Chapter 6

Color Image Processing

◇Preview(1)

- Motivation of using color in image processing
  - Color is a powerful descriptor that often simplifies object identification and extraction from scene.
  - Human can discern thousands of color shades and intensities, compared to about only two dozen shades of gray : particularly important factor in manual image analysis

- Two major areas in color image processing
  - Full-color processing
  - Pseudo color processing

◇Preview(2)

- Full-color image
  - Acquired with a full color sensor, such as a TV camera or a scanner
  - At present, color sensors or hardwares have become available.
  - Has a broad range of applications, including publishing, visualization and internet

- Pseudo-color image
  - Assign a color to a particular monochrome intensity or range of intensities
  - Until recently, most digital color processing was done at pseudo color level

- Color Models
  - RGB, CMY, YIQ, HIS, etc.

6.1 Color Fundamentals(1)

- Newton discovered through prism that the emerging beam of light consists of a continuous spectrum of colors ranging from violet to red.
- The color spectrum is divided into six broad regions : violet, blue, green, yellow, orange, red

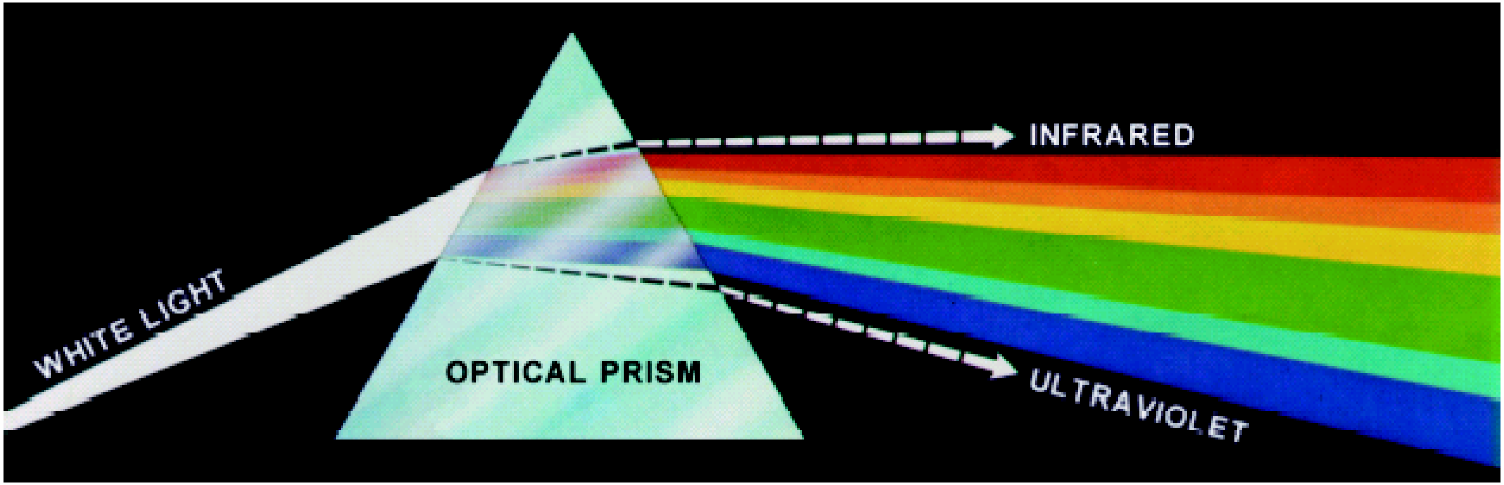


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

◇ Color Fundamentals(2)

- No color in the spectrum ends abruptly, but rather each color blends smoothly into next.
- Basically, the colors that human perceives in an object are determined by the nature of the light reflected from object.
  - For example, a body that reflects all visible wavelengths appears white.
  - Green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelengths.

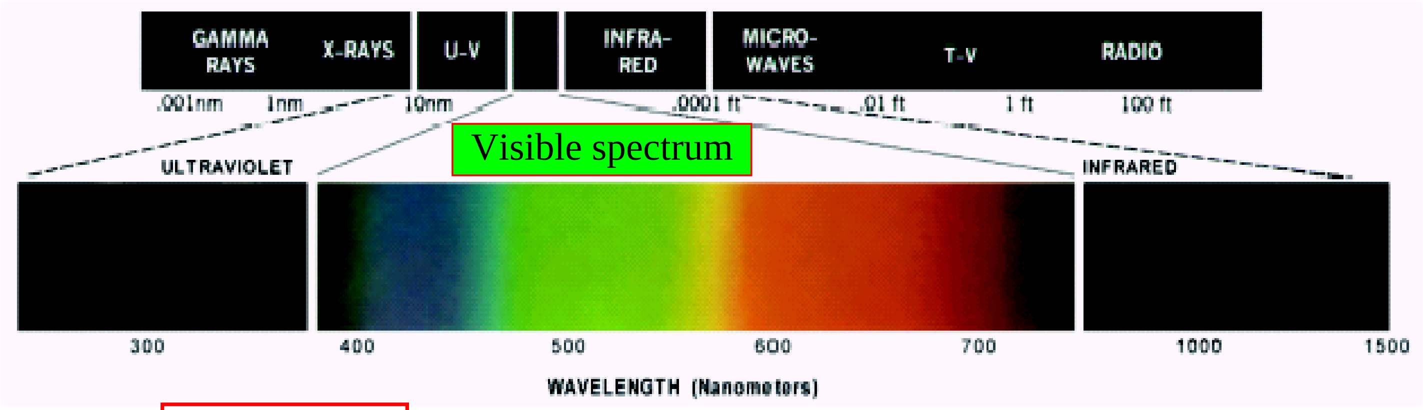


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

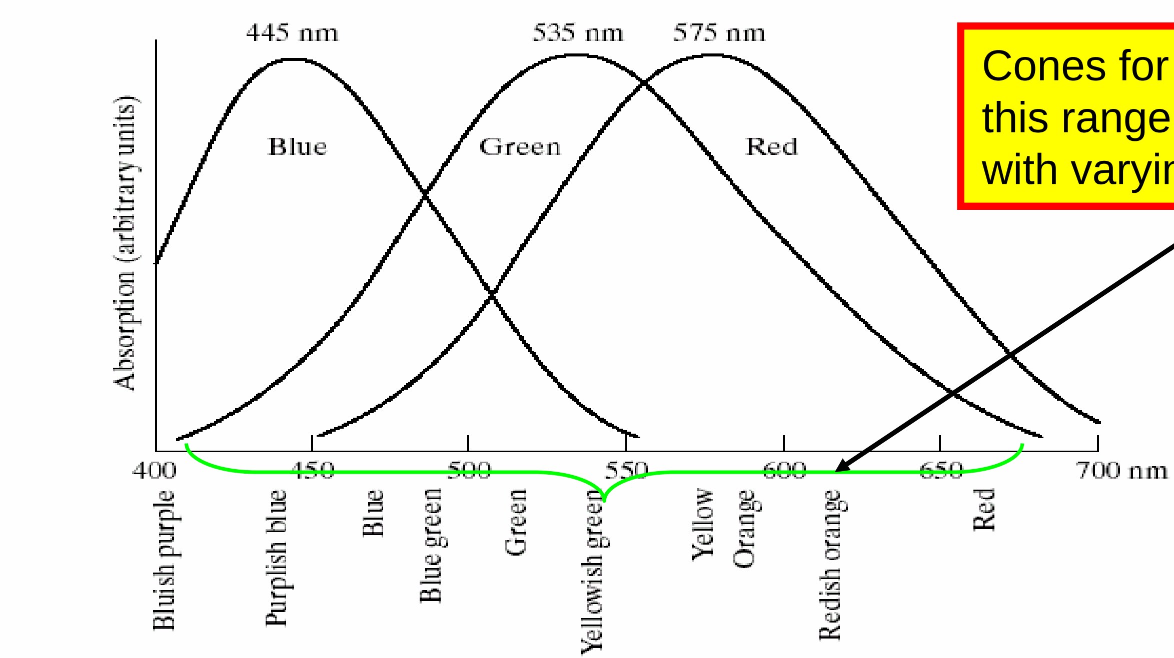
◇ Color Fundamentals(3)

- Chromatic light spans the electromagnetic spectrum from ~400 to 700nm.
- The three basic quantities are used to describe the quality of a chromatic light source : radiance, luminance and brightness
- Radiance is the total amount of energy that flows from the light source [watt, W].
- Luminance gives a measure of the amount of the energy an observer perceives from a light source[lm].
  - Example : light source with the far infrared spectrum has significant energy (radiance), but an observer hardly perceives it ; its luminance is zero
- Brightness embodies achromatic notion of intensity and one of the key factors in describing color sensation.

