CMPUT 206: Color Image Processing

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Slide material source: Digital Image Processing, 3rd Ed. by Gonzalez and Woods

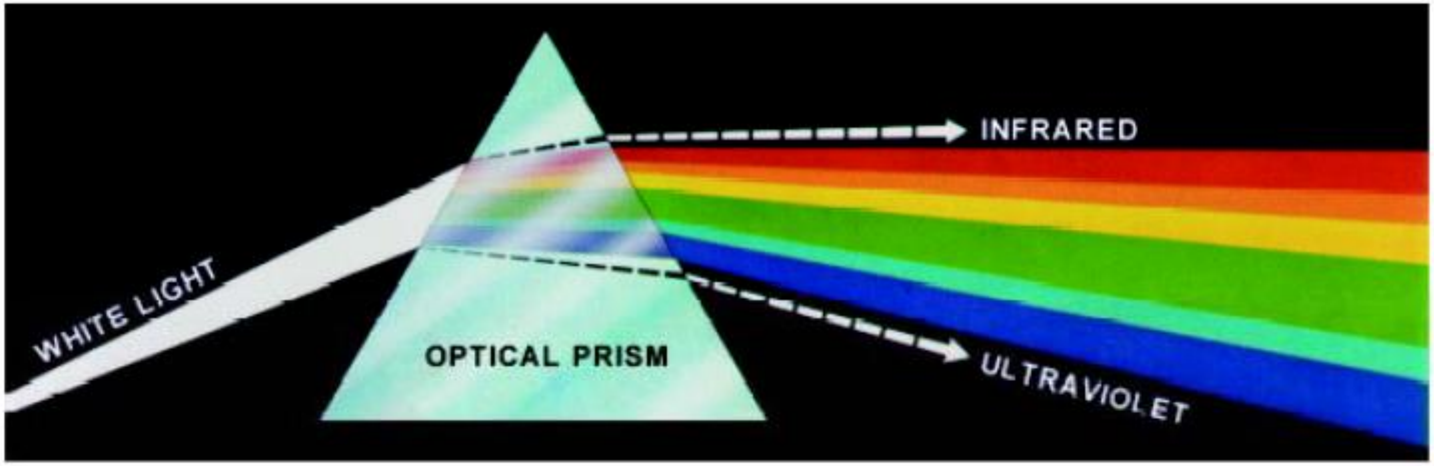


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

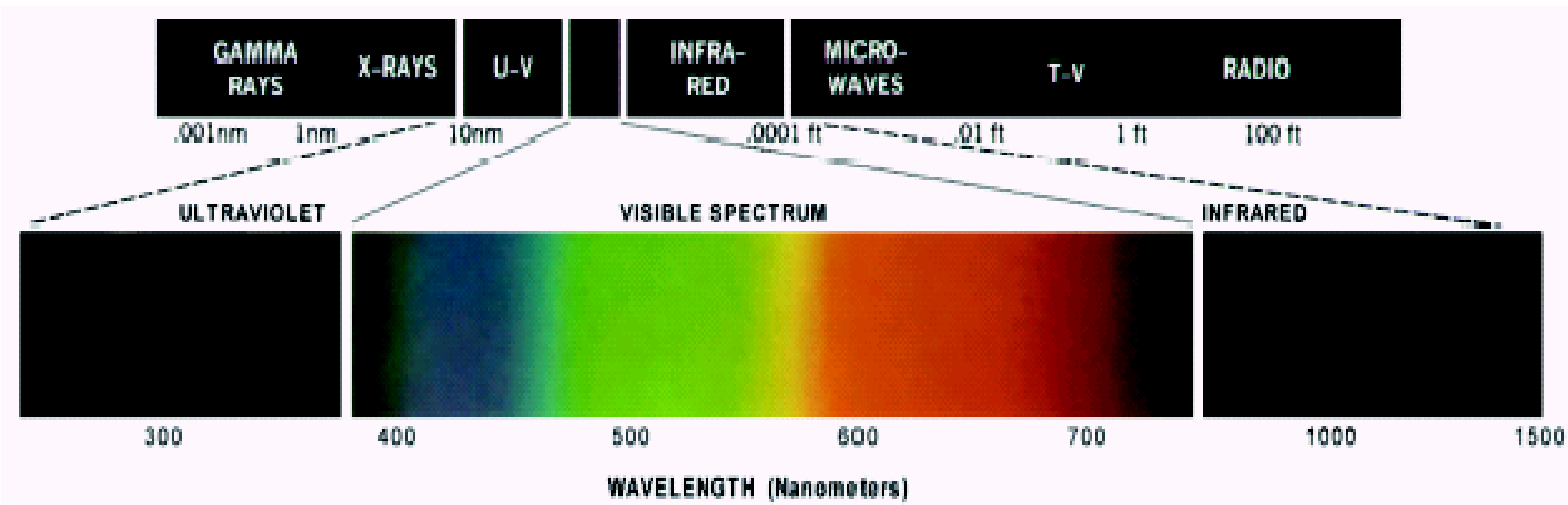


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Human Eye and Color

- Color is the visible manifestation of light's wavelength
- Human perception of color of an object is determined by the nature of the light reflected from object
- The light is visible to human eyes if its wavelength is between 380-780nm.
- For human eye
  - Approximately 65% of all cone are sensitive to red light
  - 33% are sensitive to green light
  - 2% are sensitive to blue light
- Blue cones are the most sensitive
- Fig 6.3 shows average experimental curves detailing the absorption of light by the red, green, and blue cones in the eye

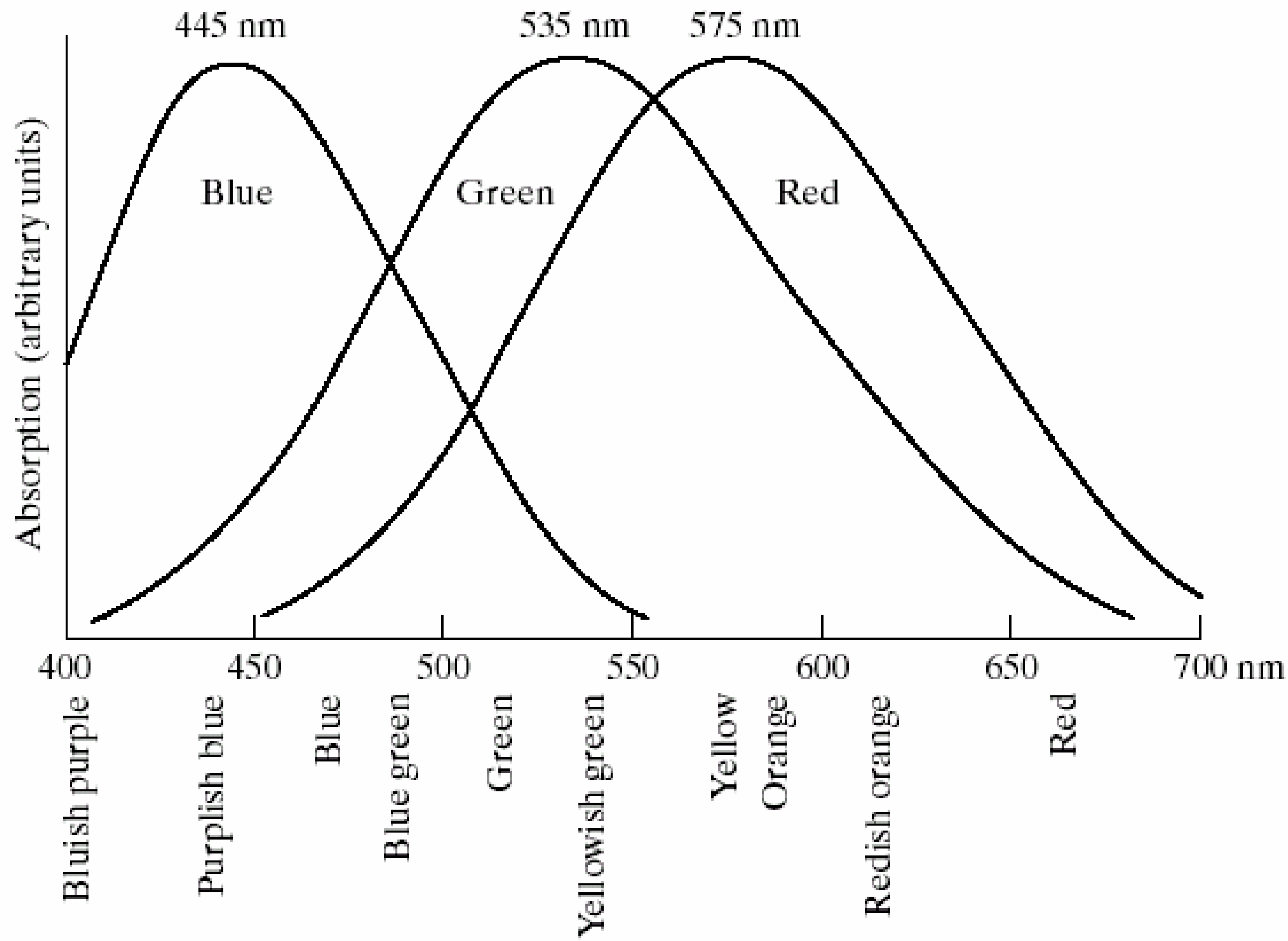


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color: Brightness and Chromaticity

