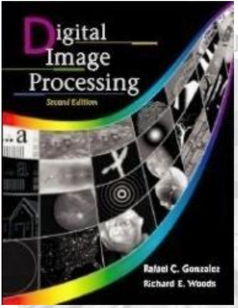
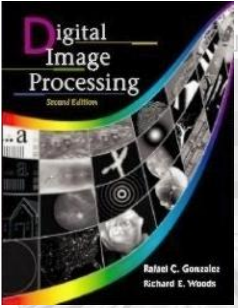


Chapter 6

Color Image Processing

Md. Hasanul Kabir, Ph.D.
Professor
Department of CSE, IUT



Chapter 6
Color Image Processing

- In automated image analysis, color is a powerful descriptor, which simplifies object identification and extraction.
- The human eye can distinguish between thousands of color shades and intensities but only about 20-30 shades of gray. Hence, use of color in human image processing would be very effective.
- Color image processing consists of two parts:

  Pseudo-color processing and Full color processing.
  - In pseudo-color processing, (false) colors are assigned to a monochrome image. For example, objects with different intensity values maybe assigned different colors, which would enable easy identification/recognition by humans.
  - In full-color processing, images are acquired with full color sensors/cameras. This has become common in the last decade or so, due to the easy and cheap availability of color sensors and hardware.

Chapter 6
Color Image Processing

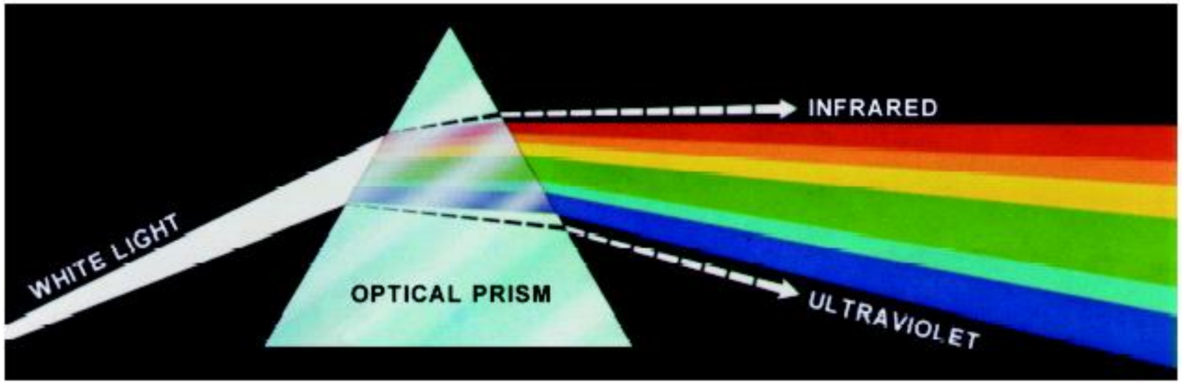


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

- When a beam of sunlight is passed through a glass prism, the emerging beam of light is not white but consists of a continuous spectrum of colors (Sir Isaac Newton, 1666).
- The color spectrum can be divided into six broad regions: violet, blue, green, yellow, orange, and red.

Color Fundamentals

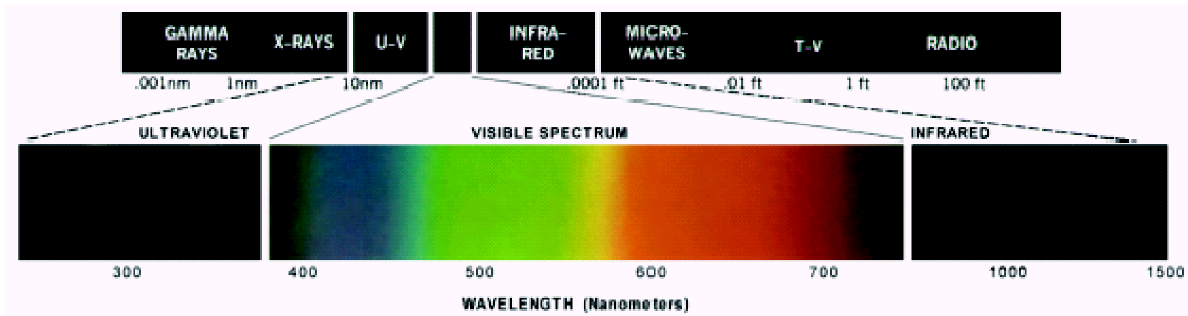


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

- The different colors in the spectrum do not end abruptly but each color blends smoothly into the next.
- Color perceived by the human eye depends on the nature of light reflected by an object. Light that is relatively balanced in all visible wavelengths is perceived as white.

Color Fundamentals

- Characterization of light is important for the understanding of color.
- If the light is **achromatic** (devoid of color), its only attribute is its **intensity** (amount of light). This is what we have been dealing with so far. The term graylevel refers to the scalar measure of the intensity of light --- black to grays to white.
- **Chromatic** light spans the electromagnetic (EM) spectrum from approximately 400 nm to 700 nm.
- Three basic quantities are used to describe the quality of a chromatic source of light:
  – **Radiance** is the total amount of light that flows from a light source (measured in Watts).
  – **Luminance** gives a measure of the amount of energy an observer perceives from a light source (measured in lumens).
  – **Brightness** is a subjective descriptor that is impossible to measure.

Color Fundamentals

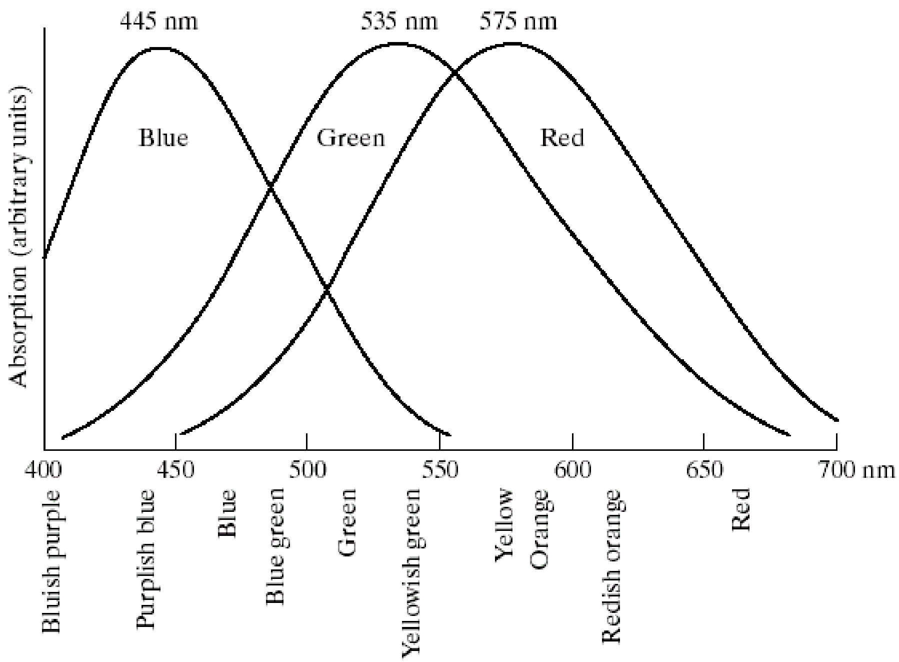
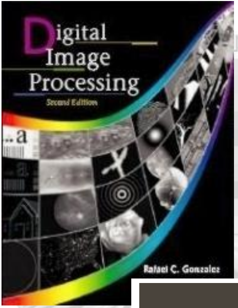
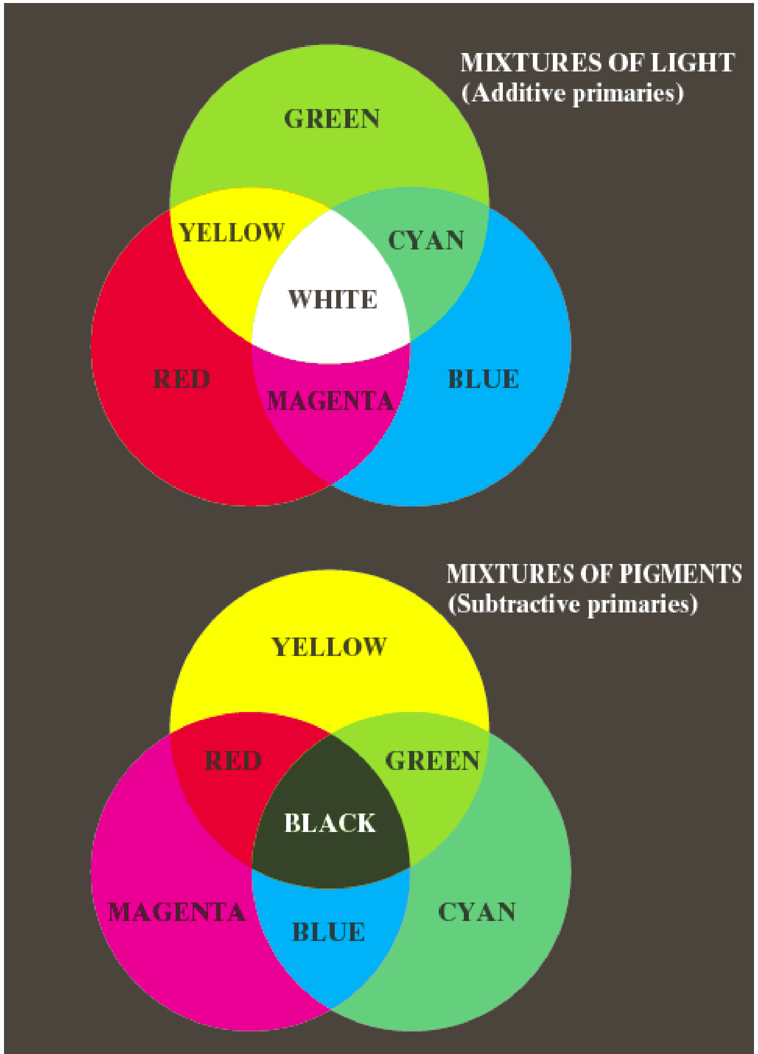