◇ Color Fundamentals(4)

- Cones are sensors in the eye responsible for color vision (from chap. 2).
- The 6 to 7 million cones can be divided into three sensing categories, corresponding to red, green and blue (by detailed experimental evidence).
  - 65% of the cones are sensitive to red light
  - 33% are sensitive to green light
  - only 2% are sensitive to blue light (but blue cones are the most sensitive)

◇ Color Fundamentals(5)



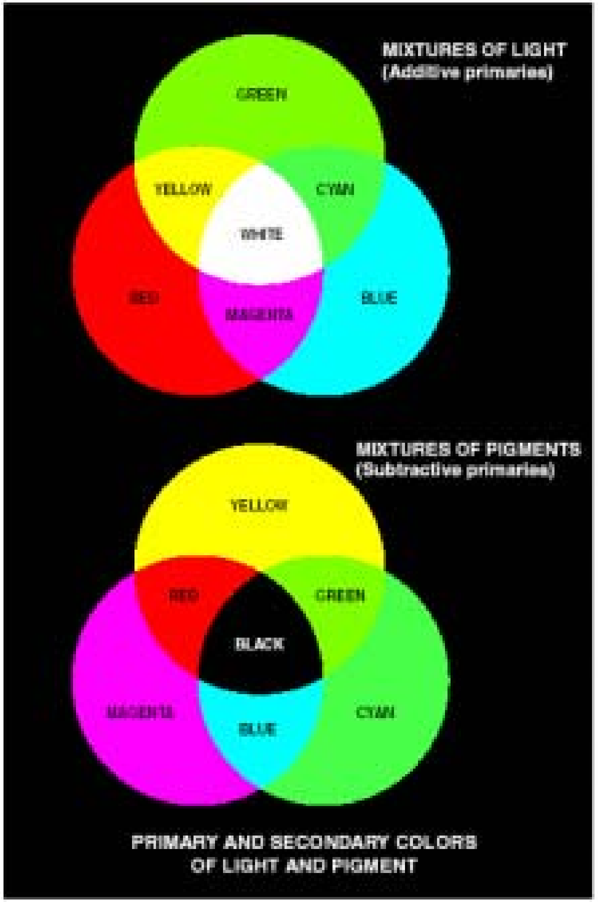
Cones for green absorb this range of colors with varying amount

- The experimental curves detail the absorption of light by the red, green and blue cones.
- Due to these absorption characteristics of the human eye, colors are seen as combination of the *so-called* primary colors red(R), green(G) and blue(B).
- CIE (Commission Internationale de l'Eclairage-International Commission of Illumination) standard
  Blue = 435.8nm, Green = 546.1 nm and Red = 700 nm
- The CIE standards correspond only approximately with these experimental data because the standards were set before the detailed experiments.

◇ Color Fundamentals(6)

- Primary colors of light : R,G,B
- Secondary colors : C, M, Y

- Primary colors of pigments or colorants : C, M, Y
- Secondary colors : R, G, B



a
b

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

◇ Color Fundamentals(7)

- The characteristics to distinguish one color from another are brightness, hue, and saturation.
- Brightness embodies achromatic notion of intensity.
- Hue represents the dominant color in a mixture of light waves.
- Saturation refers to the relative purity or the amount of the white light mixed with a hue.
  - The pure spectrum colors are fully saturated.
  - Colors such as pink (red and white) and lavender (violet and white) are less saturated.
- Hue and saturation taken together are called *chromaticity.*

◇ Color Fundamentals(8)

- The amounts of red, green, and blue needed to form any particular color are called the tristimulus values and are X, Y, Z.
- A color is then specified by trichromatic coefficients, defined as :

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

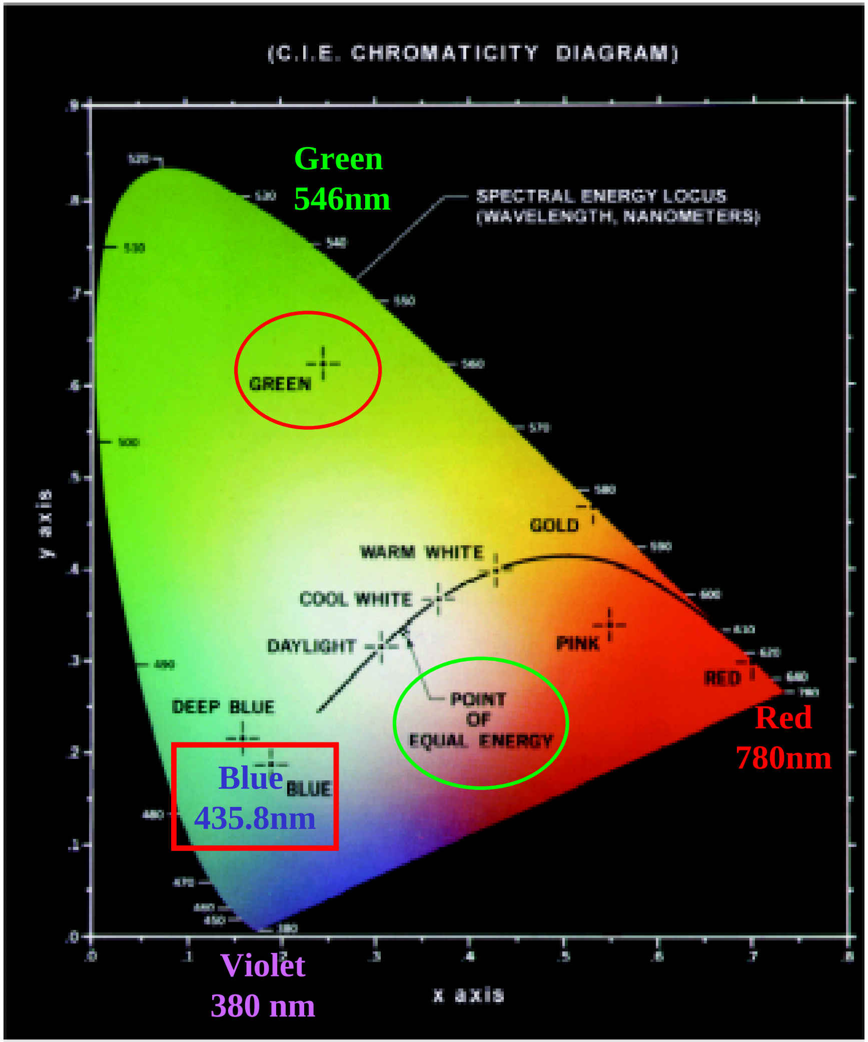
X, Y, Z : tristimulus values

x, y, z : trichromatic coefficients

◇ Color Fundamentals(9)

CIE chromaticity diagram

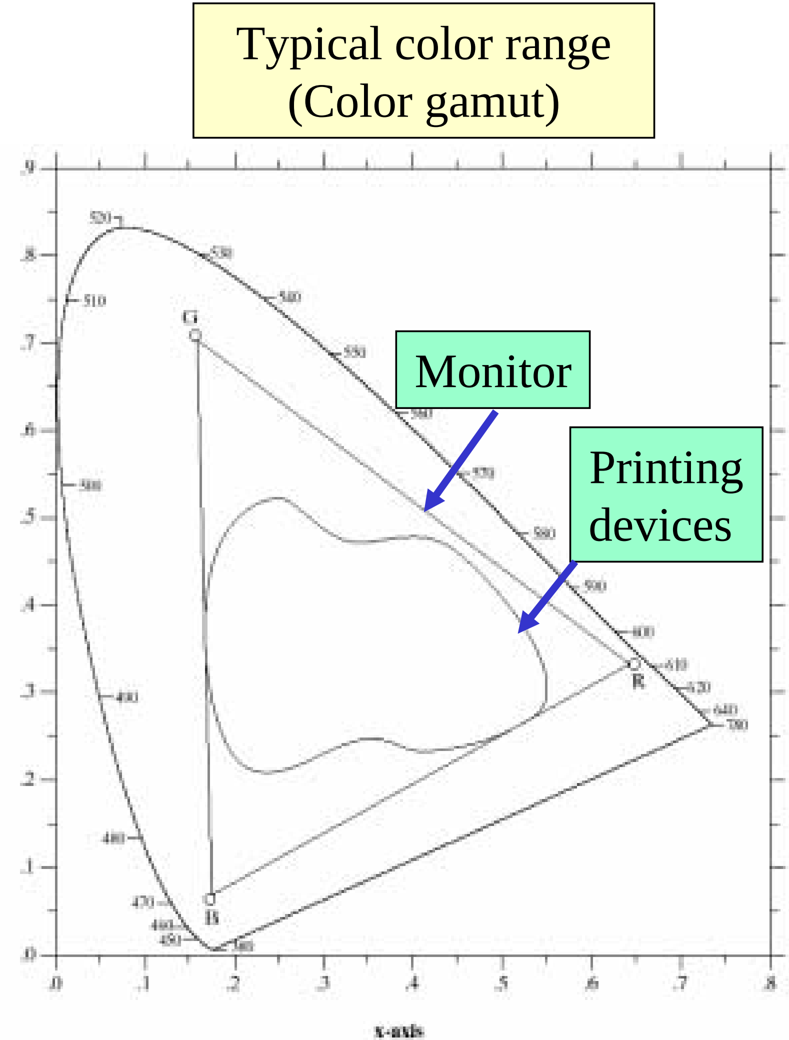
- Point marked green
  - 62% green, 25% red, 13% blue
- Boundary of diagram
  - Pure color
  - Fully saturated
- Point of equal energy
  - Equal fractions of the three primary colors
  - Standard for white light
  - Zero saturation
- Any point inside diagram
  - Some mixture of spectrum colors
  - More white light is added
  - Less saturated
- Useful for color mixing



◇ Color Fundamentals(10)

- Color mixing
  - A straight line joining any two points defines all the different colors obtained by combination of these two colors.
  - A line drawn from the point of equal energy to any point on the boundary will define all the shades of that color.
  - A color inside the triangle connecting any three colors is a combination of the three colors.

- Color gamut
  - Color printing is a combination of additive and subtractive color mixing, thus having irregular shape of range.
  - Controlling colors in printing is much more difficult than that in monitor.



