UNIVERSITY OF SOUTH CAROLINA

CSCE 590 INTRODUCTION TO IMAGE PROCESSING

Color Images

Color Spaces

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Color Image Processing

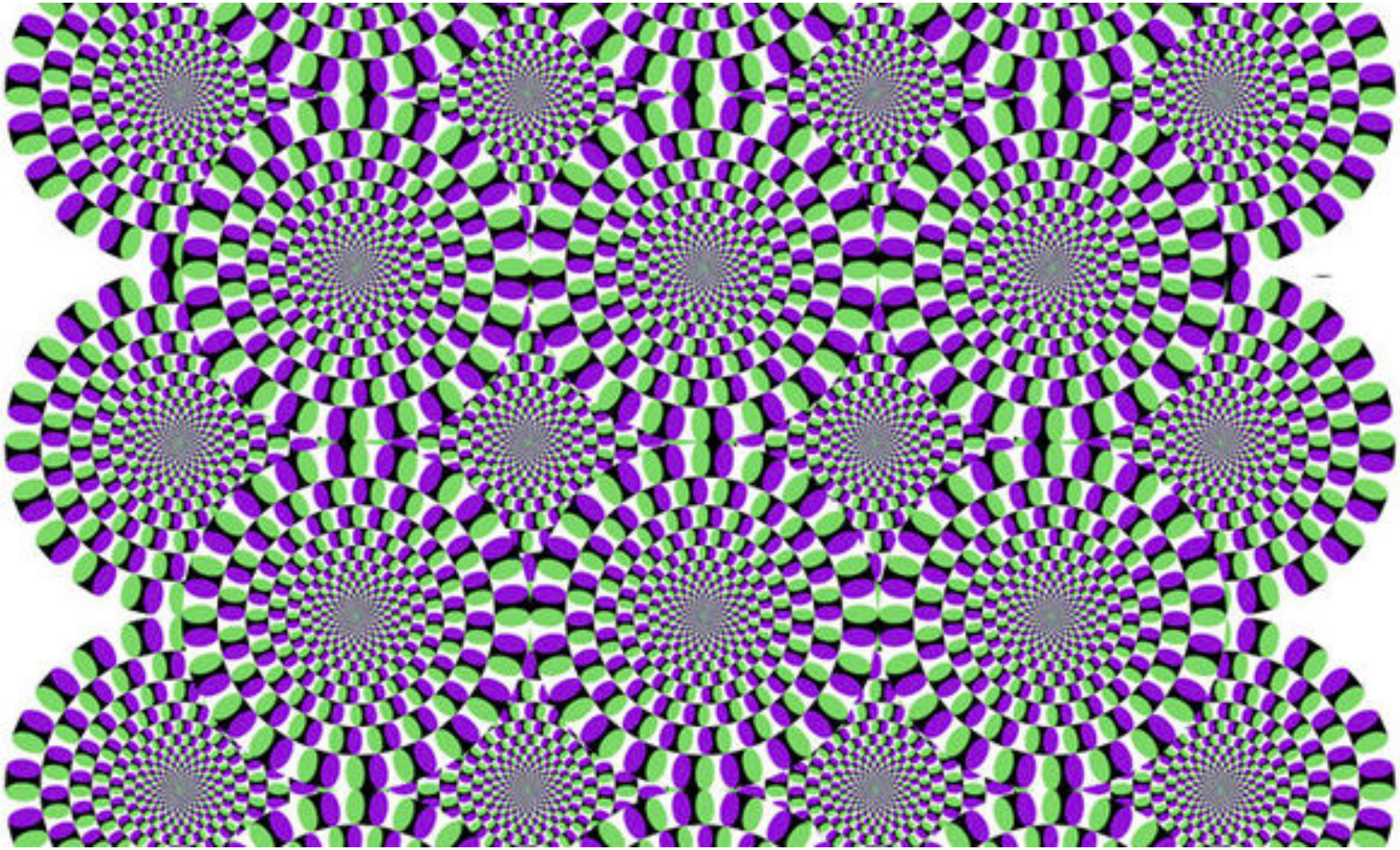
- The world is colorful
- Color feature is one of the natural cue human used for object detection/recognition
  - Thousands of color shades vs dozens of gray levels
  - Various applications
- Challenges
  - Illumination
  - Variations

http://okanaganokanogan.com/2015/10/

https://johnhowie.wordpress.com/2009/12/22/445/

http://www.tutorialized.com/tutorial/Grasslands-in-3ds-Max/57927

Color is powerfull



https://positivr.fr/illusions-optique/

Fundamentals of Color Image Processing

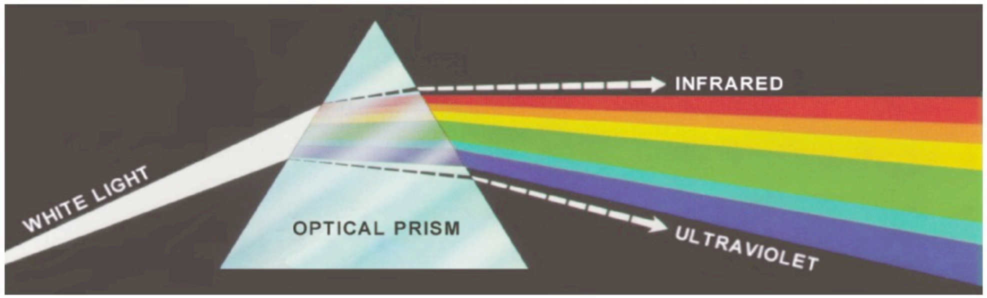


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

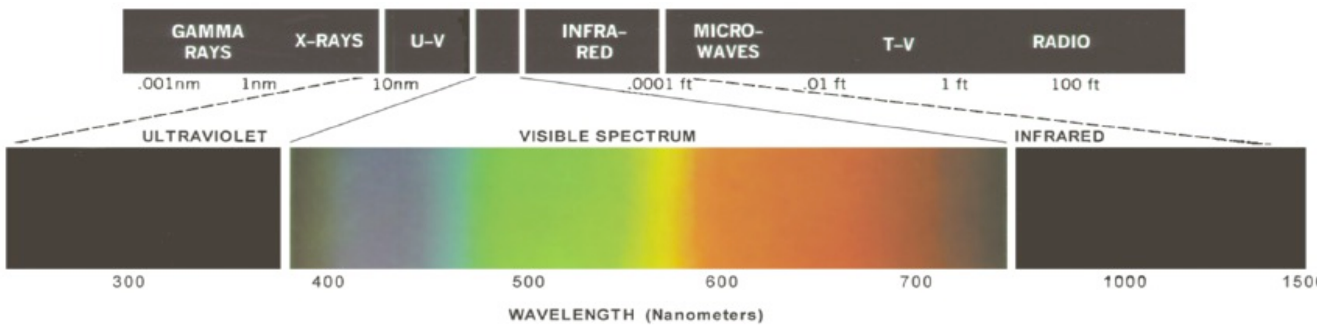


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Representations

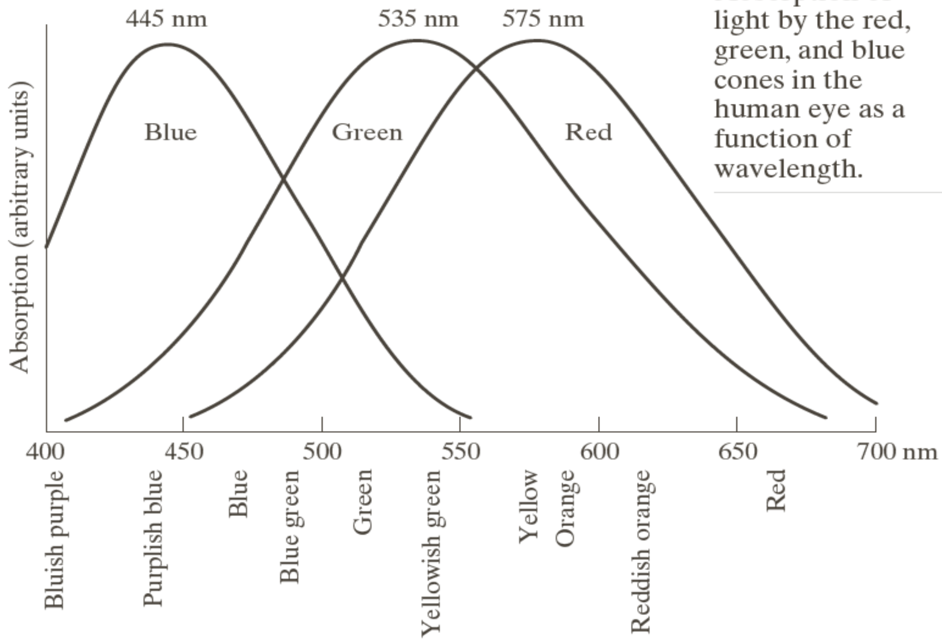
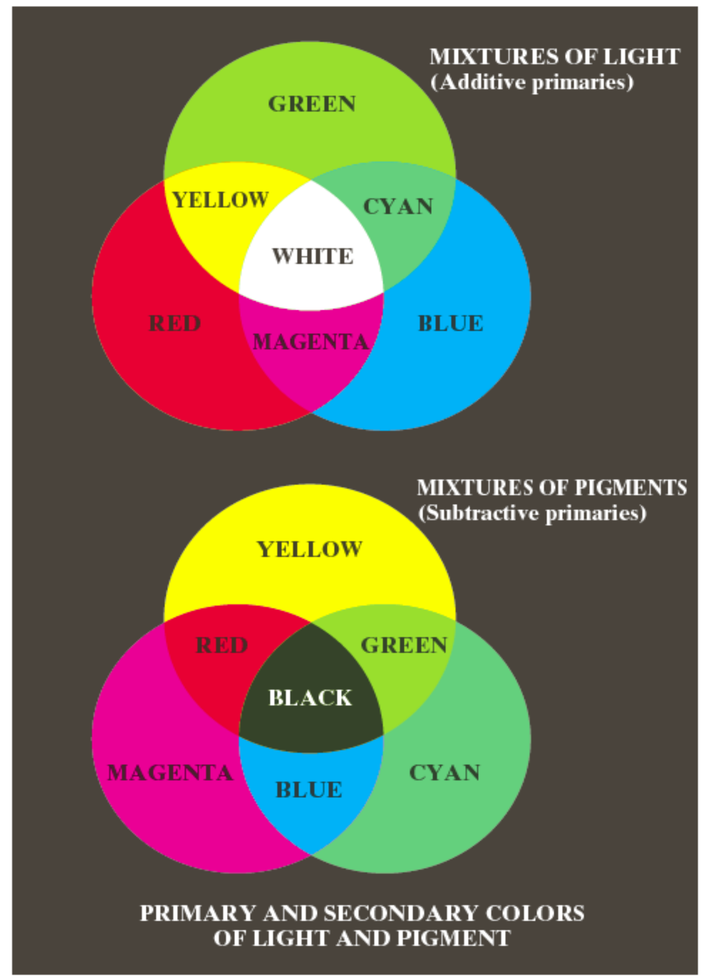