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

- ➢Cones in the retina are responsible for color perception in the human eye.
- ➢ Six to seven million cones in the human eye can be divided into three categories: red light sensitive cones (65%), green light sensitive cones (33%) and blue light sensitive cones (2%).
- ➢The combination of the responses of these different receptors gives us our color perception
- ➢This is called the tri-stimulus model of color vision

Chapter 6
Color Image Processing





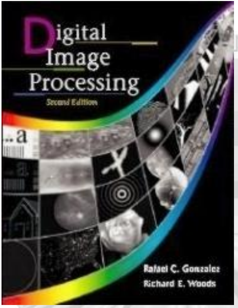
PRIMARY AND SECONDARY COLORS OF LIGHT AND PIGMENT

- Due to the absorption characteristics of the human eye, all colors perceived by the human can be considered as a variable combination of the so called three **primary colors**:
  - ✓Red (R) (700 nm)
  - ✓Green (G) (546.1 nm)
  - ✓Blue (B) (435.8 nm)
  - Note that the specific color wavelengths are used mainly for standardization.
  - Primary colors when added produce secondary colors:
  - ✓Magenta (red + blue)
  - ✓Cyan (green + blue)
  - ✓Yellow (red + green)

Additive vs. Subtractive Color Systems

- involves light emitted directly from a source
- mixes various amounts of red, green and blue light to produce other colors.
- Combining one of these additive primary colors with another produces the additive secondary colors cyan, magenta, yellow.
- Combining all three primary colors produces white.

- Subtractive color starts with an object that reflects light and uses colorants to subtract portions of the white light illuminating an object to produce other colors.
- If an object reflects all the white light back to the viewer, it appears white.
- If an object absorbs (subtracts) all the light illuminating it, it appears black.



Color Space

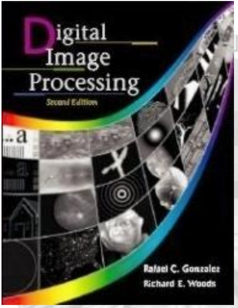
- Color space: A 3-dimensional coordinate system for specifying color
- A color is specified as a single point in the color space
- Commonly Used Color Space:
  - RGB (Red, Green, Blue)
    - used for screen displays (e.g. monitor)
  - CMYK (Cyan, Magenta, Yellow, Black)
    - used for printing
  - HSI (Hue, Saturation, Intensity)
    - used for manipulation of color components
  - L*a*b*, L*u*v* ("perceptual" color spaces)
    - distances in color space correspond to distances in human color perception

Color Terms

- Hue - dominant wavelength
  e.g. Red roses, green traffic light
- Saturation - relative purity; amount of white light mixed
  e.g. Bright orange, pink milk
- Chromaticity - Hue and Saturation taken together
- Intensity (brightness) - amount of achromatic light
  - light apart from color
  - gray level; B & W
- Tristimulus values - amount of red, green and blue
  to form a particular color
- Color gamut - range of colors

CIE XYZ

- CIE: International Commission on Illumination
- Not the same as RGB and not tied to hardware
- Describes the entire visible gamut
- Provides a standard for sharing color information between disciplines
  - Computer graphics and fabric design

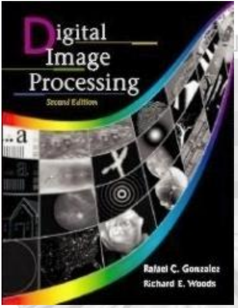


CIE XYZ

- The amount of R, G, B needed from any particular color(or tristimulus values) : X, Y, Z
- *Trichromatic coefficients (or* Normalized CIE primaries): x,y,z

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

- On the plane $x + y + z = 1$, every point can be characterized by unique x and y ($z = 1 - x - y$). Plotting on this plane the color of each wavelength gives the CIE chromaticity diagram



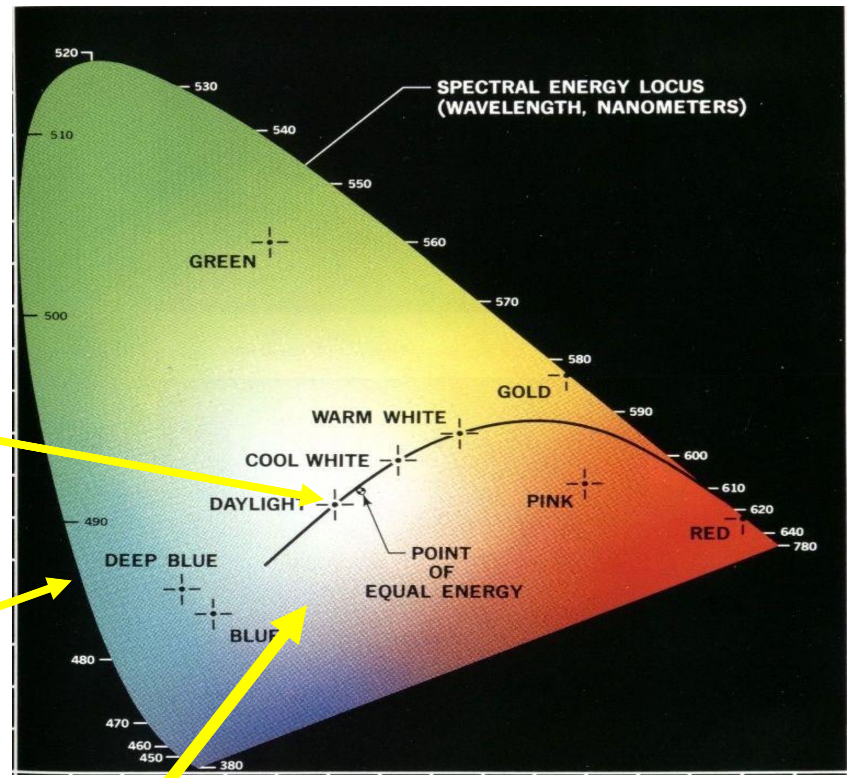
CIE Chromaticity Diagram

Specifying color in the absence of brightness

Z(blue)= 1-X-Y

0.9

Y (green)



As you go deeper, become less saturated

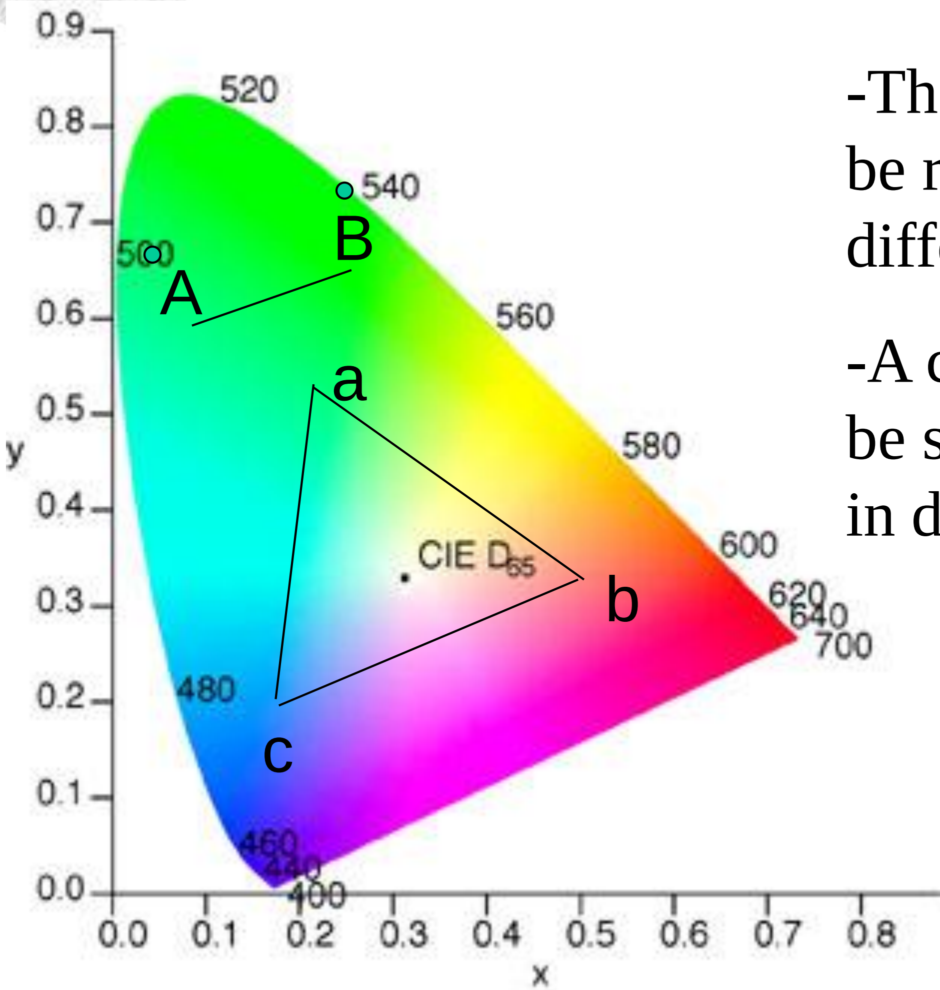
Fully saturated (or pure) colors

0

0.8

X (red)