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

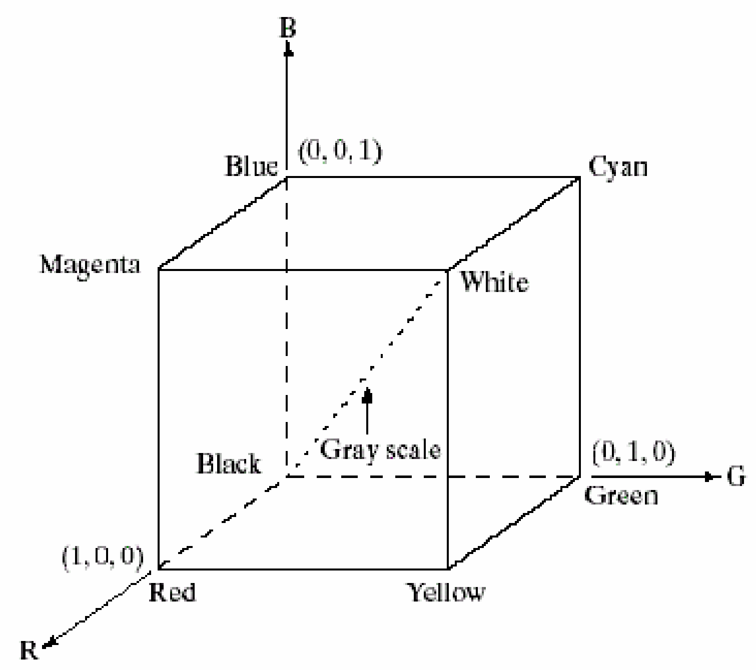
6.2 Color Models

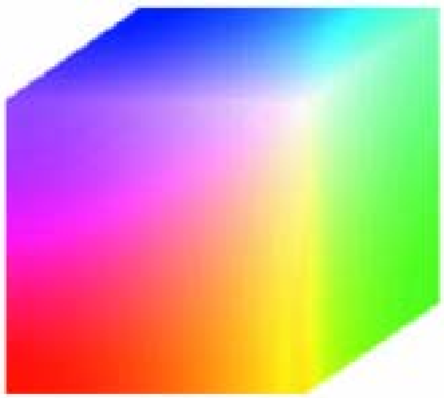
- Applications of the color models
  - Hardware such as color monitors and printers
  - Color manipulation

- Color models
  - RGB model : monitor
  - CMY and CMYK model : printer
  - HSI color model : color manipulation

6.2.1 RGB Color Model (1)

Schematic of the RGB color cube





- Application : Color monitor, Color video camera
- Full color image

- Pixel depth : 8-bit x 3(RGB) = 24-bit

- The number of colors : $(2^8)^3$ = 16,777,216 color

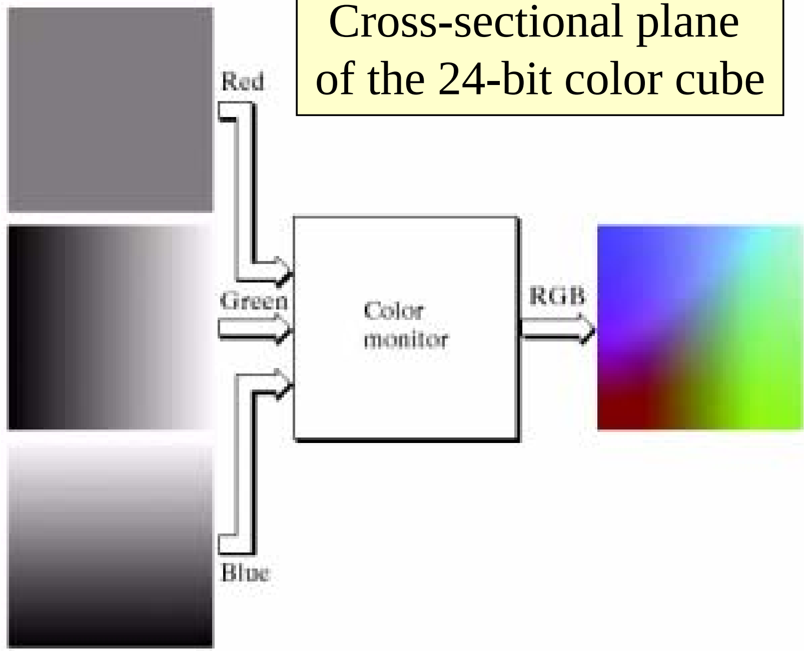
◇ RGB Color Model (2)

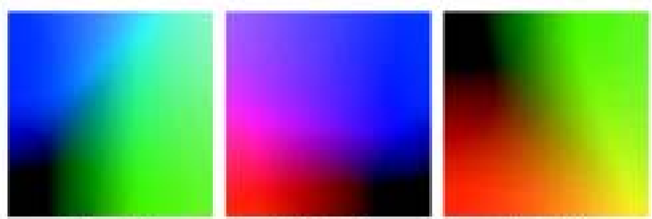
Cross-sectional plane of the 24-bit color cube

R=128

G : variable

B : variable





$(R = 0)$ $(G = 0)$ $(B = 0)$

Hidden surface plane in the color cube

◇ RGB Color Model (3)

- Safe RGB colors or all-system-safe colors
  - A subset of colors that are likely to be reproduced faithfully, reasonably independently of viewer hardware capabilities.
  - Internet application : safe Web colors or safe browser colors

- Assume that 256 colors are the minimum number of colors, especially in internet applications
  - 40 colors are processed differently by various operating system.
  - 216 colors is for safe colors.
  - RGB values(hex) : 0(00), 51(33), 102(66), 153(99), 204(CC), 255(FF)
    (6 kinds in each of R, G, and B)
  - $(6)^3 = 216$ possible values
  - For example, Red : FF0000, White : FFFFFF, Black : 000000

- Gray colors in a 256-color RGB system
  - All the possible grays (256) : $(KKKKKK)_{16}$, for K = 0, 1, 2, …, F
  - The grays inside the safe color (6) : $(KKKKKK)_{16}$, for K = 0, 3, 6, 9, C, F
  - The grays outside the safe color (10) are represented properly.

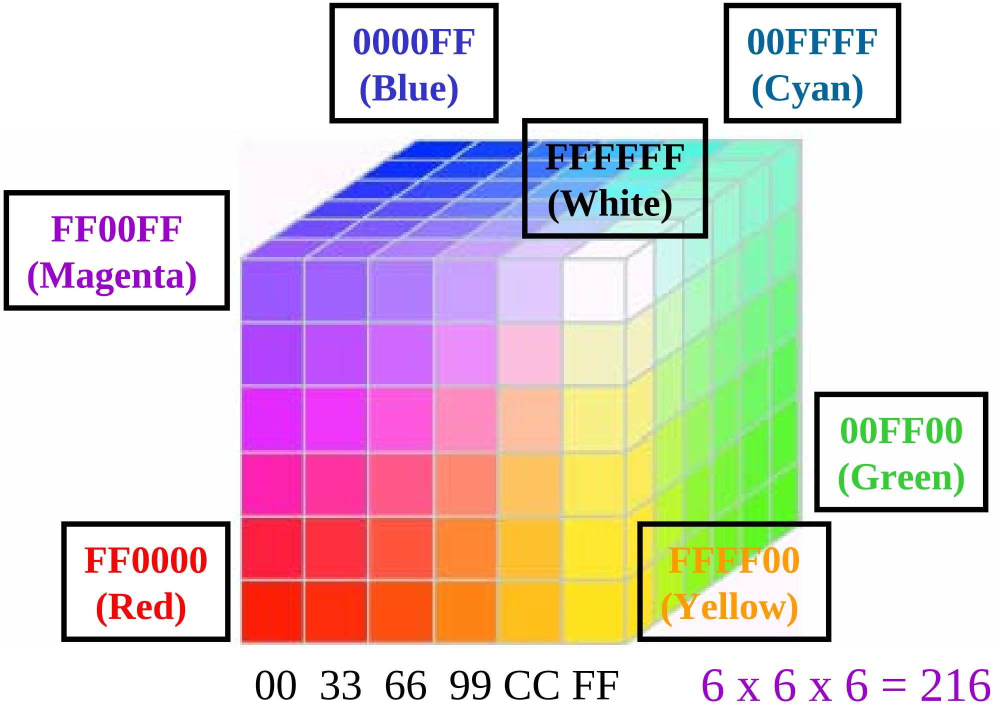
◇ RGB Color Model (4)

RGB values in safe colors

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.

RGB safe color cube



6 x 6 x 6 = 216 colors

◇ RGB Color Model (5)

6 x 6 x 6 = 216 colors

216 safe RGB colors

FFFFCC

FFFFFF

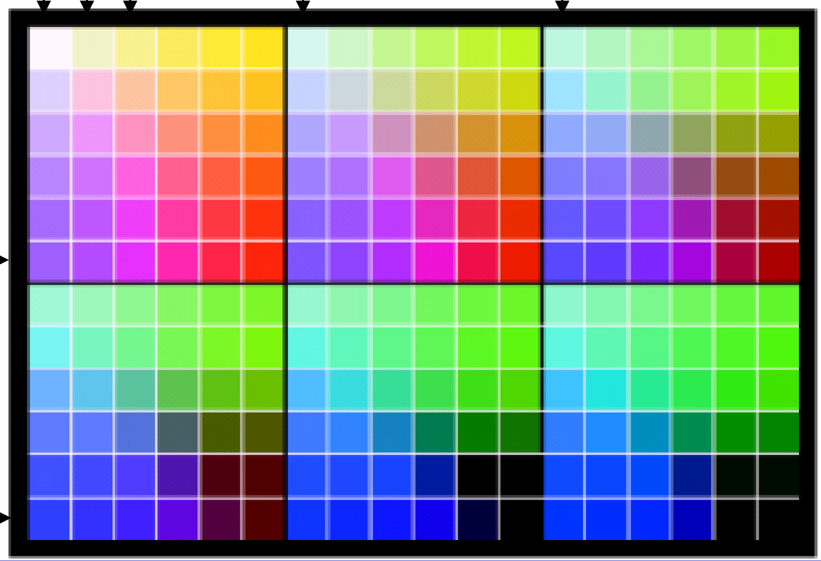
FFFF99

CCFFFF

99FFFF

FF00FF

6600FF

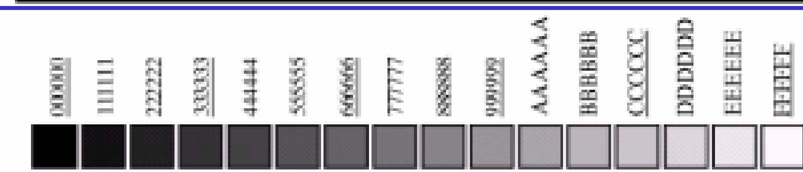


000000

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).