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



a
b

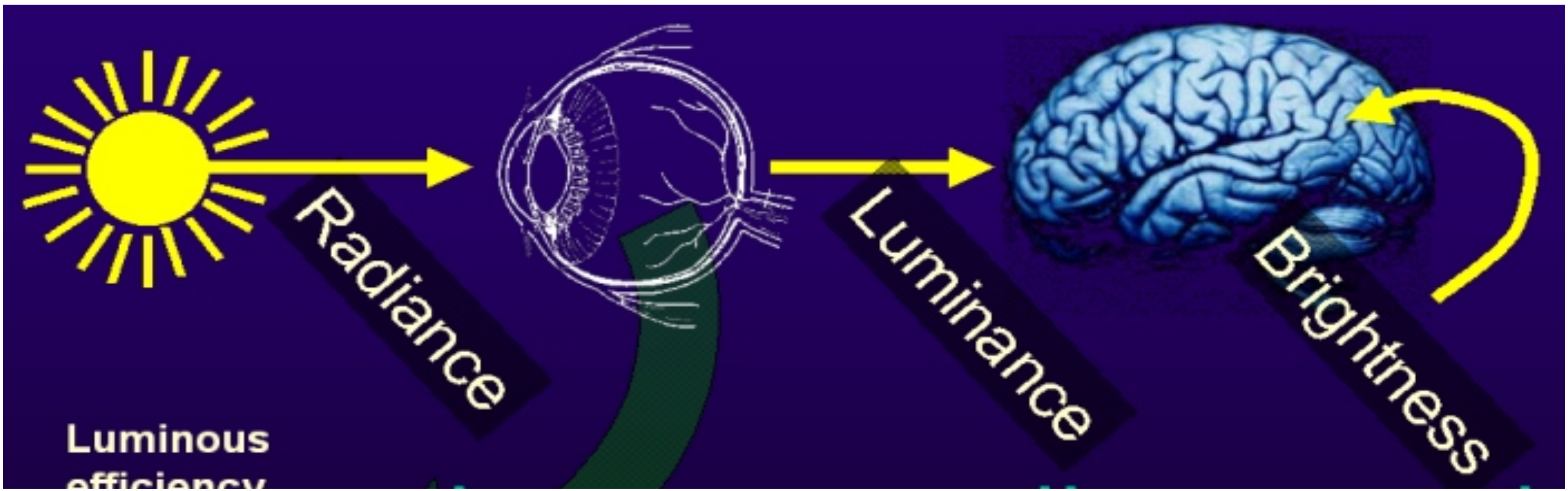
FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

- primary/secondary colors
- primary/secondary pigments
- all visible colors

Characteristics of Light

- Radiance
- Luminance
- Brightness

Slides courtesy f Prof. Yan Tong



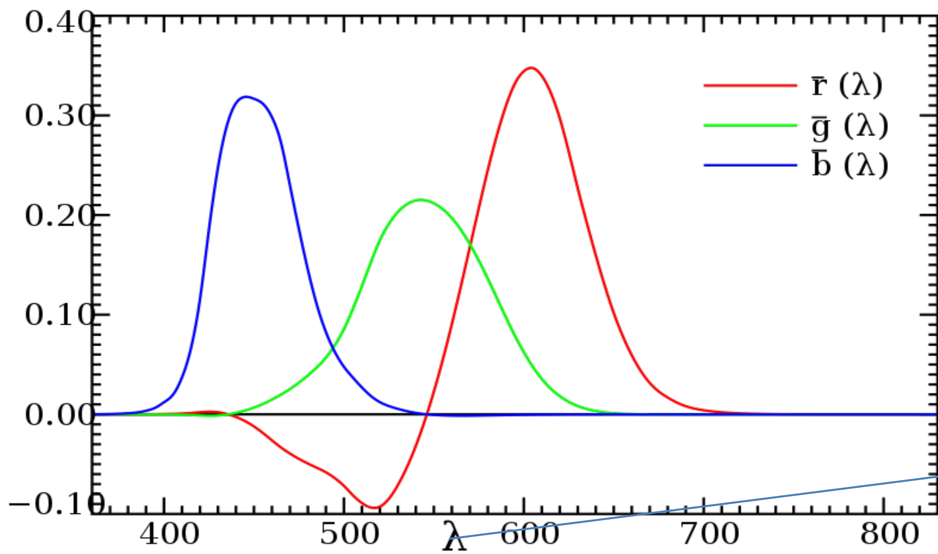
Picture was adapted from Dr. Gordon Kindlmann's talk "**Face-based Luminance Matching for Perceptual Colormap Generation**"
http://www.cs.utah.edu/~gk/papers/vis02/talk/

Characteristics of Color Light

- Radiance
- Luminance
- Brightness
- Chromaticity
  - Hue – dominant color/wavelength
  - Saturation – color purity
- White and grey has the same chromaticity, while different brightness

Chromaticity

- Tristimulus values of a color: The amounts of the three primary color to match a test color



The CIE 1931 RGB Color matching functions.

wavelength

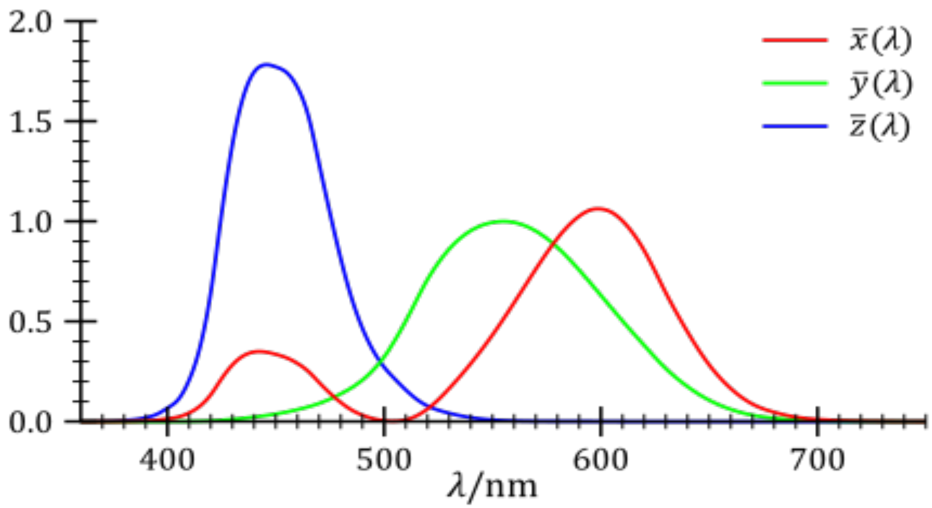
CIE (International Commission on Illumination) RGB matching function

$$R = \int_0^\infty I(\lambda)\bar{r}(\lambda)d\lambda \qquad G = \int_0^\infty I(\lambda)\bar{g}(\lambda)d\lambda \qquad B = \int_0^\infty I(\lambda)\bar{b}(\lambda)d\lambda$$

$$\int_0^\infty \bar{r}(\lambda)d\lambda = \int_0^\infty \bar{g}(\lambda)d\lambda = \int_0^\infty \bar{b}(\lambda)d\lambda$$

Chromaticity

- Tristimulus values of XYZ space



CIE XYZ matching function

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$X = \int_0^\infty I(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int_0^\infty I(\lambda)\bar{y}(\lambda)d\lambda$$ → **Luminance**

$$Z = \int_0^\infty I(\lambda)\bar{z}(\lambda)d\lambda$$

xy-Y space

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

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

} **Chromaticity**

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

$$\Rightarrow z = 1 - x - y$$

Chromaticity Diagram

- x and y to represent colors

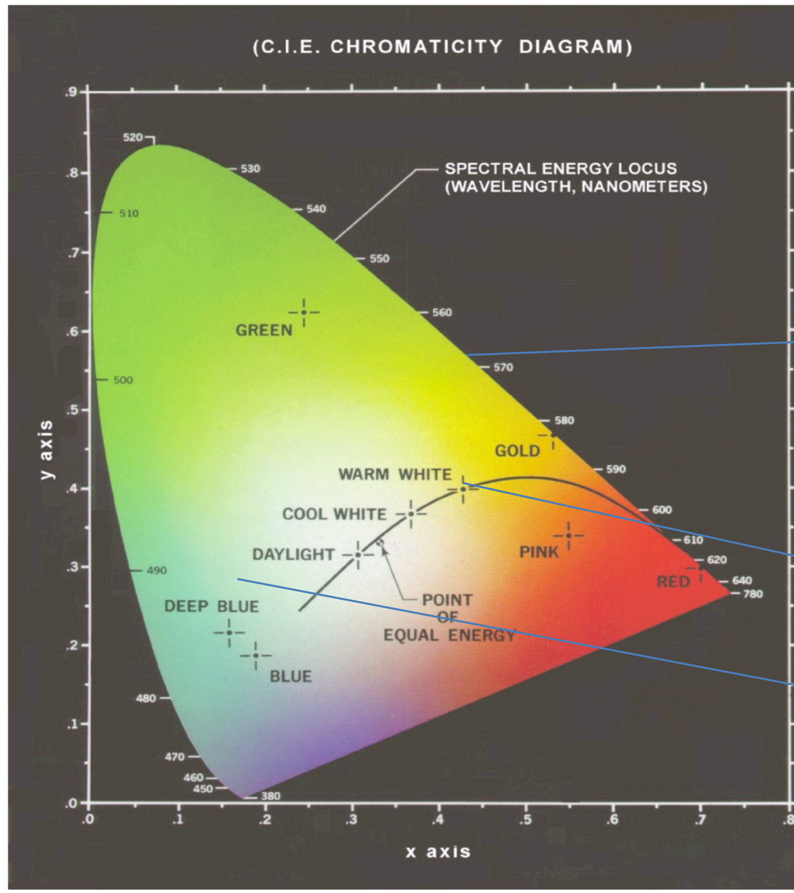


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

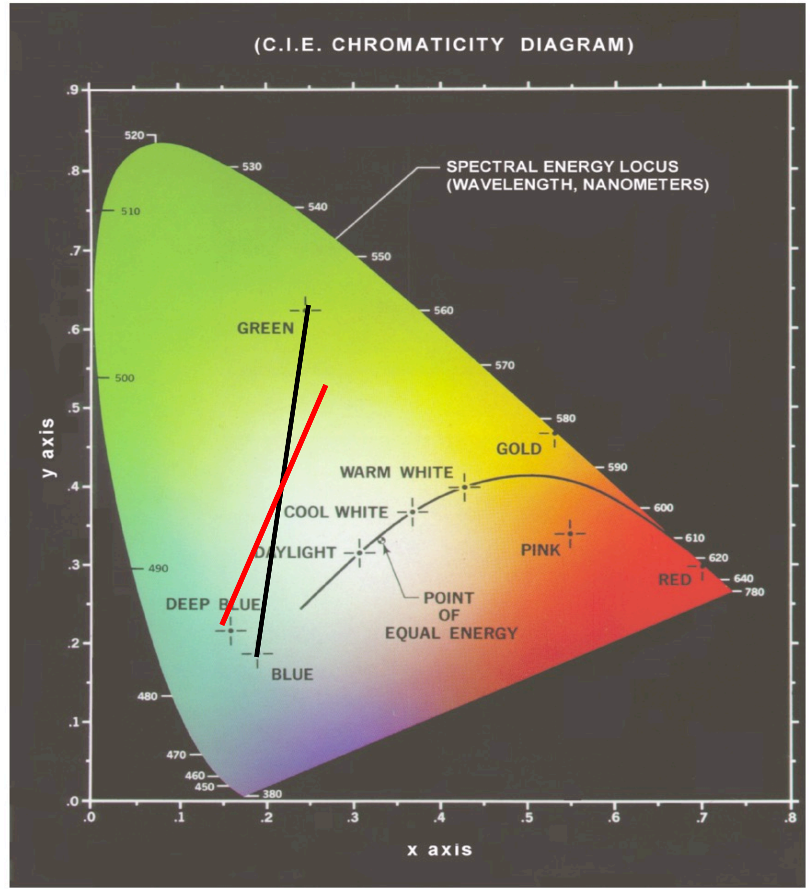
Pure color and fully saturated

Equal energy with zero saturation

Mixed color with less saturation

Chromaticity Diagram (Cont'd)