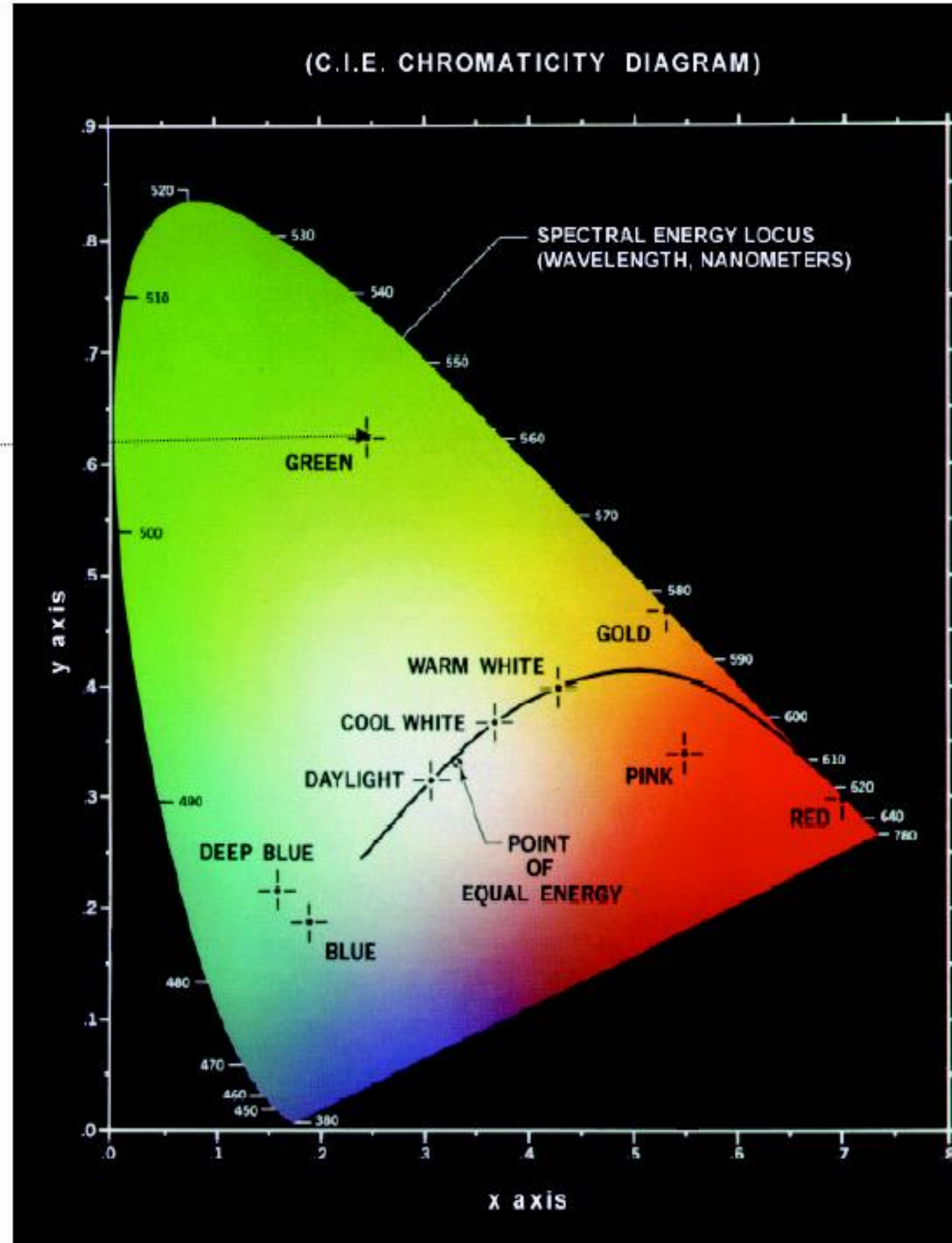
- Tristimulus nature of the human eye suggests that color space is 3D
- Experiments found out that the 3D color space can be conceived by two independent spaces:
  - Brightness (1D space)
  - Chromaticity (2D space)
- Example: a white and a gray shade have same chromaticity, but different brightness values
- CIE xyY color space (look at: http://en.wikipedia.org/wiki/CIE_1931_color_space) has the convention that Y is the brightness value, while x and y specifies chromaticity
- To obtain, 3D tristimulus color values (X, Y, Z) from xyY, use the following formula:

$$X = \frac{Y}{y}x, \qquad Z = \frac{Y}{y}(1 - x - y).$$

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

Specify color by using chromaticity diagram

y=62% green
x=25% red
z=13% blue



Chromaticity diagram shows the 2D xy space of “CIE xyY color space”

Notice that xy values are normalized (0-1)

Chromaticity diagram is useful for color mixing.

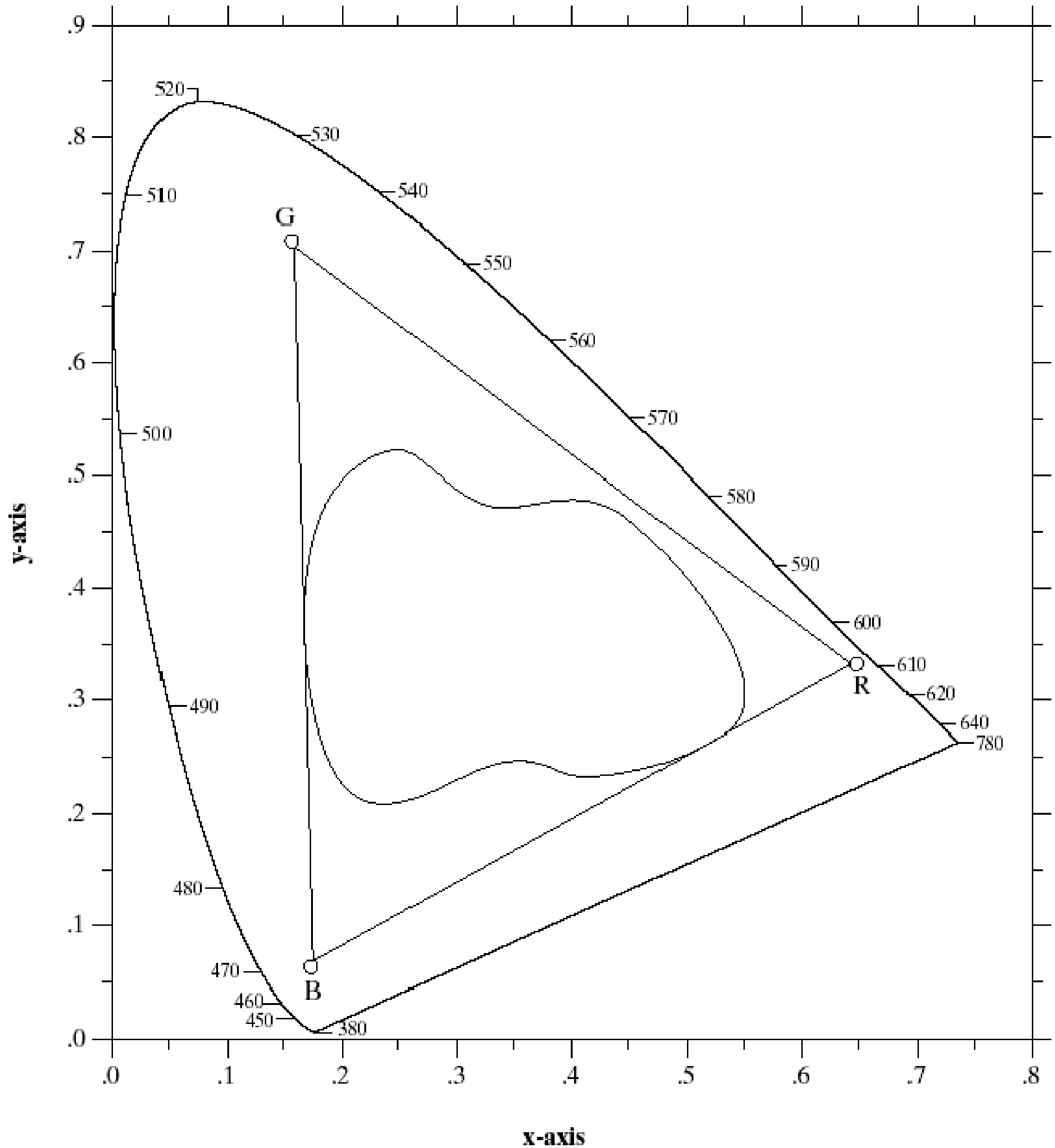


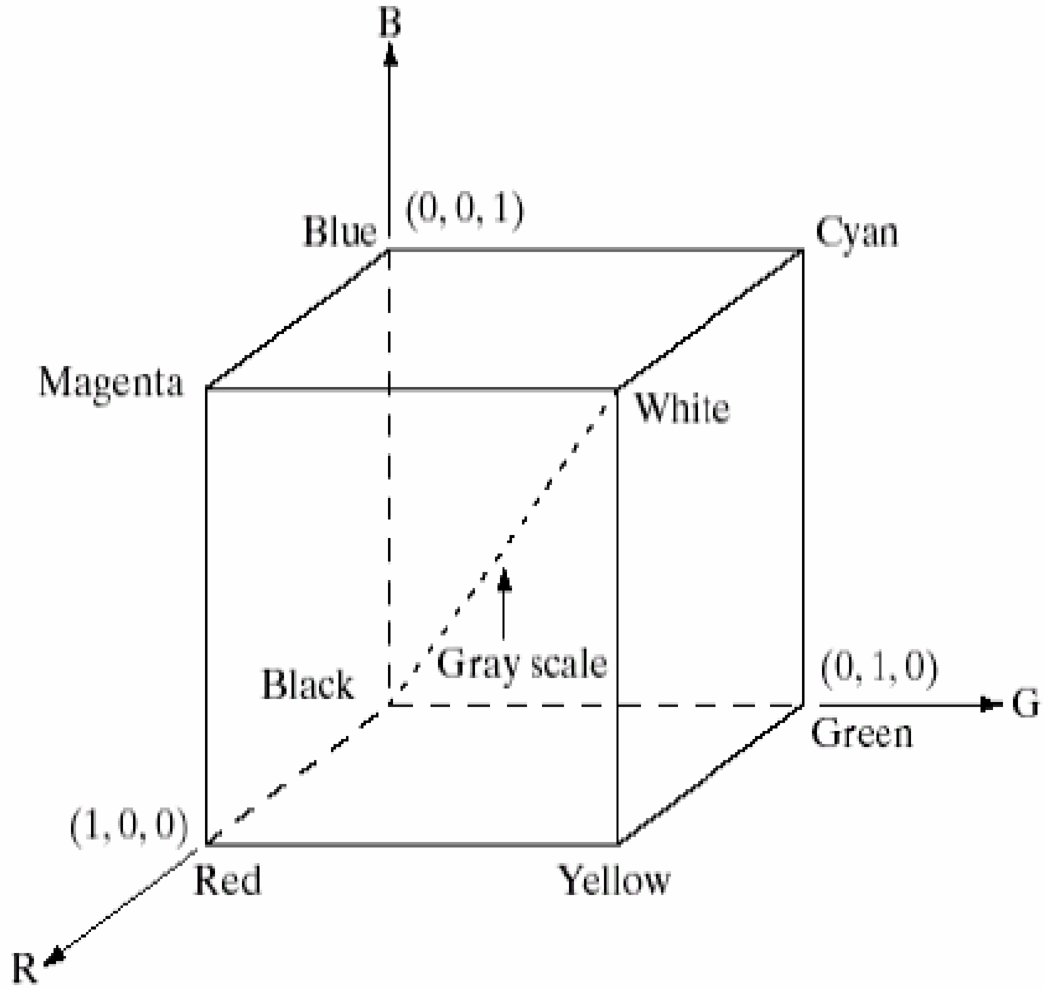
FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Models