All the grays in 256 colors



Underlined grays are inside safe color group.

6.2.2 CMY and CMYK Color Model

- CMY : Cyan, Magenta, Yellow
  - The secondary colors of light
  - The primary colors of pigments
- Applications : Color printer, Color copier
- CMYK (CMY+K)
  - Equal amounts of the pigment primaries (cyan, magenta and yellow) should produce black.
  - In practice, combining these colors for printing produces a muddy-looking black
  - In order to produce true black, a fourth color, *black*, is added
- Conversion from RGB to CMY

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

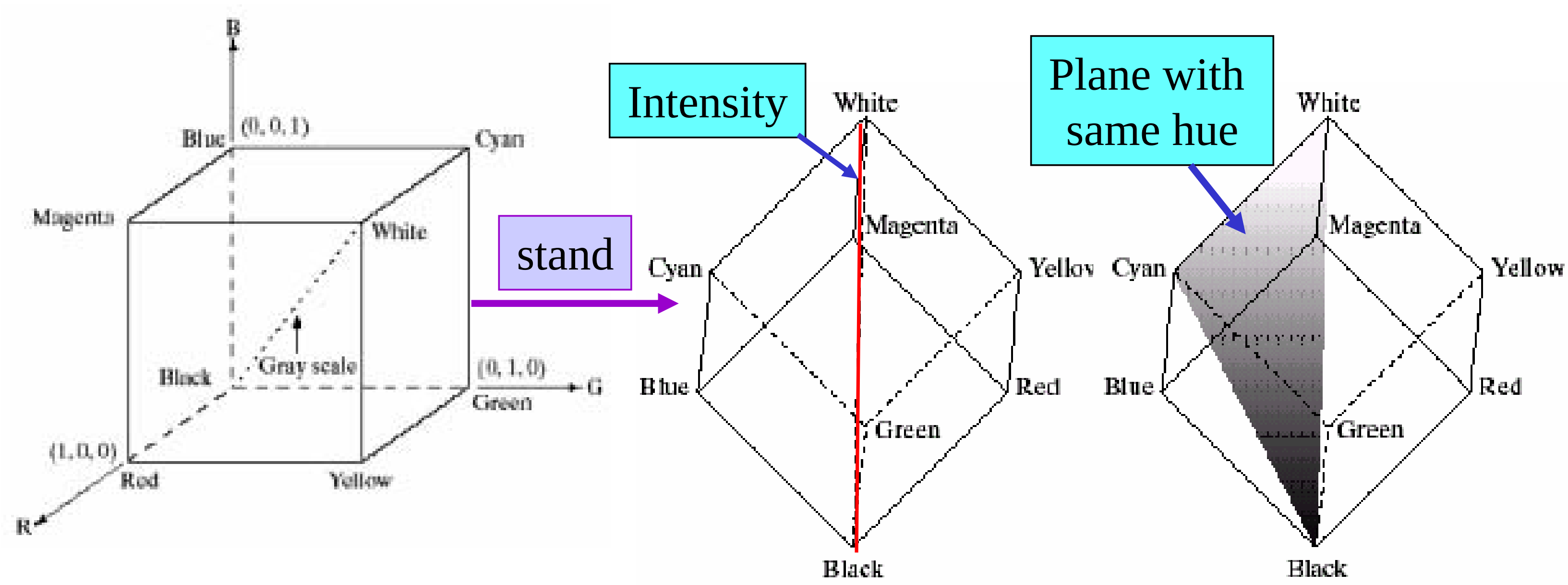
6.2.3 HSI Color Model (1)

- H(hue), S(saturation), I(intensity)
- The intensity component is decoupled from the color information (hue and saturation).
- The HSI components are intimately related to the way in which human beings perceive color.
  - Human does not perceive the color by giving the percentage of each of the primaries composing its color but its hue, saturation and brightness.
- HSI vs RGB model
  - The HSI model is an ideal tool for developing image processing algorithms based on color descriptions that are natural and intuitive to humans.
  - RGB model is ideal for image color generation as in color camera or monitor.

◇ HSI Color Model (2)

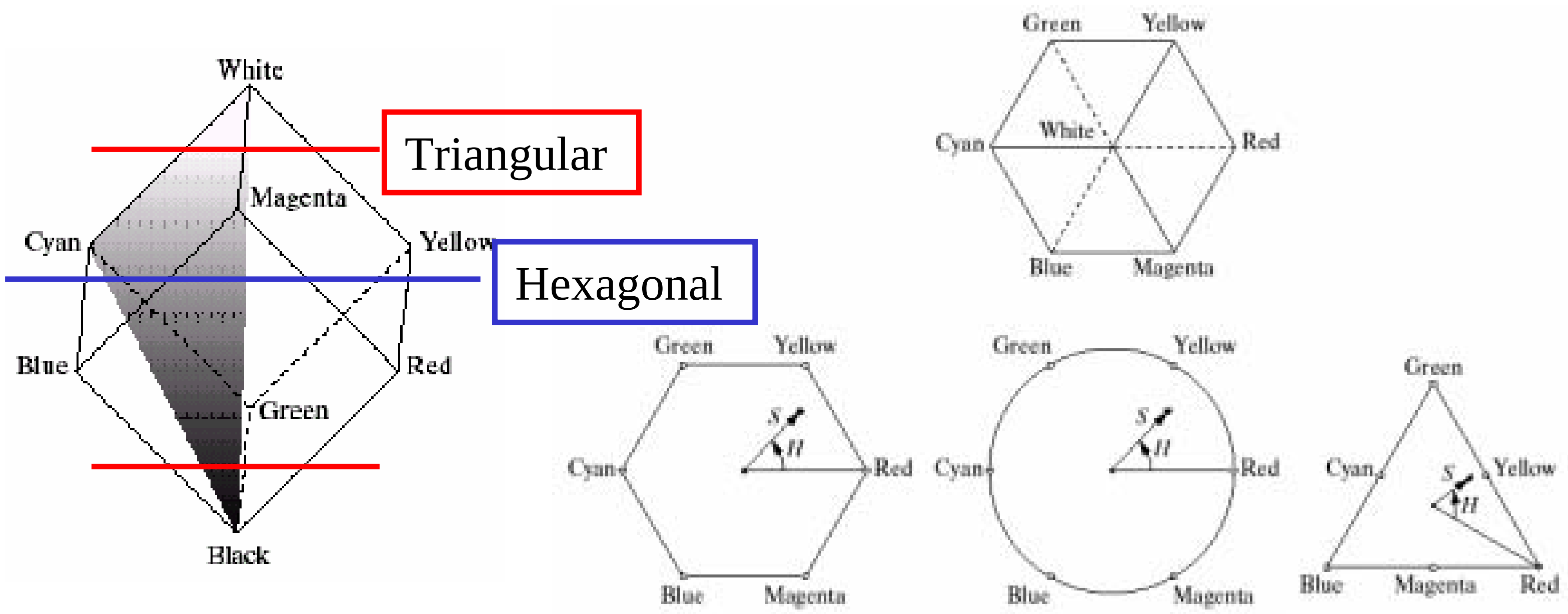
RGB model

HSI model



- The HSI model can be obtained by standing the RGB color cube on the black (0,0,0) vertex, with the white vertex (1,1,1) directly above it.

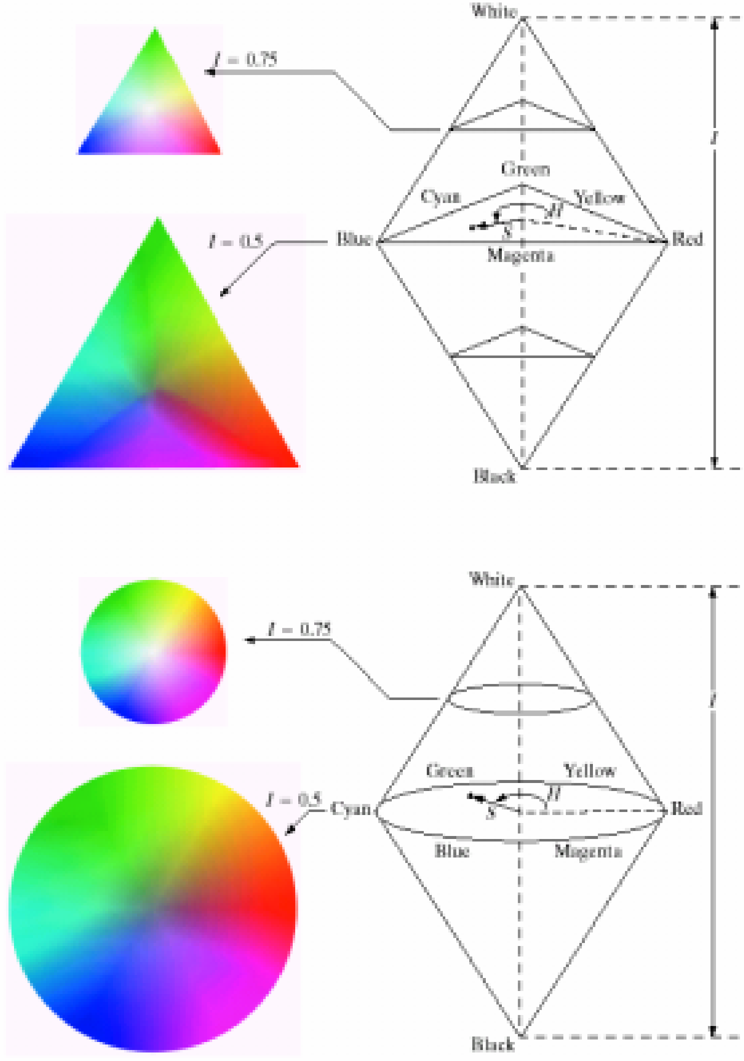
◇ HSI Color Model (3)



- Hue and saturation in the HSI model
  - Planes perpendicular to the intensity axis
  - The planes have a triangular or hexagonal shape.
- Hue
  - An angle from some reference point (usually red)
  - The primary colors(RGB) are separated by 120^{o}
  - The secondary colors(CMY) are 60^{o} off from the primaries.
- Saturation (distance from the vertical axis)
  - Length of the vector from the origin to the point

Shape of model does not matter since one shape can be converted into another by warping.