- Color mixing: any color on a line segment can be generated by the two ending points in the color diagram
- Metamerism: the same color can be generated with different combinations of source colors with the same tristimulus values



Color Gamut

- Color gamut: a complete subset of colors can be displayed on a device or represented by a color space.
- The color represented by 3 given colors resides in the triangle formed by the 3 points
- Not all colors can be represented by 3 primary colors

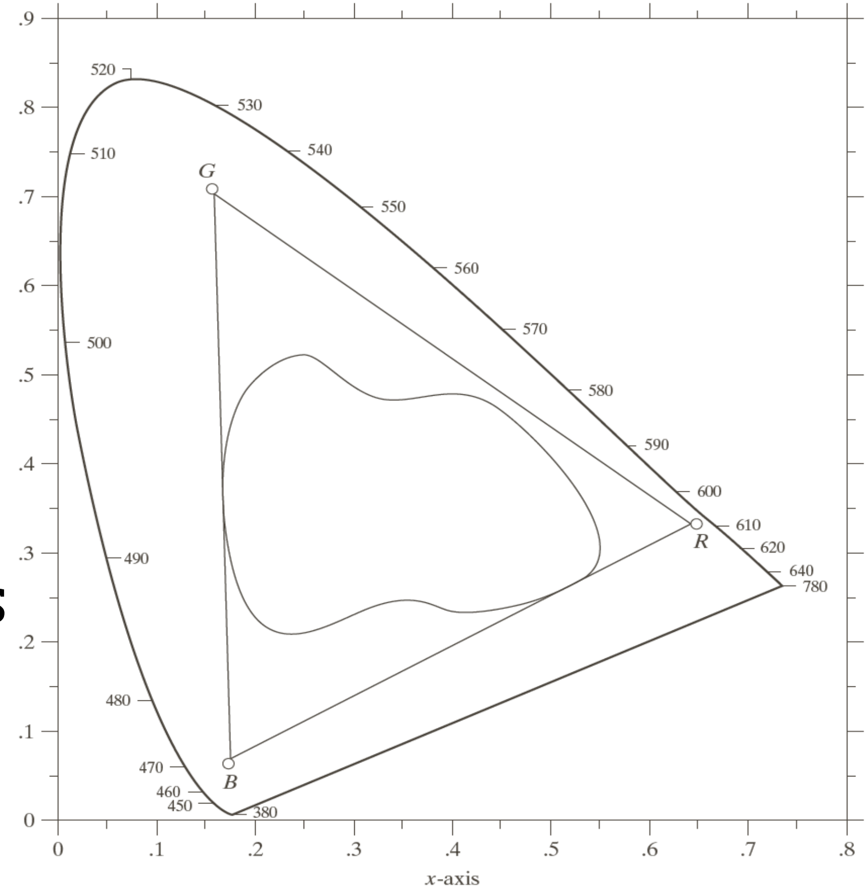


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Models

- Color model (space/system): a coordinate system or a subspace to represent the colors
- RGB model: monitors and cameras
- CMY (Cyan, magenta, and yellow): printing
- HSI (Hue, saturation, and intensity): separate color and gray level information

RGB Model

- 3D Cartesian coordinate system
- All colors are normalized to [0, 1]
- Pixel depth: number of bits to represent each pixel in the RGB space

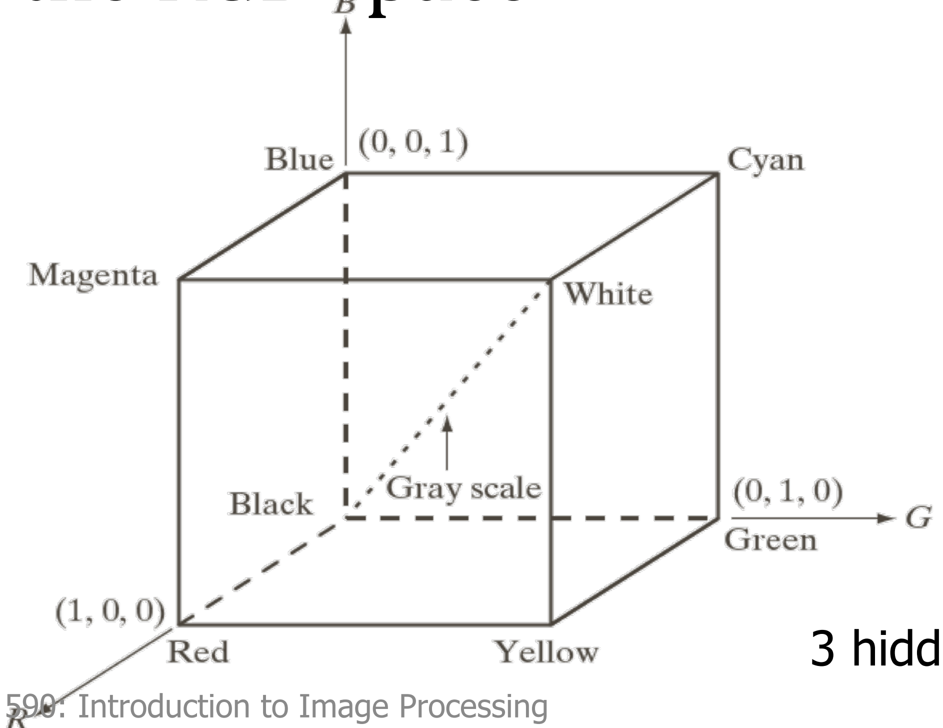
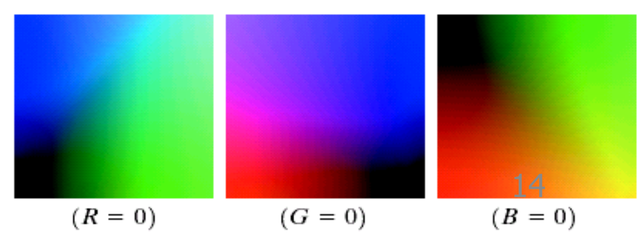


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

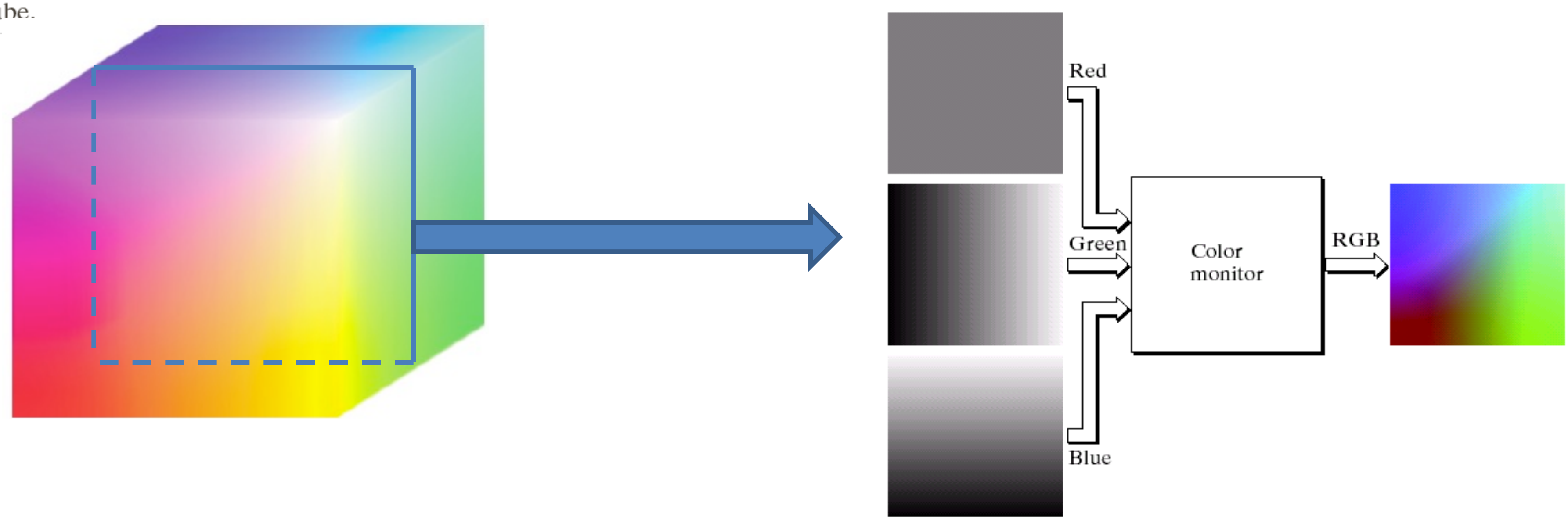
FIGURE 6.8 RGB 24-bit color cube.

3 hidden planes



RGB Model (Cont’d)

FIGURE 6.8 RGB 24-bit color cube.

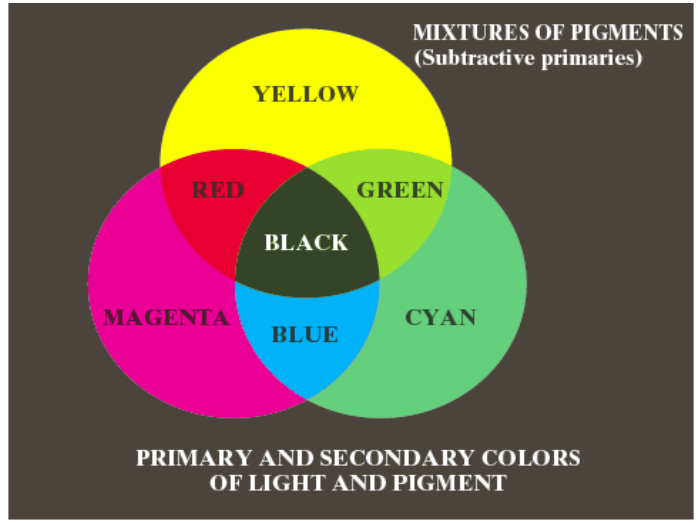


CMY/CMYK Model

- CMY (Cyan, Magenta, Yellow)

Represent the light reflected from the surface.