- Color models facilitate the specification of colors in some standards
- It is a specification of a coordinate system (3D) and a subspace within the system where a color is represented
  - RGB for color monitor
  - CMY (cyan, magenta, yellow) for color printing
  - HSI (hue, saturation and intensity): decouples color (chromaticity) and gray-scale (brightness) information
  - CIE LAB: derived from CIE xyY space
  - YCbCr: Used in JPEG compression standards
  - …

RGB Color models

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 Channels

Color image

R channel

G channel

B channel

CMY Color models

- RGB to CMY conversion

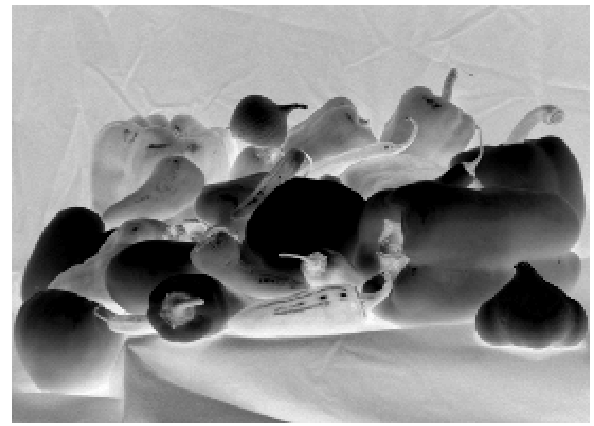
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Instead of adding C, M and Y to produce black, a fourth color *black* is added: CMYK model
- CMYK model is used in color printers

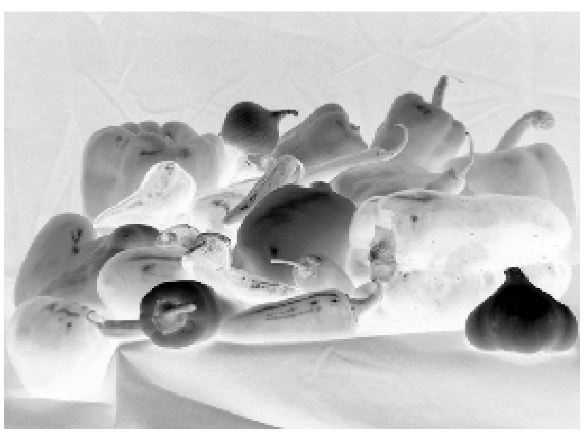
CMY Channels

Color image

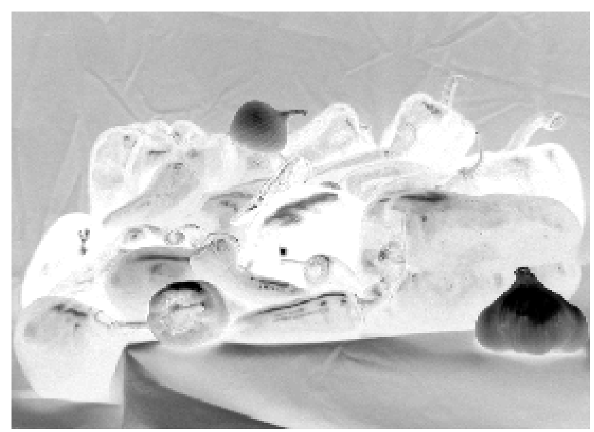
C channel

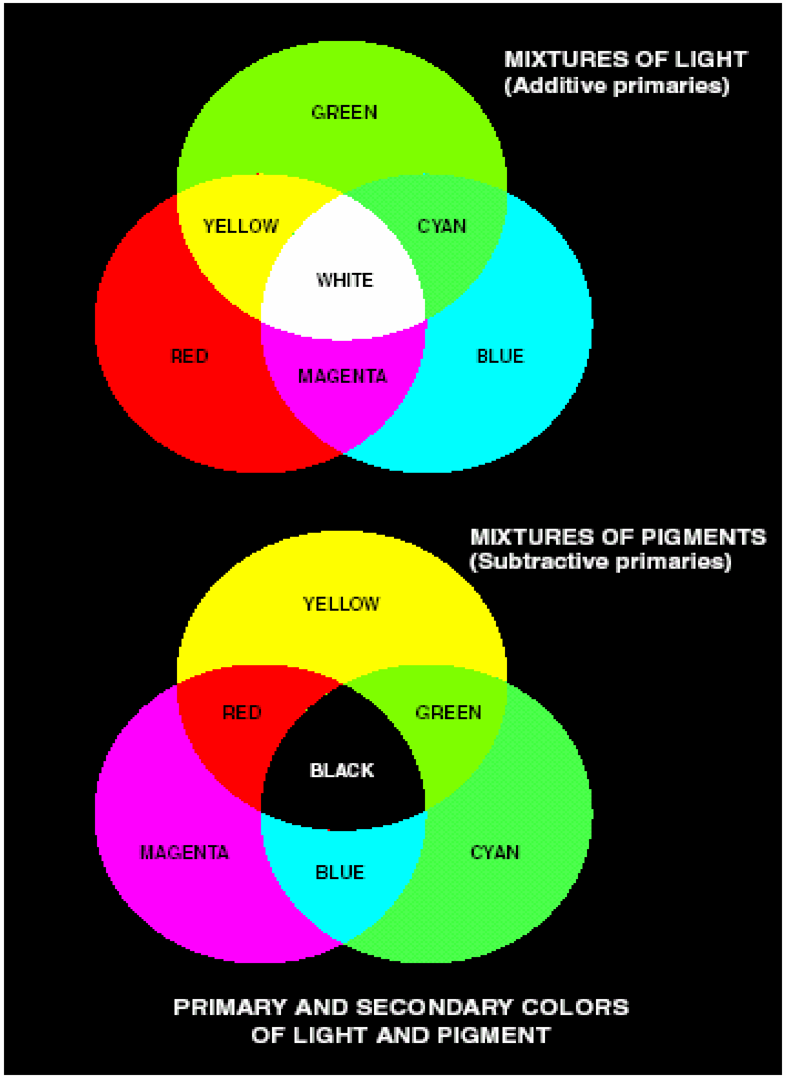


M channel



Y channel





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

a
b

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

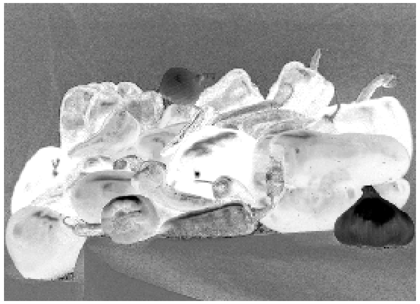
HSI Color Models

- Human describes color in terms of hue, saturation and brightness or intensity
  - Hue: describe the pure color, pure yellow, orange, green or red.
  - Saturation measures the degree to which a pure color is diluted by white light.
  - Brightness is a subjective descriptor difficult to be measured.

Color image

H channel

S channel



V channel

HSI Color models

- RGB to HSI conversion

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

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

$S = 1 - [3/(\mathrm{R+G+B})][min(\mathrm{R, G, B})]$

$I = (\mathrm{R+G+B})/3$

Pseudocolor Image Processing

- Pseudocolor image processing consists of assigning colors to gray level values based on some specific criterion
- Goal and Motivation
  - improve human visualization
    - human can distinguish at most 20-30 gray shades but thousands of colors!
  - attract attention
- Major techniques
  - intensity slicing
  - gray level to color transformation