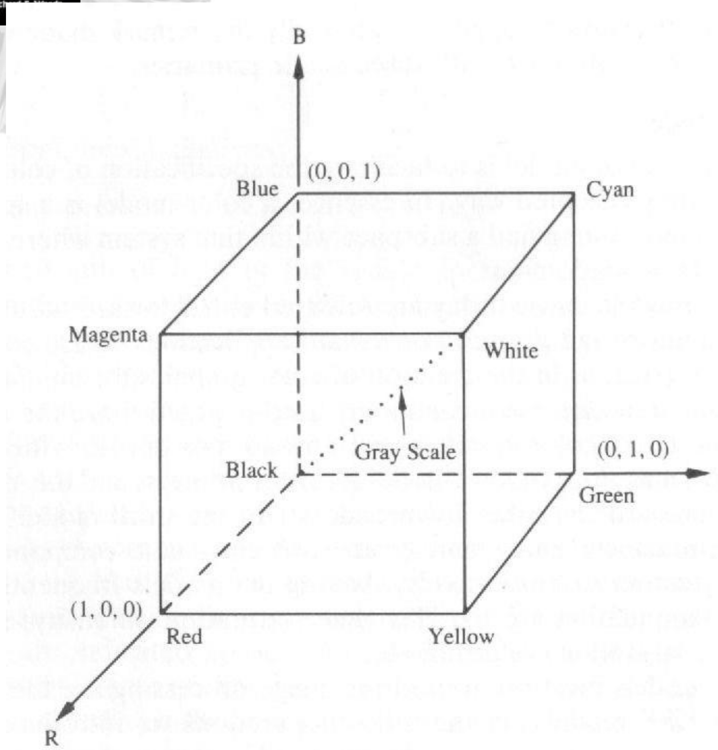
Mixture of the pure colors

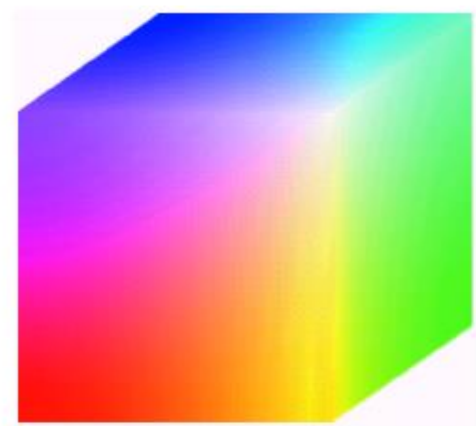


-The color along the line can be reproduced by mixing different amount of A and B

-A color gamut (or range) can be specified by mixing a, b, c in different amounts

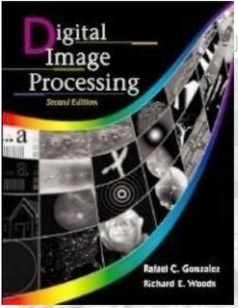
RGB Space





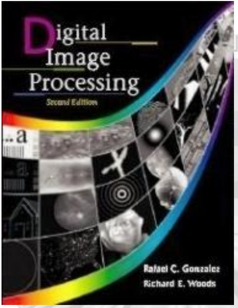
GB 24-bit color cube.

24bit color cube composed of
256x256x256=16,777,216 colors



RGB Space

- When light is mixed, wavelengths combine (add)
- The Red-Green-Blue (*RGB*) model is used most often for *additive models.* Additive to produce other colors
- Can’t produce all visible colors
- Contained within CIE *XYZ*
- Perfect for imaging since hardware uses three color phosphors



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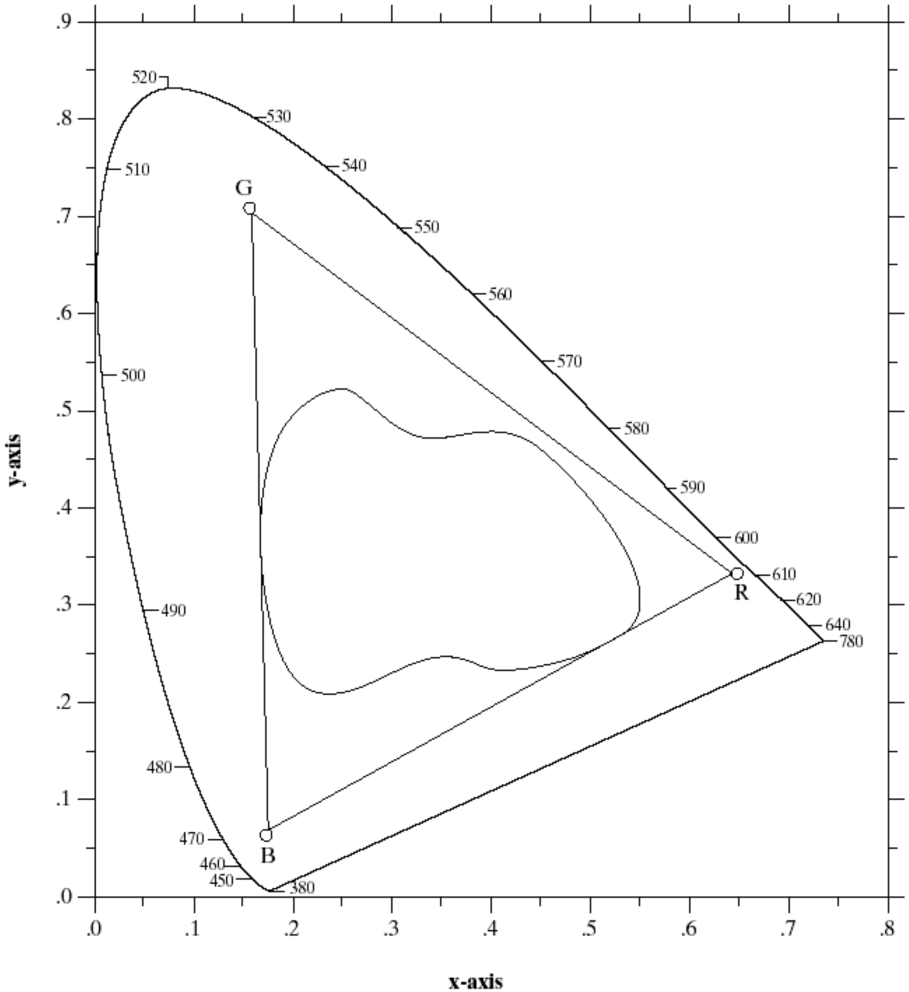
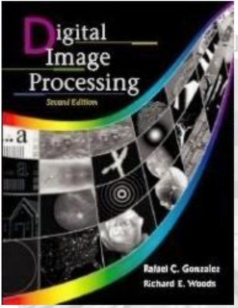


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).



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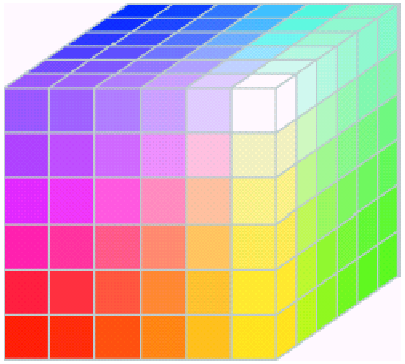
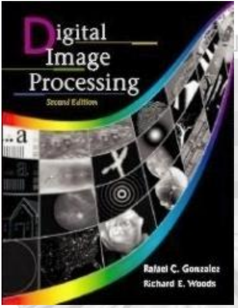


FIGURE 6.11 The RGB safe-color cube.

Safe color: a subset of colors hat are likely to be reproduced faithfully, reasonably independently of viewer hardware capabilities.



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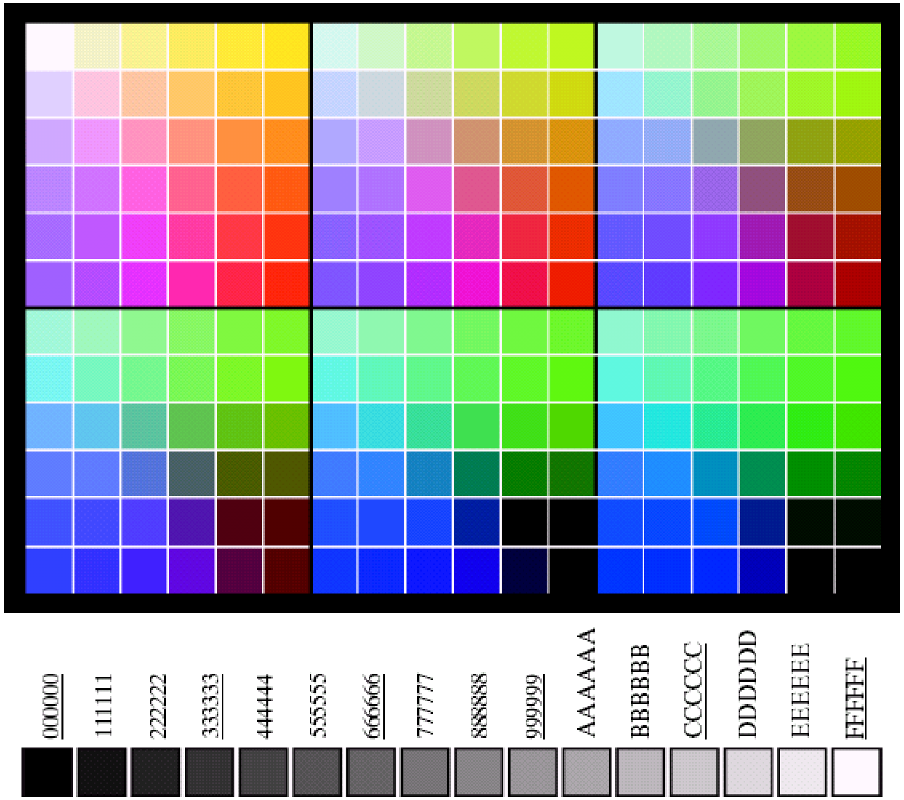
Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

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

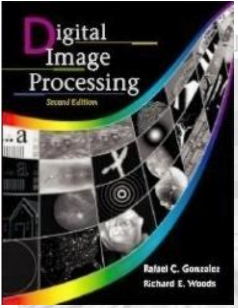


a
b

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).

