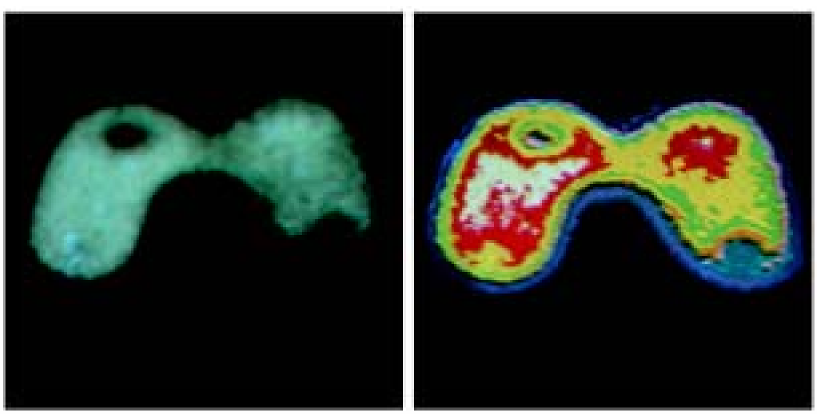
COLOR IMAGE PROCESSING

Why do we use color image (motivation):

- In automated image analysis, color is a powerful descriptor→ simplify object identification and extraction from a scene
- For human vision→ human eye can discern thousands of color shades and intensities (only two dozen shades of gray)

• Two major areas:

- Full color processing→ images are acquired with a full-color sensor (color TV camera or color scanner …)
- Pseudo-color processing→ pseudo-color images are generated by assigning a shade of color to a monochrome intensity (or range of intensities)



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.)

Outlines

- Color Fundamentals
- Color Models
- Pseudocolor Image Processing
- Basics of Full-Color Image Processing
- Color Transformation

Color Fundamentals

Achromatic versus chromatic

- achromatic light: void of color, only attribute is its intensity measured by gray levels , e.g., black-and-white TV (the kind of images that we discussed so far)
- chromatic light: (wavelength: 400~700nm) 3 basic quantities are used to describe the quality of a chromatic light source:
  - radiance: total amount of energy that flows from the light source (in watts)
  - luminance: amount of energy an observer perceives from a light source (in lumens, lm); e.g., far infrared light has large radiance, but an observer would hardly perceive it
  - brightness: (a subjective descriptor) similar to the achromatic notion of intensity, one of the key factors in describing color sensation

Primary colors versus secondary colors (of light):

- primary colors: red (R), green (G), blue (B); note RGB components acting alone cannot generate all spectrum colors
- secondary colors: magenta (R+B), cyan (G+B), yellow (R+G)
- mixing the 3 primaries ⇨ white light

Primary colors versus secondary colors (of pigments):

- primary colors: magenta, cyan, yellow (def: absorb a primary color of light and reflect or transmit the other two)
- secondary colors: R, G, B