Pseudocolor Image Processing…

Each slicing plane is assigned a different color

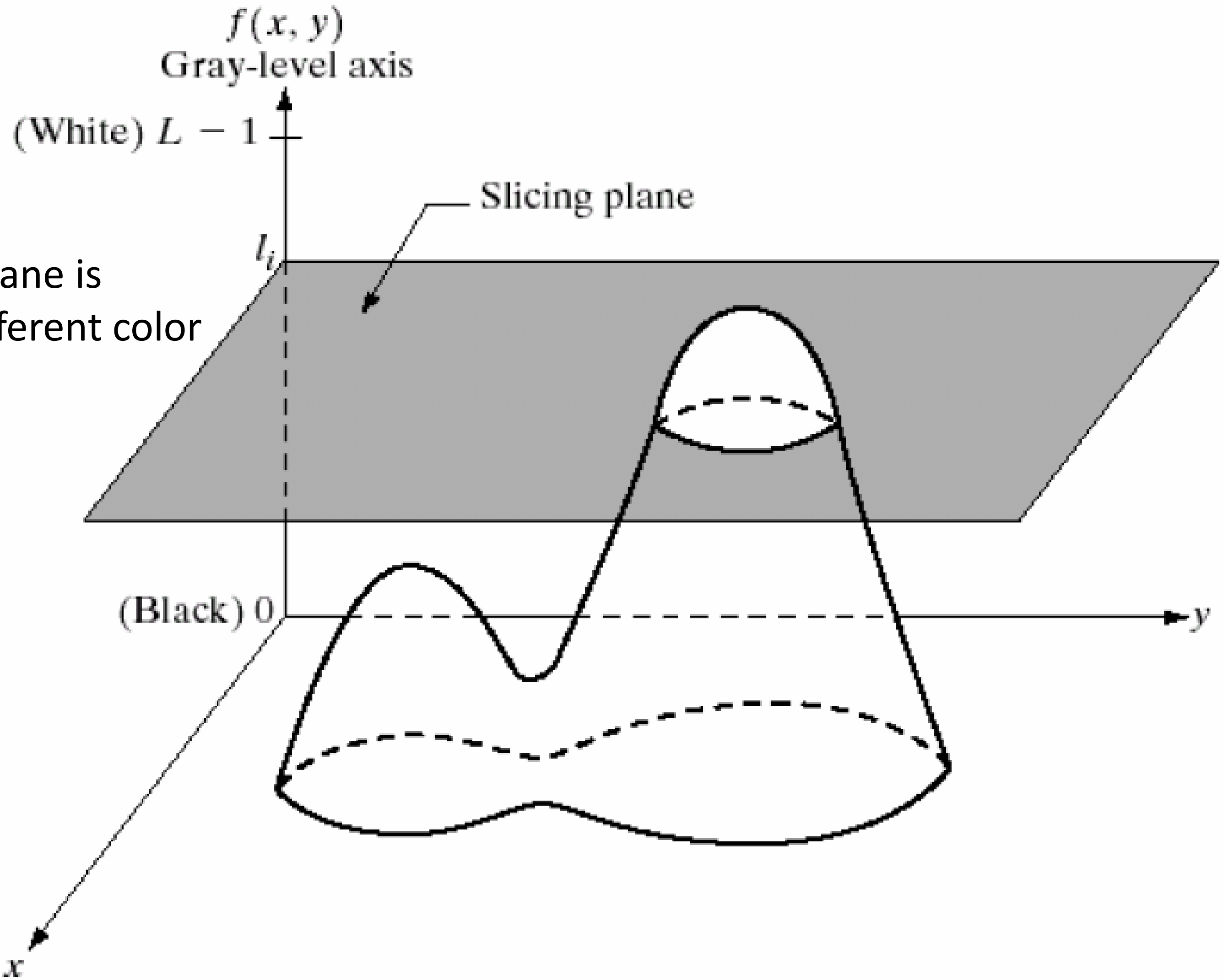
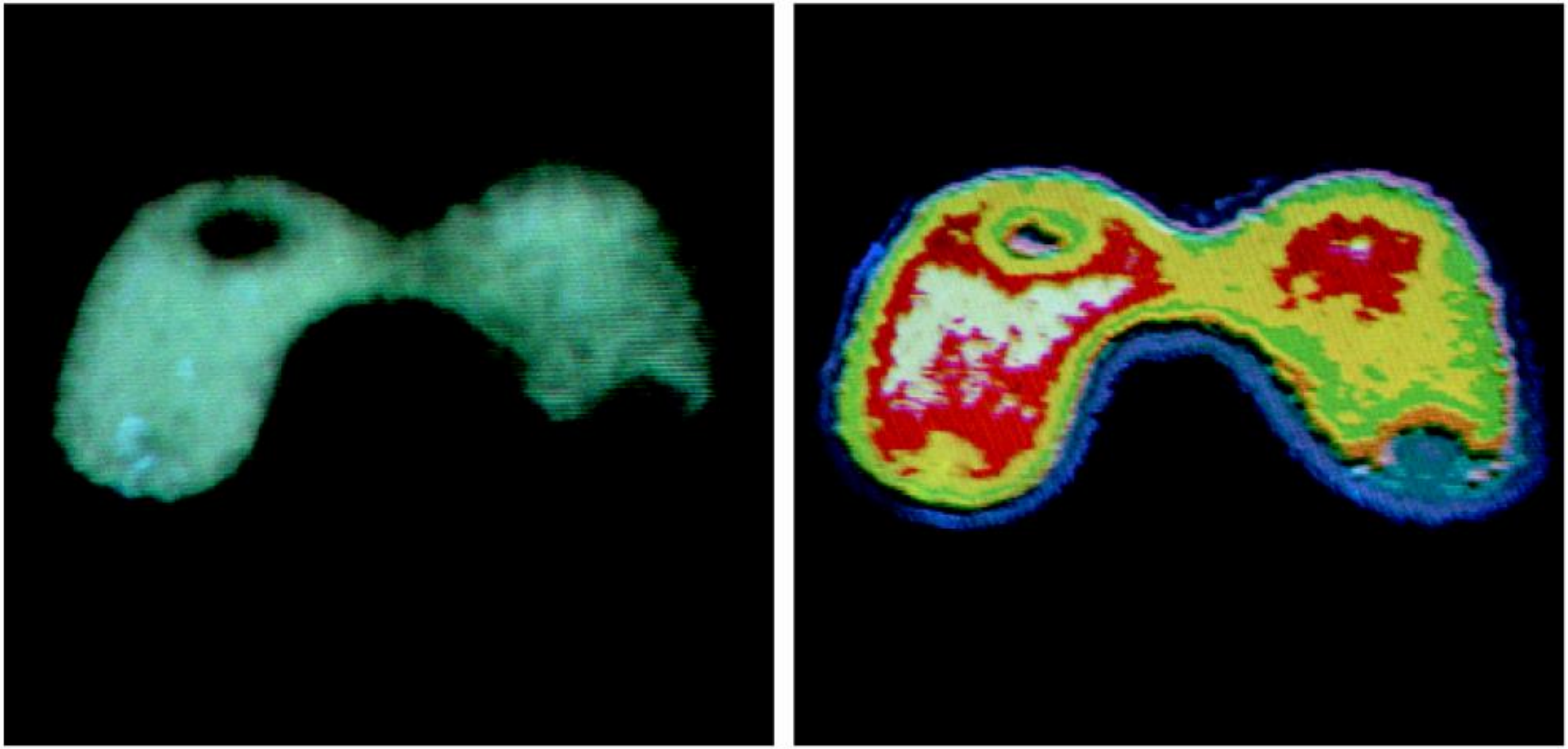


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

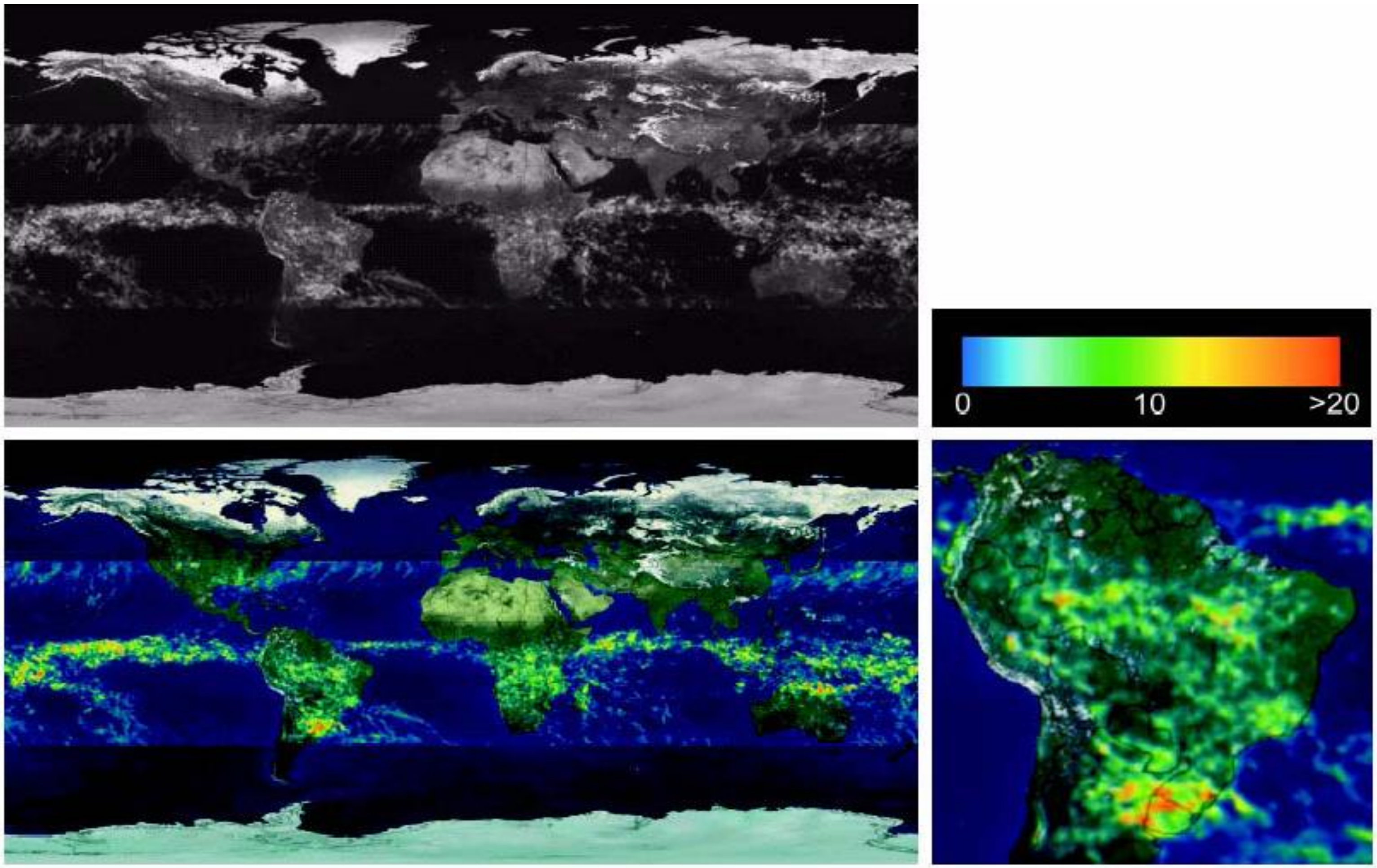
Pseudo-color image processing



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.)