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



- CMYK (CMY + Black)

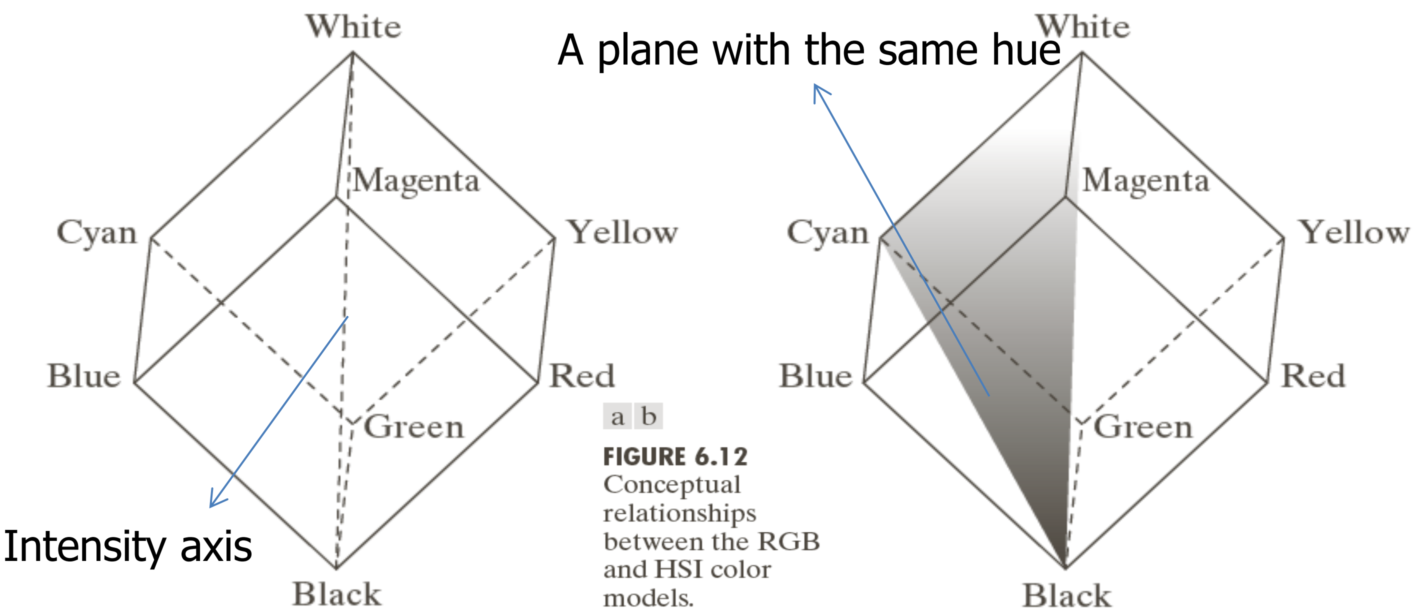
HSI Model

A better model to describe colors.
- Hue: the dominant color observed
- Saturation: the purity of the color (how much the color is polluted by white color)
- Value/Intensity: intensity level

HSI Model

A better model to describe colors.

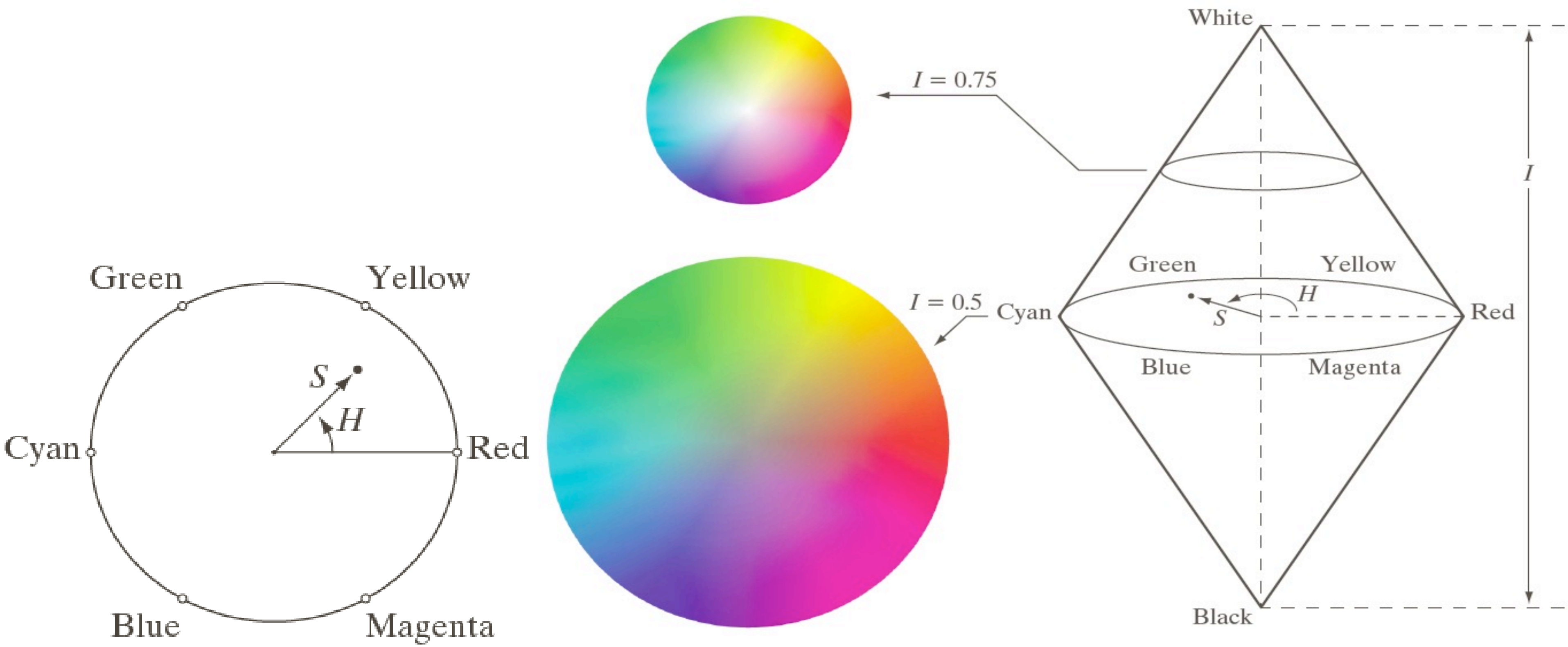
- Hue: the dominant color observed
- Saturation: the purity of the color (how much the color is polluted by white color)
- Value/Intensity: intensity level



a b

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

HSI Model



RGB to HSI

Assume RGB values have been normalized to [0,1]

$$H = \begin{cases} \theta / 360 & if B \le G \\ 1 - \theta / 360 & if B > G \end{cases}$$ where $$\theta = \cos^{-1}\left\{ \frac{0.5\left[(R-G)+(R-B)\right]}{\left[(R-G)^2 + (R-B)(G-B)\right]^{1/2}} \right\}$$

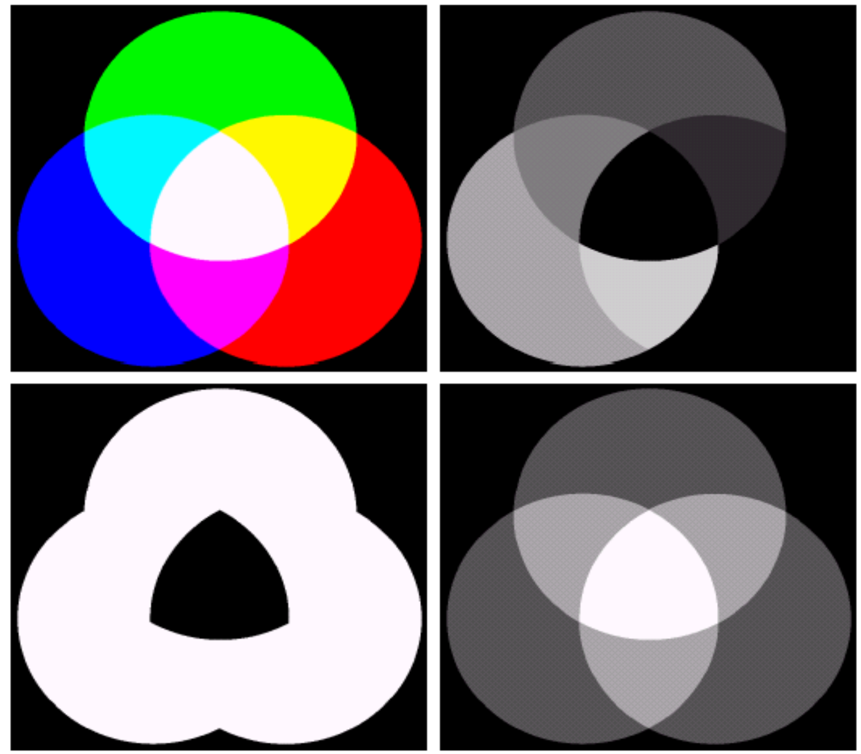
$$S = 1 - \frac{3}{R+G+B}\min(R,G,B) \qquad I = \frac{R+G+B}{3}$$

HSI values are in [0,1]

Case Study for RGB-HSI

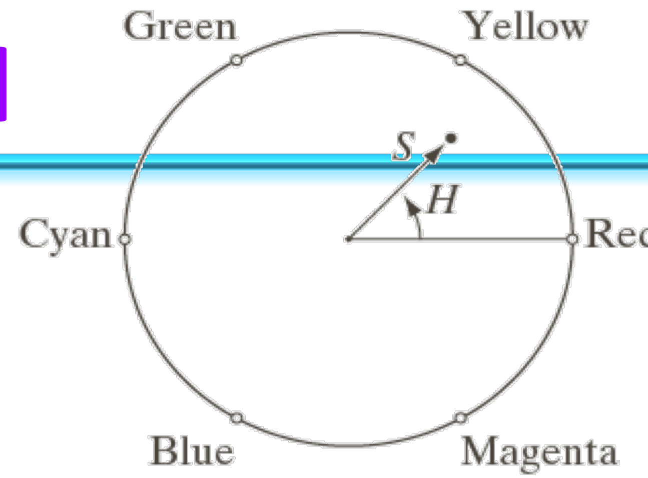
$$\begin{bmatrix}0\\0\\0\end{bmatrix} \begin{bmatrix}1\\0\\0\end{bmatrix} \begin{bmatrix}0\\1\\0\end{bmatrix} \begin{bmatrix}0\\0\\1\end{bmatrix} \begin{bmatrix}1\\1\\0\end{bmatrix} \begin{bmatrix}1\\0\\1\end{bmatrix} \begin{bmatrix}0\\1\\1\end{bmatrix} \begin{bmatrix}1\\1\\1\end{bmatrix}$$

Original RGB Hue



Saturation Intensity

RGB to HSI



- Recover H to [0 360]
- RG sector ($0 \le H < 120$):

$$B = I(1-S) \qquad R = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad G = 3I - (R+B)$$

