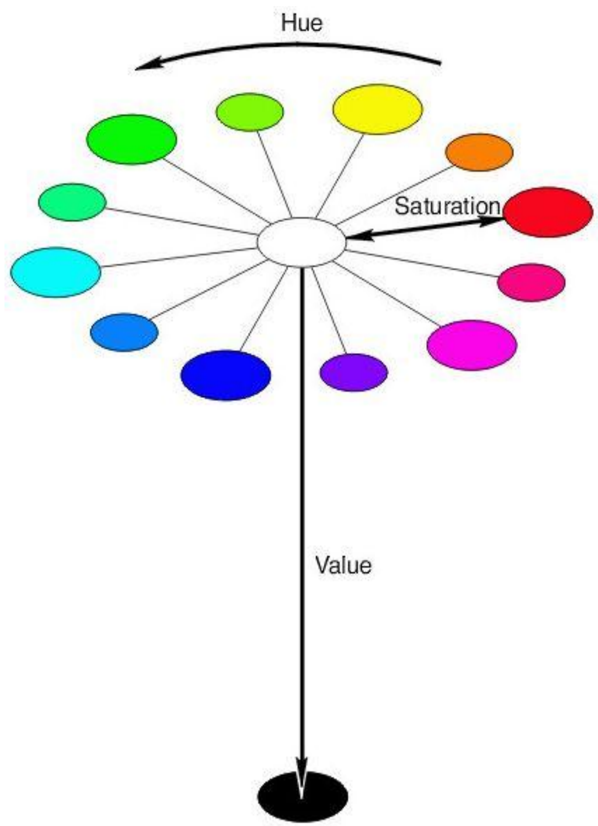
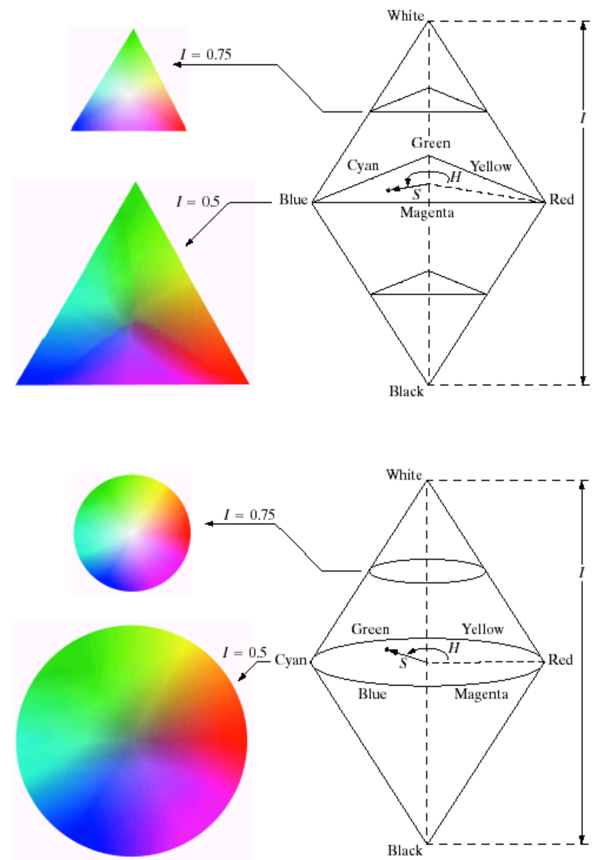
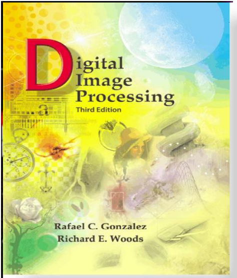


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

Color Image Processing

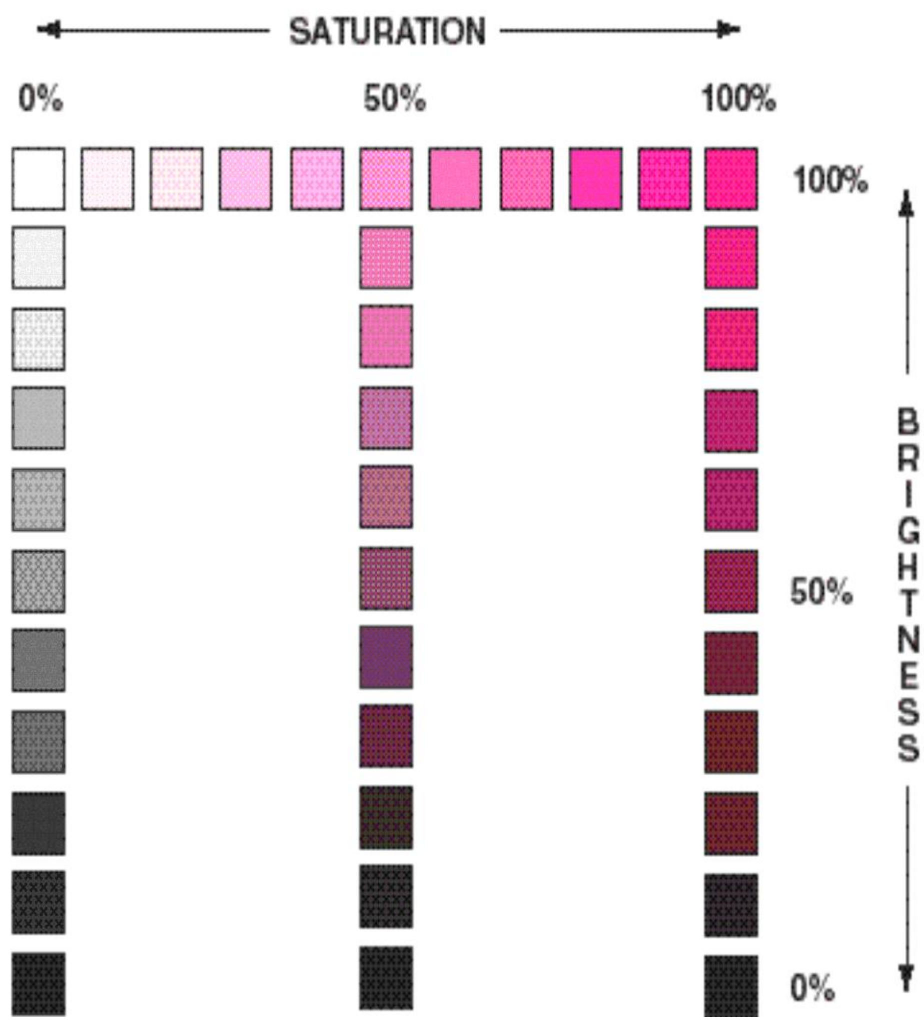






Color Image Processing

- Single Hue

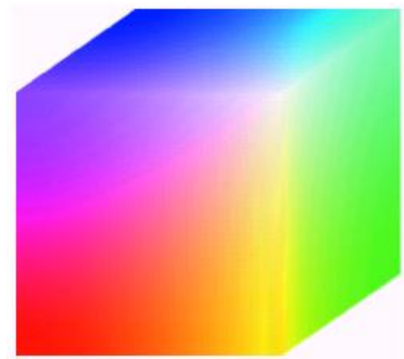


Quiz:
If H = 60 deg, S = 0.5, I = 0.5
what will be the color??
Ans: Light Yellow
Because color is yellow at 60 deg
in slide#45 diagram while saturation
is 0.5 means 50% bright.

2) H = 180, S = 1, I = 1 ??
Ans: White
Because intensity is 1. zero intensity
means black color whatever the
hue and saturation is.
3) H = 300 deg, S = 0, I = 0.5
Ans: Gray
Because saturation is maximum.
if saturation is one, pure color will
be available.