Pseudo-color image processing



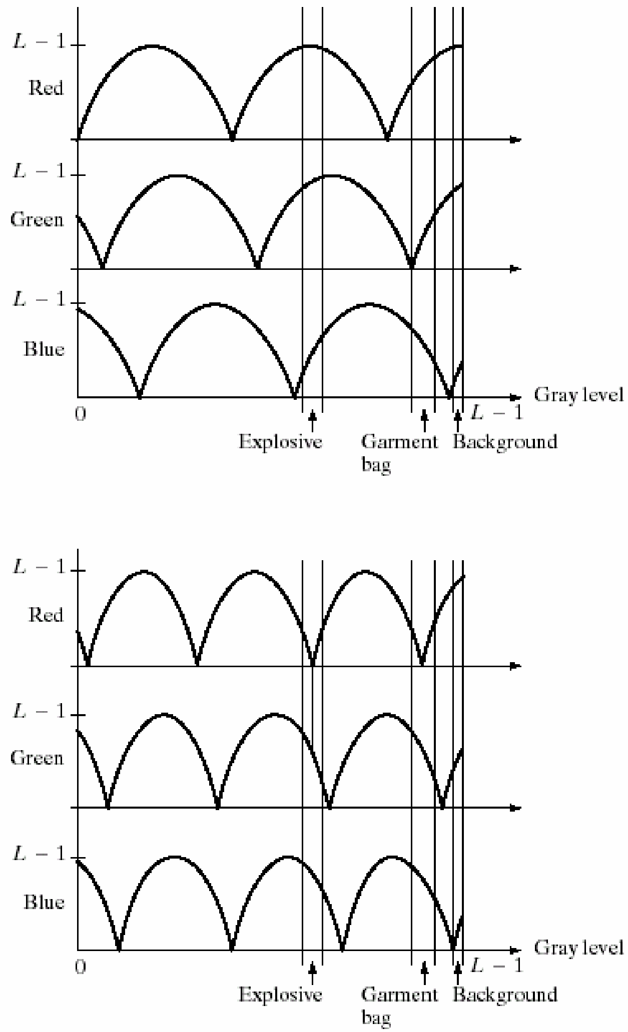
a b
c d

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.)

Intensity to color transformation

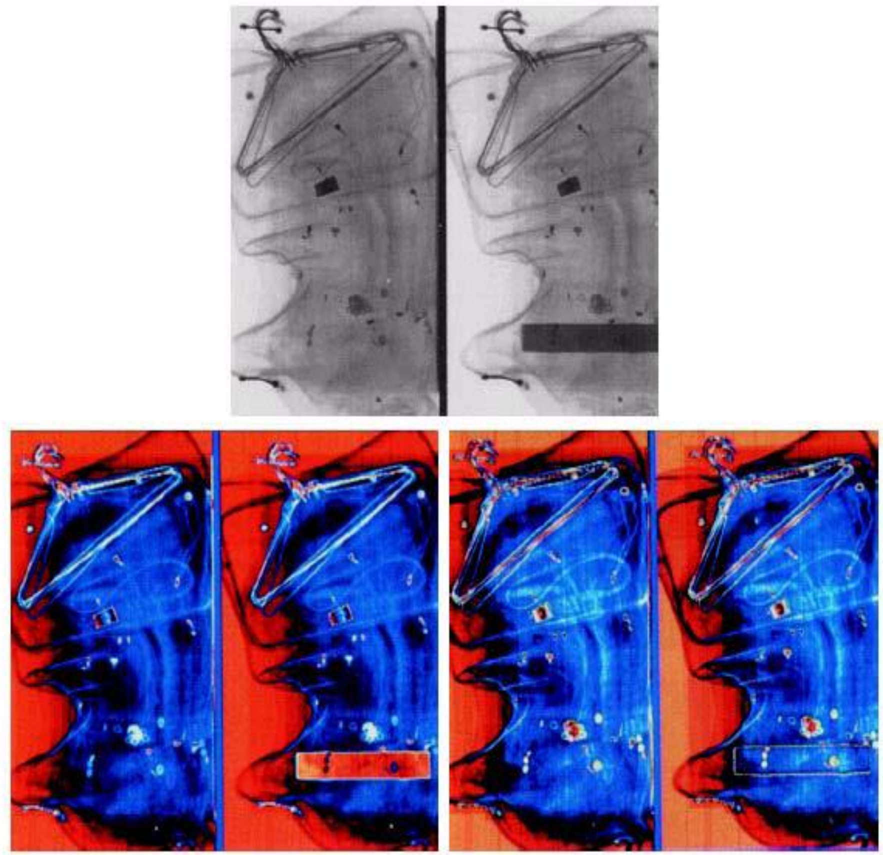
- Three independent transformation functions on the gray-level of each pixel
- Piecewise linear function
- Smooth non-linear function

Intensity To Color Transformation



a
b

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



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.)

Pseudo image processing

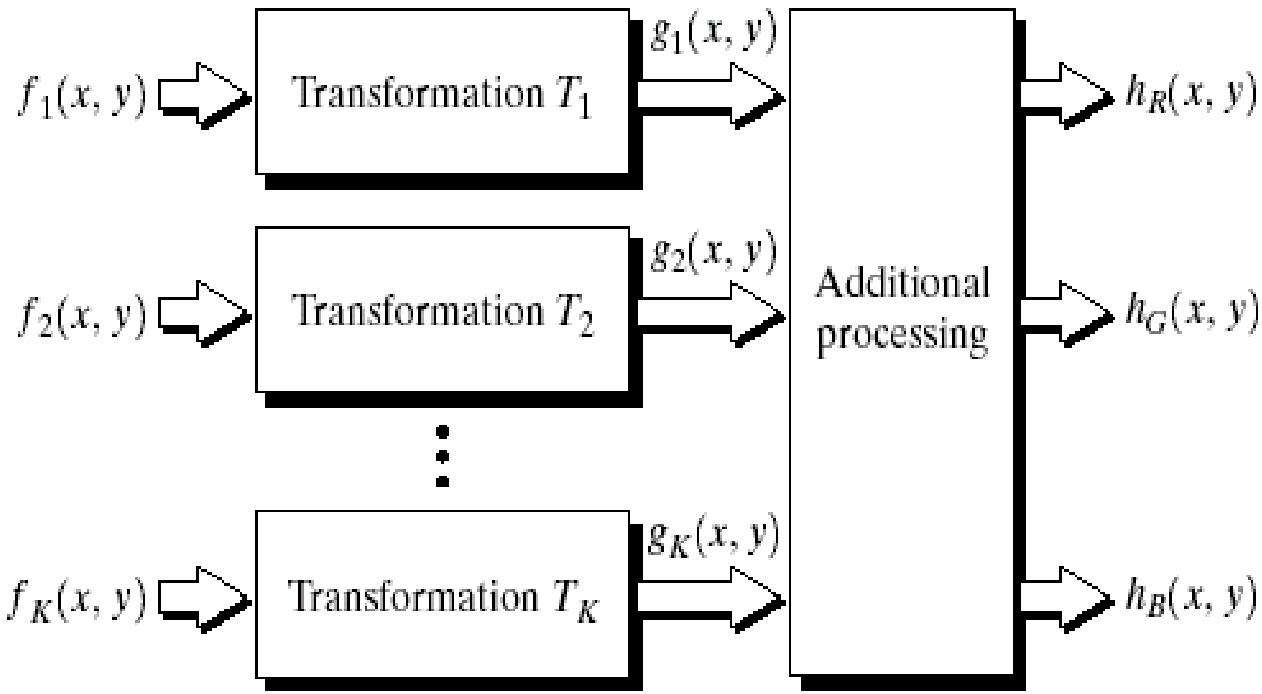
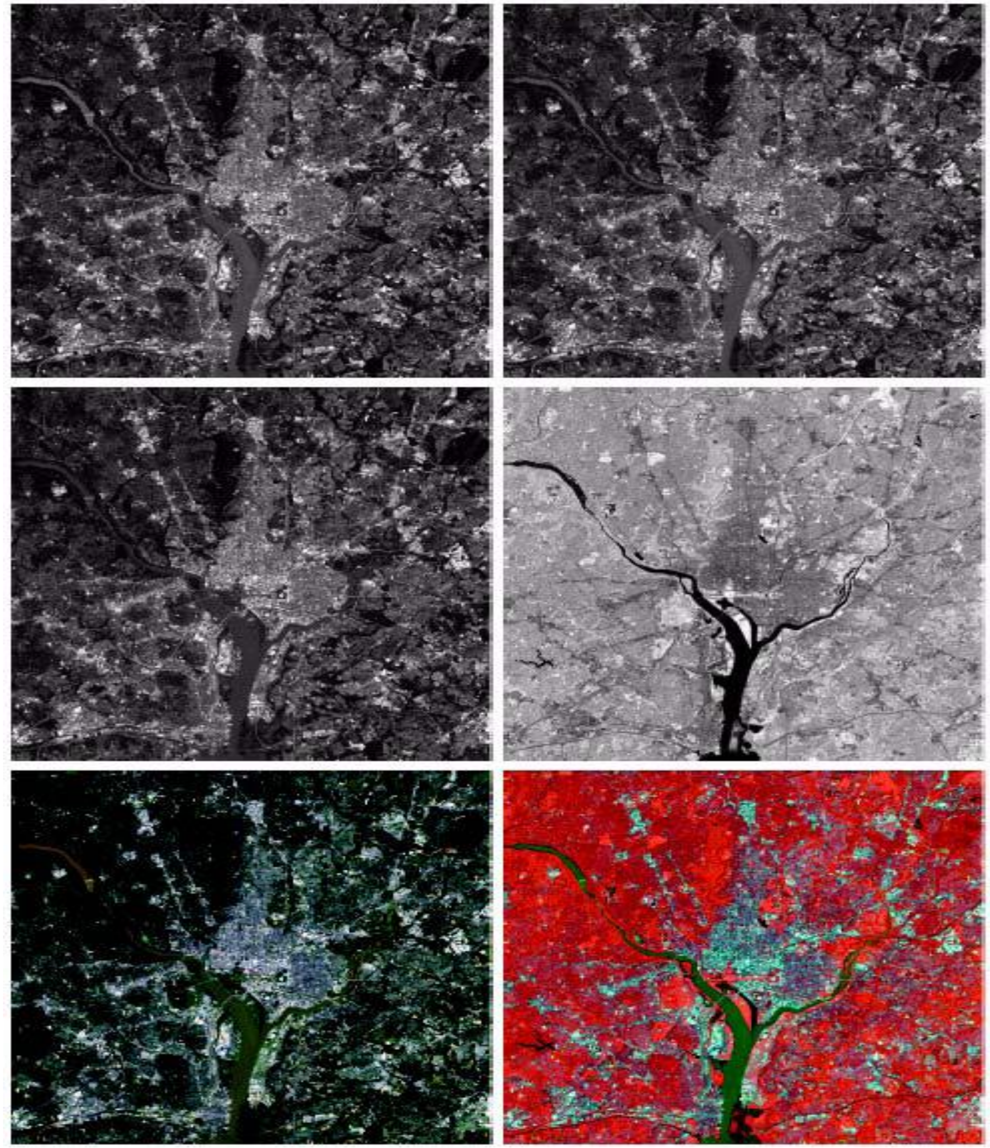