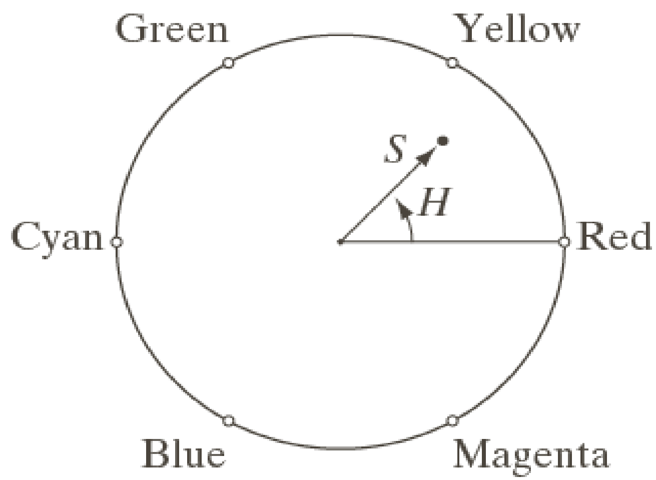
- GB sector($120 \le H < 240$): $H = H - 120$

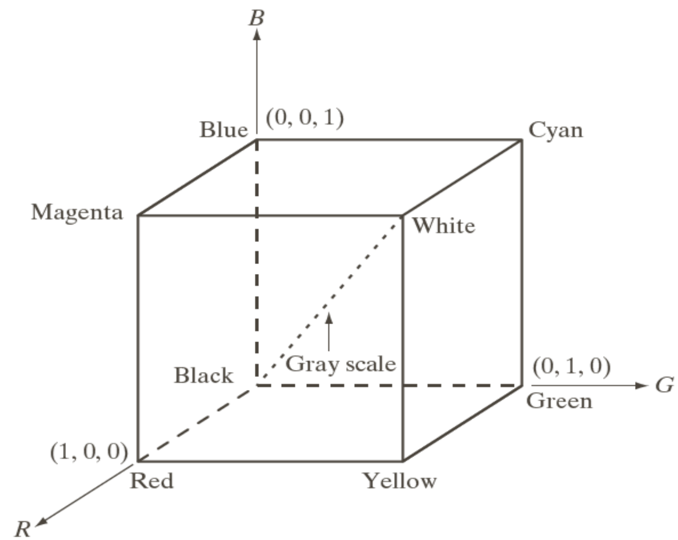
$$R = I(1-S) \qquad G = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad B = 3I - (R+G)$$

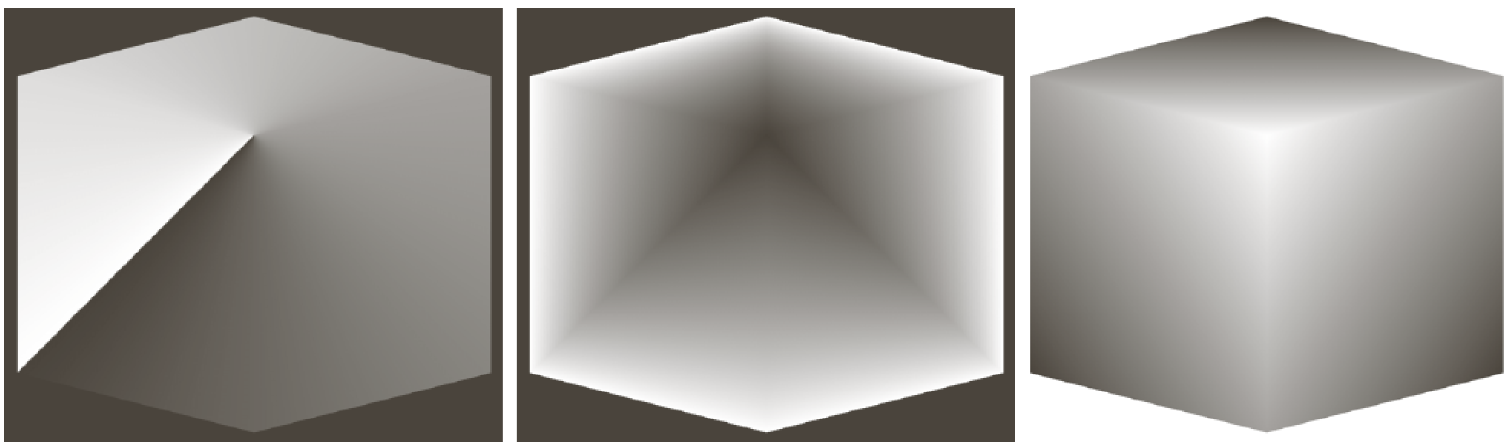
- BR sector($240 \le H \le 360$): $H = H - 240$

$$G = I(1-S) \qquad B = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad R = 3I - (G+B)$$

HSI Model



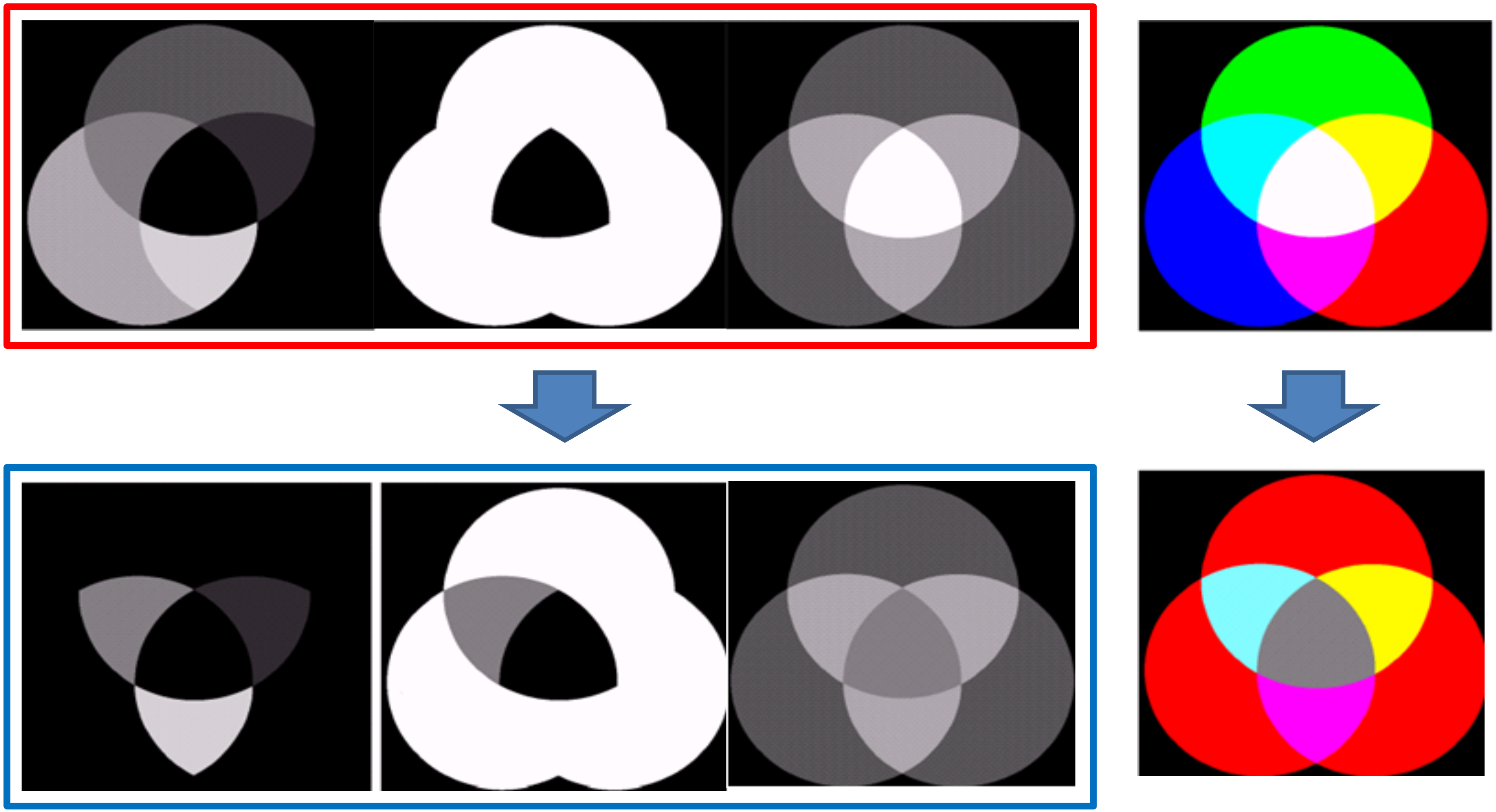




a b c

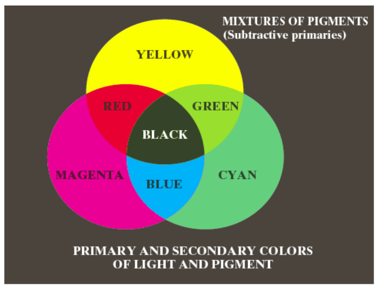
FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