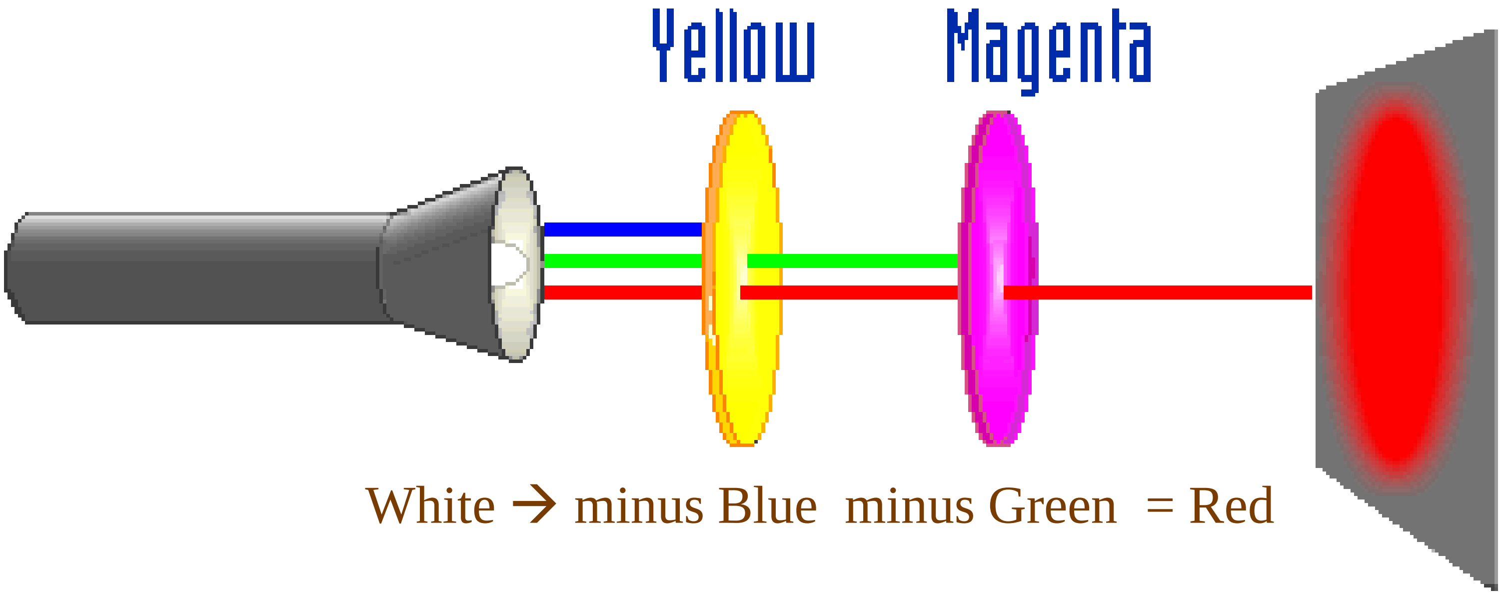
CMY Model

- Paint/ink/dye subtracts color from white light and reflects the rest
- Mixing paint pigments subtracts multiple colors
- The Cyan-Magenta-Yellow (*CMY*) model is the most common *subtractive model*
  - Same as RGB except white is at the origin and black is at the extent of the diagonal
- Very important for printing devices
  - Already white so we can’t add to it!!



CMY Model

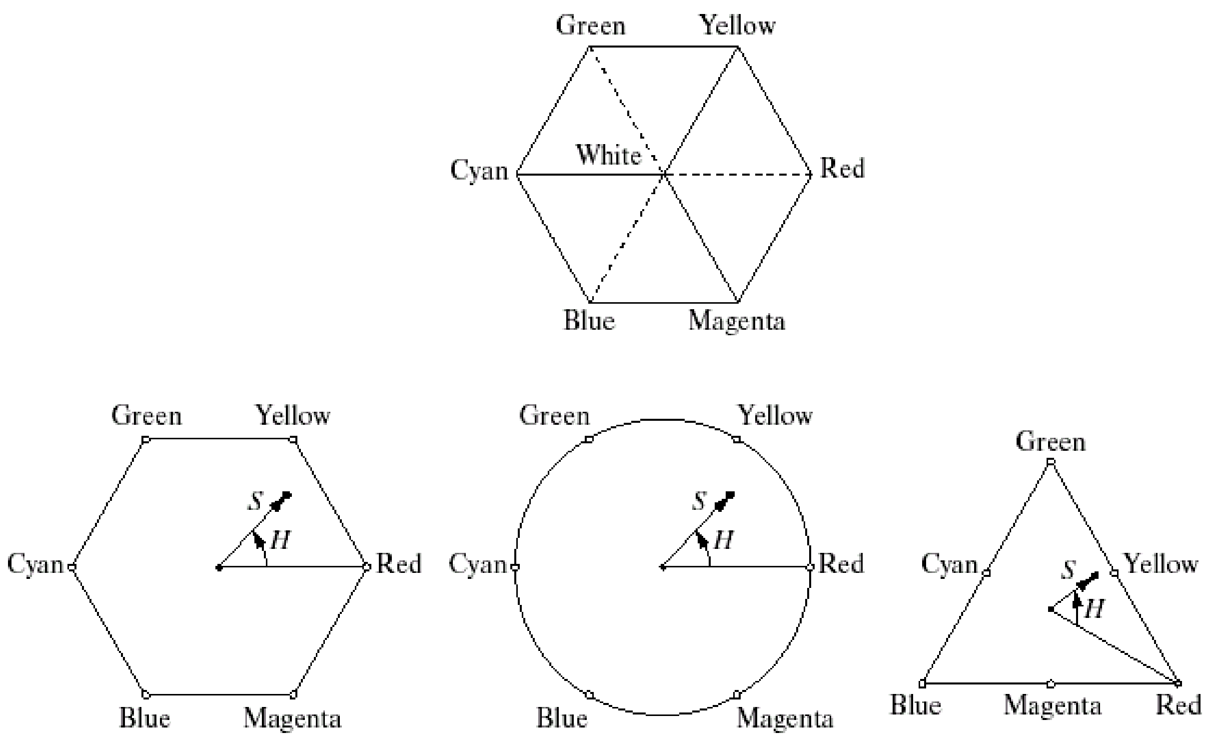
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



HSI Model

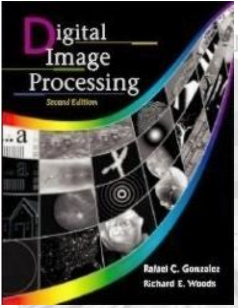
- The intensity component (I) is decoupled from the color components (H and S)
  - Ideal for developing image processing algorithms
- H and S are closely related to the way human visual system perceives colors
- HSI allows us to separate intensity and chromaticity → color is decomposed

Hue and Saturation

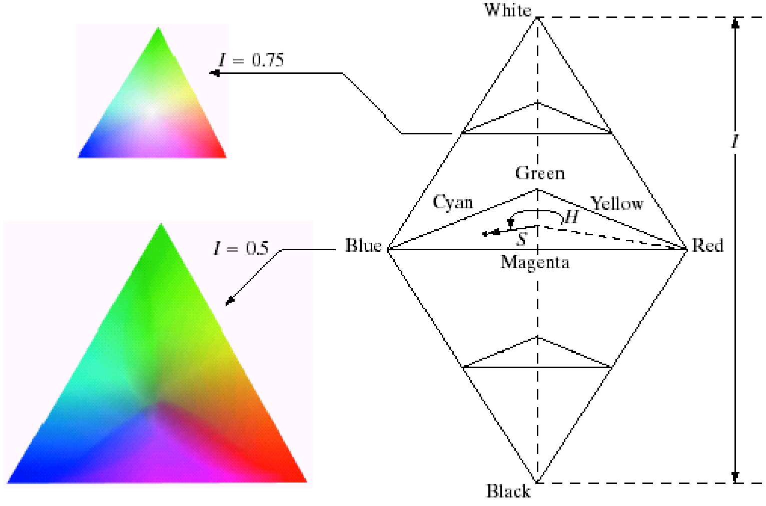


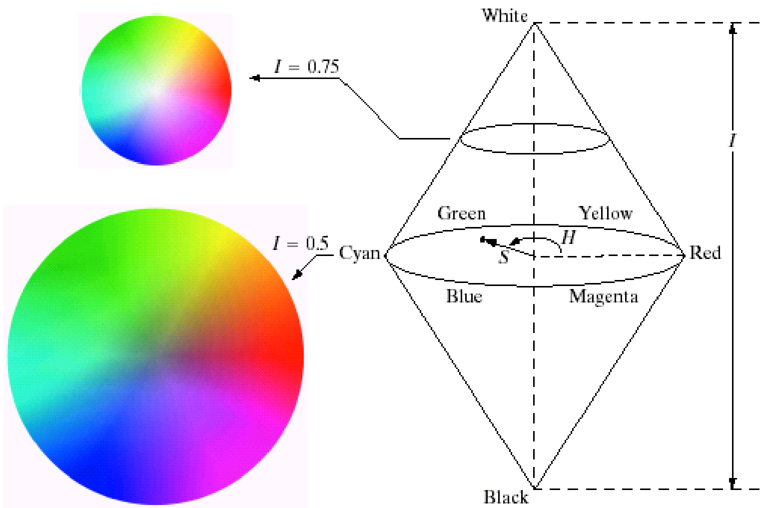
a
b c d

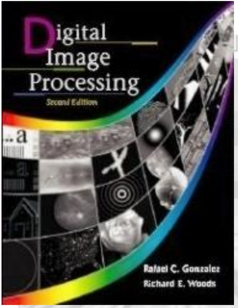
FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.