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

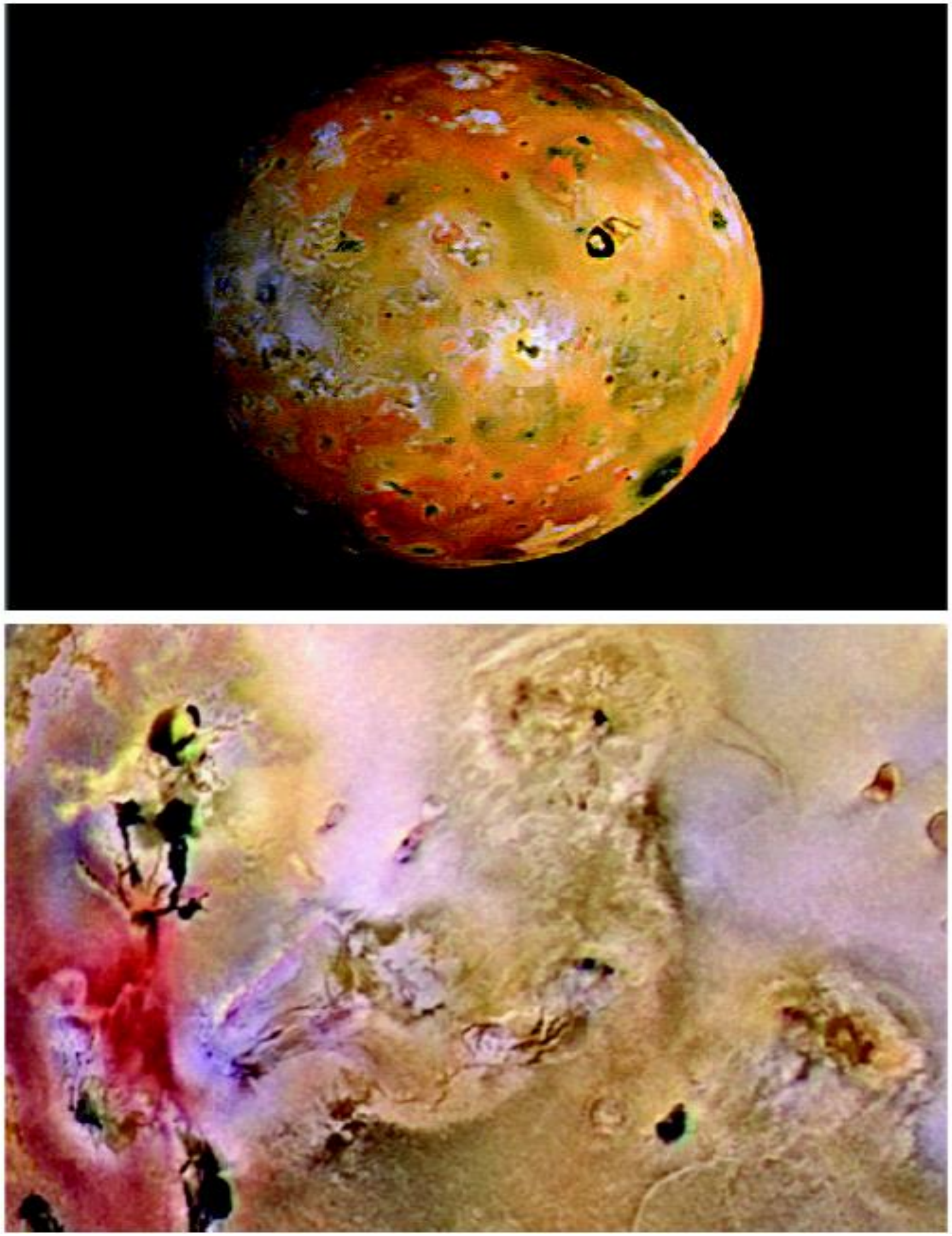
Combine several monochrome images into a single color image

Pseudo image processing



a b
c d
e f

FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)



a
b

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

Full-color image processing

- Two categories:
  - Process each component individually and then form a composite processed color image from the components.
  - Work with color pixels directly. In RGB system, each color point can be interpreted as a vector.

$$c(x, y) = \left[c_R(x, y), c_G(x, y), c_B(x, y)\right]$$

Full-color image processing

a b

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

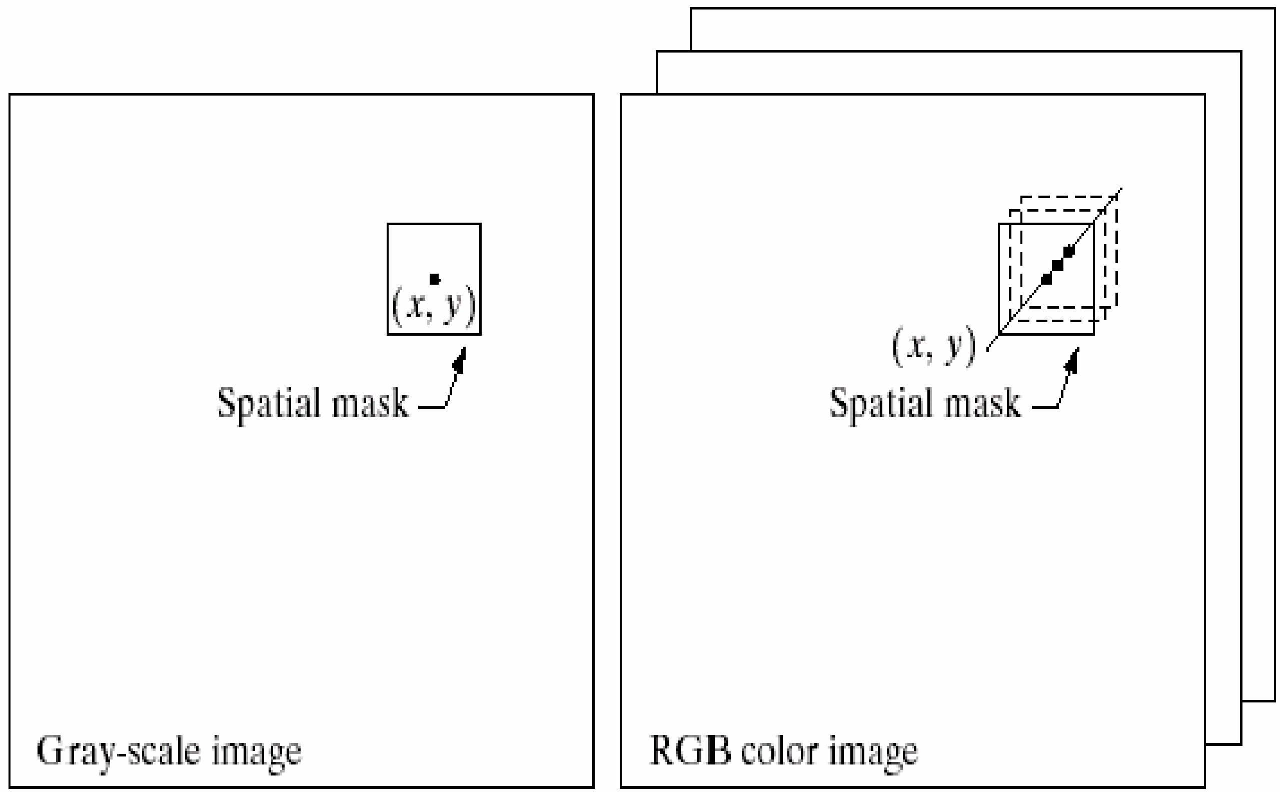


FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)