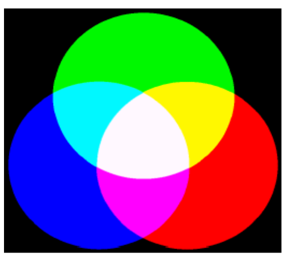
Manipulate

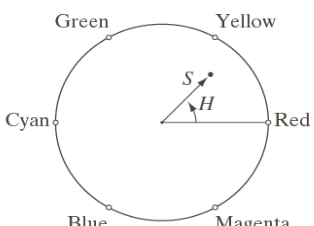


Hue Saturation Intensity

Full Color Image in Different Color Space







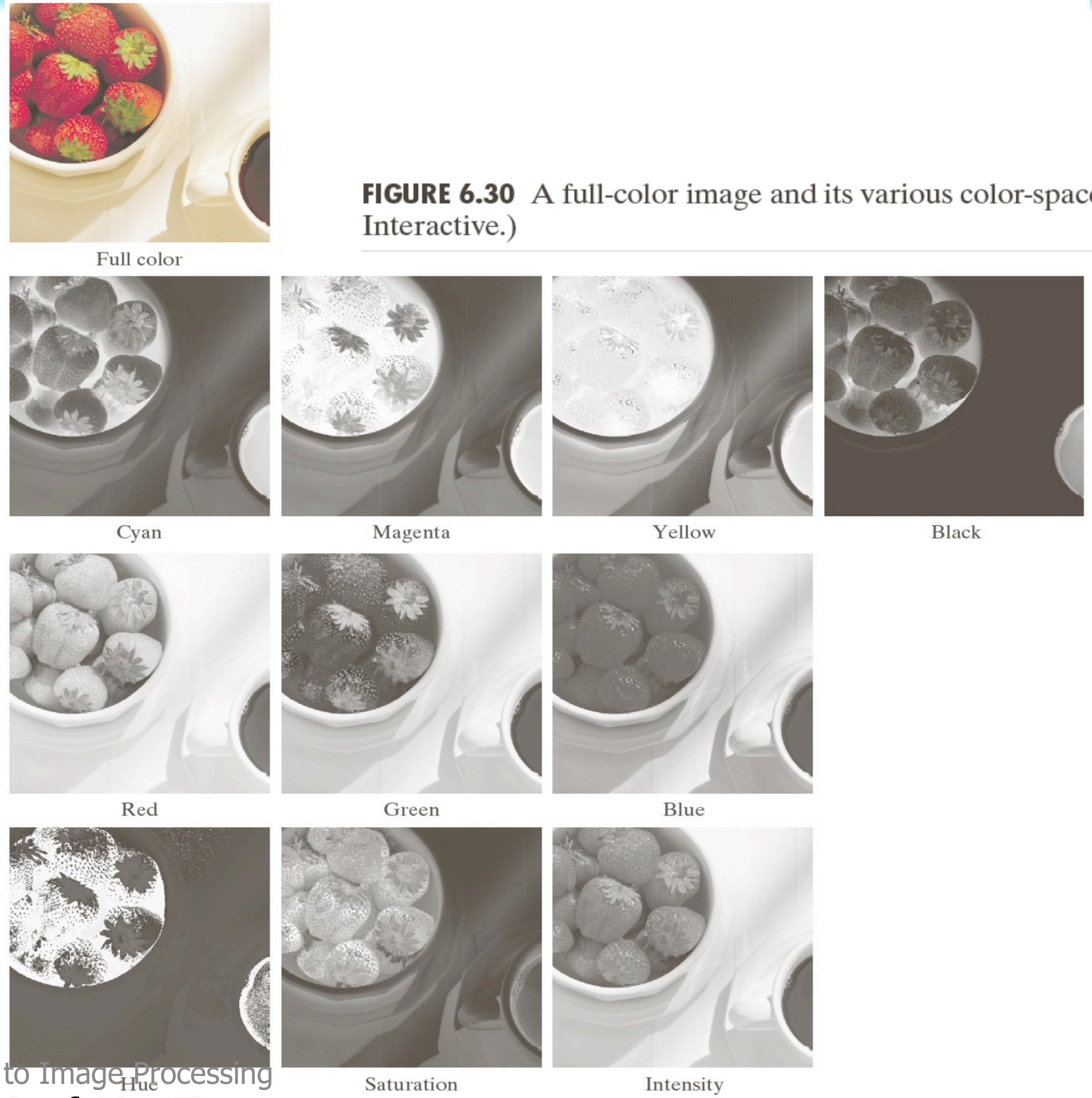


FIGURE 6.30 A full-color image and its various color-space components. Interactive.)

Pseudo Color Image Processing

- Pseudo color/false color: assign colors to gray values
- Enhance the visualization quality of the image
- Segmentation results
- Enhance the intensity difference

Intensity Slicing

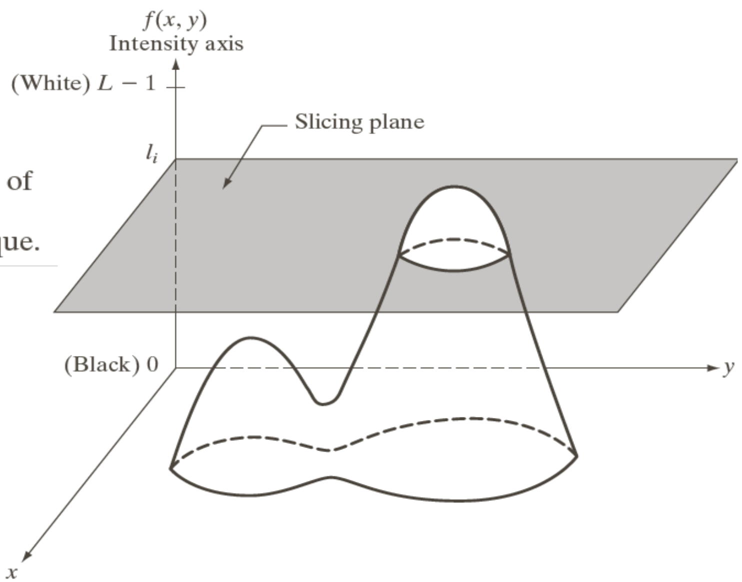


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

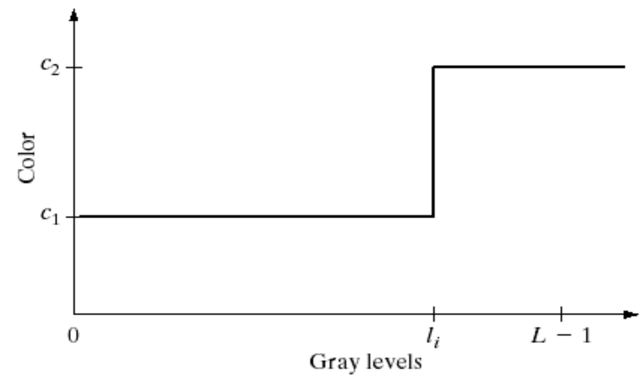
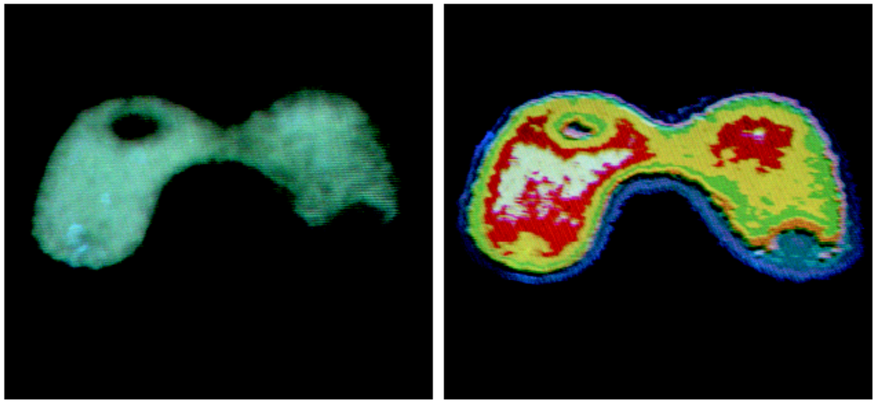


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

Examples of Intensity Slicing

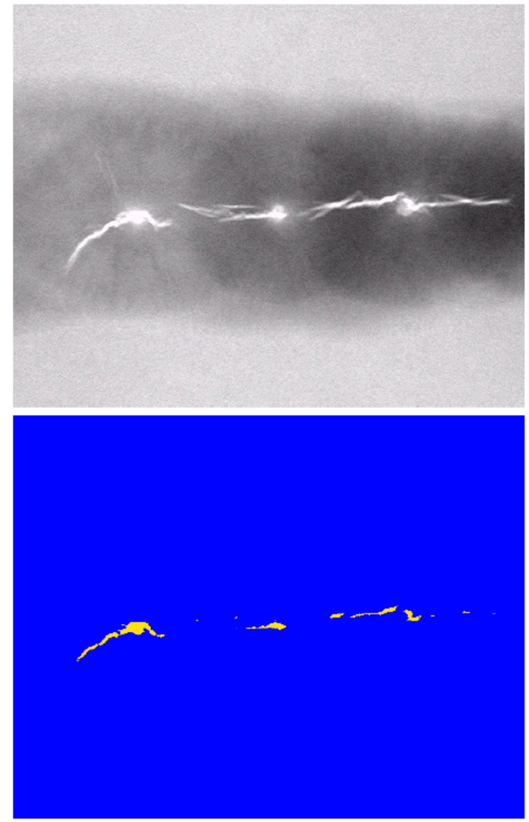


a b

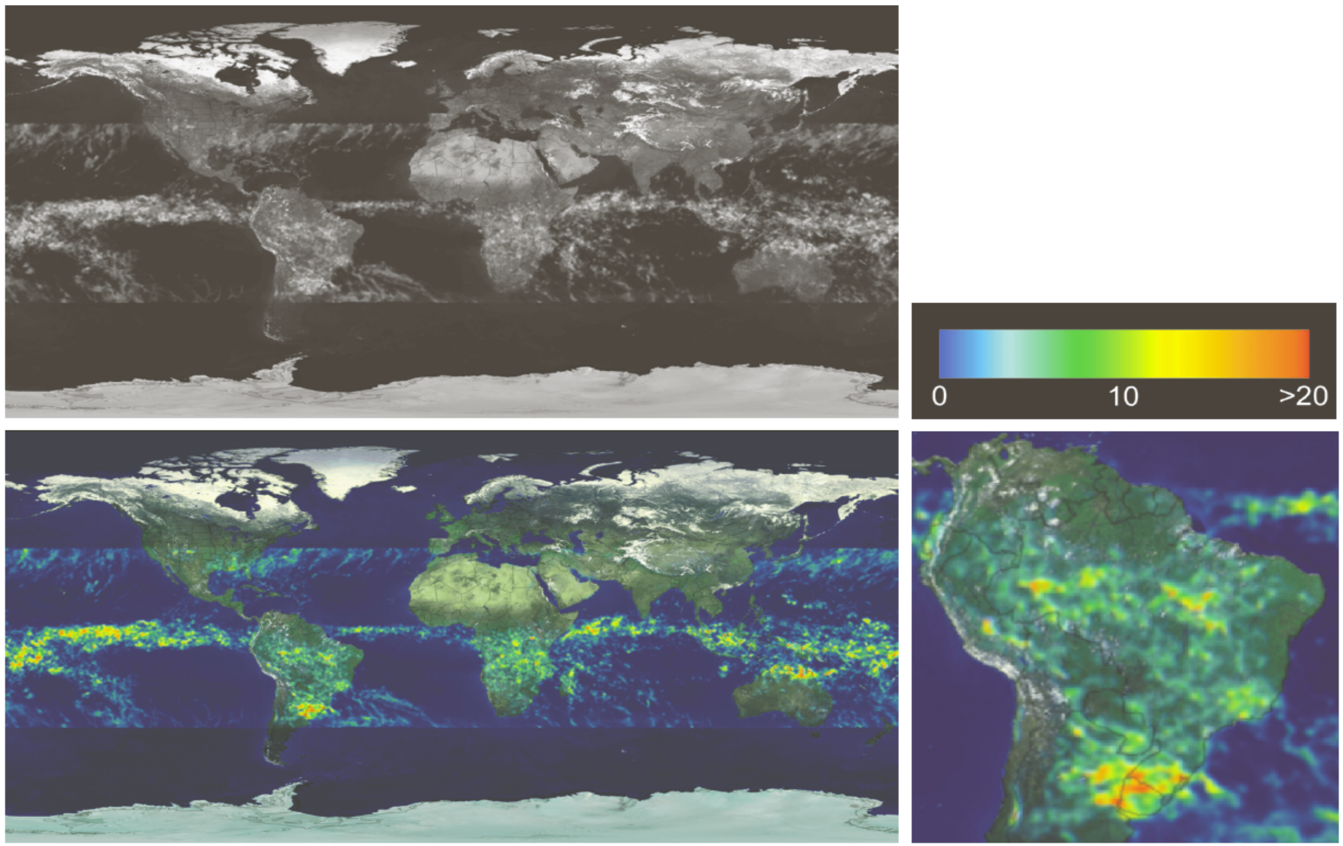
FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

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.)