◇ HSI Color Model (4)



HSI color model

(a) Triangular plane

(b) Circular plane

◇ HSI Color Model (5)

- Conversion from RGB to HSI

The hue component

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

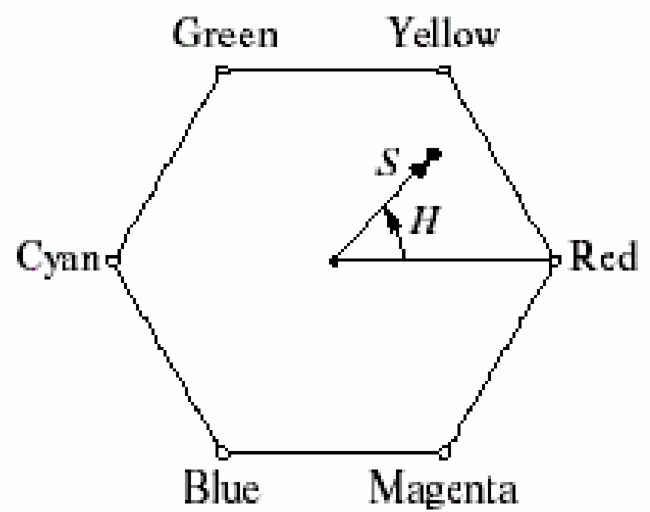
$$where, \quad \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G) + (R-B)\right]}{\left[(R-G)^2 + (R-B)(G-B)\right]^{1/2}} \right\}$$

The saturation component

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

The intensity component

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



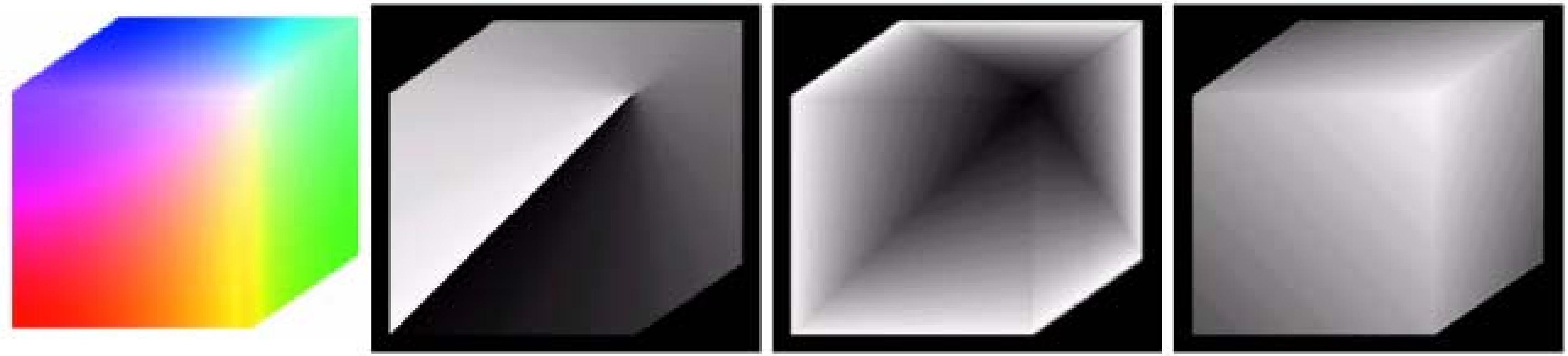
◇ HSI Color Model (6)

- Conversion from HSI to RGB

RG sector	GB sector	BR sector
$0^{o} < H \leq 120^{o}$	$120^{o} < H \leq 240^{o}$	$240^{o} < H \leq 360^{o}$
	$H = H - 120^{o}$	$H = H - 240^{o}$
$B = I(1-S)$	$R = I(1-S)$	$G = I(1-S)$
$R = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$	$G = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$	$B = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$
$G = 3I - (R+B)$	$B = 3I - (R+G)$	$R = 3I - (G+B)$

◇ HSI Color Model (7)

HSI components of the RGB model



(a) RGB model (b) Hue (c) Saturation (d) Intensity

- Fig. 6.15(b) : Discontinuity along a 45^{o} line is the boundary between the lowest(red) and the highest(magenta) value of hue
- Fig. 6.15(c) : Progressively darker values toward the white vertex
- Fig. 6.15(d) : The average of the RGB values

◇ HSI Color Model (8)

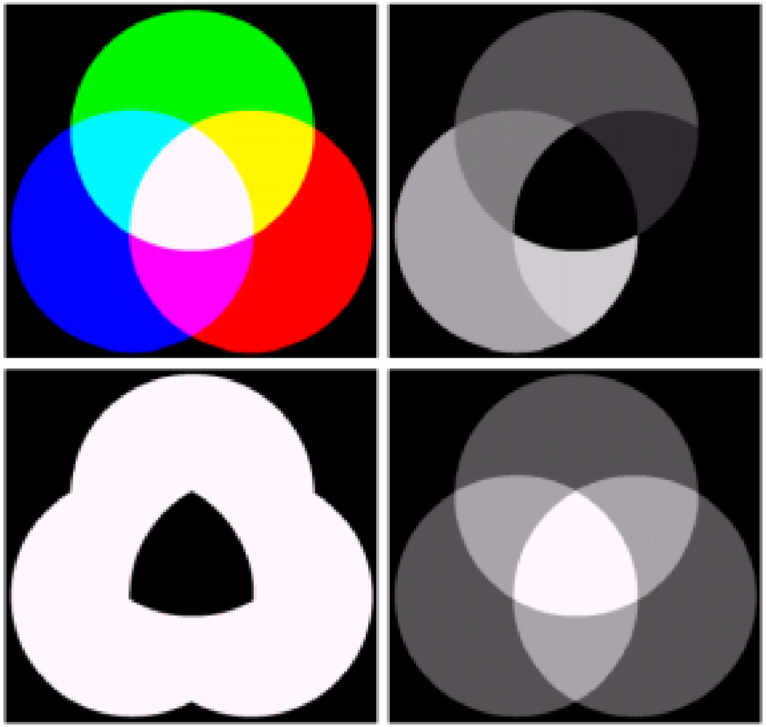
The RGB image and HSI components

(a) RGB

(b) Hue

(c) Saturation

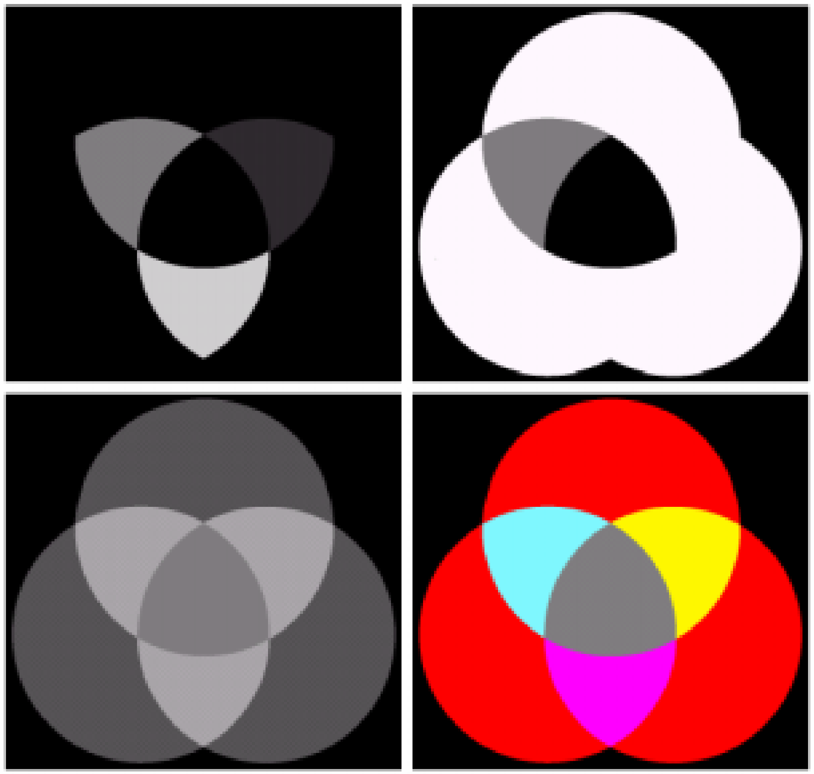
(d) Intensity



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.

◇ HSI Color Model (9)



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.)

Manipulating HSI components

-Fig.(a) : change to 0 the pixels in the blue and green region
- Fig.(b) : reduce by half the saturation of the cyan region
- Fig.(c) : reduce by half the intensity of the central white region
- Fig.(d) : convert HSI to RGB

- This means independent control over hue, saturation and intensity in the HSI model
- The HSI model is the powerful tool in manipulating the image

6.3 Pseudo Color Image Processing

- Pseudocolor (called *false color*) image processing consists of assigning colors to gray values based on a specified criterion
- The principal use of pseudocolor is for human visualization and interpretation of gray-scale events in an image or a sequence of images.
- Methods

  - Intensity Slicing

  - Gray Level to Color Transformations

6.3.1 Intensity Slicing (1)

- The technique of intensity slicing and color coding is one of the simplest examples of the pseudocolor image processing.
- An intensity slicing and color coding method
  - Place a plane parallel to the coordinate plane of the image
  - The plane at $f(x,y) = l_i$ slices the image function into two levels.
  - Different colors are assigned to each side of the plane
  - Appearance of a two-color image can be controlled by moving the slicing plane up and down the gray-level axis.