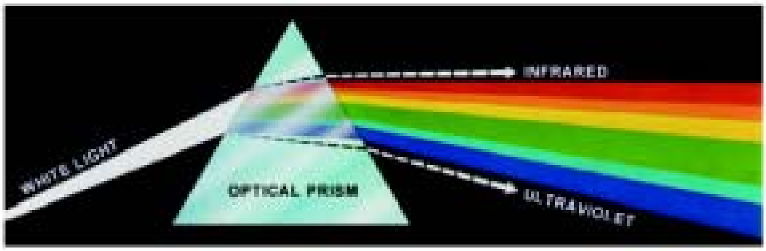


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

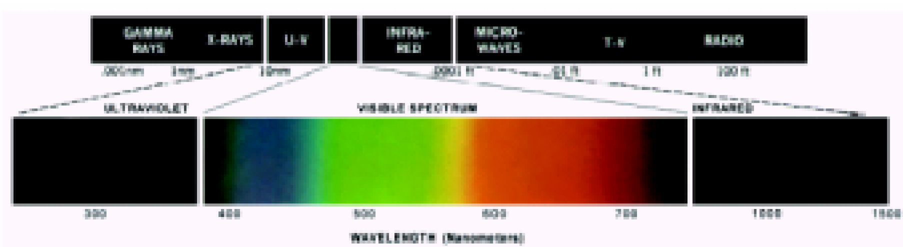


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

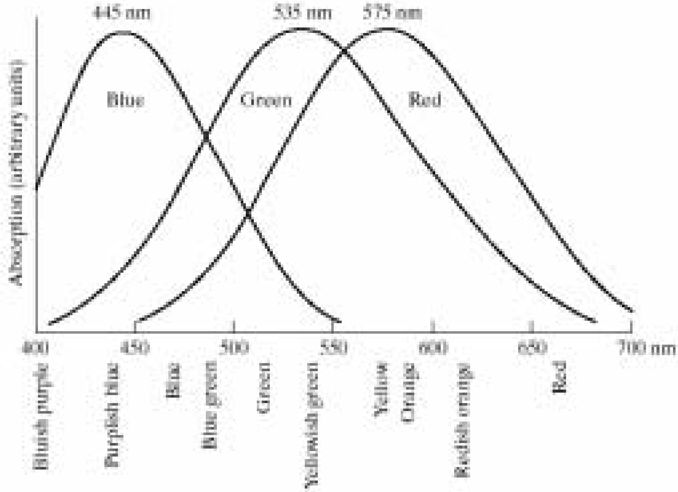
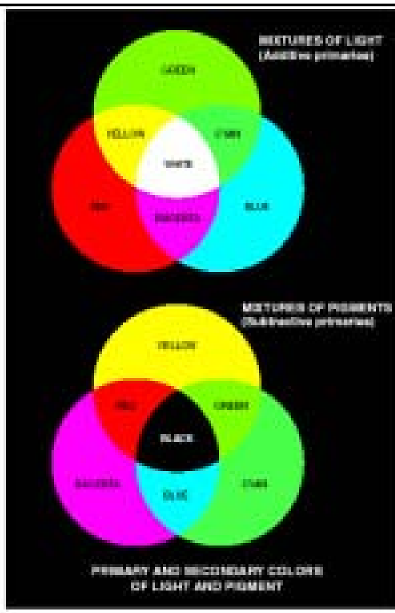


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



Primary/secondary colors of light

Primary/secondary colors of pigment

a
b

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

3 characteristics used to distinguish one color from another: brightness, hue, saturation

- brightness: chromatic notion of intensity
- hue: attribute associated with the dominant wavelength in a mixture of light waves (dominant color perceived by an observer); e.g., we call an object red or yellow⇨ we specify its hue
- saturation: relative purity (e.g., the pure spectrum colors, red, orange, yellow, green, blue, and violet, are fully saturated); pink is less saturated
- hue+saturation⇨ chromaticity
- tristimulus values: amounts of R, G, and B needed to form a particular color (X, Y, Z)

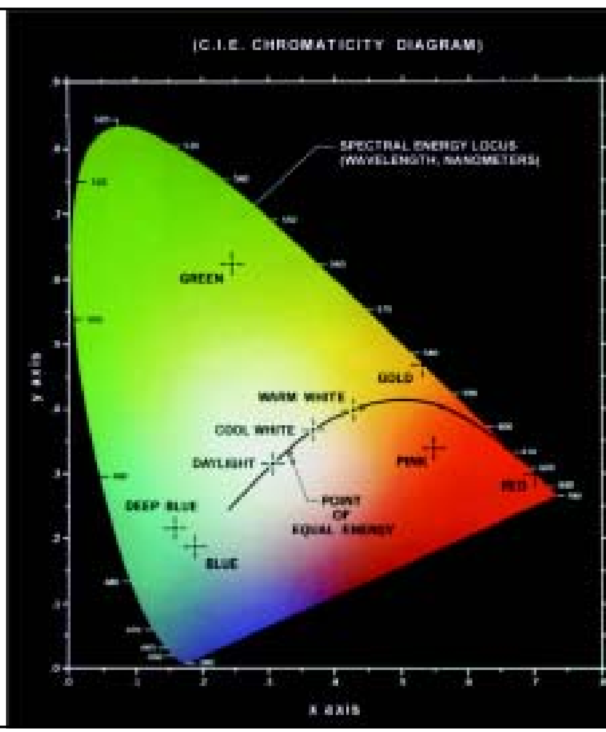
- Trichromatic coefficients: proportion of R, G, and B (x, y, z)

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

so $\boldsymbol{x+y+z=1}$

- Chromaticity diagram— a function of x (red) and y (green)
  - – point of equal energy (x=y=z)⇨ white light
  - – any point located on the boundary of the chromaticity chart (Plate IV)⇨ completely saturated
  - – a point leaves the boundary and approaches the point of equal energy⇨ saturation→0

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

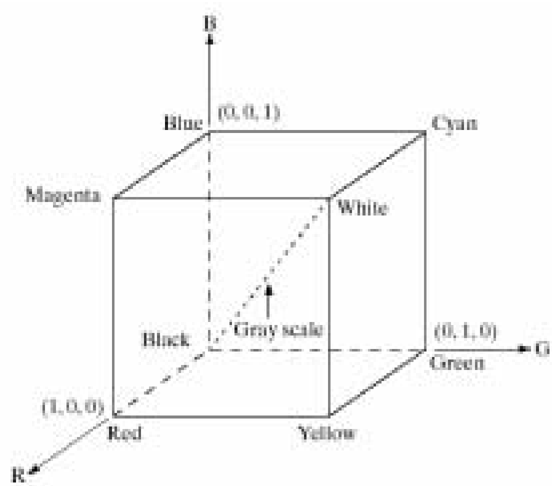


Color Models

- Color models: to facilitate the specification of colors, a color model is used to specify a 3D coordinate system for color representation
  - Hardware-oriented color models: RGB model for color monitors and color video cameras, CMY model for color printers; YIQ model for color TV broadcast