Examples of Intensity Slicing

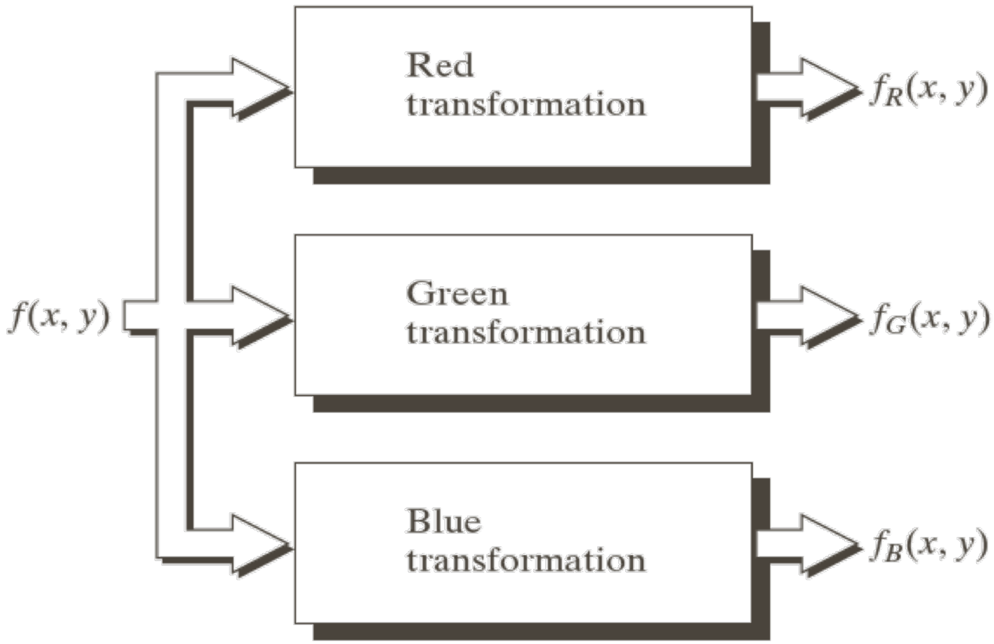


a b
c d

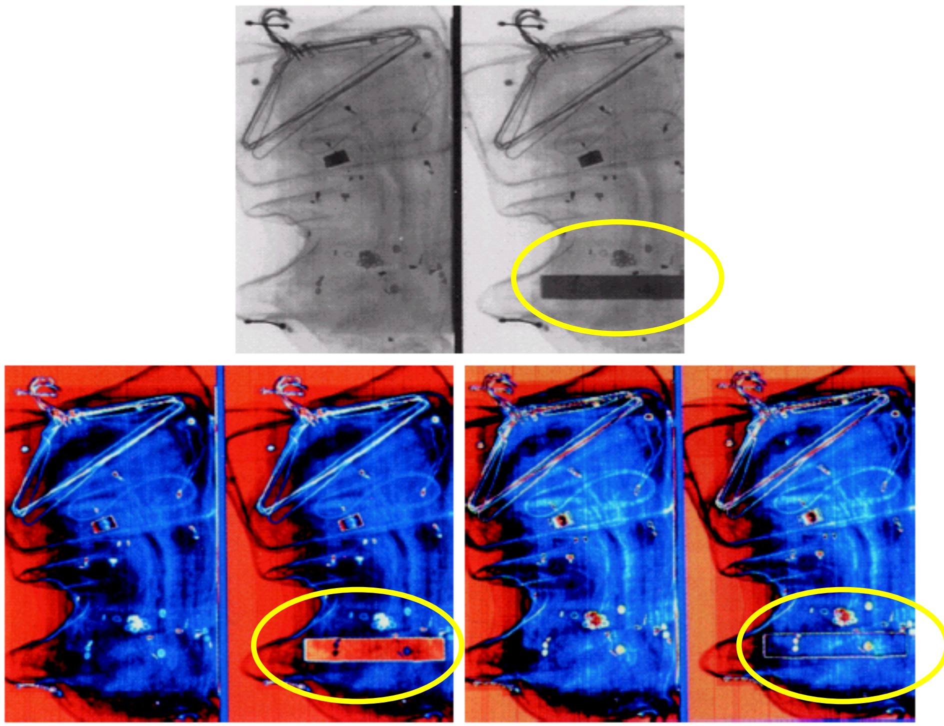
FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

Intensity to Color Transformation

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.

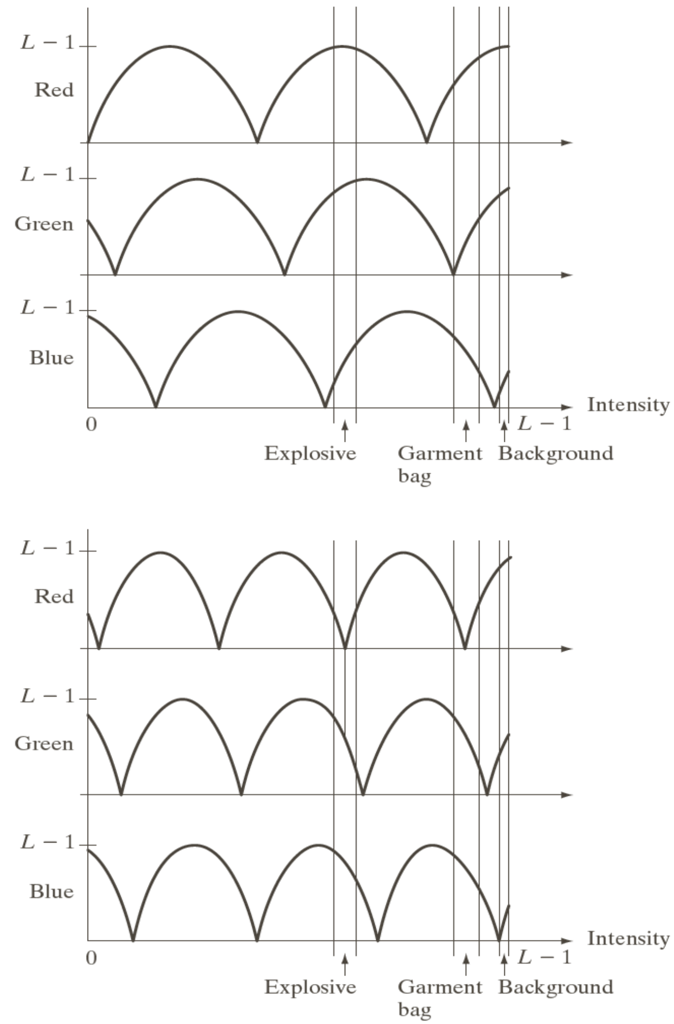


Example



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.)



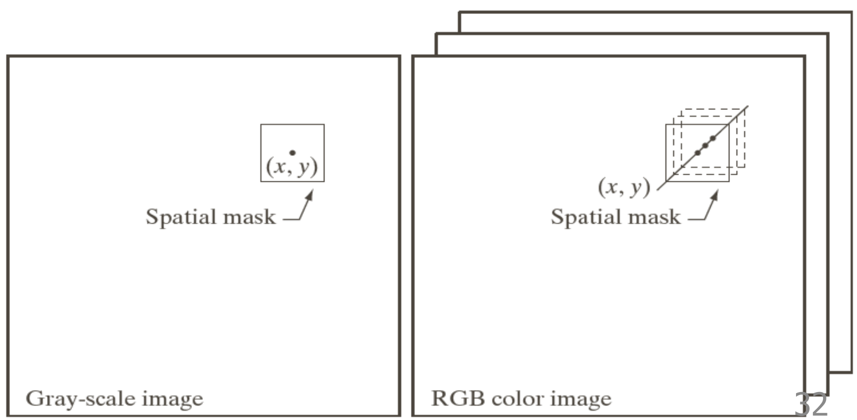
a
b

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Full-color Image Processing

Pixel in color image $\mathbf{p}(x,y)=\begin{bmatrix} p_r(x,y) \\ p_g(x,y) \\ p_b(x,y) \end{bmatrix}$

- Process each component/channel individually, then generate the composite image
- Work on each pixel individually



Color Transformation

For a color image with n components

input values for all components

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

Output value for i^{th} component Transformation functions

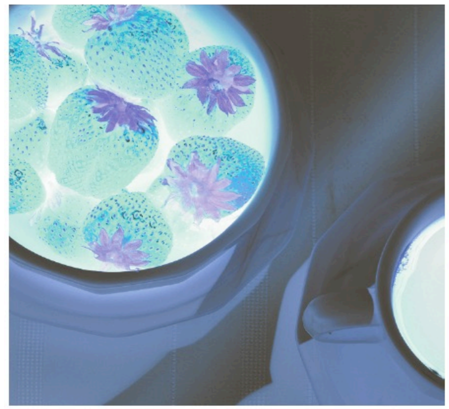
- Modify intensity
- Color complement ("negative" color image)
- Color slicing
- Tonal correction
- Color balancing
- Histogram processing

Examples of Color Image Transformation

Original image

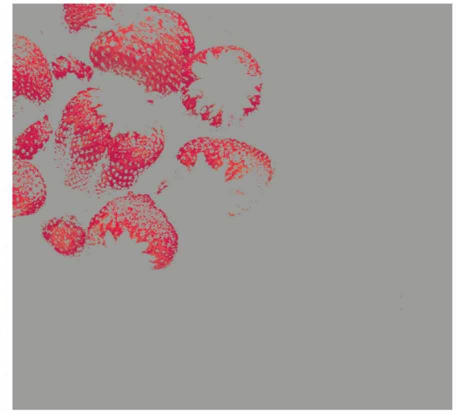
Intensity modification

HSI



Complement color

RGB



Color slicing

RGB

Tonal Correction

- Correct the tonal range (distribution of color intensities)
- Recall the intensity transformation in the gray level images
- For RGB model, each component has the same transformation function
- For HSI model, the transformation is applied on the intensity component only