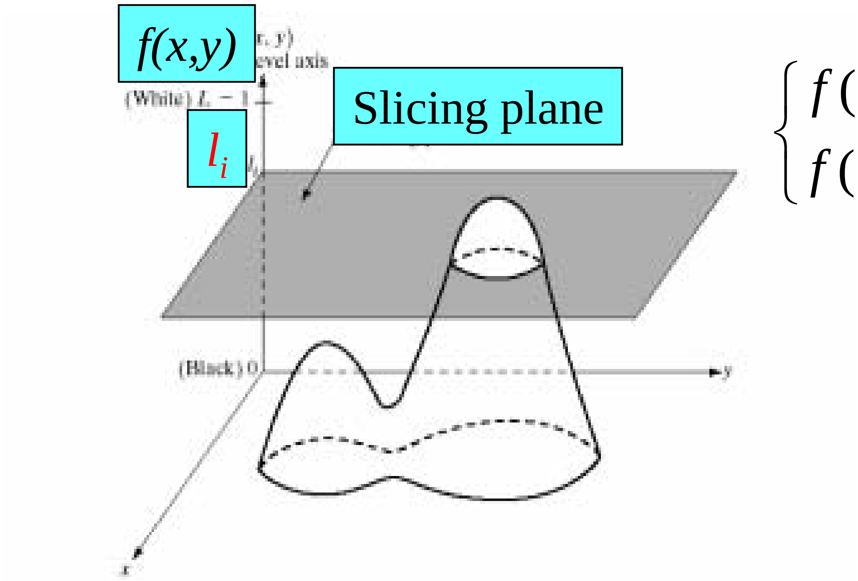


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

$$\begin{cases} f(x,y) \geq l_i \ \ \textit{assign one color} \\ f(x,y) < l_i \ \ \textit{assign a different color} \end{cases}$$

◇ Intensity Slicing (2)

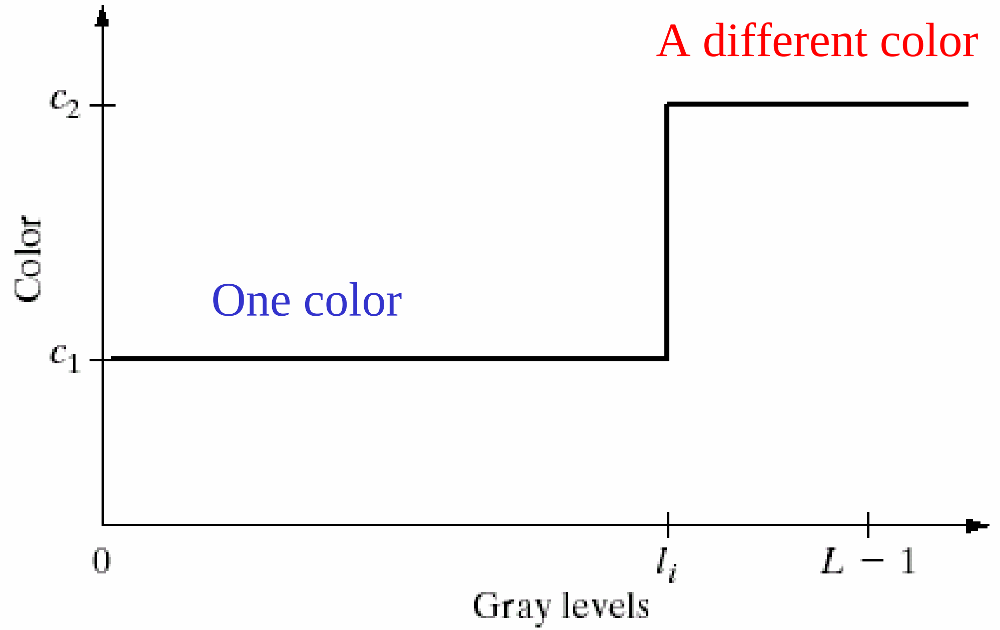


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

◇ Intensity Slicing (3)

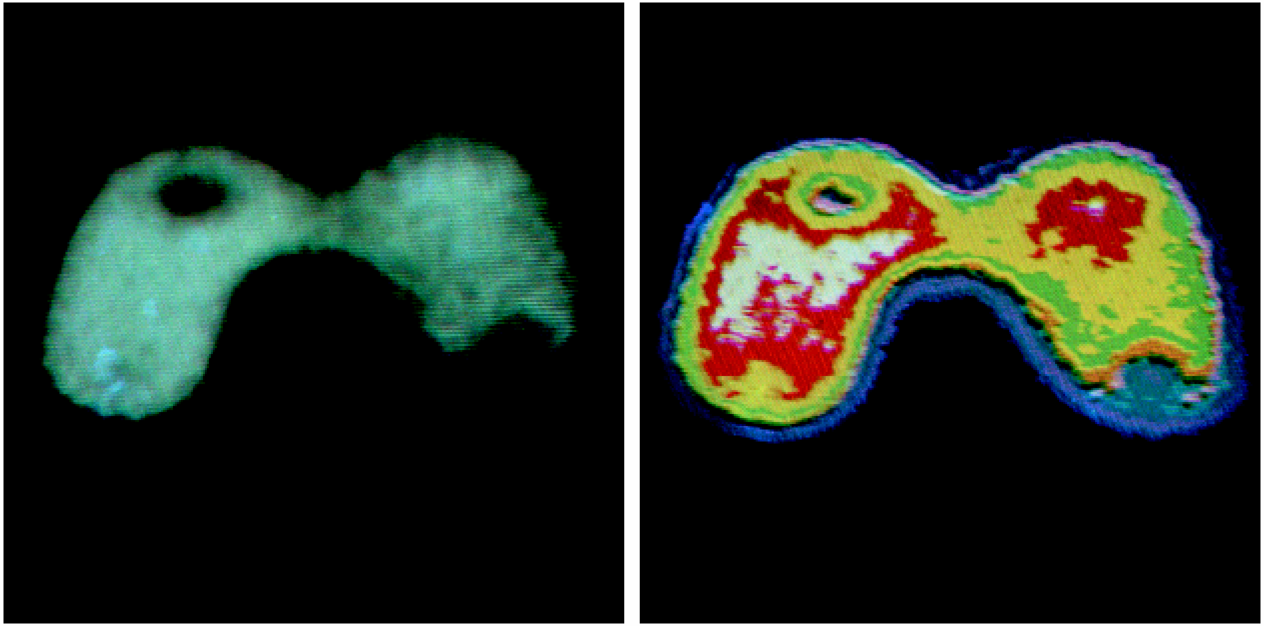
- Generalization of the intensity slicing method
  - Suppose that *P* planes are defined at gray levels $l_1, l_2, \ldots, l_p$ between the gray scale interval [0, L-1]
  - Then, the *P* planes partition the gray scale into *P+1* intervals, $V_1, V_2, \ldots, V_{p+1}$.
  - Color is assigned to gray-level in each interval.

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

C_k : a color

V_k : *kth* intensity interval

◇ Intensity Slicing (4)



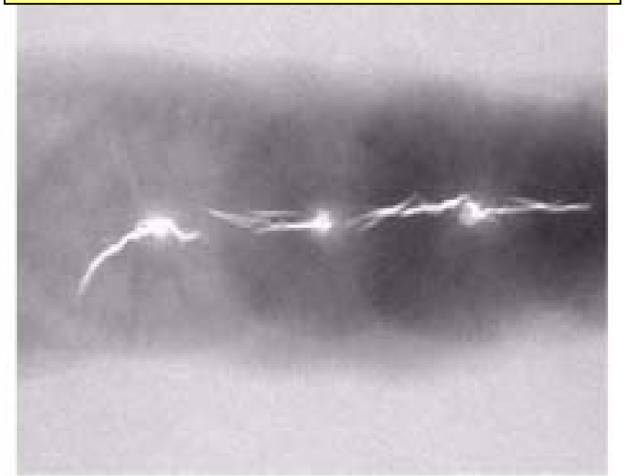
(a) A monochrome image (b) Pseudocolor image

- Fig.(a) : A monochrome image of the Picker Thyroid Phantom
- Fig.(b) : The result of slicing the intensity of the image into eight color regions and assigning eight different colors to the regions
- Regions that appear of constant intensity in the monochrome image are really quite variable as shown in the pseudocolor image.

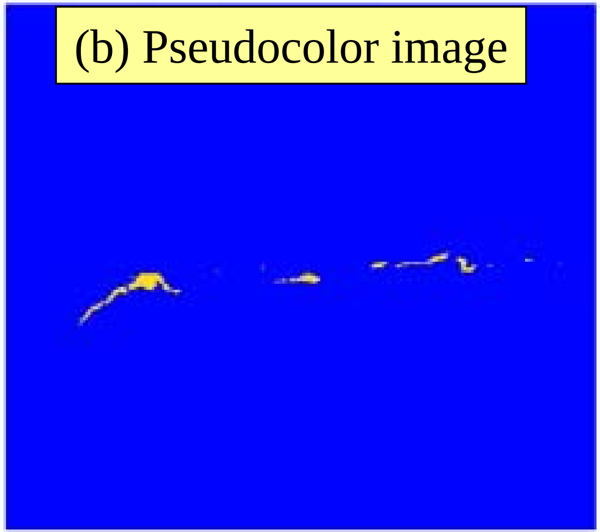
◇ Intensity Slicing (5)

- Intensity slicing plays much more meaningful and useful role, when the gray scale is divided on the basis of the physical characteristics.
- An X-ray image of a weld (the horizontal dark region) containing several cracks and porosities (the white region)
- The region with gray level 255 implies the problem with weld, since the full strength of the X-rays saturates the image sensor through the cracks and porosities.
- A simple color coding assigns one color to level 255 and another to all other gray levels.
- If a human inspects the weld with the pseudo-color image, the error rates of the inspection would be lower.