- RGB color model
  - ①p.226, Figure 4.44: normalized to [0,1] (unit cube)
    - 3 coordinates: red, green, blue
    - 3 corners: cyan, magenta, yellow
    - origin: black
    - (1,1,1): white
  - ②images in RGB model⇨ 3 independent image planes (red, green, blue) that can be processed independently
  - ③one useful application: processing of aerial and satellite multispectral image data (one frame consists of 4 digital images taken through a different spectral range)⇨ each image plane has specific physical meaning; useful for image segmentation (based on spectral components)

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 cube. Points along the main diagonal have gray values

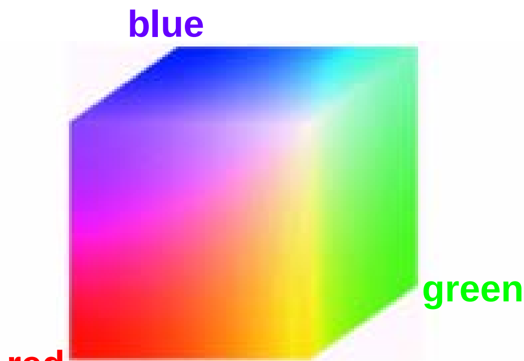
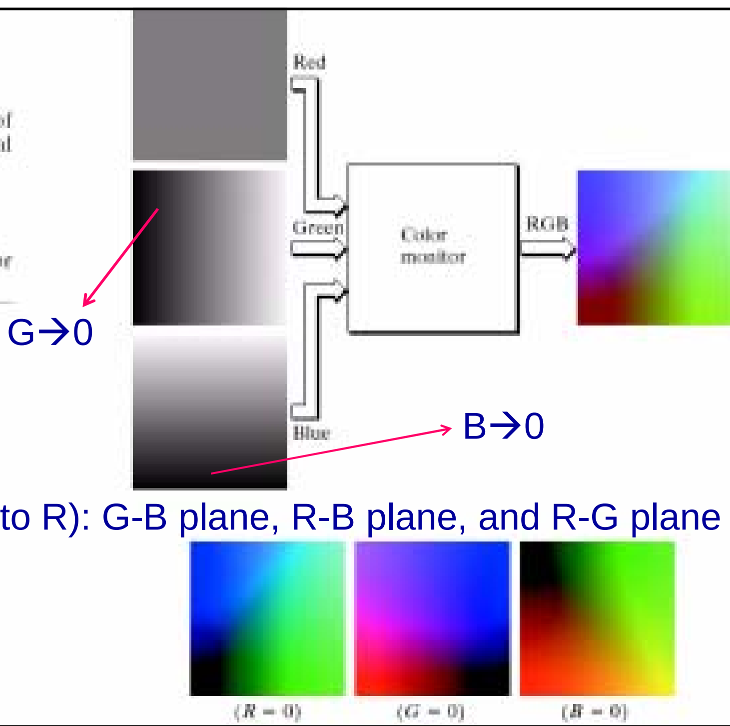


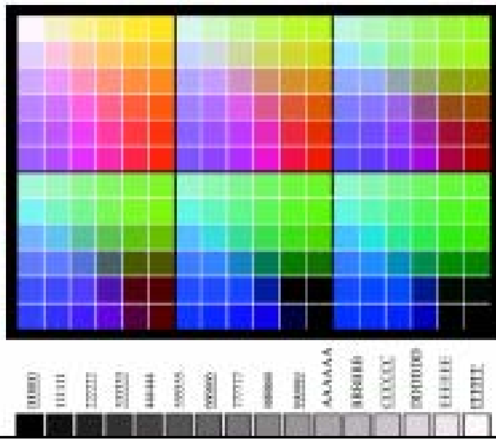
FIGURE 6.8 RGB 24-bit color cube.

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.



- Many systems are limited to 256 colors although 24-bit RGB image is available
- The set of safe (or, the set of all-systems-safe) RGB colors A subset of colors that are likely to be reproduced faithfully (reasonably independently of viewer hardware capabilities)



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).