HSI Color Space







RGB-to-HSI Conversion

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

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

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

$$H = \begin{cases} \theta & G \geq B \\ 2\pi - \theta & G \leq B \end{cases}$$

HSI-to-RGB Conversion

- For 0º <= H < 120º

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

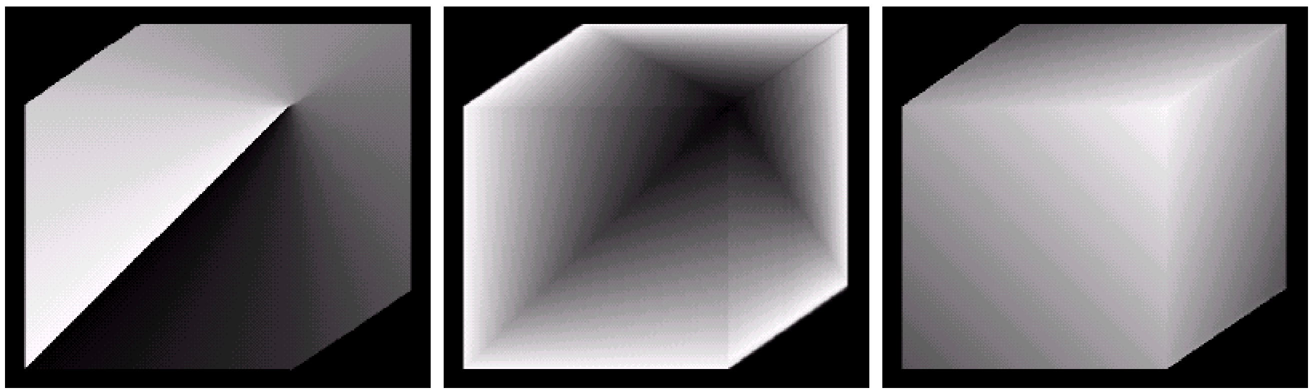
- For 120º <= H < 240º

$$G = I\left[1 + \frac{S\cos(H - 120^\circ)}{\cos(180^\circ - H)}\right], R = I(1 - S), B = I - R - G$$

- For 240º <= H < 360º

$$B = I\left[1 + \frac{S\cos(H - 240^\circ)}{\cos(300^\circ - H)}\right], G = I(1 - S), R = I - G - B$$

HSI Components of Image



a b c

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

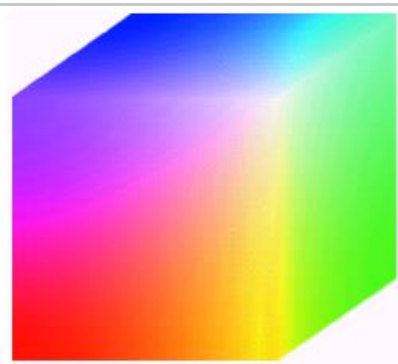
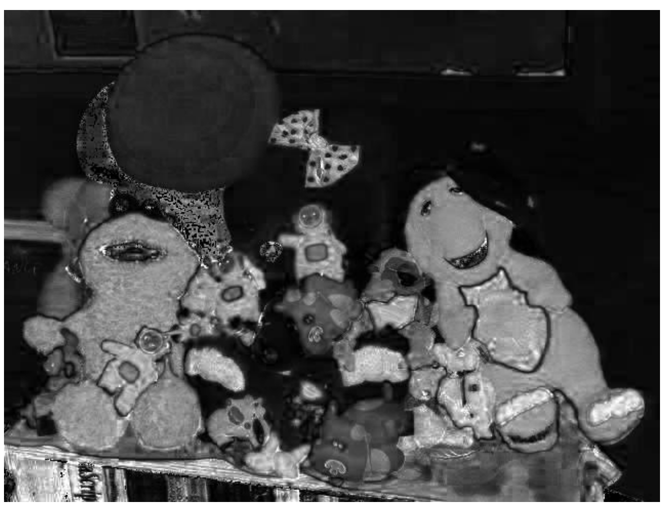


FIGURE 6.8 RGB 24-bit color cube.

Image

Hue

Saturation



Intensity

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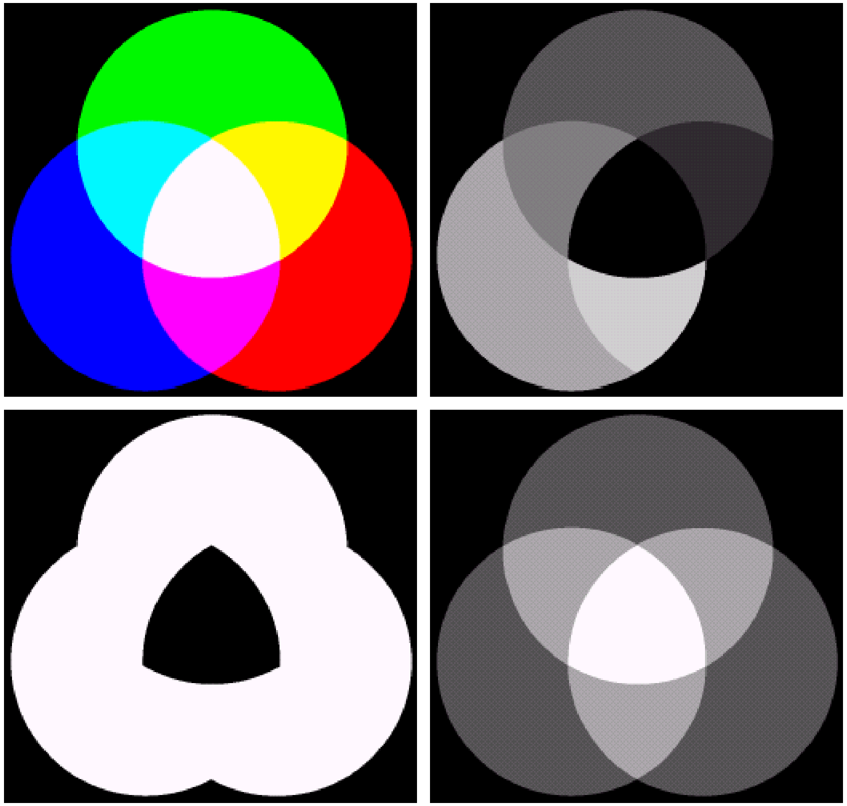
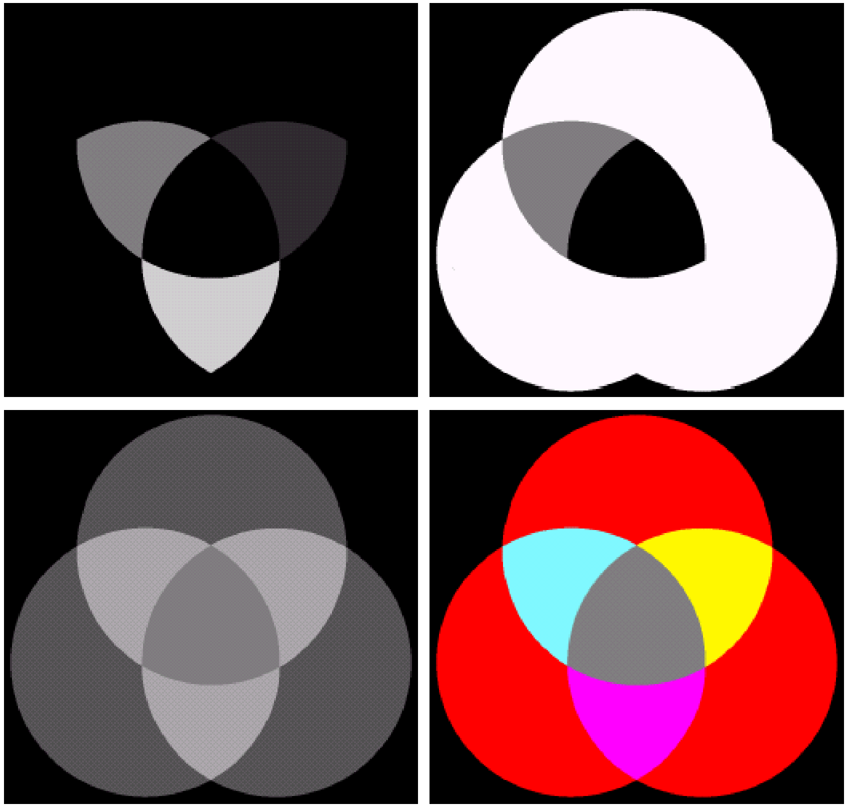