Color Image Processing

- Split Channel



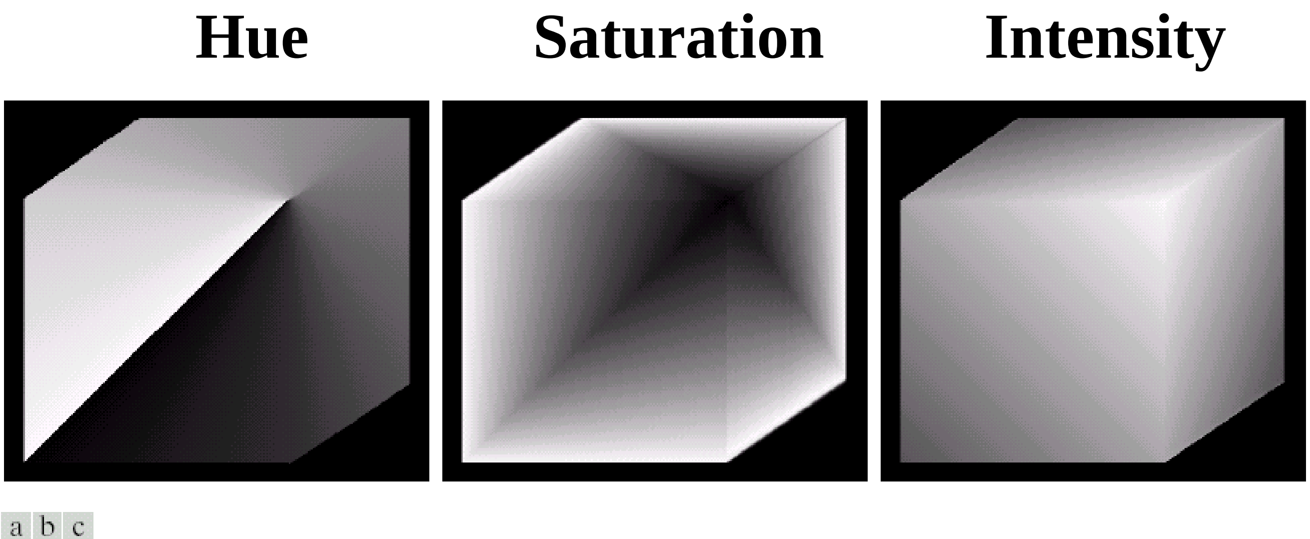
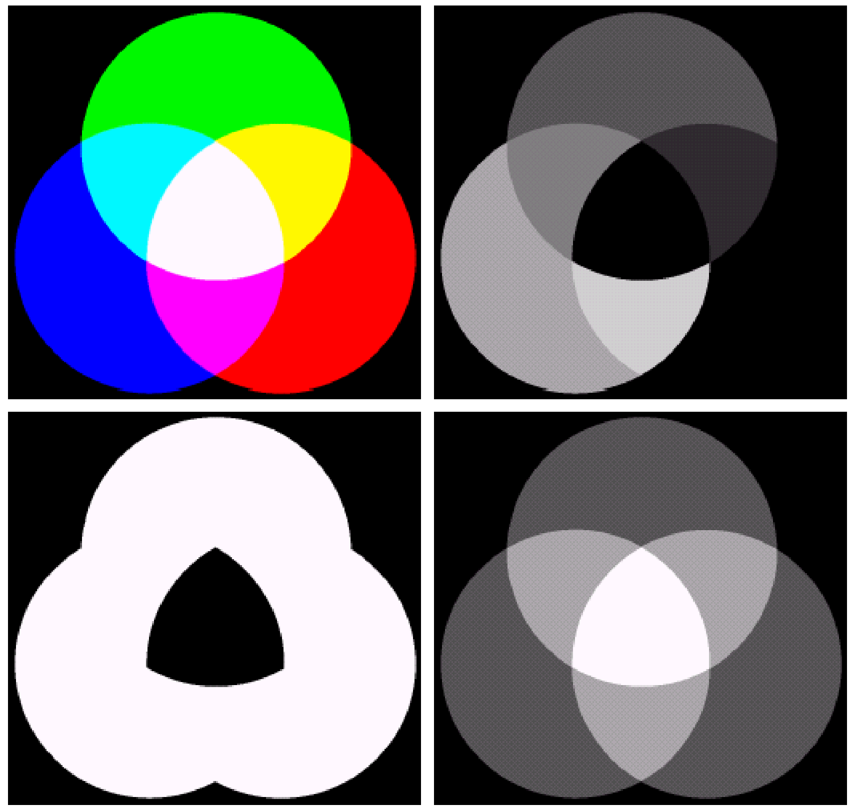


FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

- Channel Split

RGB

Hue



Saturation

Intensity

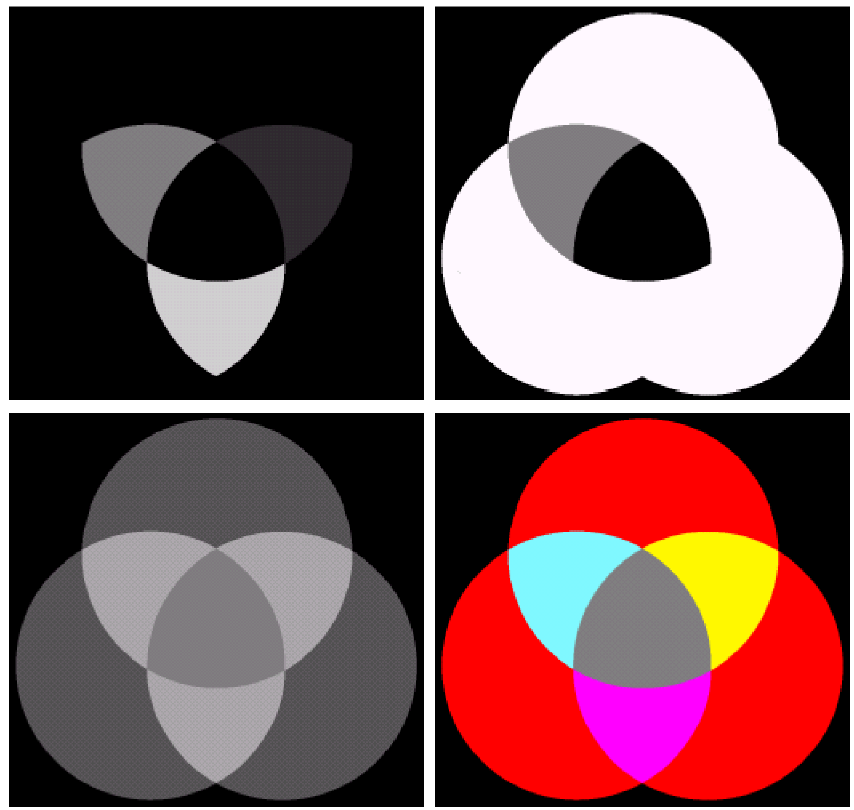
a b
c d

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

- Modifying Channel

Hue

saturation



intensity

Reconstructed

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.)

Color Image Processing

- Split Channel (RGB Model)

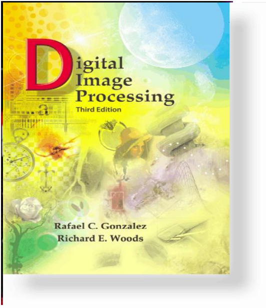
RGB R G B

- Split Channel (CMYK Model)

CMYK **C** **M** **Y** **K**

Color Image Processing

- Pseudo-color image processing
  - **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



- Gray Level Slicing

$$f(x,y)=c_k \quad f(x,y)\in[G_k,G_{k+1}]$$

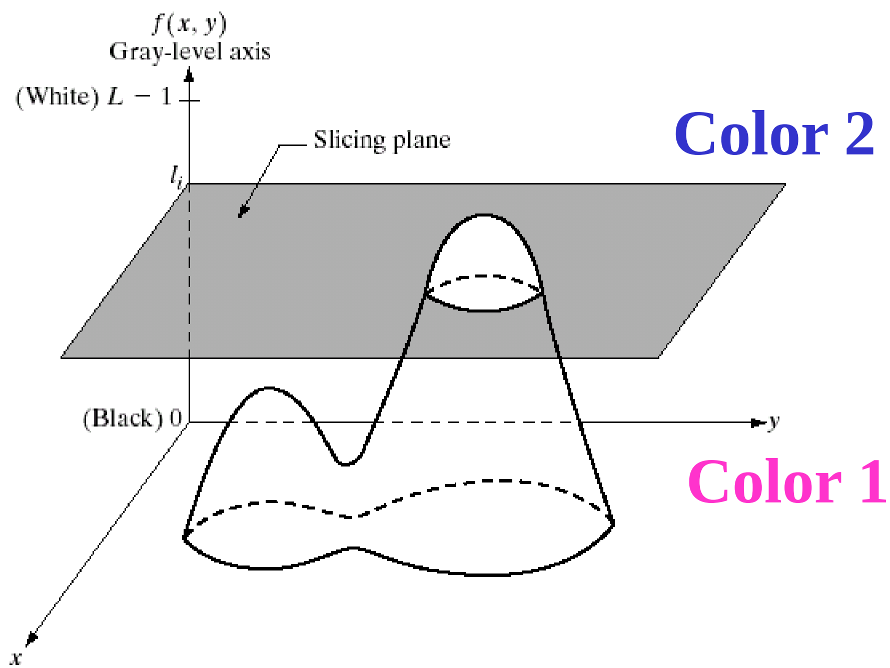


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

- Gray Level Slicing (Two Levels)