- Assume all color values are normalized to [0,1]
- The CMY color model is used in connection with generating hardcopy output
- CMYK→ K is the fourth color, black; because equal amount of CMY produces a muddy-looking black, since black is the predominant color in printing, we need to produce true, pure black
- CMY color model:

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

HSI color model

- RGB and CMY are not well suited for describing colors for human interpretation
- Hue (H), saturation (S), and intensity (I)
  - Hue→ color attribute that describes a pure color (e.g., pure yellow or red)
  - Saturation→ a measurement of the degree to which a pure color is diluted by white light
  - Intensity→ can be decoupled from the color information (H and S)
- HSI is ideal for processing color image based on the color sensing properties of the human visual system

- I (intensity)→ The line joining vertex (0,0,0): black and vertex (1,1,1): white
- All points along this axis are gray

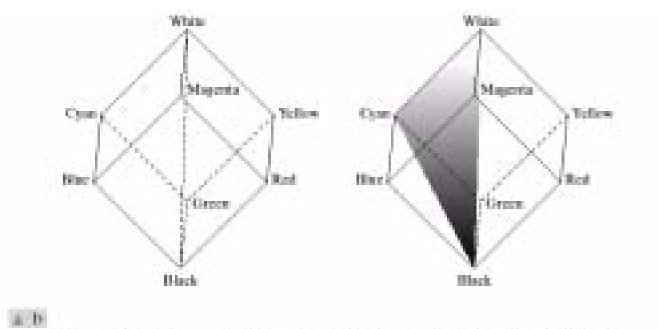


FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

- H (hue)→ All points in the plane defined by black, white, and color$_a$ have the same hue (color$_a$)

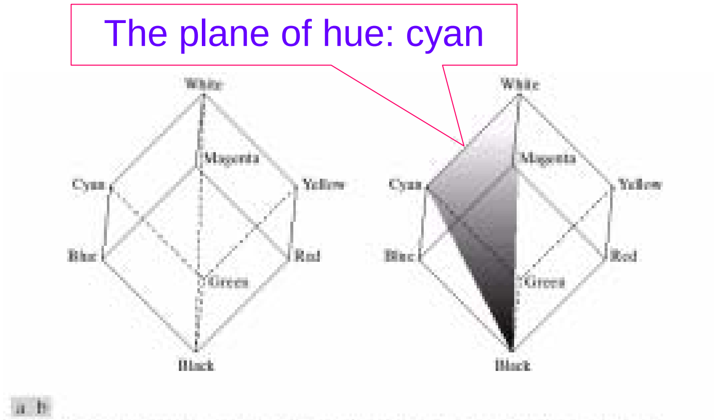
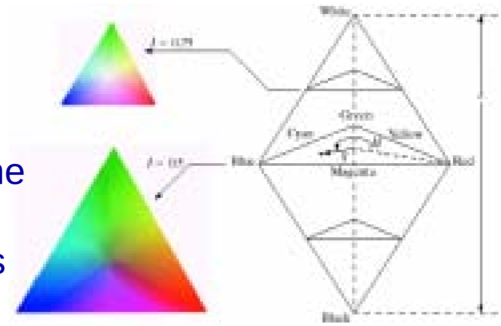


FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

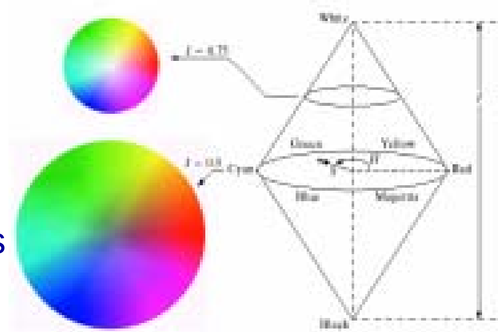
- S (saturation)→ To determine the saturation (purity) of color$_a$, draw a plane containing color$_a$ and perpendicular to the intensity axis and have the same hue (color$_a$); saturation is the perpendicular (shortest) distance between the point color$_a$ and the intensity axis
- Thus, the hue, saturation, and intensity values required to form the HIS space can be obtained from the RGB color cube