a b
c d

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

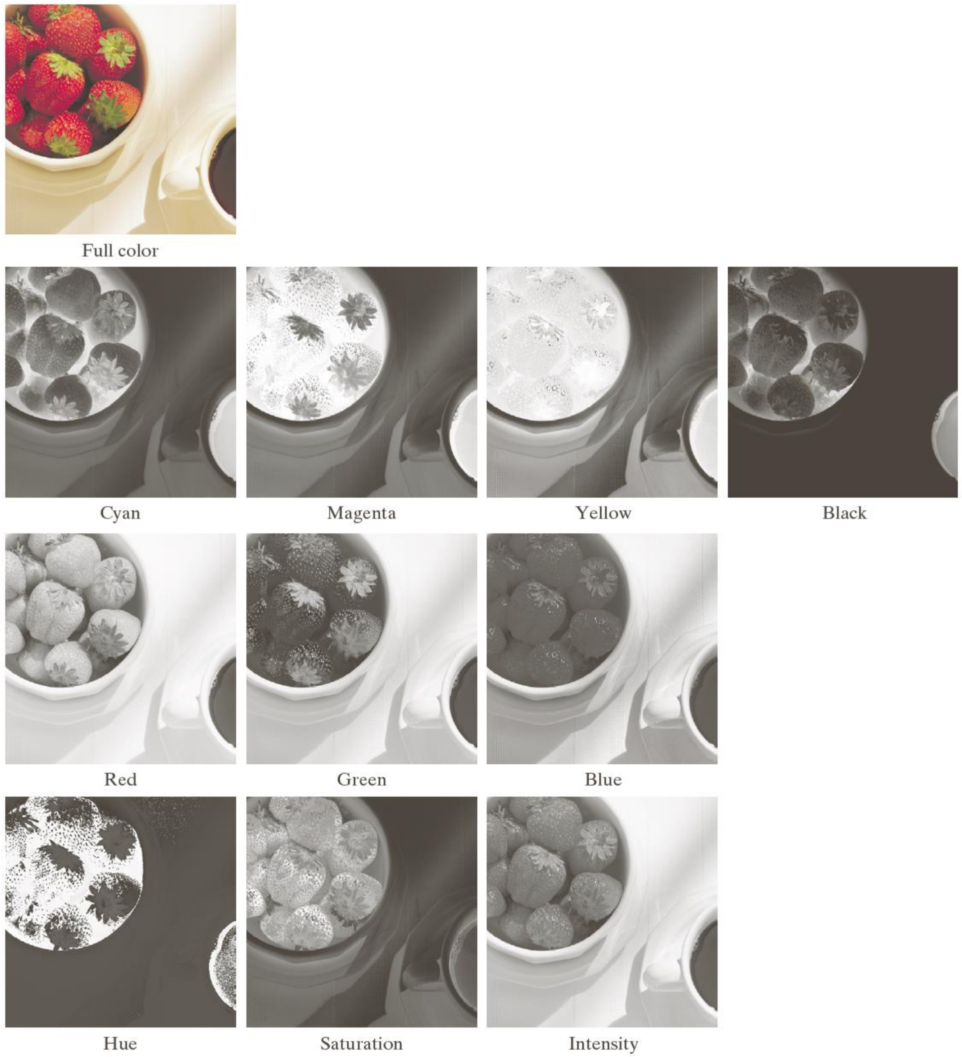
Color Image Processing

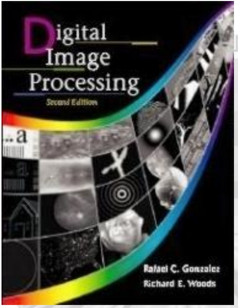


a b
c d

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

Color Components





Color Image Processing

- Pseudo-color image processing
  - Assign color to monochrome images
  - Intensity slicing
  - Gray level to color transformation
    - Spatial domain approach – three different transformation functions
    - Frequency domain approach – three different filters
- Full-color image processing
  - Color image enhancement and restoration
  - Color compensation

Example of Pseudocolor Image Processing

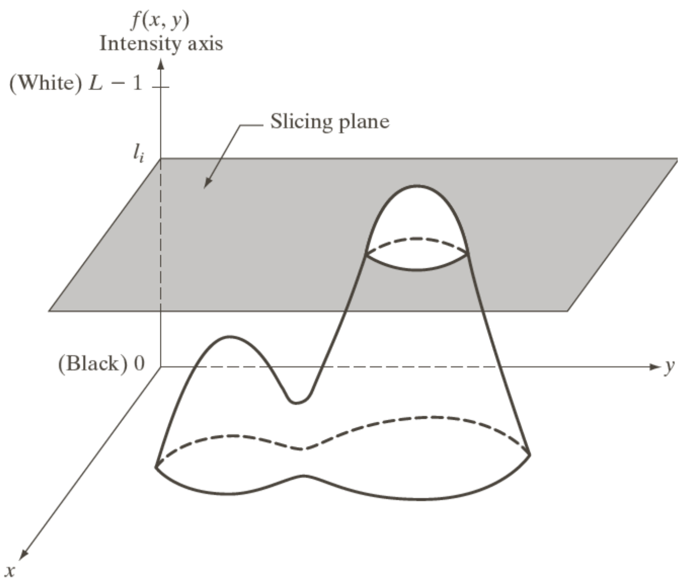
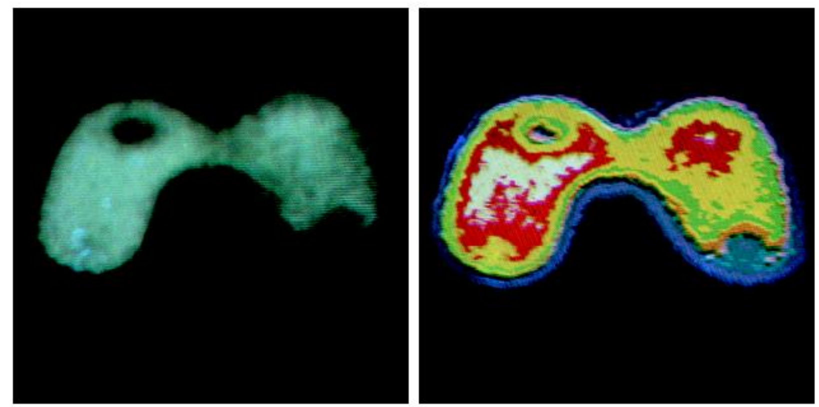
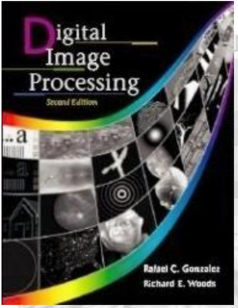


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.



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.)



Basics of Full Color Image Processing

- Full-color image processing approaches fall into two major categories.
  - ✓ In the first category, we process each component image individually and then form a composite processed color image from the individually processed components.
  - ✓ In the second category, we work with color pixels directly

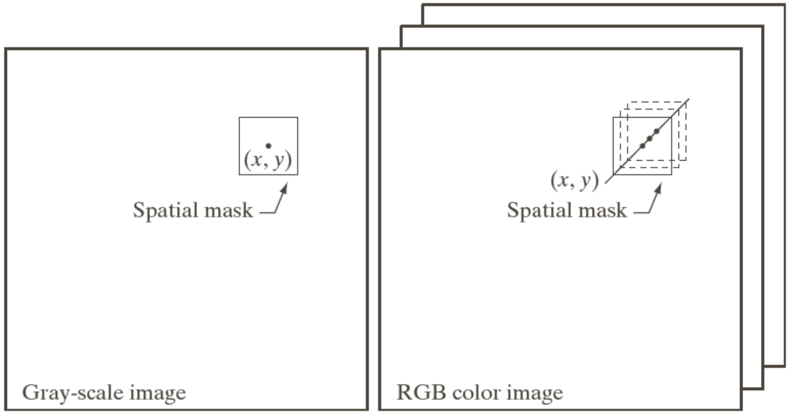
Let **c** represent an arbitrary vector in RGB color space:

$$\mathbf{c} = \begin{bmatrix} c_R \\ c_G \\ c_B \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{6.4-1}$$

This equation indicates that the components of **c** are simply the RGB components of a color image at a point. We take into account the fact that the color components are a function of coordinates (x, y) by using the notation

$$\mathbf{c}(x, y) = \begin{bmatrix} c_R(x, y) \\ c_G(x, y) \\ c_B(x, y) \end{bmatrix} = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix} \tag{6.4-2}$$

Color Transformation



a b

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

As for color transformations:

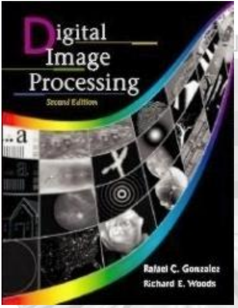
$$g(x, y) = T[f(x, y)]$$

The pixel values here are triplets or quartets (i.e., groups of three or four values)

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

An example

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 Complements

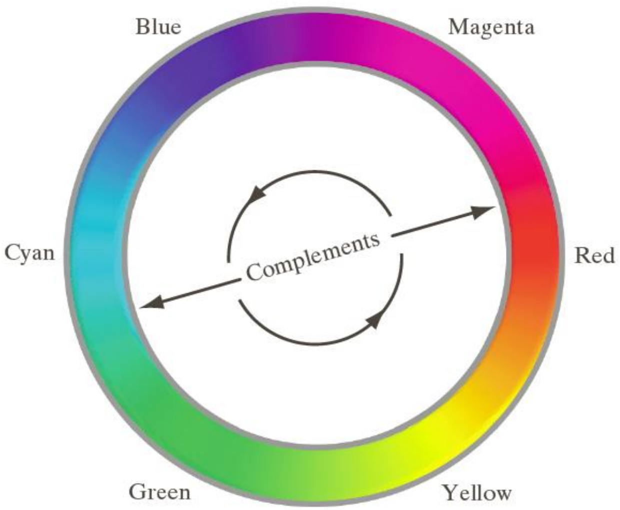


FIGURE 6.32 Complements on the color circle.