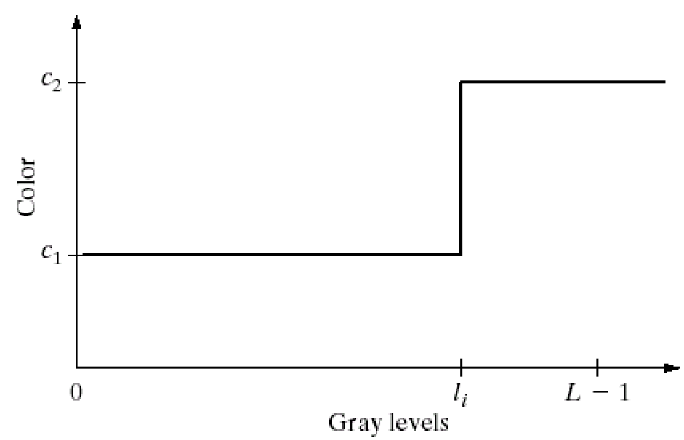
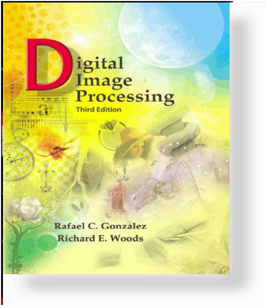
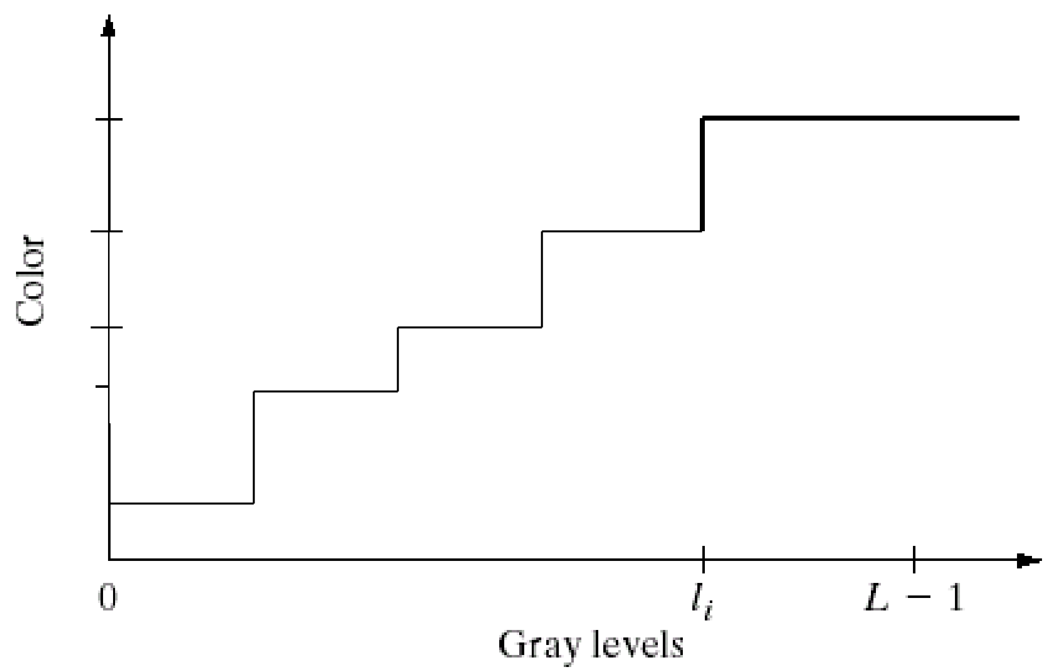


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

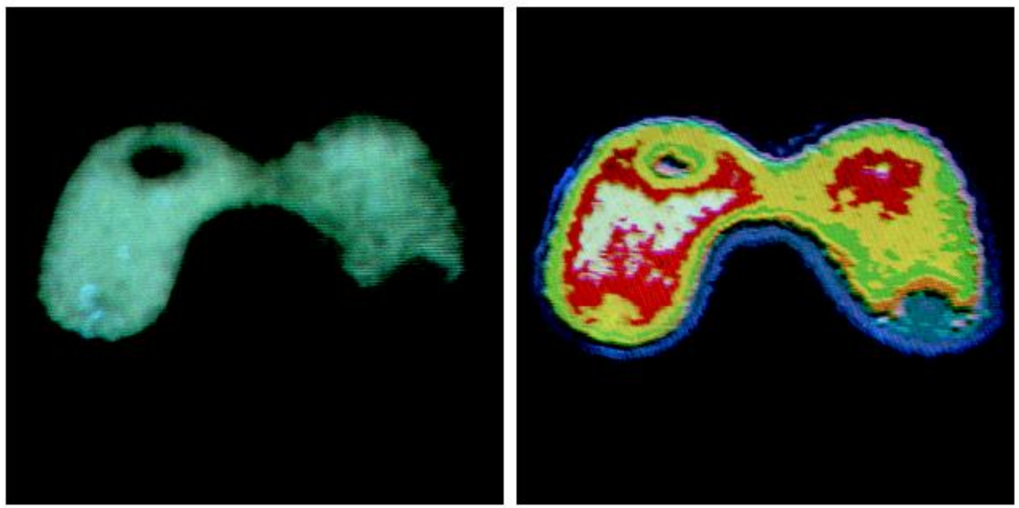


- Gray Level Slicing (More Levels)



Color Image Processing

- Example (Nuclear Imaging) with 8 levels

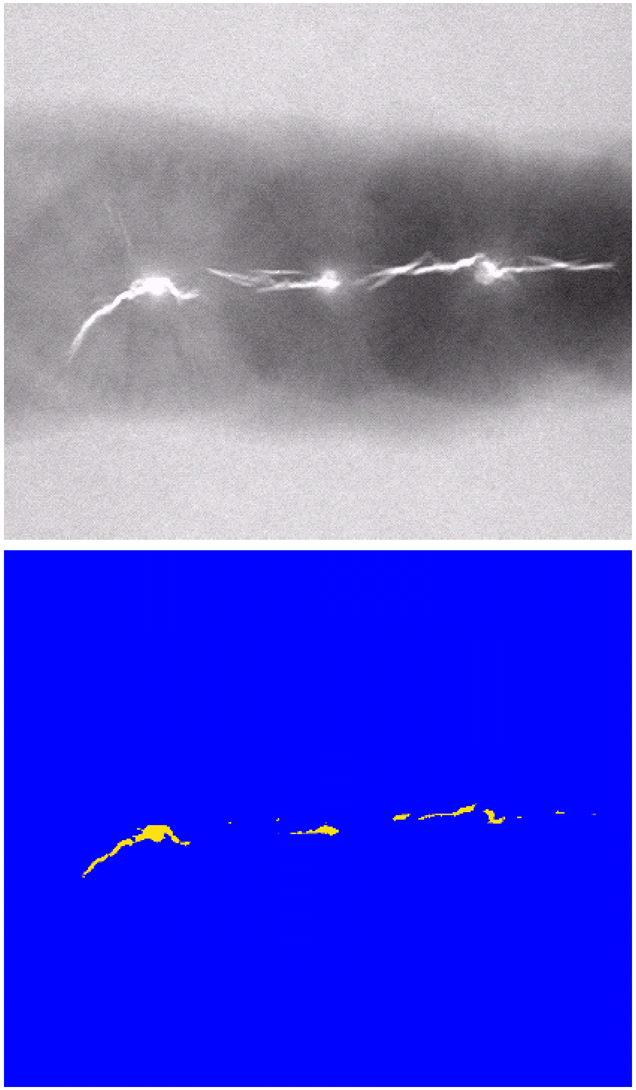


a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

Color Image Processing

- Industrial Application
  - Welding

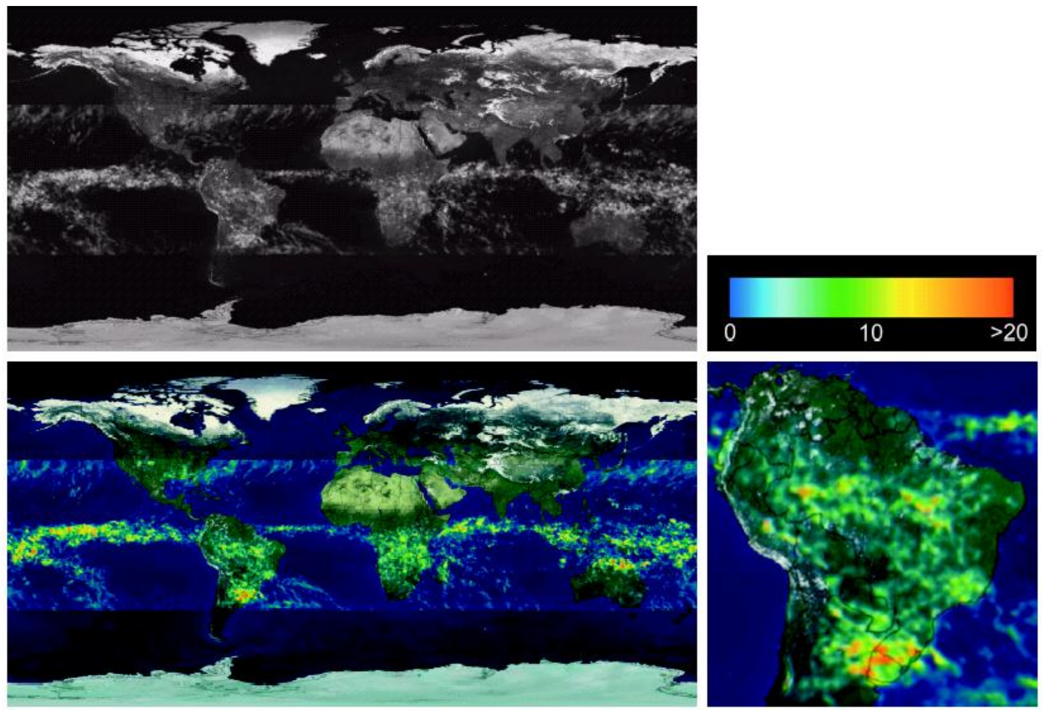


a
b

FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)

Color Image Processing

- Example:



a b
c d

FIGURE 6.22 (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 America region. (Courtesy of NASA.)