HIS color model

Triangular color plane perpendicular to the vertical intensity axis



Circular color plane perpendicular to the vertical intensity axis



RGB → HSI

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

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

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

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

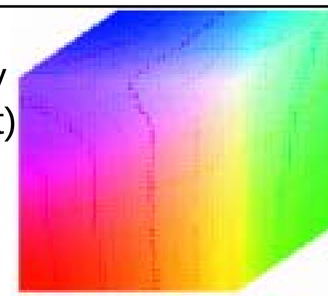
RGB ← HSI

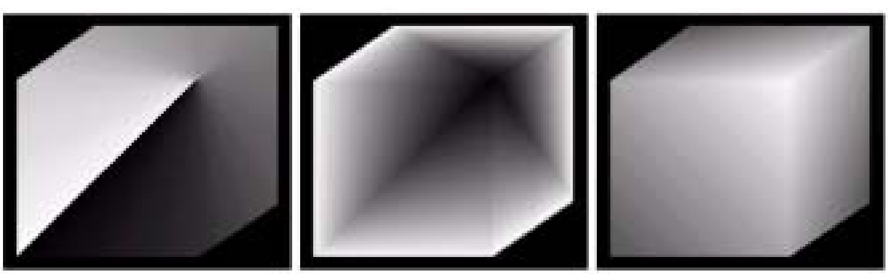
$$B = I(1 - S)$$

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

$$G = 1 - (R + B)$$

Hue (L), saturation (M), and intensity (R) images for the RGB values (right)





a b c

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

Pseudocolor Image Processing

- Pseudo-color image processing→ approaches for assigning color to monochrome images based on properties of gray-level content
- Discuss three approaches:
  - Intensity slicing and color coding
  - Gray-level to color transformations
  - Filtering approach

Intensity slicing (density slicing) and color coding

- Based on 3D representation of intensity function $f(x,y)=l$ (3 coordinates: x-, y-, l-axis)
  - step①: M planes defined by $f(x,y)=l_i$, i=1,..., M (l_0=0: the x-y plane, l_M =L) are used to slice the 3D function into M+1 regions R_k k=0,..., M
  - step②: assign color c_k to the (x_k,y_k) at region R_k $f(x_k,y_k)= c_k$
- An example⇨ strong color-region correlation

Intensity-slicing technique

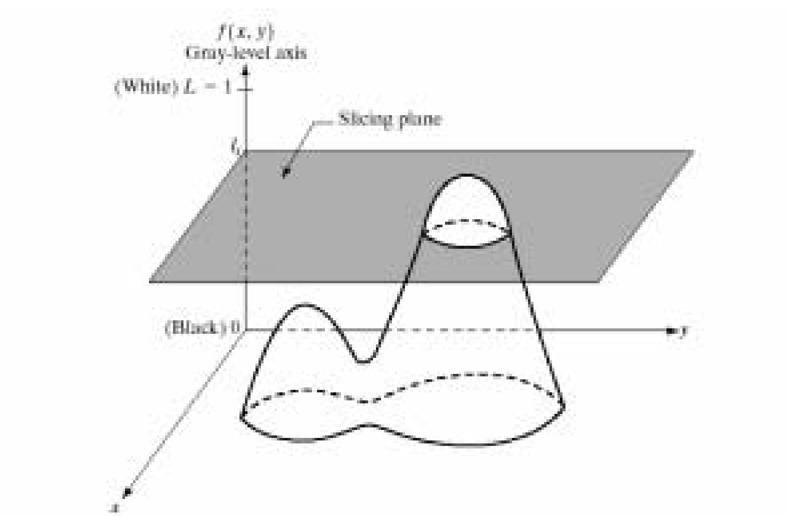
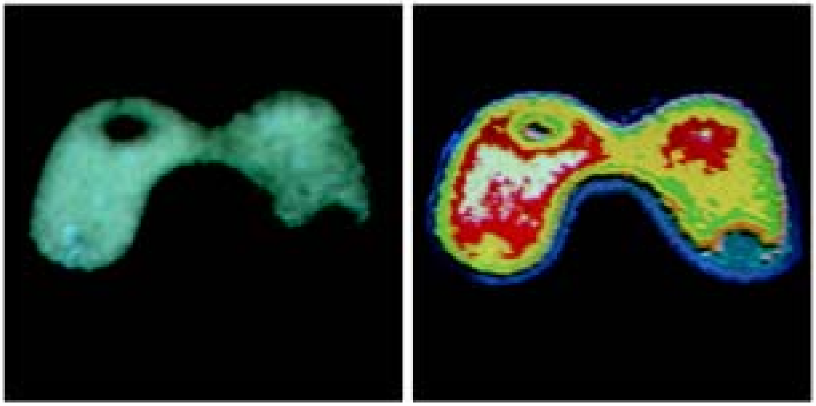


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

Monochrome image of the Picker Thyroid Phantom (a radiation test pattern)