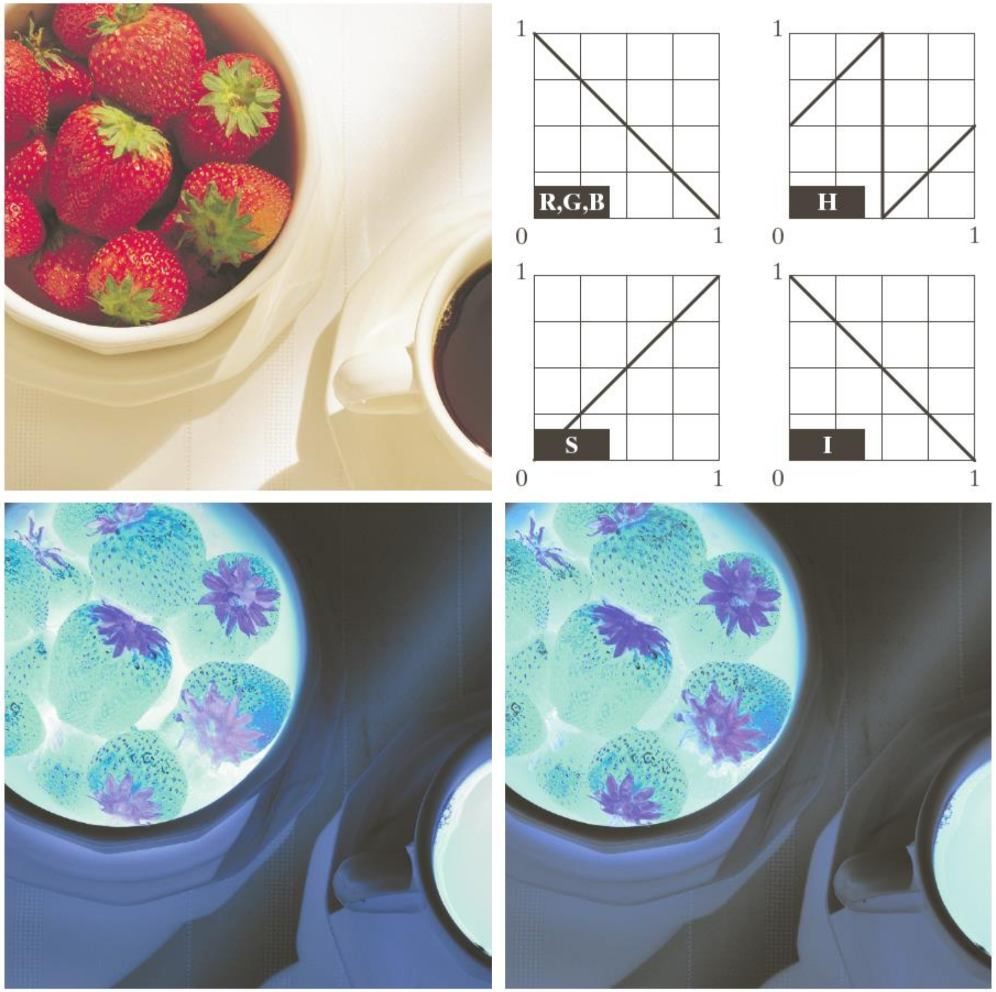
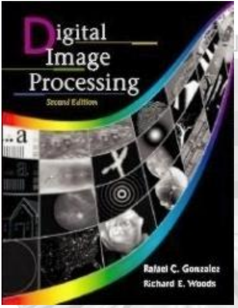
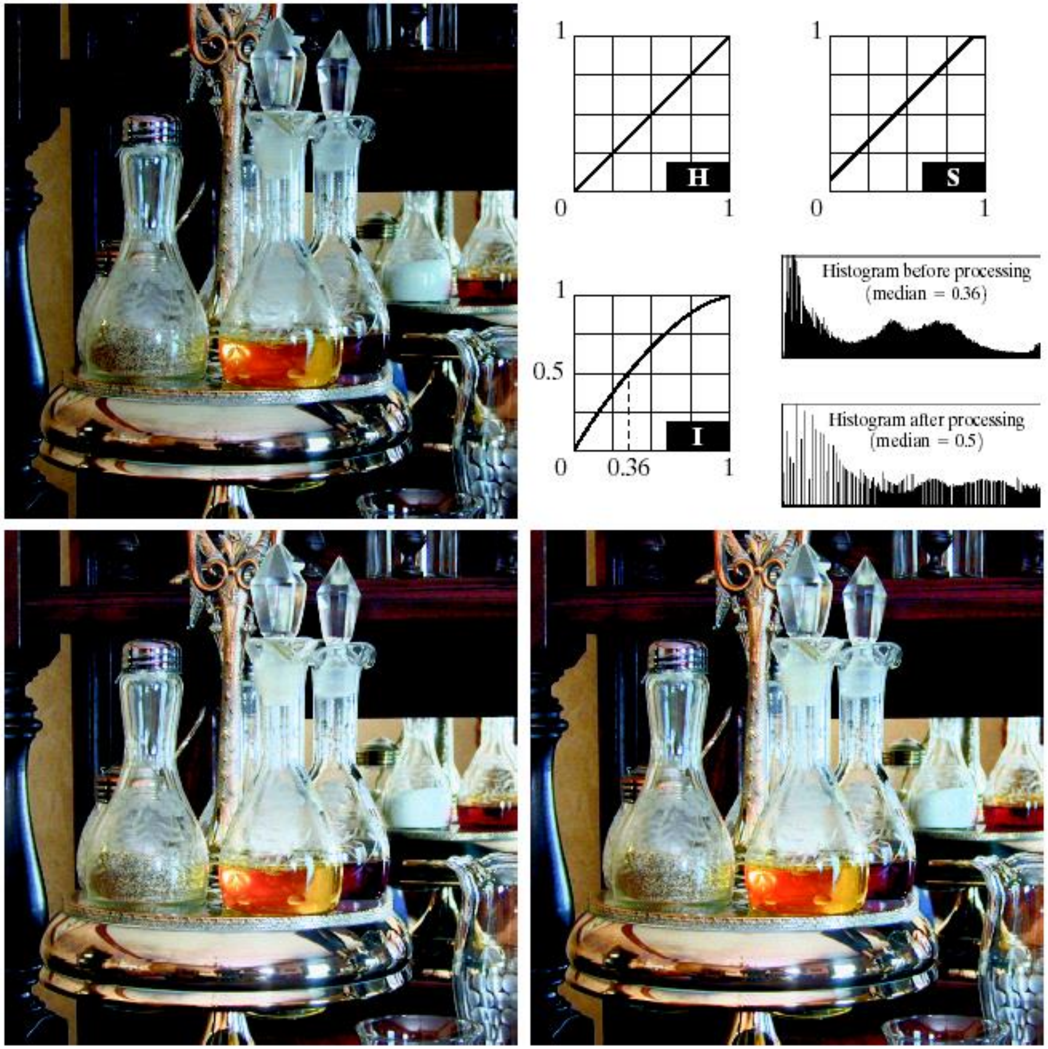


FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.



Histogram Processing



a b
c d

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

a b
c d

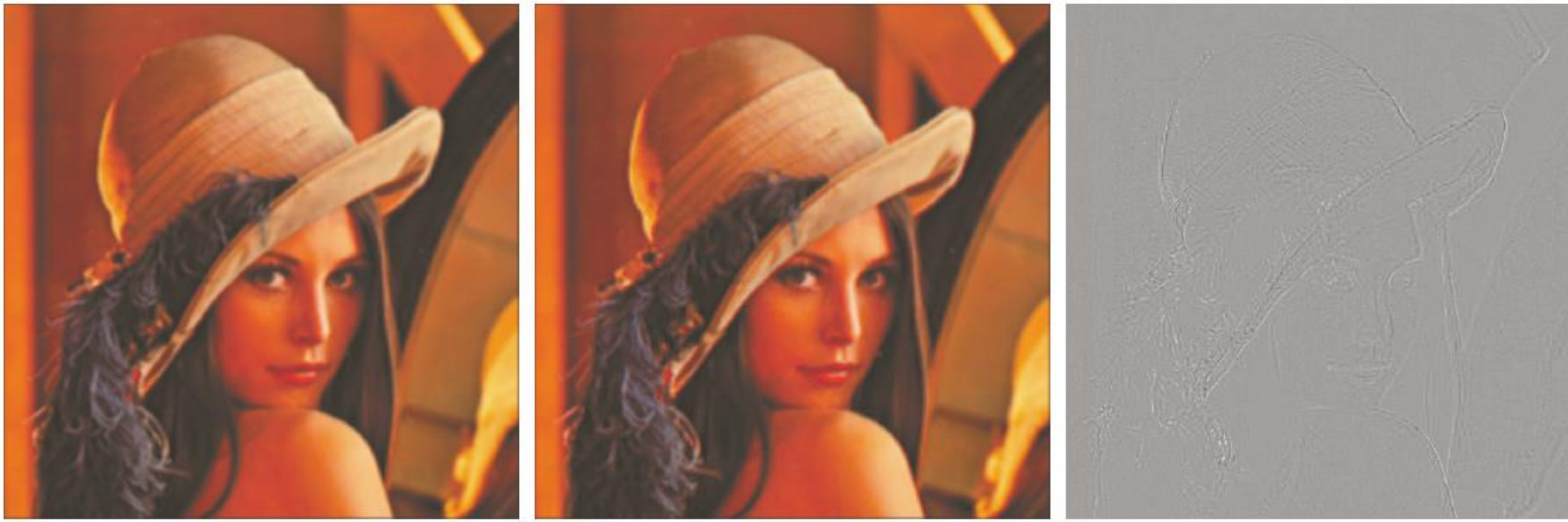
FIGURE 6.38 (a) RGB image. (b) Red component image. (c) Green component. (d) Blue component.

Color Image Before Smoothing

a b c

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

After Smoothing



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 Sharpening

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

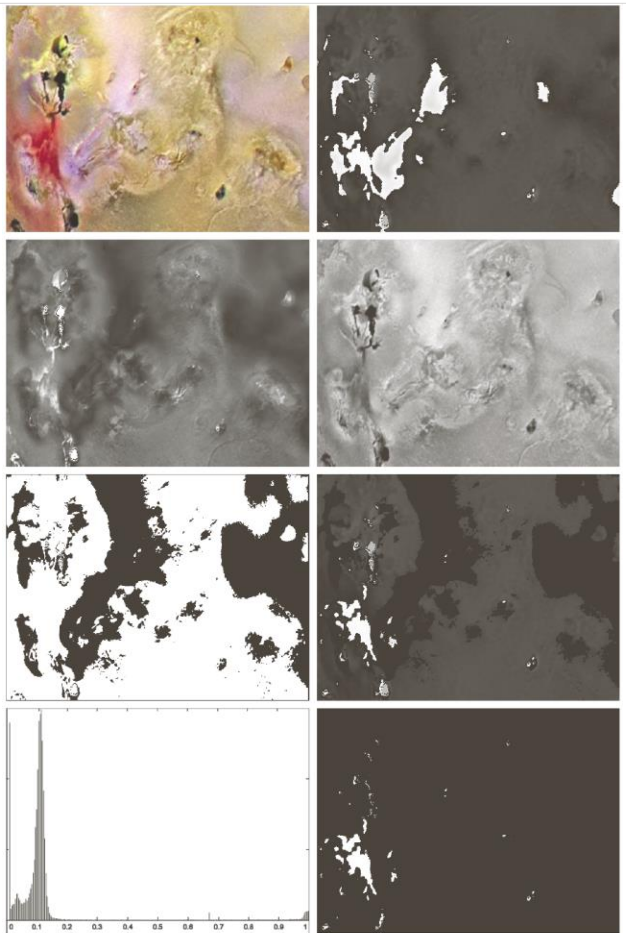
a b c

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

Color Image Segmentation

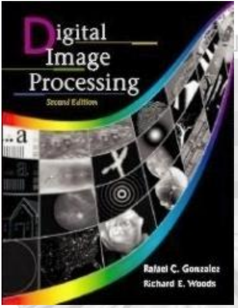
Segmentation in HSI:

- saturation is used as a masking image in order to isolate further ROI in the hue image.
- intensity image is used less frequently for segmentation of color images because it carries no color information.