Color Image Processing

- Gray Level to Color Transform

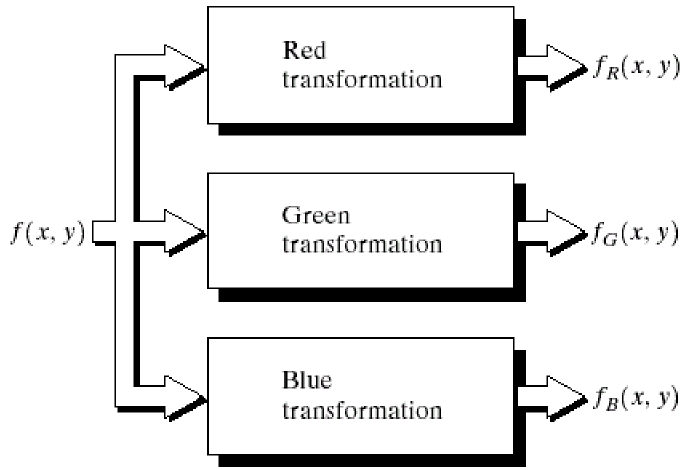
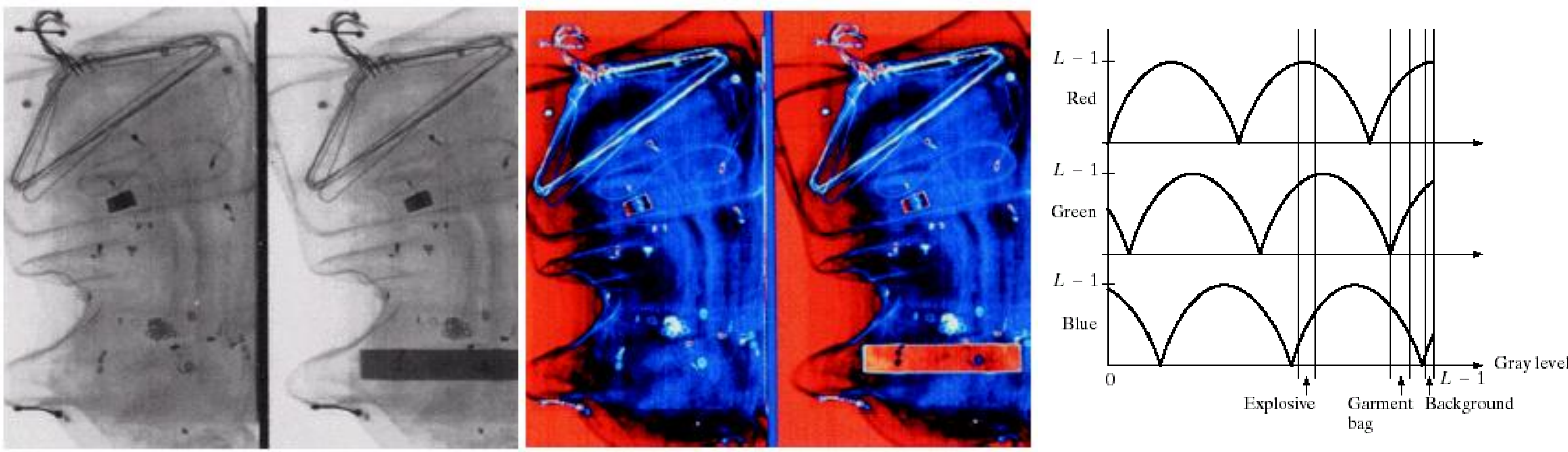


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

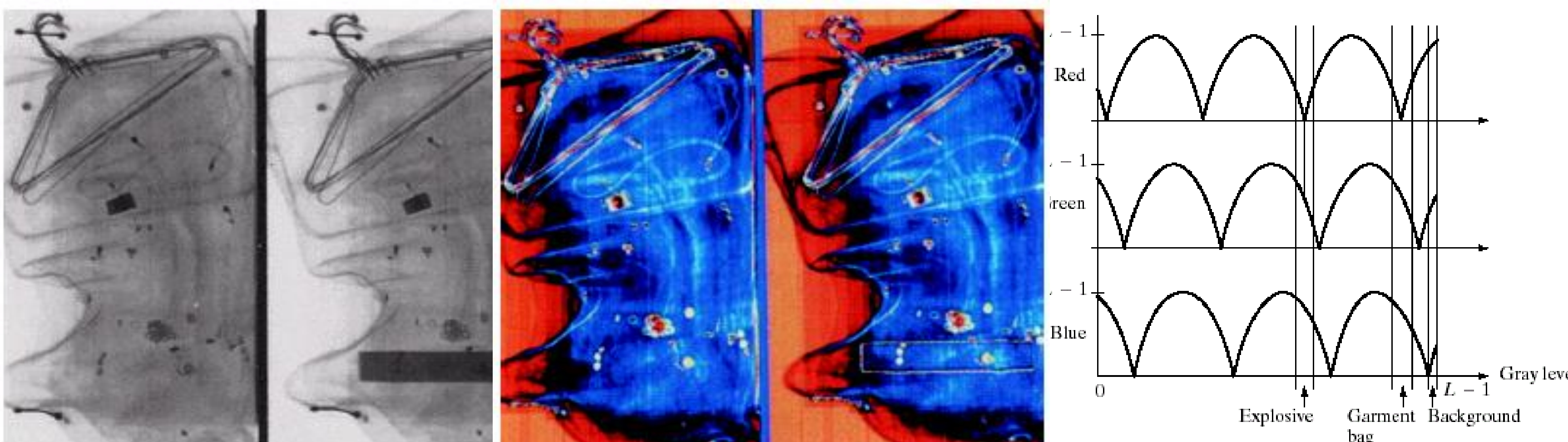
Color Image Processing

- Example



Color Image Processing

- Example:



Color Image Processing

- Combine several monochrome images:
  - multi-spectral images (Remote Sensing/Medical)

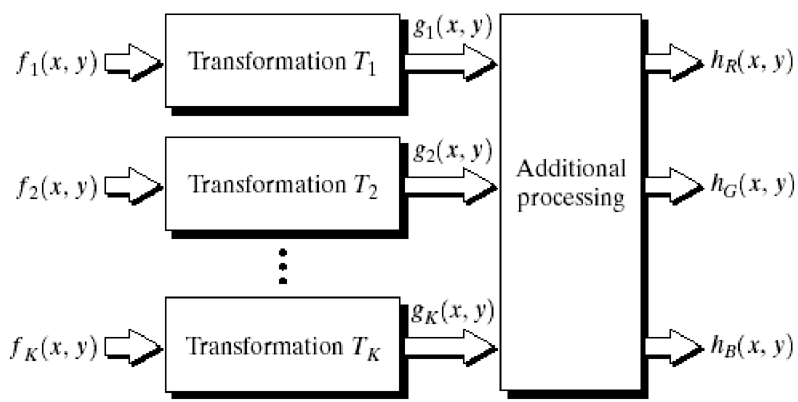
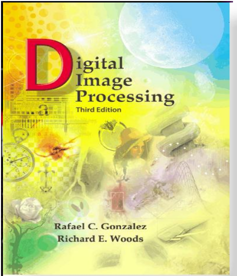
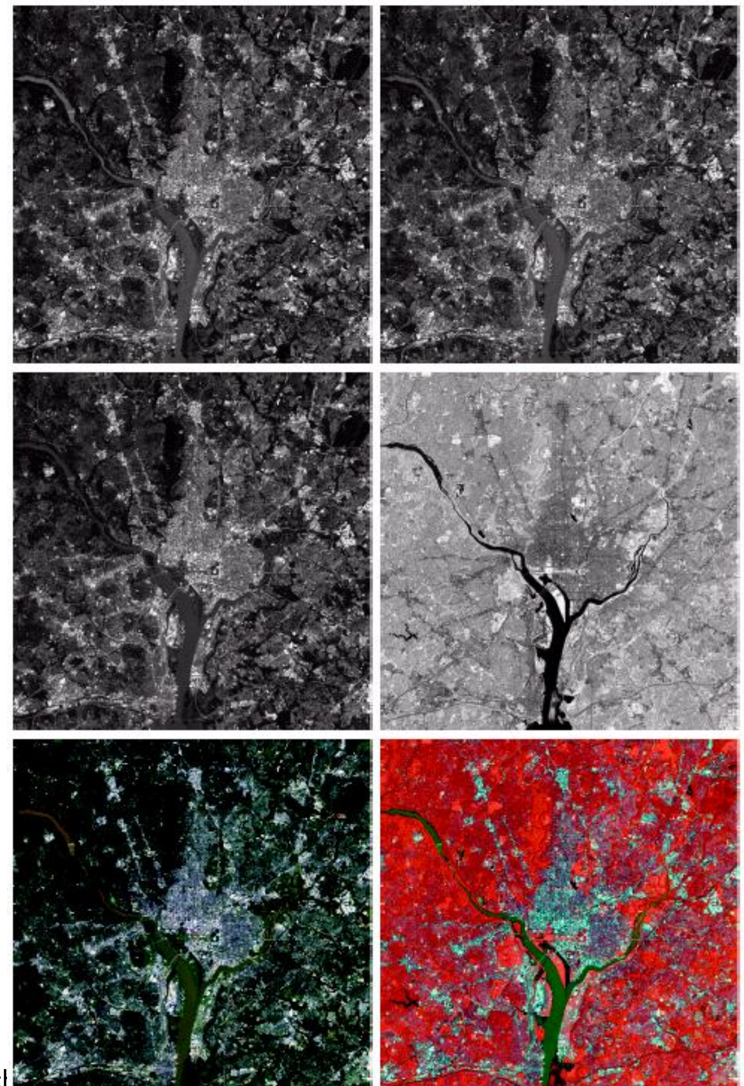