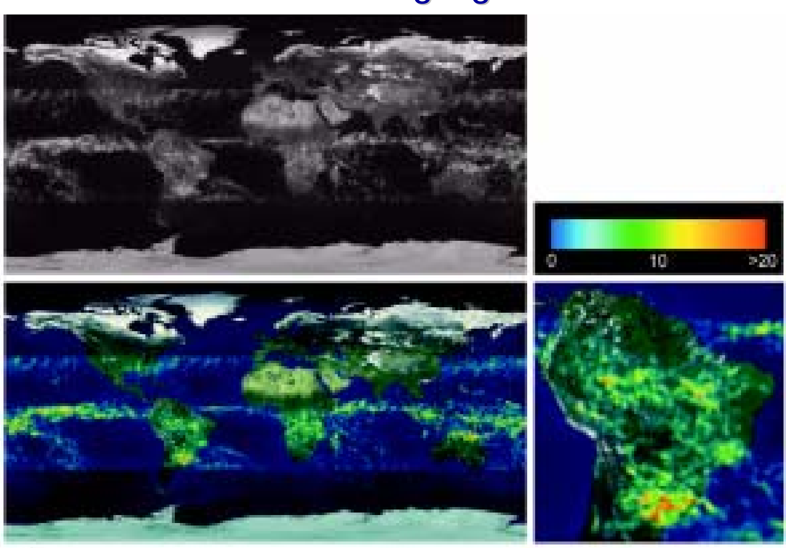
Result of density-slicing into 8 color regions



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.)

Use of color to highlight rainfall levels



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.)

Gray level to color transformations

- Perform three independent transformations on the gray level of any input pixel and combine the three results (e.g., for color television monitor: feed the 3 results separately into the red, green and blue guns)
- Properties: (Figure 6.25) phase and frequency of sinusoid affect color ranges in the gray scale (e.g. pixels with gray levels in the steep section of sinusoids are assigned a much stronger color content)

Figure 6.24 (images of luggage obtained from an airport x-ray scanning system)

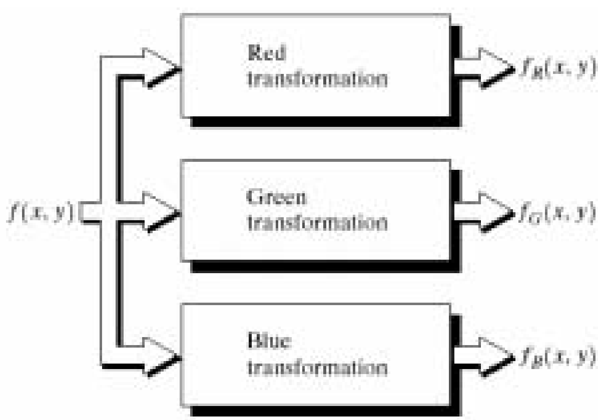
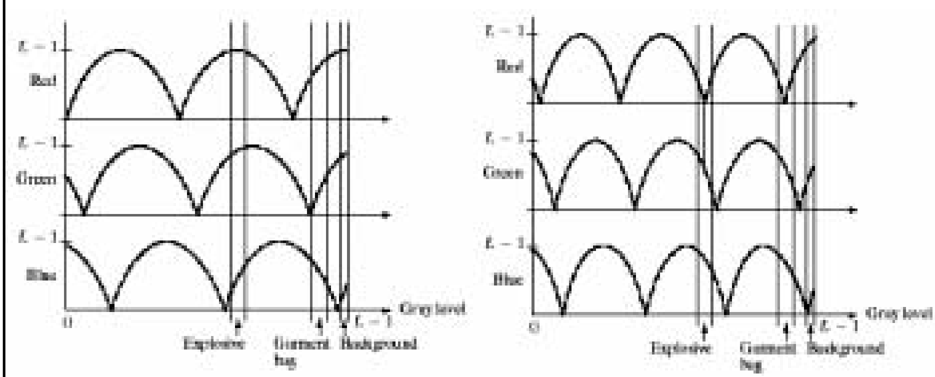


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

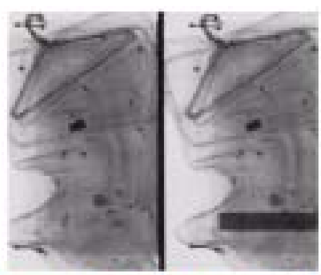
Gray level to color transformations

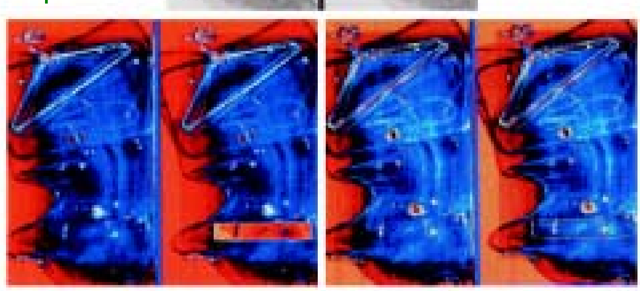
Transformation functions used to obtain images in Fig 6.24



Pseudo-color enhancement by Fig 6.25

2 images of luggage from airport x-ray scanning system
(left) ordinary articles
(right) same as left + a block of simulated plastic explosives