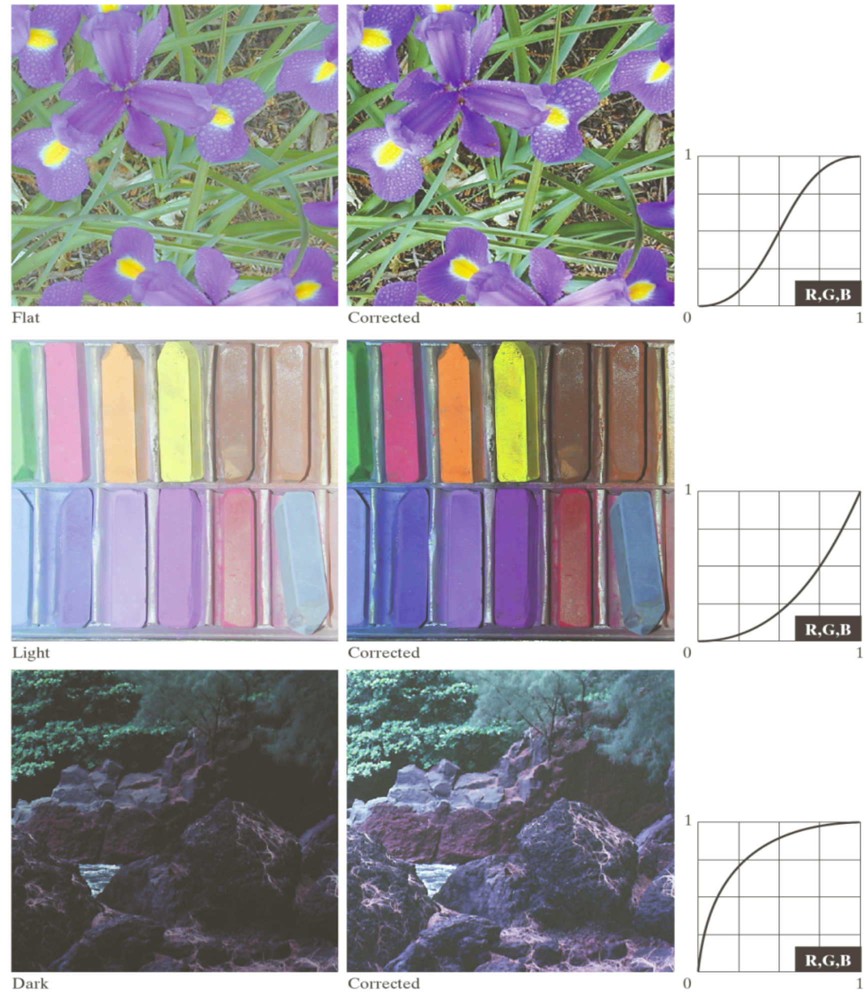
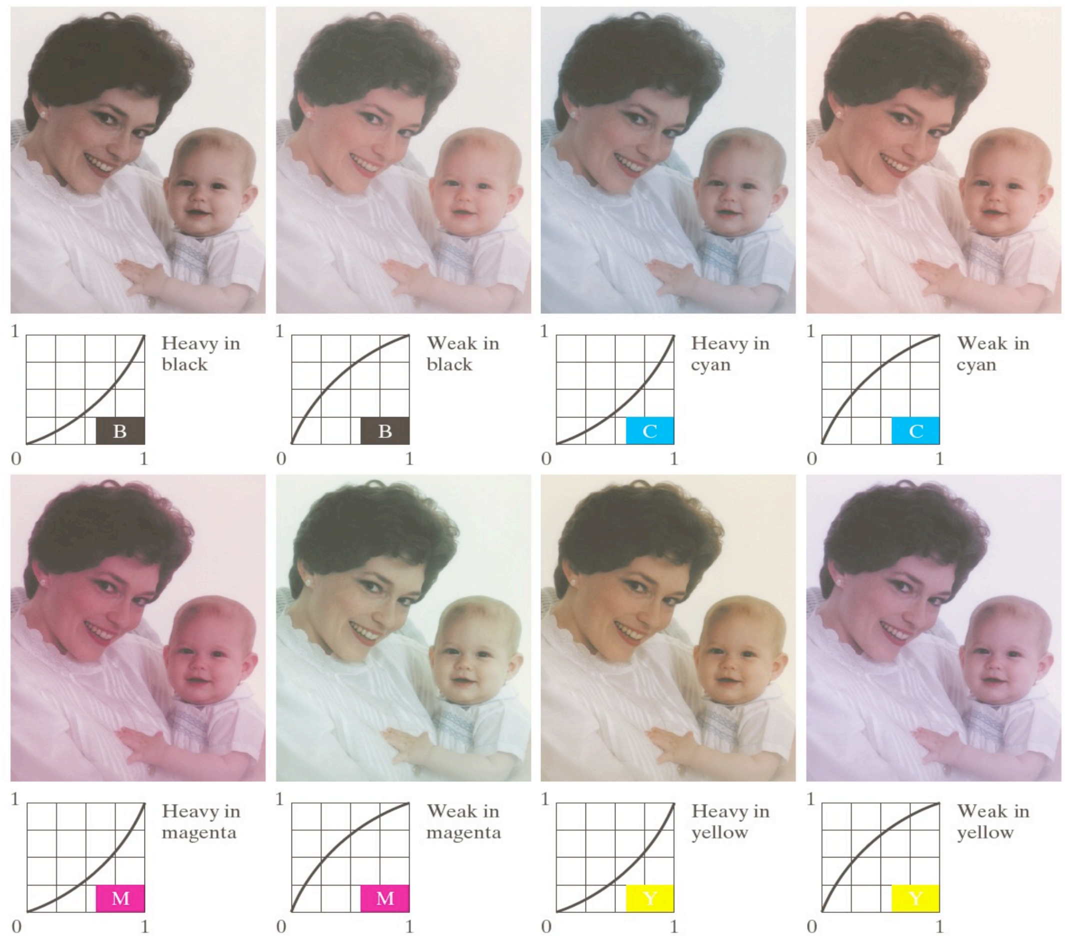


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Color Balancing

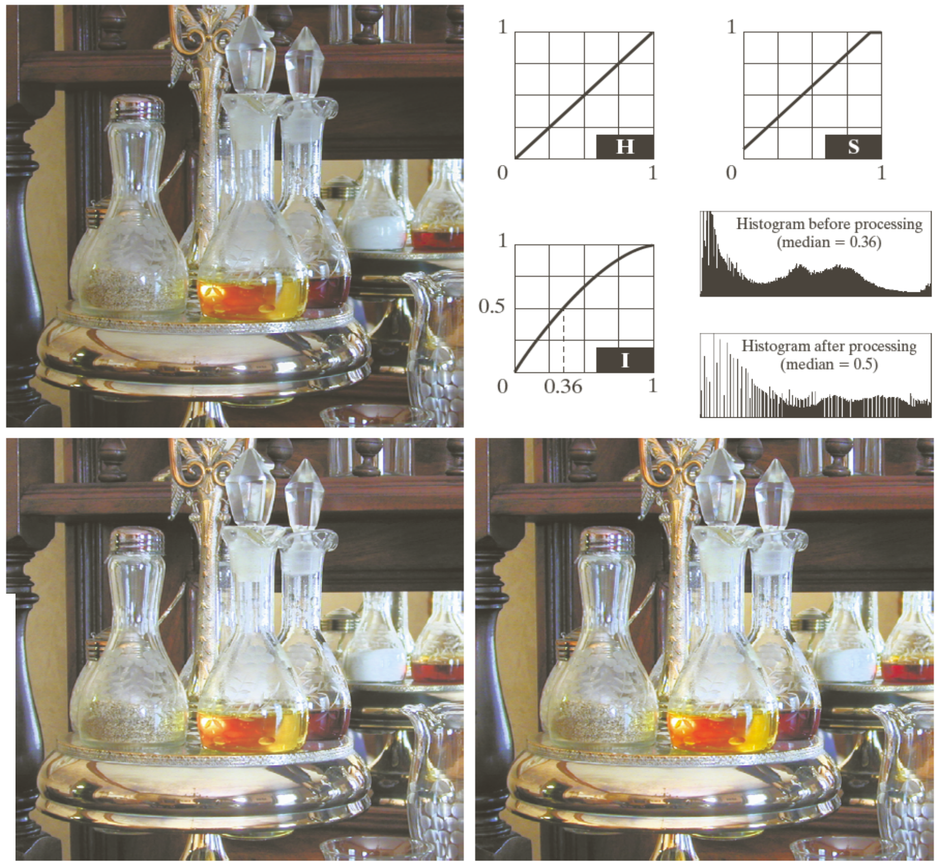
- Correct color unbalance by analyzing a known color in image

Original/Corrected



Histogram Processing

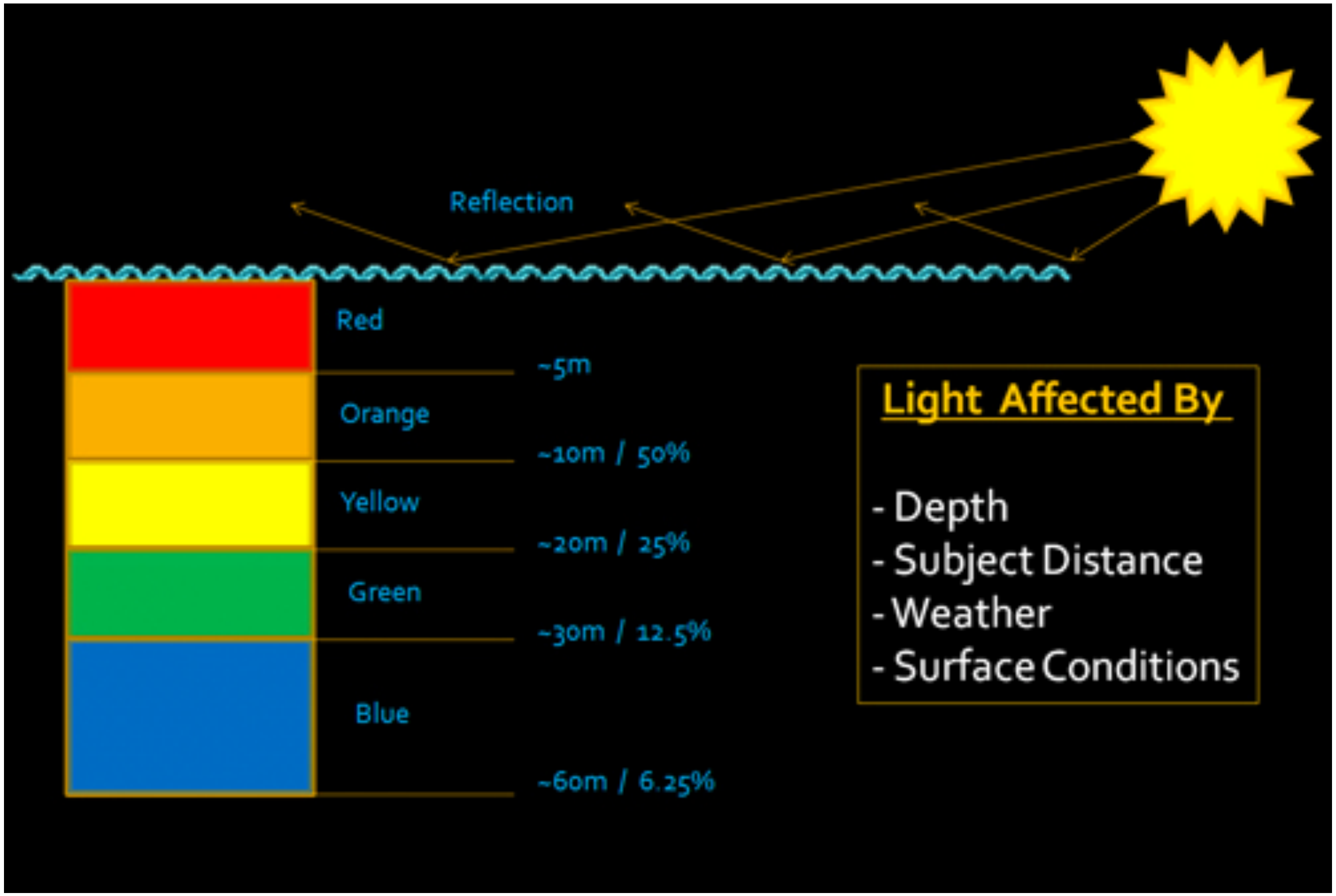
- Step 1: Histogram equalization
- Step 2: Saturation adjustment



a b
c d

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

Color Loss Underwater



Color Loss Underwater