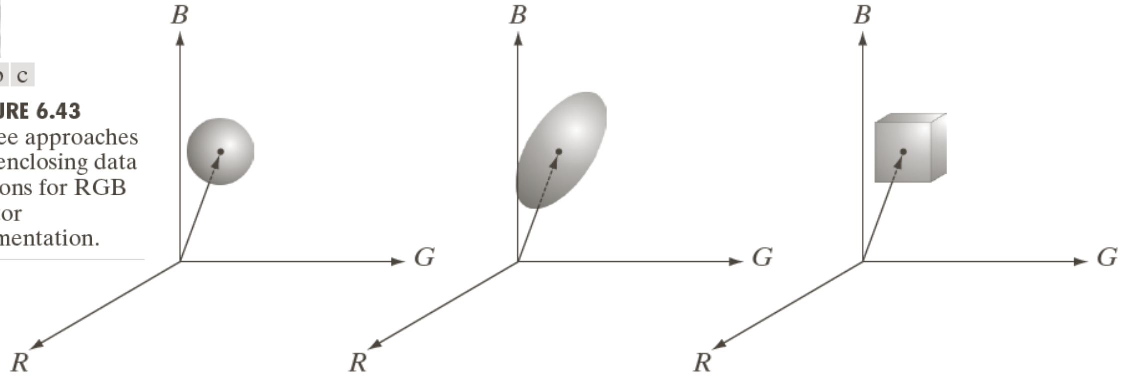


a b
c d
e f
g h

FIGURE 6.42 Image segmentation in HSI space. (a) Original. (b) Hue. (c) Saturation. (d) Intensity. (e) Binary saturation mask (black = 0). (f) Product of (b) and (e). (g) Histogram of (f). (h) Segmentation of red components in (a).



Segmentation in RGB



a b c

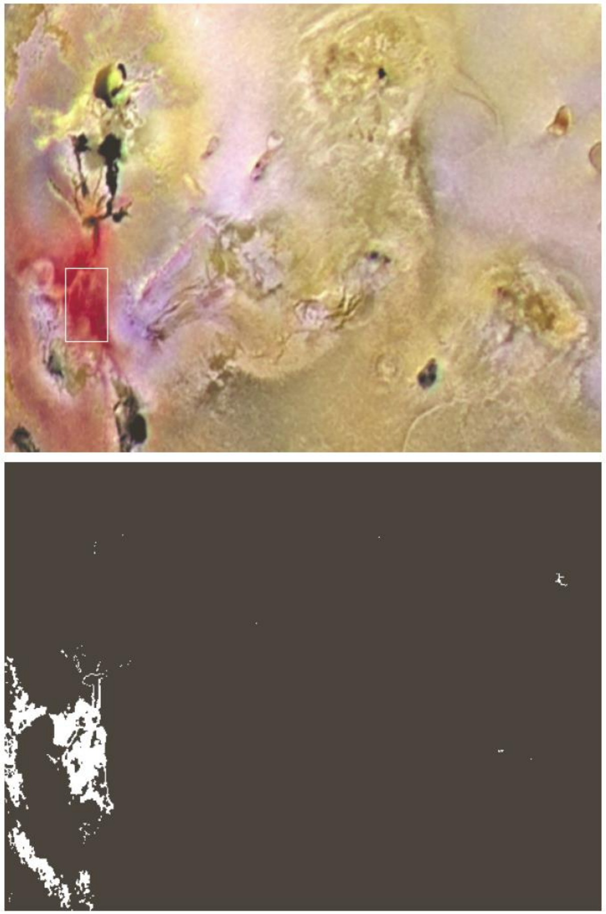
FIGURE 6.43 Three approaches for enclosing data regions for RGB vector segmentation.

Euclidean Distance between z and a points

$$
\begin{aligned}
D(\mathbf{z}, \mathbf{a}) &= \|\mathbf{z} - \mathbf{a}\| \\
&= \left[(\mathbf{z} - \mathbf{a})^T(\mathbf{z} - \mathbf{a})\right]^{\frac{1}{2}} \\
&= \left[(z_R - a_R)^2 + (z_G - a_G)^2 + (z_B - a_B)^2\right]^{\frac{1}{2}}
\end{aligned}
$$

Mahalanobis Distance between z and a points

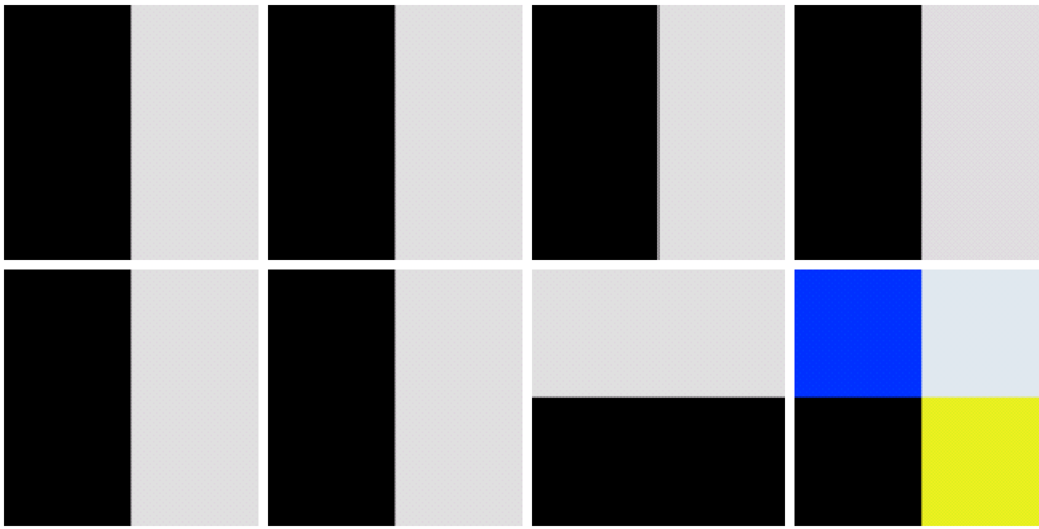
$$
D(\mathbf{z}, \mathbf{a}) = \left[(\mathbf{z} - \mathbf{a})^T \mathbf{C}^{-1} (\mathbf{z} - \mathbf{a})\right]^{\frac{1}{2}}
$$



a
b

FIGURE 6.44 Segmentation in RGB space. (a) Original image with colors of interest shown enclosed by a rectangle. (b) Result of segmentation in RGB vector space. Compare with Fig. 6.42(h).

Color Edge Detection



a b c d
e f g h

FIGURE 6.45 (a)–(c) R, G, and B component images and (d) resulting RGB color image. (f)–(g) R, G, and B component images and (h) resulting RGB color image.

Let **r**, **g**, and **b** be unit vectors along the R,G, and B axis of RGB color space

$$\mathbf{u} = \frac{\partial R}{\partial x}\mathbf{r} + \frac{\partial G}{\partial x}\mathbf{g} + \frac{\partial B}{\partial x}\mathbf{b}$$

$$\mathbf{v} = \frac{\partial R}{\partial y}\mathbf{r} + \frac{\partial G}{\partial y}\mathbf{g} + \frac{\partial B}{\partial y}\mathbf{b}$$

$$g_{xx} = \mathbf{u} \cdot \mathbf{u} = \mathbf{u}^T\mathbf{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

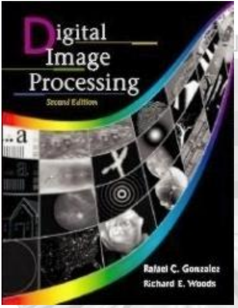
$$g_{yy} = \mathbf{v} \cdot \mathbf{v} = \mathbf{v}^T\mathbf{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

$$g_{xy} = \mathbf{u} \cdot \mathbf{v} = \mathbf{u}^T\mathbf{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

$$\theta(x, y) = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{g_{xx} - g_{yy}}\right]$$

$$F_\theta(x, y) = \left\{\frac{1}{2}\left[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\theta(x, y) + 2g_{xy}\sin 2\theta(x, y)\right]\right\}^{\frac{1}{2}}$$

Processing the three individual planes to form a composite gradient image can yield erroneous results.



Color Edge Detection

a b
c d

FIGURE 6.46 (a) RGB image. (b) Gradient computed in RGB color vector space. (c) Gradients computed on a per-image basis and then added. (d) Difference between (b) and (c).

Color Edge Detection in RGB space

a b c

FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

Noise in Color Image

a b
c d

FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]

Noise in Color Image

a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.

Noise In Color Image

a b
c d

FIGURE 6.50 (a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.

Color Image Compression

Compression is the process of reducing or eliminating redundant and/or irrelevant data.

More to follow in Chapter 8.

a
b

FIGURE 6.51 Color image compression. (a) Original RGB image. (b) Result of compressing and decompressing the image in (a).