Obtained from Fig 6.25(a) Obtained from Fig 6.25(b)

a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

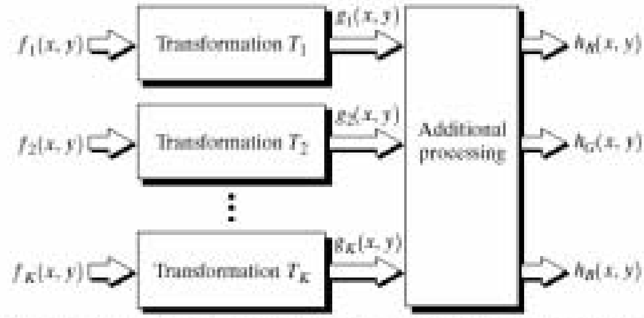


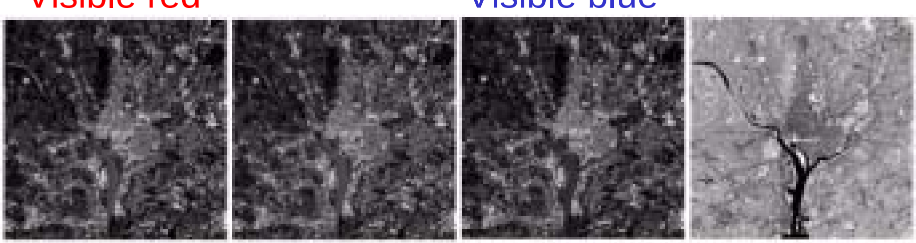
FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

- Combine several monochrome images into a single color composite
- Often applied in multispectral image processing (different monochrome images acquired by different spectral bands)

Spectral satellite images of Washington, D.C.
(from left to right) visible red, green, blue, and NIR

Visible red

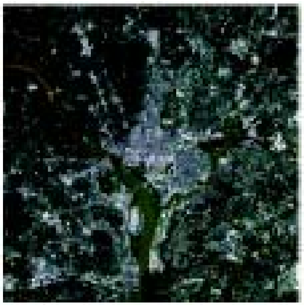
Visible blue



Visible green

Near infrared

Full-color image obtained by combining the visible red, green, and blue images (a)-(c) into an RGB image



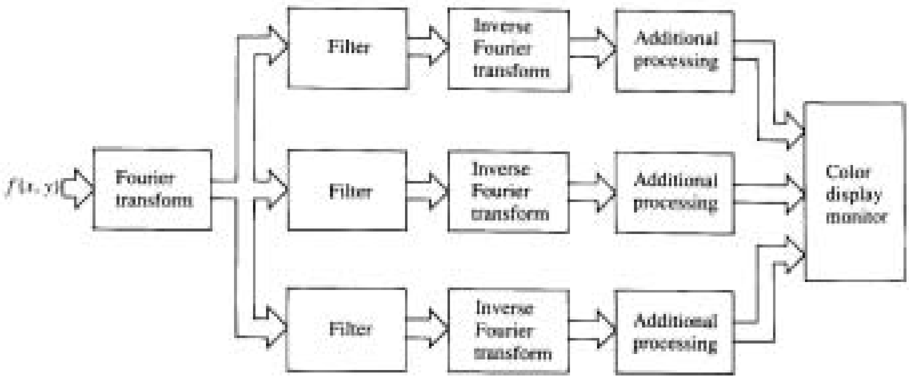
Full-color image obtained by combining the visible green, blue, and NIR images (b)-(d) into an RGB image

NIR→ strongly responsive to the biomass components (in red) of a scene, in comparison with the human-made features composed primarily of concrete and asphalt (in blue)

A filtering approach

- Color-coding scheme based on frequency domain operations—Fourier transform of an image is modified independently by 3 (different) filter functions to produce 3 images (representing red, green, blue image planes) which are fed into color monitor
- An image is color coded based on its frequency content

Figure 4.52 (1992 edition)



P.242 Fig 4.52
Filtering model for pseudo-color image processing

Basics of Full-Color Image Processing

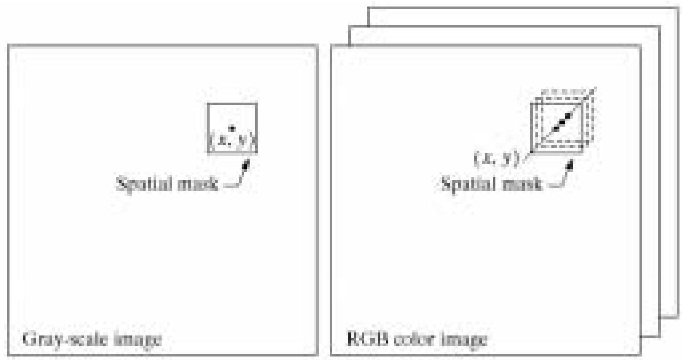
- Two major categories of full-color image processing approaches
  - Per-color-component processing: Process each component image individually→ form a composite processed color image
  - Vector-based processing: Work with color pixels (as a vector) directly
- To make results of two approaches equivalent:
  - The image processing method has to be applicable to both vectors and scalars
  - The operation on each component of a vector must be independent of the other components