Tone And Color Correction

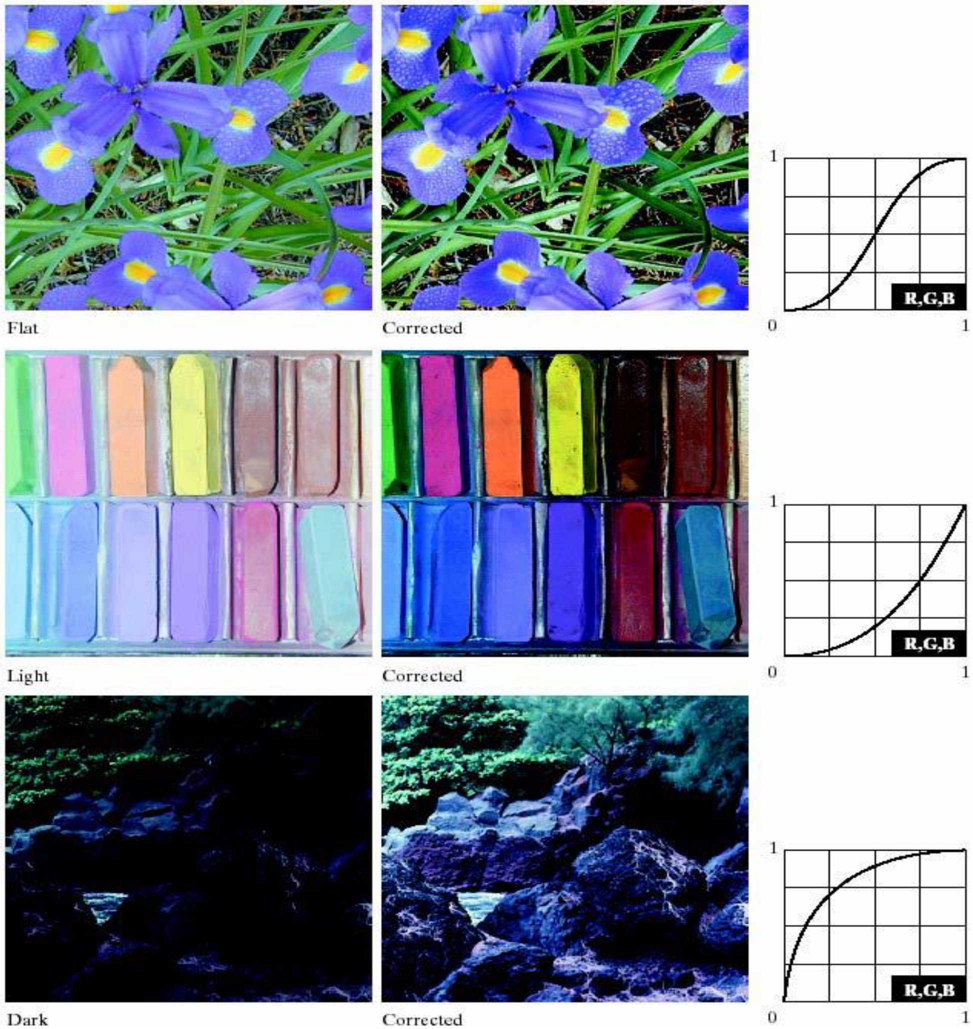
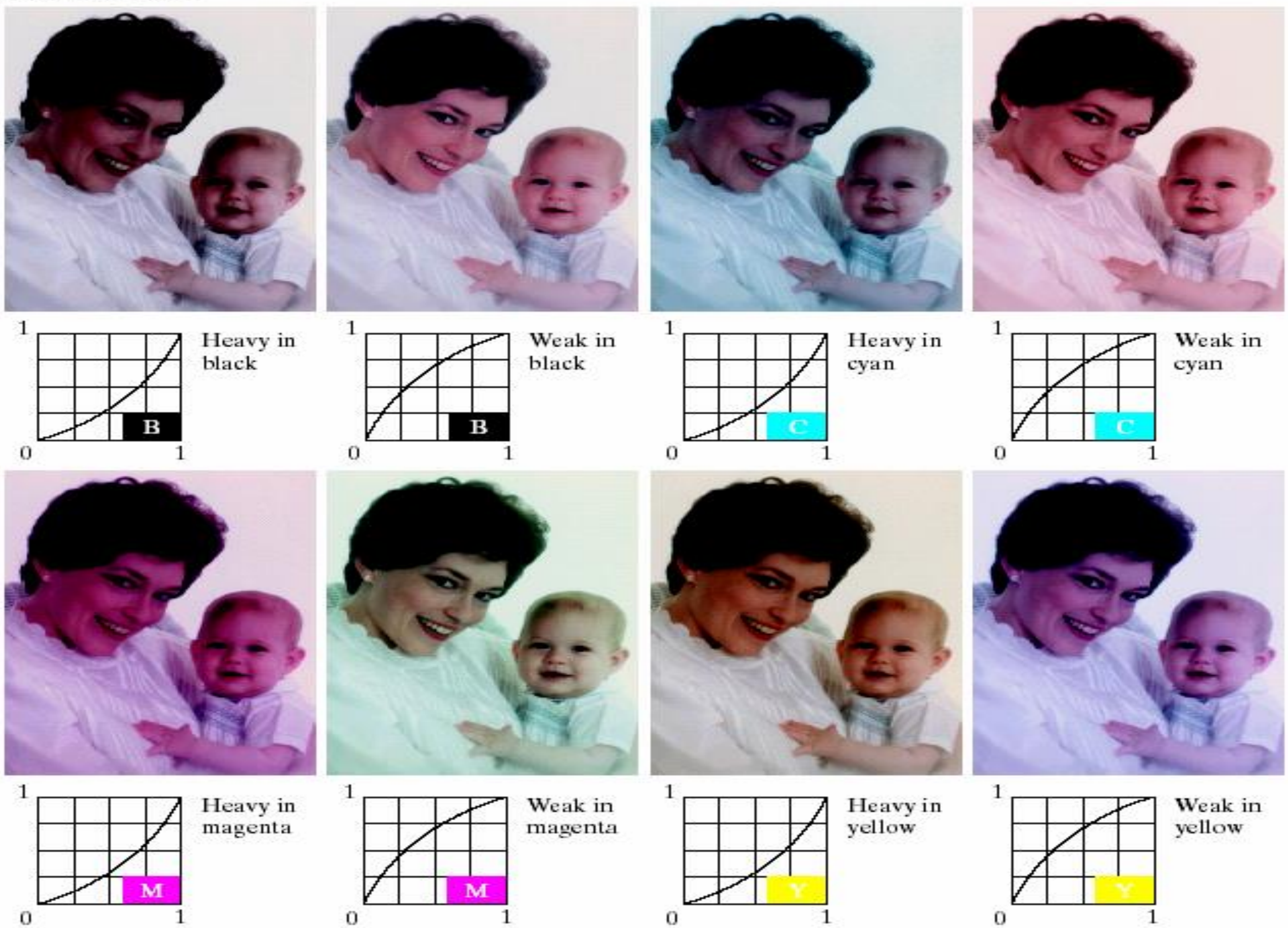


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.

FIGURE 6.36 Color balancing corrections for CMYK color images.



Histogram processing

- Equalized the histogram of each component will results in erroneous color
- Spread the intensity (I) uniformly, leaving the colors (hue and saturation) unchanged
- Equalizing the intensity histogram affects the relative appearance of colors in an image
- Increasing the image’s saturation component after the intensity histogram equalization

Histogram processing

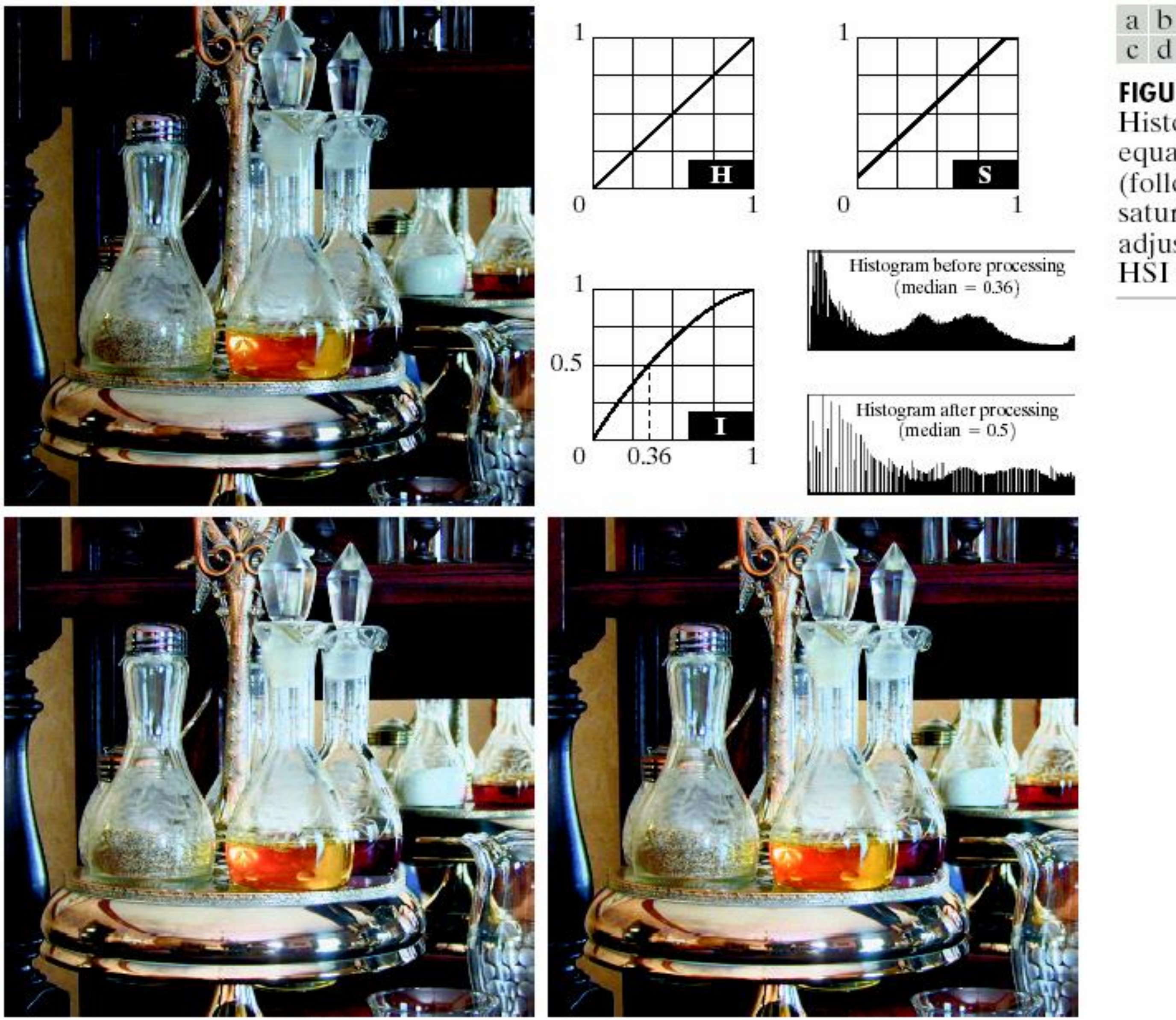


FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Color Image Smoothing

- Let S_{xy} denote the set of coordinates defining a neighborhood centered at (x, y) in an RGB color space.

$$\bar{c}(x,y) = \begin{bmatrix} \dfrac{1}{K} \sum_{(x,y)\in S_{xy}} R(x,y) \\ \dfrac{1}{K} \sum_{(x,y)\in S_{xy}} G(x,y) \\ \dfrac{1}{K} \sum_{(x,y)\in S_{xy}} B(x,y) \end{bmatrix}$$

Color image smoothing

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

Color image 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.