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.



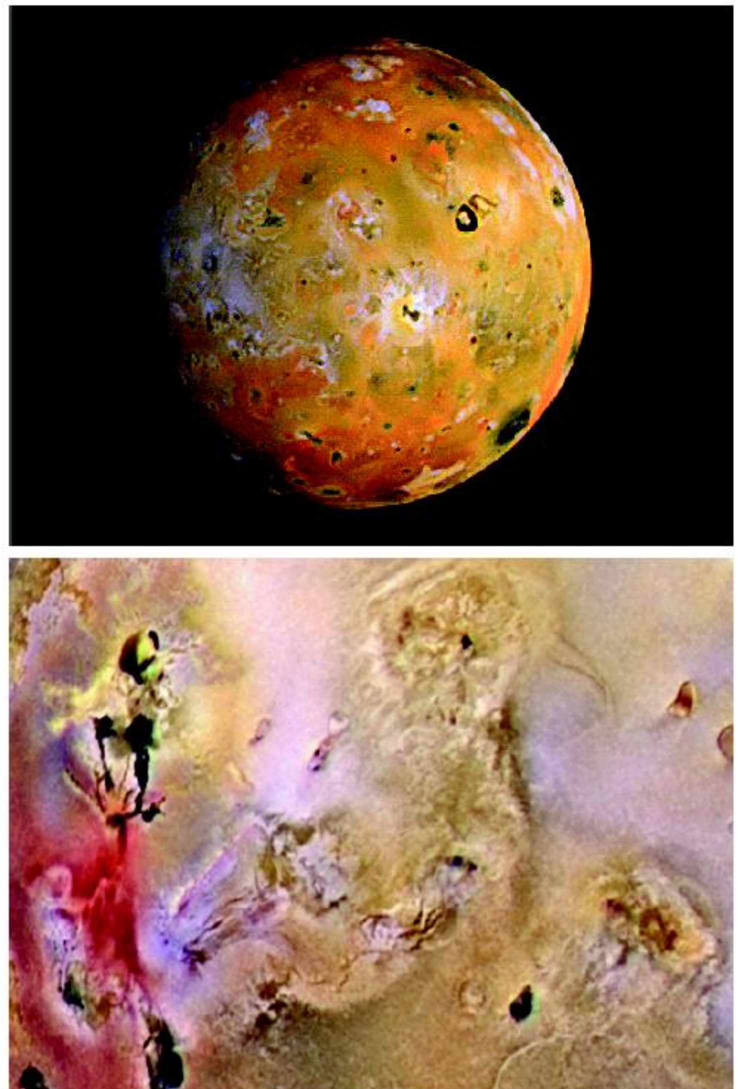
Color Image Processing

R
G
B
Near IR
R-G-B
IR-G-B



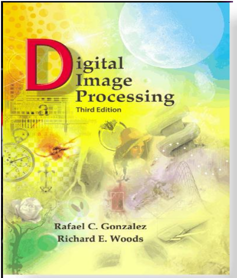
Color Image Processing

- Using Knowledge



a
b

FIGURE 6.28 (a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)



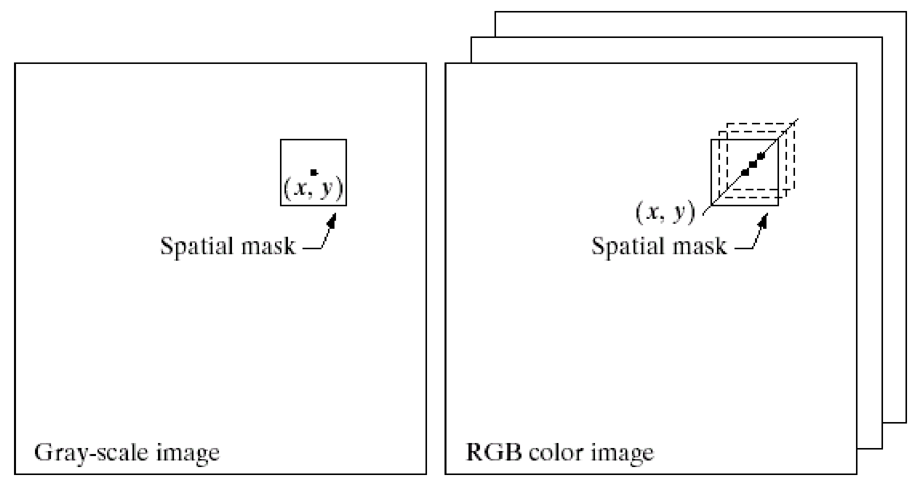
Color Image Processing

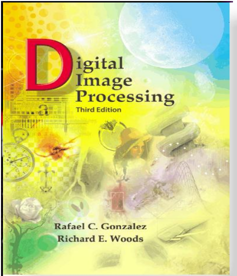
- Full-Color Image Processing
  - Process each color components individually
  - Process color vector directly

$$\mathbf{c}(x,y)=\begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

a b

FIGURE 6.29 Spatial masks for gray-scale and RGB color images.





Color Image Processing

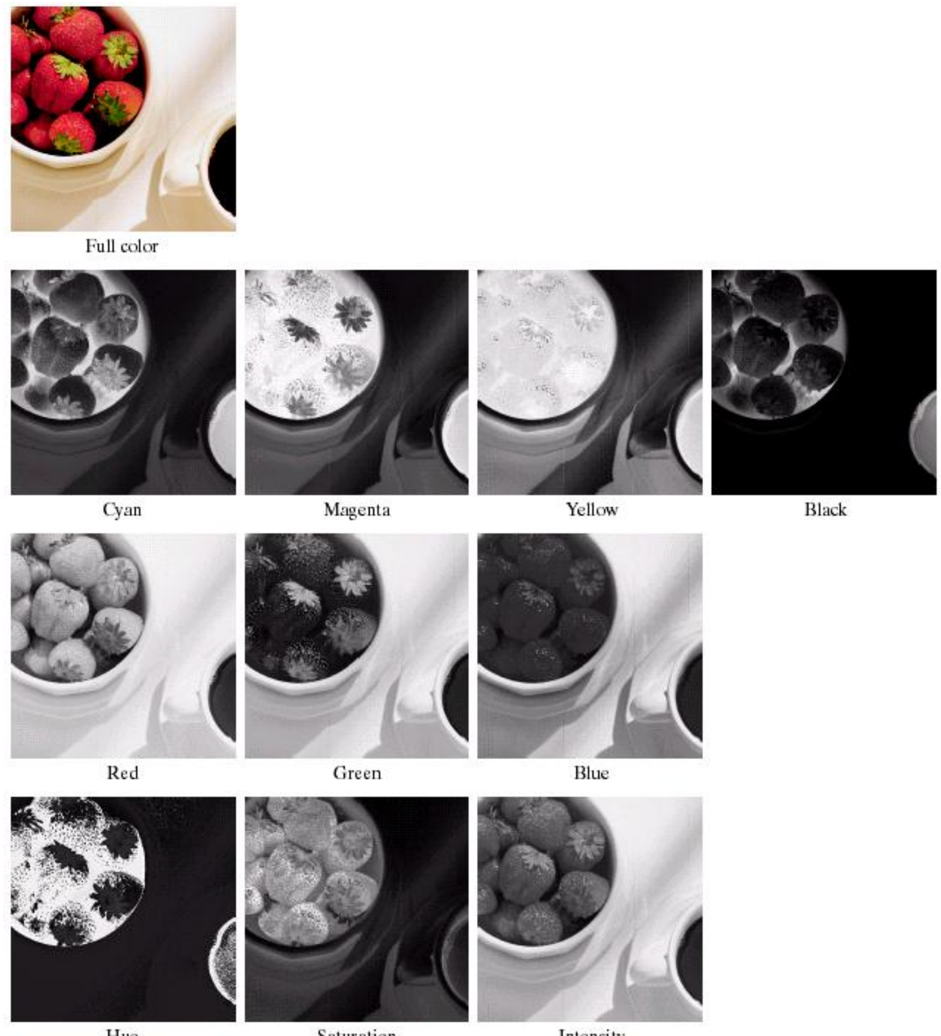
- Color Transform
  - Gray Level Transform: $g(x,y)=T\left[f(x,y)\right]$
  - Color Image Transform: $s_i=T_i\left(r_1,r_2,\cdots,r_n\right),\quad i=1,2,\cdots,n$
    - n=3 for RGB/HSI/CMY
    - n=4 for CMYK