(a) An X-ray image of a weld

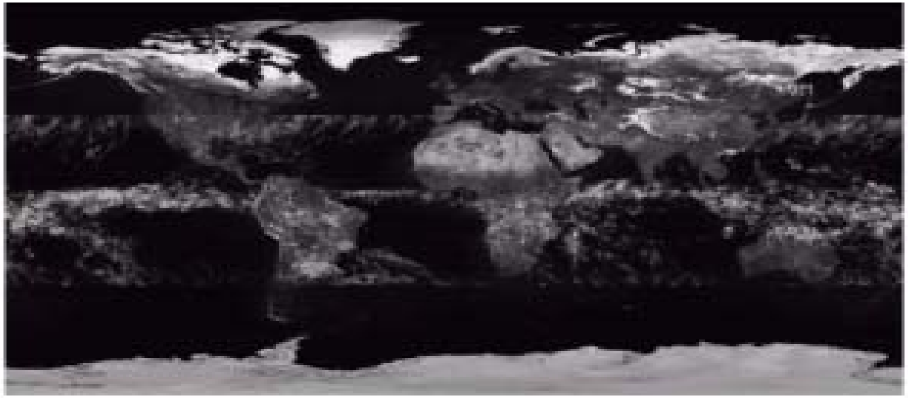


(b) Pseudocolor image



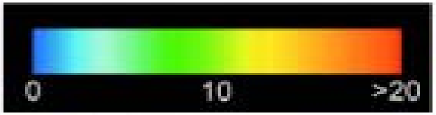
◇ Intensity Slicing (6)

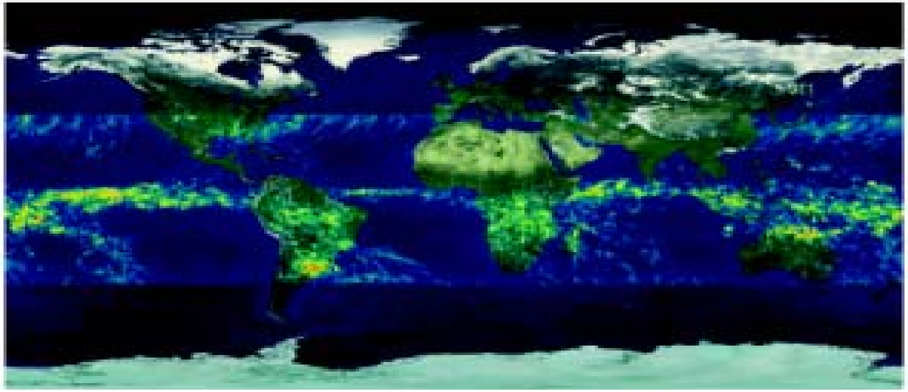
- Measurement of rainfall levels in the tropical regions of the Earth Using the satellite

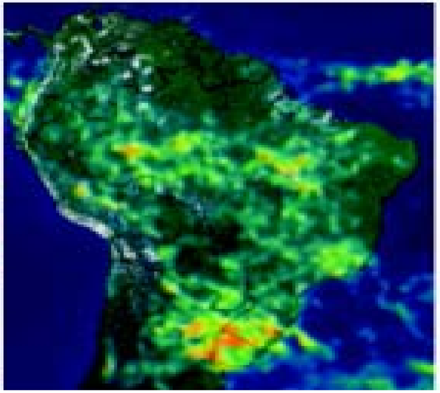


(a) Gray scale image

(b) Colors assigned to intensity values







(c) Color coded image

(d) Zoom of the South America area

◇ Intensity Slicing (7)

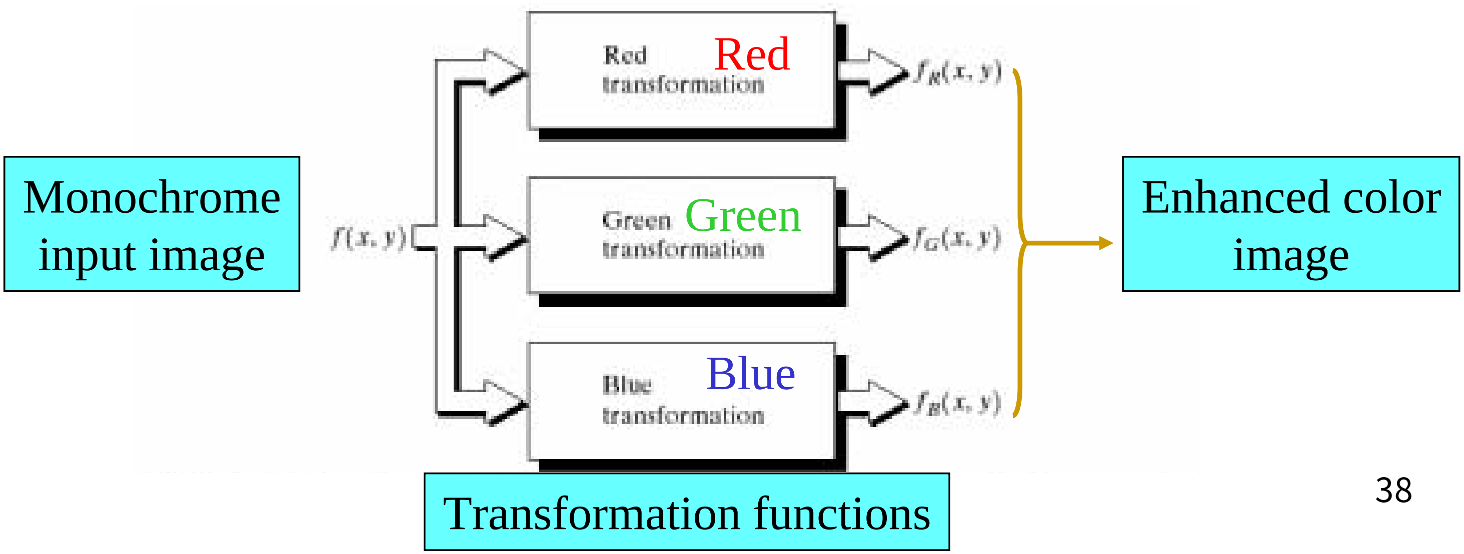
- Fig. 6.22(b)
  - Values toward the blues signify low values of rainfall, with the opposite being true for red
  - Note that the scale tops out at pure red for values of rainfall greater than 20 inches

- Fig. 6.22(c) and (d)
  - Color coding of the gray image with the color map
  - It is much easier to interpret with this result.

6.3.2 Gray Level to Color Transformations (1)

Color transformations in monochrome input image

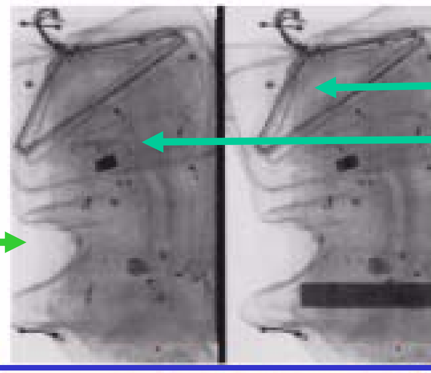
- Other types of transformations are more general than the slicing technique.
- Thus, they can achieve wider range of pseudocolor enhancement results.
- An approach of other types of transformations
  - Perform three independent transformations on the gray level of any input pixel
  - The three results are fed separately into the red, green, and blue channels.
  - Color content of the enhanced image is modulated by the transformation functions



◇ Gray Level to Color Transformations (2)