Color image 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

- The Laplacian of vector *c* is

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

Color image sharpening

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.

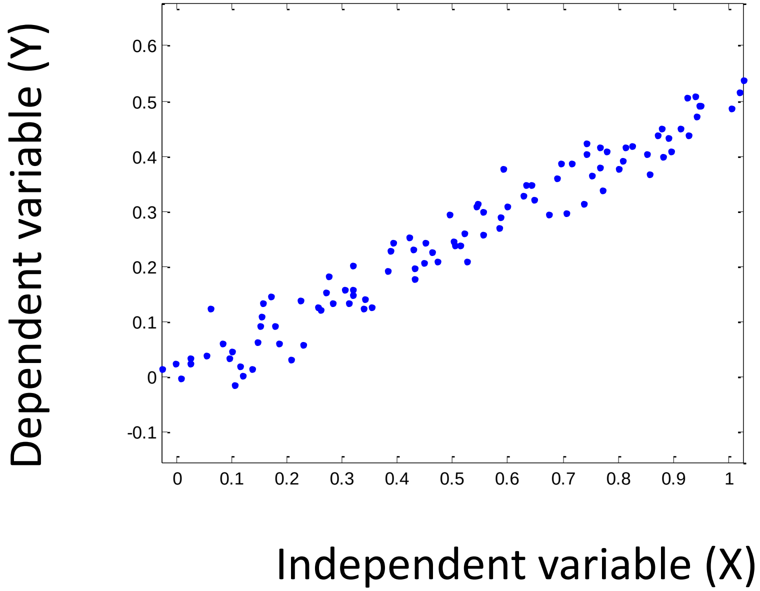
Color edge detection

- Let’s look at: http://ai.stanford.edu/~ruzon/compass/color.html

Decorrelation Stretch For Color Images

- Interesting application: http://www.dstretch.com/index.html
- What is correlation?
- How can we “decorrelate” data?
- What would be stretching?
- I am going to sweep a lot of Math under the rug!

Correlation in Data



Is the relationship between dependent and independent variable linear?

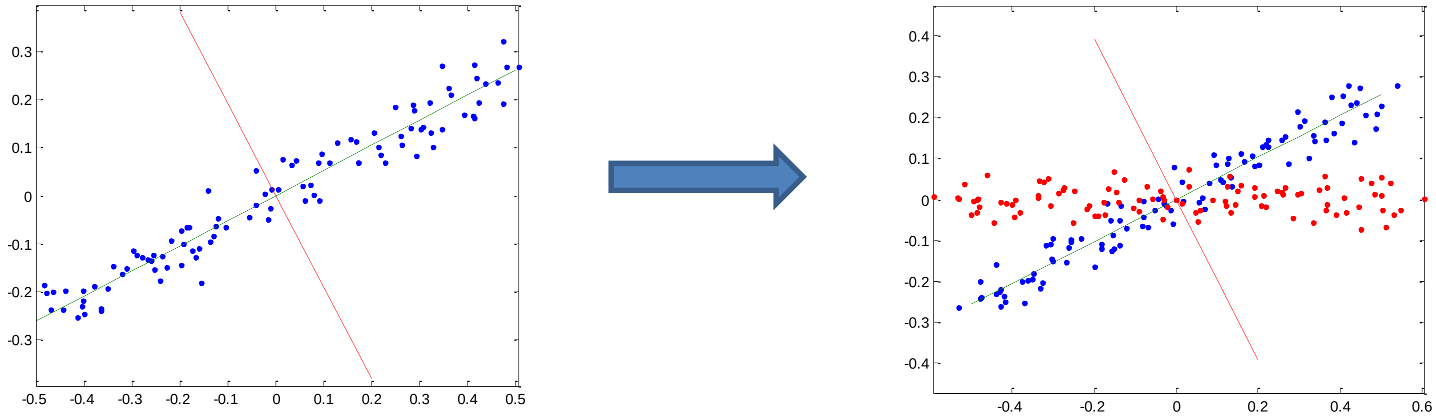
If so, positive correlation means increase in X increases Y; negative correlation means increase in X will decrease Y

“Decorrelating” Data

- Suppose X and Y have linear relationship, but increase in X does not result in increase or decrease in Y => X and Y are not correlated
- How can we decorrelate correlated data then?
  – By rotation!

“Decorrelating” Data…

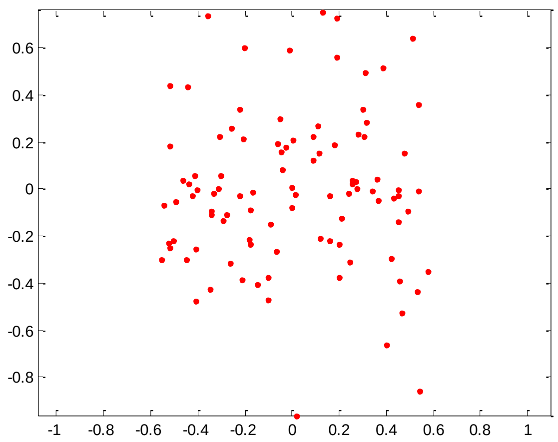
- Step 1: Center the data
- Step 2: Find out axes (both major and minor) for the data
- Step 3: Rotate data so that major axis becomes horizontal

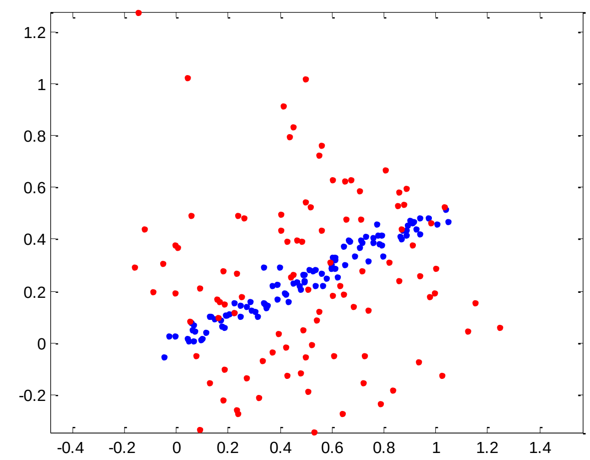


How did we find the major axis? By fitting a straight line?

Stretching Decorrelated Data

- Stretch data along y axis, so that variances become same along both axes
- Then, rotate back and add data mean





Color Image: Decorrelation Stretch

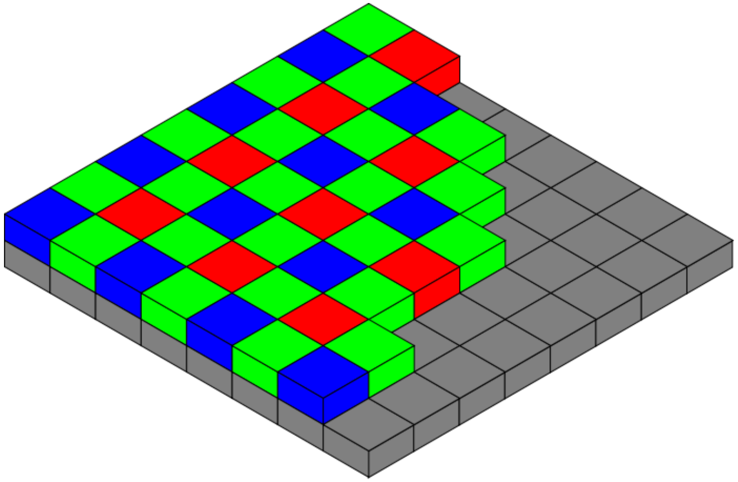
- In higher dimension, decorrelation stretch means transforming ellipsoidal data cloud into a spherical data cloud
  - In machine learning community this is known as “data whitening”
- For a color image, the point cloud is 3D (R-G-B space)
- Decorrelation stretch in color image:
  - Assumes the point cloud is ellipsoidal
  - Makes the point cloud spherical
- A nice blog: http://dhanushkadangampola.blogspot.ca/2015/02/decorrelation-stretching.html

Demosaicing

- Any given element (pixel) on a sensor array in a digital camera receives only red, green or blue light
- This R-G-B pattern is called Bayer filter pattern
- How do we reconstruct a color image from this incomplete information
  - The underlying family of algorithms is called demosaicing
- http://www.cambridgeincolour.com/tutorials/camera-sensors.htm

Bayer Pattern

- A typical Bayer pattern taken from wikipedia
- Notice that 50% pixels are G, 25% are B and 25% are R; why?
- Demosaicing simply interpolates missing R,G,B values



Demosaic: Strategies

- The simplest strategy could be to interpolate R,G,B channels independently
- Observe that:
  - #of G pixels is twice as much as the R’s and B’s; so we should trust them more
  - R,G,B are typically very much correlated in a natural image (recall our discussion on decorrelation stretch)
  - While interpolating, one should be cautious about rapid intensity changes (i.e., edges)
- Modern algorithms exploit these ideas

Demosaicing…

- Matlab demo: BayerDemo.m
- Reference:
  - "Comparison of color demosaicing methods" https://hal.inria.fr/hal-00683233/PDF/AEIP_SOUMIS.pdf