Color Image Processing

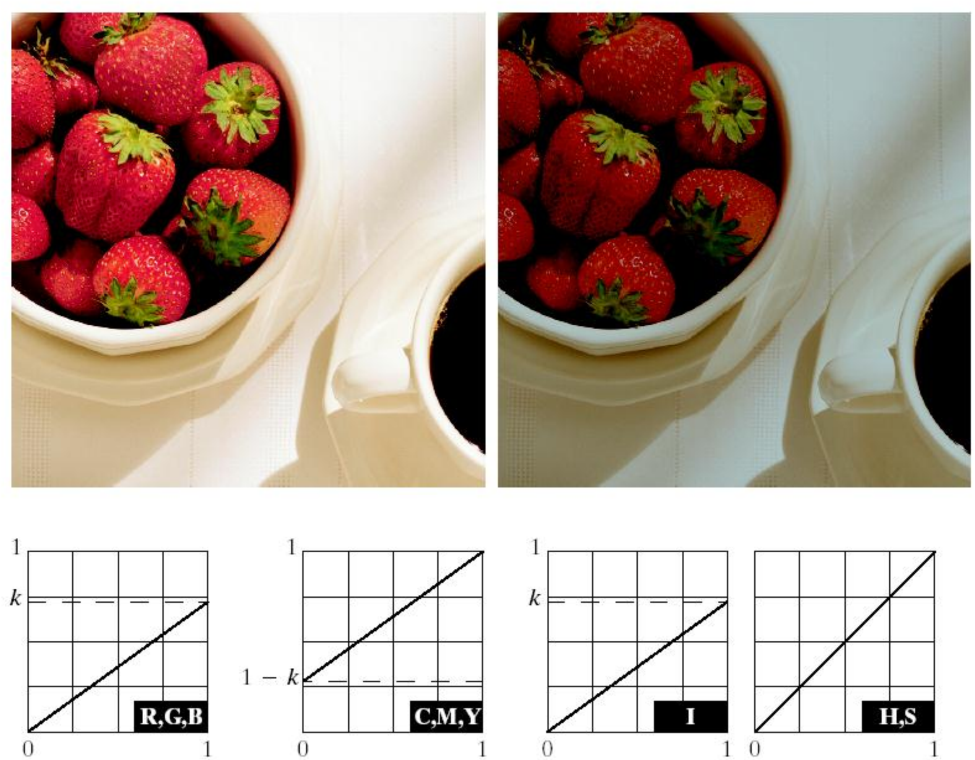
- Intensity Magnification: $g(x,y)=T\left[f(x,y)\right]$
  - HSI: $s_3=kr_3,\ s_2=r_2,\ s_1=r_1$
  - RGB: $s_i=kr_i$
  - CMY: $s_i=kr_i+(1-k)$

Color Image Processing

- Sample Image:
  - CMYK
  - RGB
  - HSI



- Intensity Adjustment (k=0.7)



a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

Color Image Processing

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

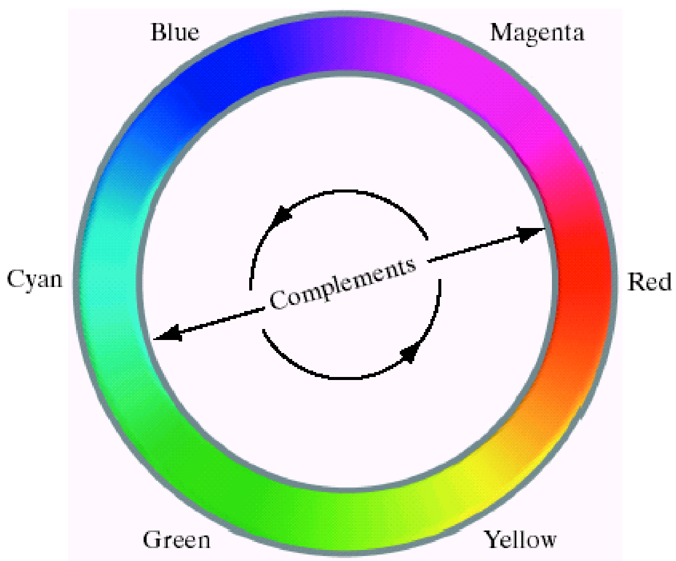
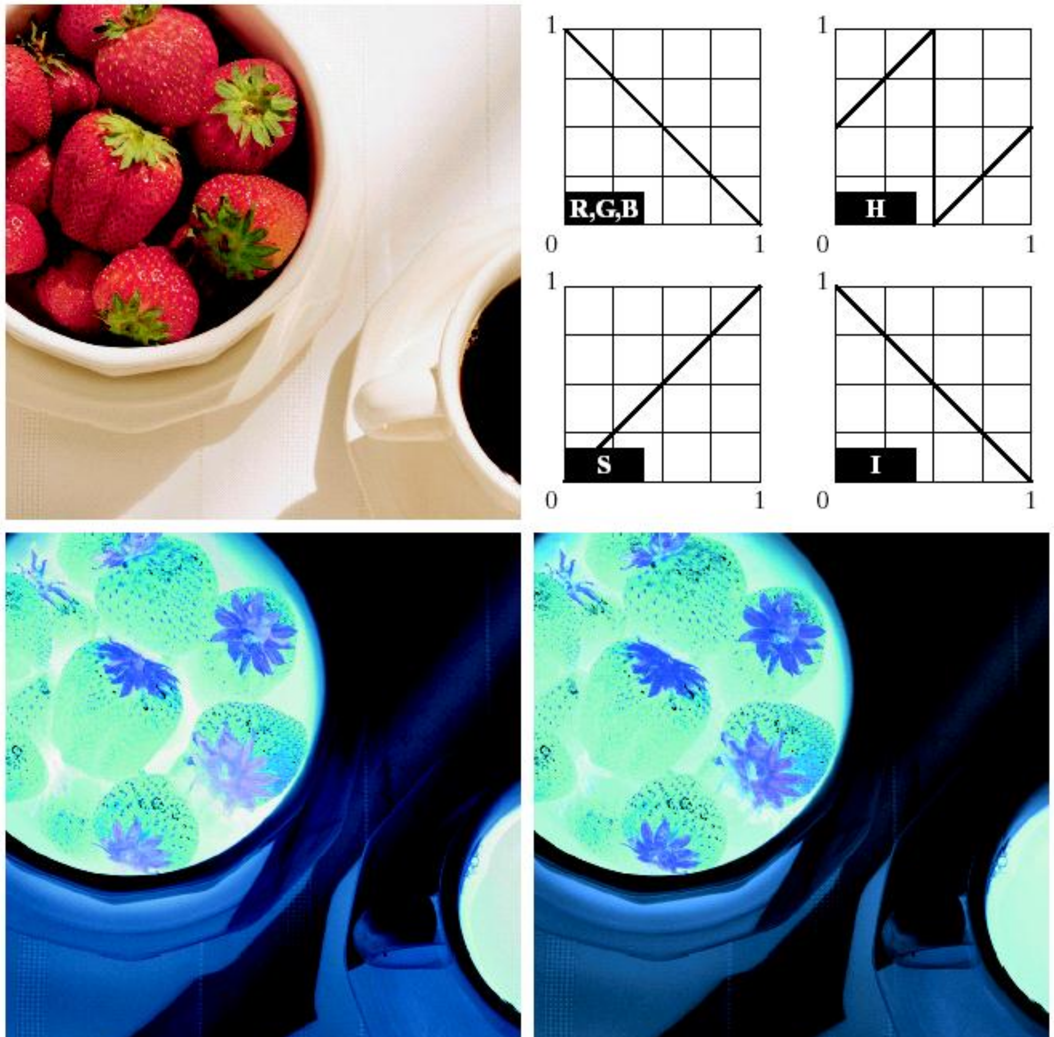


FIGURE 6.32 Complements on the color circle.