Let ***c*** represent an arbitrary vector in RGB color space, the color components can be represented as a function of coordinates (x,y)→

$$\boldsymbol{c}(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

$$\text{for } \begin{cases} 0 \le x \le M-1 \\ 0 \le y \le N-1 \end{cases}$$

Neighborhood average: cannot satisfy the two conditions, results of two full-color processing approaches are different



a b

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

Color Transformations

- Color transformations→ process the components of a color image within the context of a single color model
- Formulation is similar to the gray-level transformation: g(x,y)=T[f(x,y)]
  - f(x,y): color input image
  - g(x,y): transformed (processed) color output image
- Pixel values are triplets (RGB, CMY, HSI) or quartets (CMYK)

$$s_i = T_i(r_1, r_2, \ldots, r_n), \qquad i = 1, 2, \ldots, n$$

$\boldsymbol{r_i}$ → color component of f(x,y) at point (x,y)

$\boldsymbol{s_i}$ → color component of g(x,y) at point (x,y)

$\boldsymbol{n}$ → number of color components (n=3 for RGB, HSI; n=4 for CMYK)

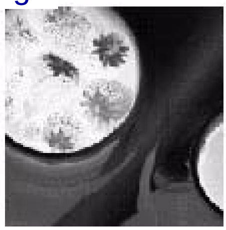
$\boldsymbol{T}:\{T_1, T_2, \ldots, T_n\}$ → a set of n transformation (or, color mapping) functions to perform $\boldsymbol{r_i} \rightarrow \boldsymbol{s_i}$

CMYK components of a full-color image
0: black, 1:white

Full-color image

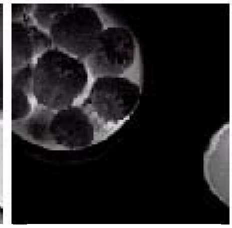
Black is confined to the coffee and shadows of strawberries

Cyan image



Magenta image

Yellow image



Black image

Strawberries are composed of large amounts of magenta and yellow

RGB components of a full-color image
0: black, 1:white

Full color

Red image

Green image

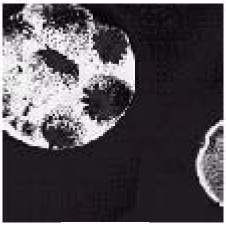
Blue image

Strawberries contain a large amount of red and very little green and blue

HSI components of a full-color image

Full color

Strawberries are relatively pure in color and possess the highest saturation



Hue

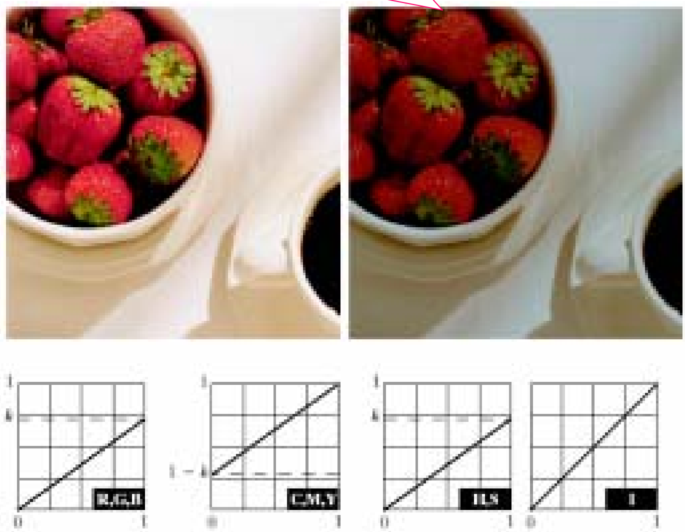
Saturation

Intensity

Intensity component is a monochrome rendition of the full-color image

- Color transformation example→ modify the intensity of the *Strawberry image*
- Transformation performed in HSI color space:
  - T_1: $s_1=r_1$ (hue)
  - T_2: $s_2=r_2$ (saturation)
  - T_3: $s_3=kr_3$ $0<k<1$ (intensity)
- RGB color space:
  - T_i : $s_i=kr_i$, $i=1, 2, 3$ (R, G, B)
- CMY color space:
  - T_i : $s_i=kr_i+(1-k)$, $i=1, 2, 3$ (C, M, Y)

Decrease intensity of the left image by 30%



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.)