• Two images of the luggage obtained from an airport X-ray scanning system

(a) Monochrome images

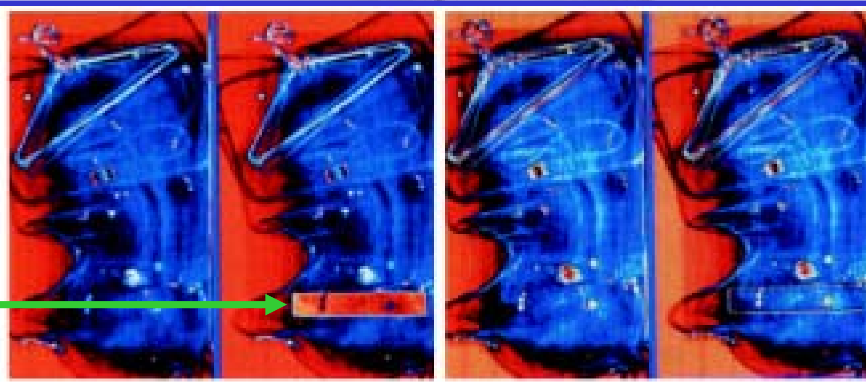


Ordinary articles

Background

Plastic explosive

(b) Enhanced color images



Plastic explosive

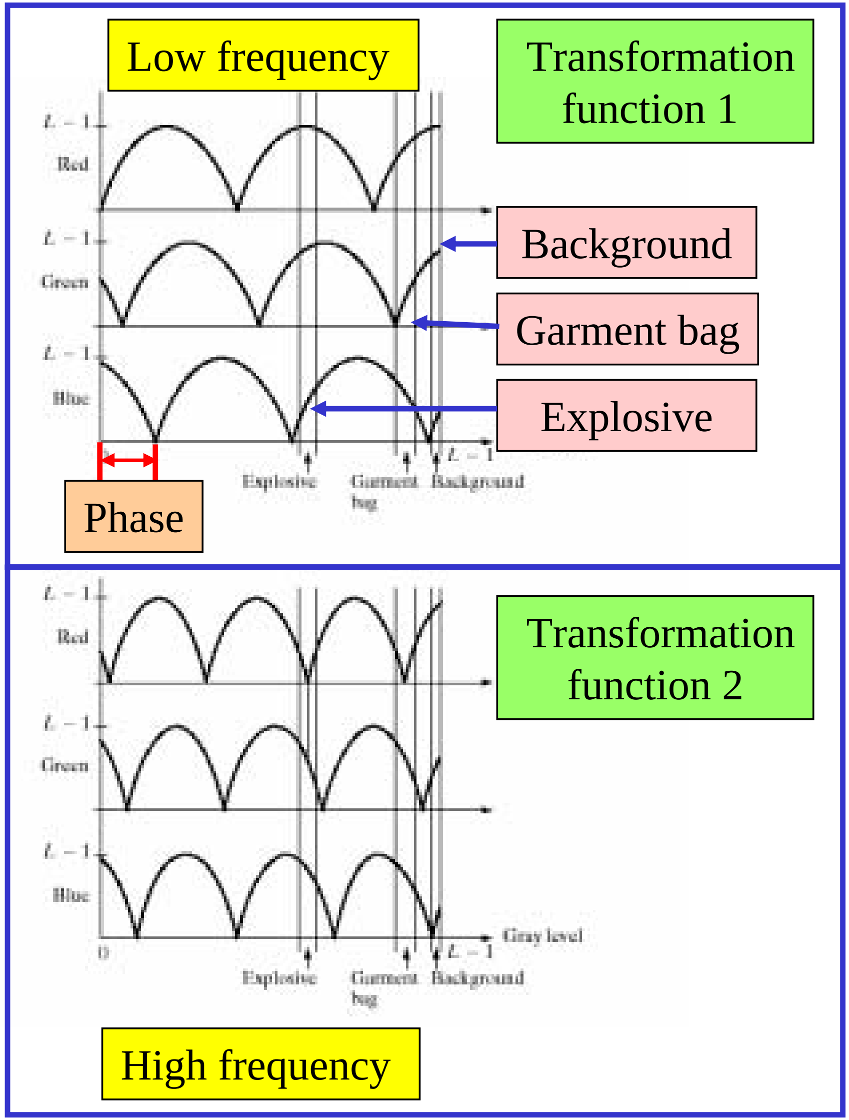
Plastic explosive

Transformation function 1

Transformation function 2

◇ Gray Level to Color Transformations (3)

- Transformation functions
  - Sinusoidal functions are used
- Characteristics of the sinusoid functions
  - Relatively constant around the peak
  - Rapidly change near valleys
  - Changing the phase and frequency of each sinusoid can emphasize (in color) ranges in the gray scale
- Effects of the phase and frequency change
  - If all three functions have the same phase and frequency, the output image is monochrome
  - A small change in phase produces little change in pixels whose gray levels correspond to peaks in sinusoid
  - Pixels with gray levels near valleys are assigned a much stronger color as a result of significant differences between the amplitudes of the three sinusoids



◇ Gray Level to Color Transformations (4)

- Monochrome input images

  - The explosive, garment bag and background have the different gray-level bands.

- The color image enhanced by transformation function 1

  - The explosive and background have quite different gray-level bands, but they are both coded with approximately the same color as a result of periodicity.

- The color image enhanced by transformation function 2

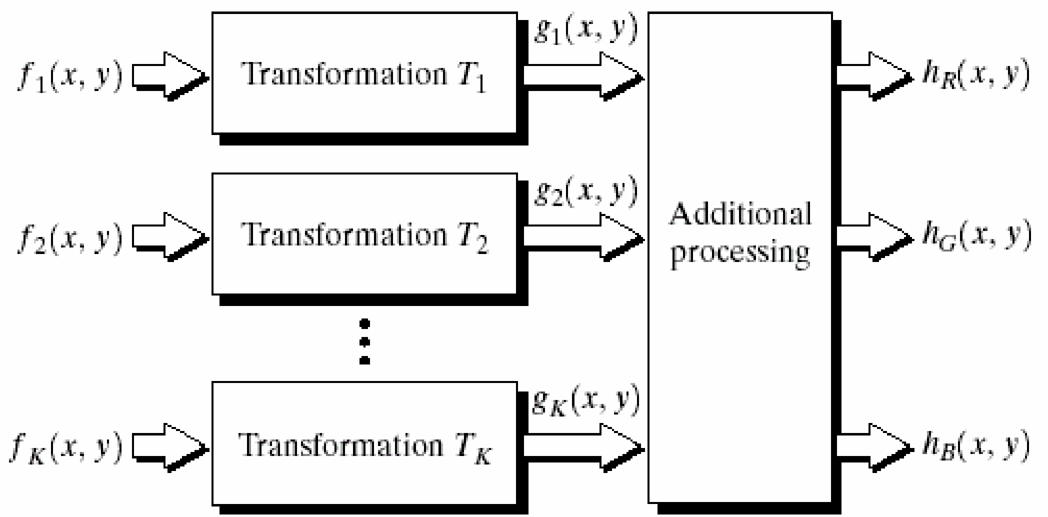
  - The explosive and garment bag intensity bands were mapped by similar transformations and thus received essentially the same color assignments.

◇ Gray Level to Color Transformations (5)

Color transformations in multi-spectral input images

- The previous approach is based on a single monochrome image.
- Another approach is to combine several monochrome images into a single color composite.
- The monochrome images are obtained from the sensors with different spectral bands.
- This approach is frequently used in multi-spectral image processing.

Several monochrome images



Single color composite

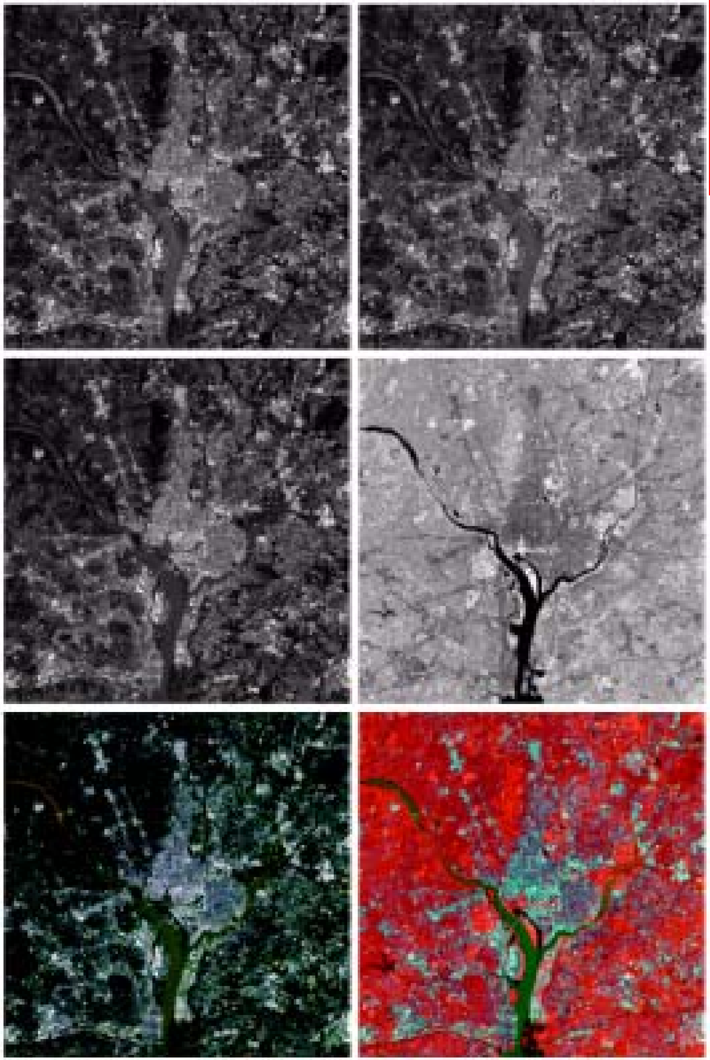
FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

◇ Gray Level to Color Transformations (6)

- Fig. 6.27(a)-(d) : Four spectral satellite images of Washington D.C including the Potomac River (see Section.1.3.4, Table 1.1)
  - (a)-(c) : Visible red, green and blue band
  - (d) : The near infrared band

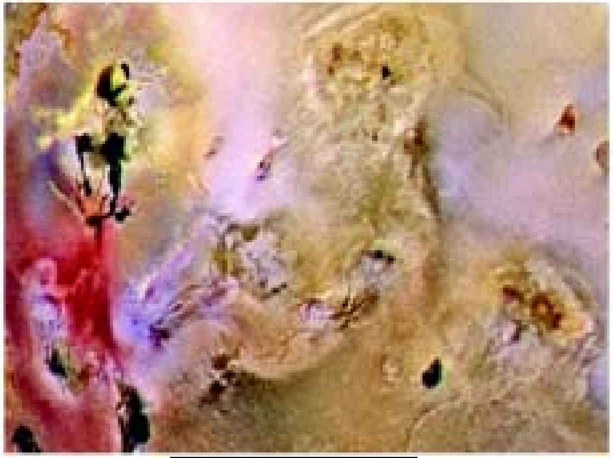
- Fig. 6.27(e) : The full-color image
  - Obtained by combining the first three images into an RGB image
  - Difficult to interpret, but notable feature is the difference in color in various parts of the Potomac River

- Fig. 6.27(f) : Another full-color image
  - Formed by replacing the red component of Fig.(e) with near-infrared band, Fig.(d)
  - Shows clearly the difference between biomass (in red) and the human-made features (concrete and asphalt) in the blue region



◇ Gray Level to Color Transformations (7)

Pseudo-color rendition of the Jupiter Moon Io



A close-up

An excellent illustration of this method

- These images are a combination of several sensor images from the Galileo spacecraft.
- Some of the sensor images are in invisible spectral regions.
- The Combination is based on understanding of differences in surface chemical composition or changes in the way the surface reflects sunlight.
- For example, bright red materials are newly ejected from active volcano on Moon Io
- Surrounding yellow materials are older sulfur deposits
- These images convey the characteristics much more readily than would be possible by analyzing the component images individually