Color Image Processing



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.

Two different approaches!

- Color Slicing:
  - Highlight a specific range of colors.
    - Set non desired color to gray level.

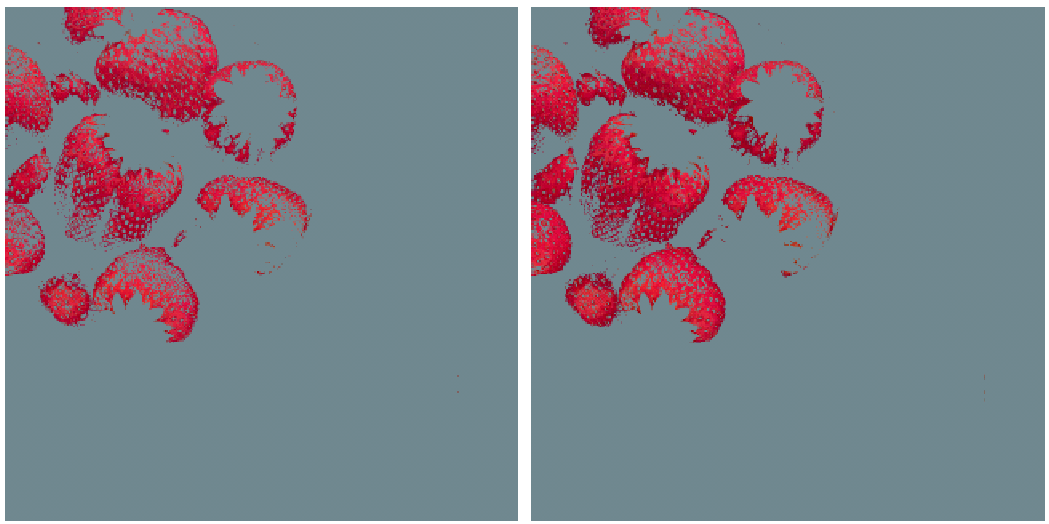
$$s_i = \begin{cases} 0.5 & \left[\left|r_i - a_i\right| > W/2\right] \\ r_i & \text{O.W.} \end{cases}$$

$$s_i = \begin{cases} 0.5 & \sum_{j=1}^{n} \left(r_i - a_i\right)^2 > R_0^2 \\ r_i & \text{O.W.} \end{cases}$$

Color Image Processing

- Examples:

$W=0.2549$



$R_0=0.1765$

a b

FIGURE 6.34 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).

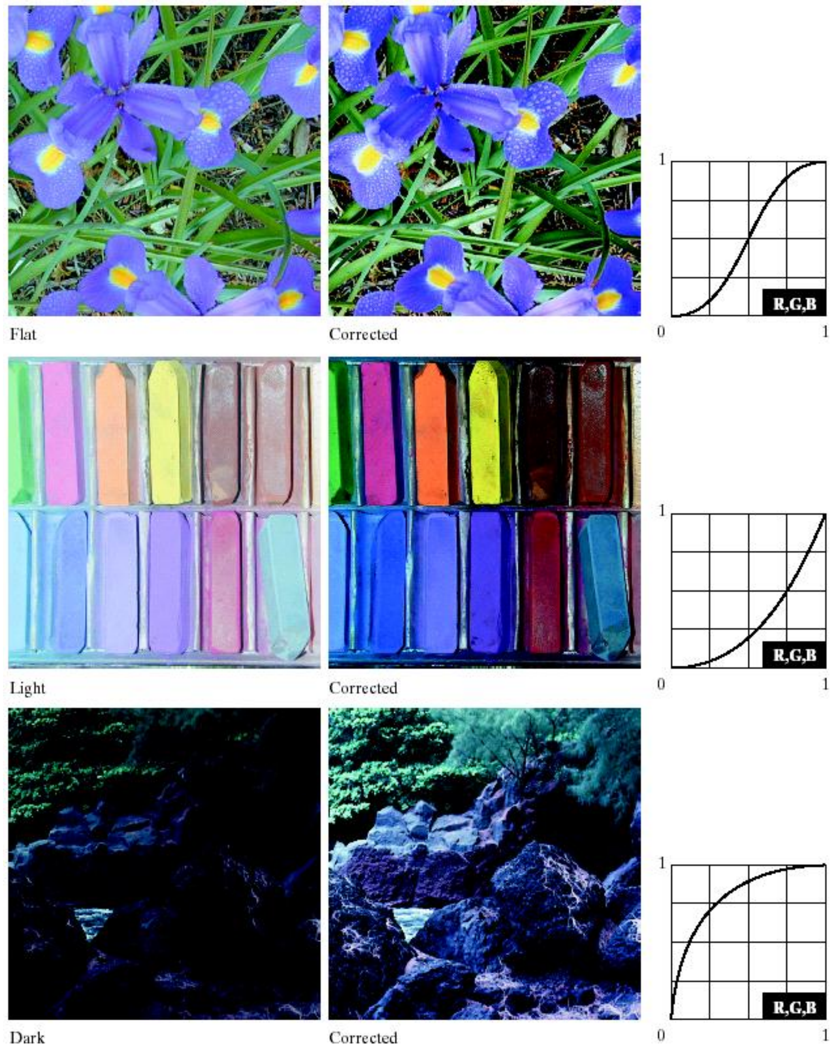
Color Image Processing

- Tonal Correction

Flat

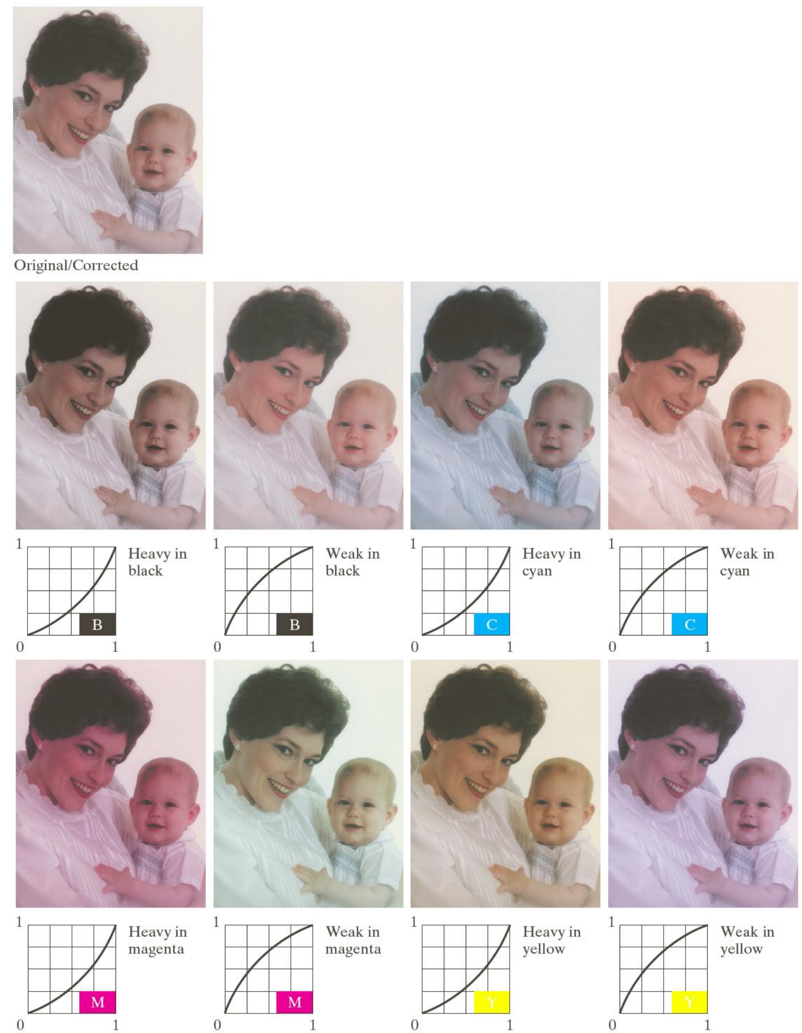
Light

Dark



Color Image Processing

- Color Balancing:

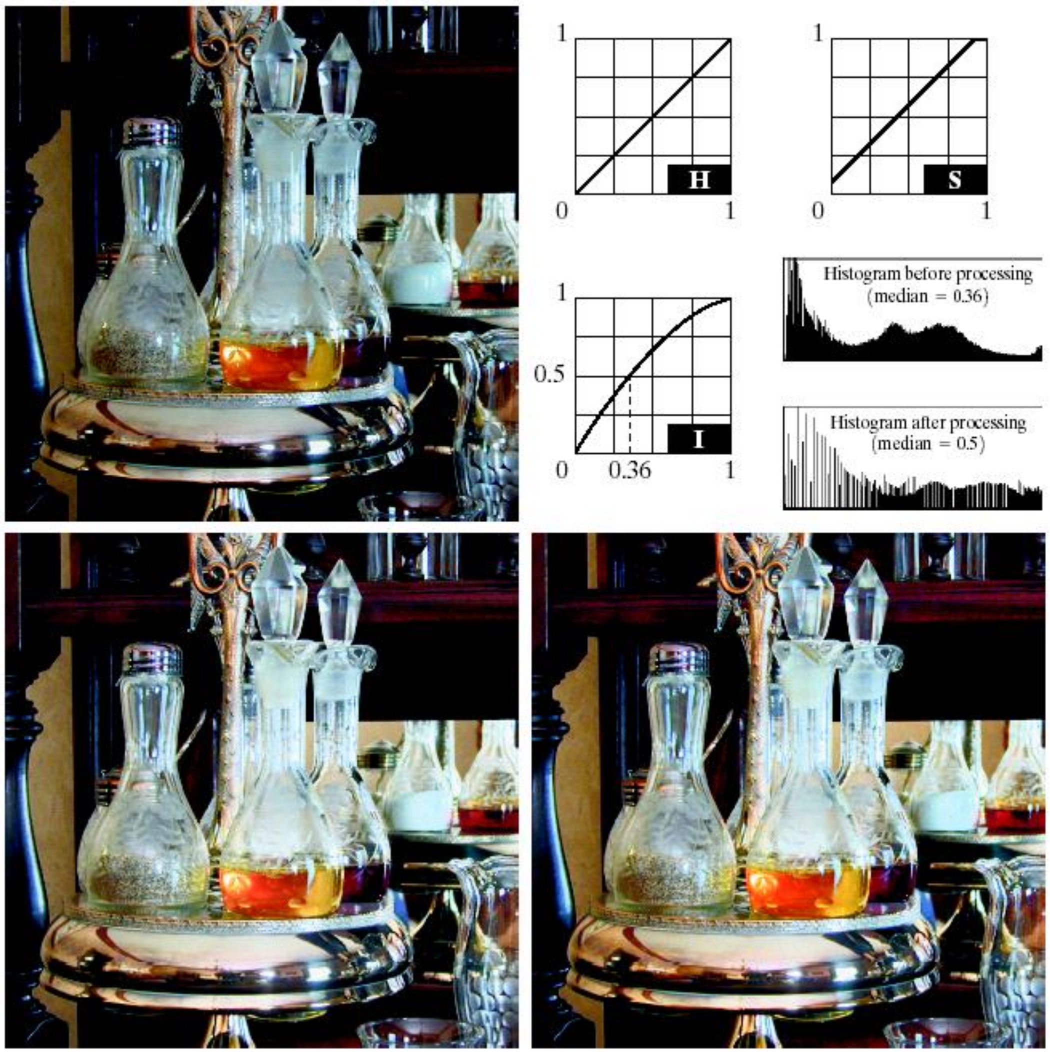


Color Image Processing

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

Color Image Processing

original



a b
c d

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

Intensity Equlization

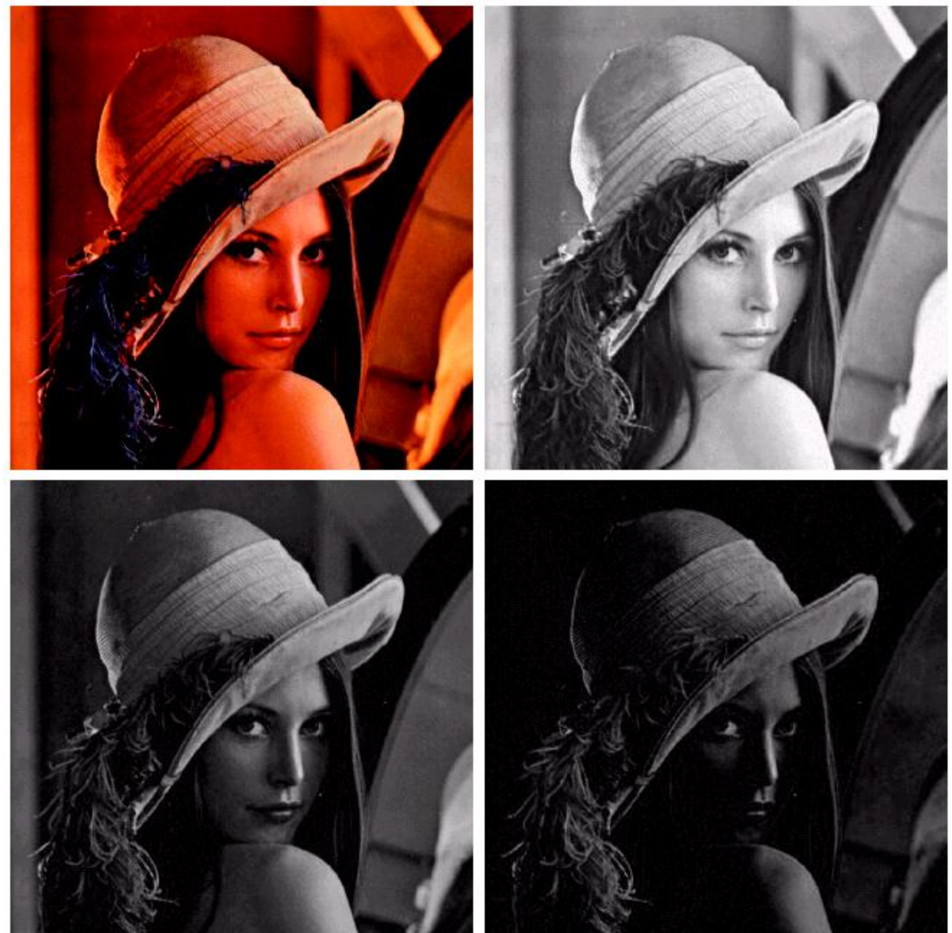
Saturation Increasing

- Color Image Smoothing:
  - Like as Gray Level Images!

$$\hat{\mathbf{c}}(x,y)=\frac{1}{MN}\begin{bmatrix}\sum\limits_{(x,y)\in S_{xy}} R(x,y)\\ \sum\limits_{(x,y)\in S_{xy}} G(x,y)\\ \sum\limits_{(x,y)\in S_{xy}} B(x,y)\end{bmatrix}$$

Color Image Processing

- RGB Components



Color Image

R-Channel

G-Channel

B-Channel

Color Image Processing

- HSI Components

H-Channel S-Channel I-Channel

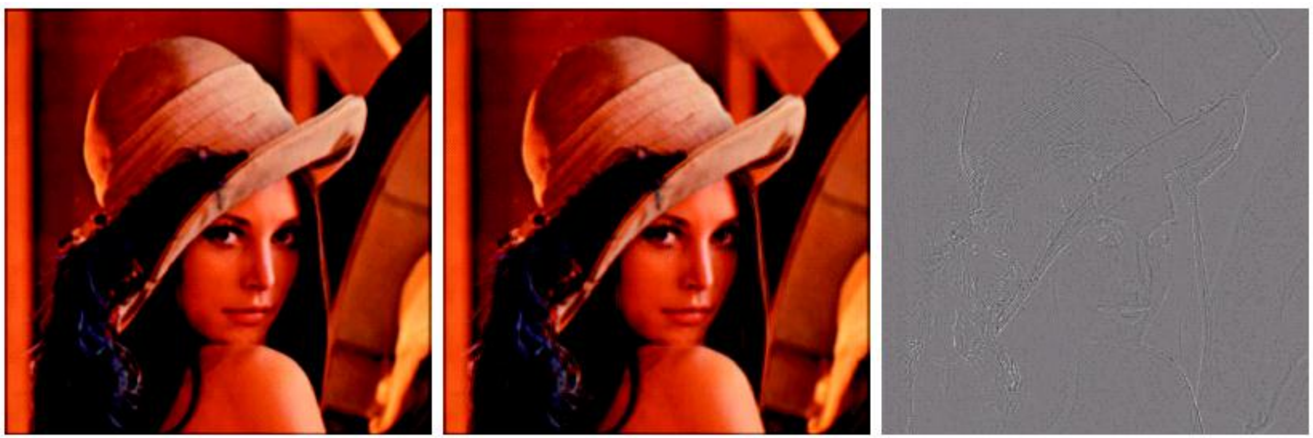
a b c

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

Color Image Processing

- Two approached for smoothing:

RGB Smoothing | I- Smoothing | Difference



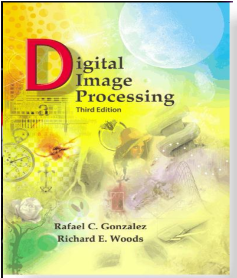
a b c

FIGURE 6.40 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 Processing

- Color Image Sharpening:

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



Color Image Processing

- Two approached for Sharpening:

RGB Sharpening I- Sharpening Difference

a b c

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