Color Image Processing

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Color

- Used heavily in human vision.
- Visible spectrum for humans is 400 nm (blue) to 700 nm (red).
- Machines can "see" much more; e.g., X-rays, infrared, radio waves.

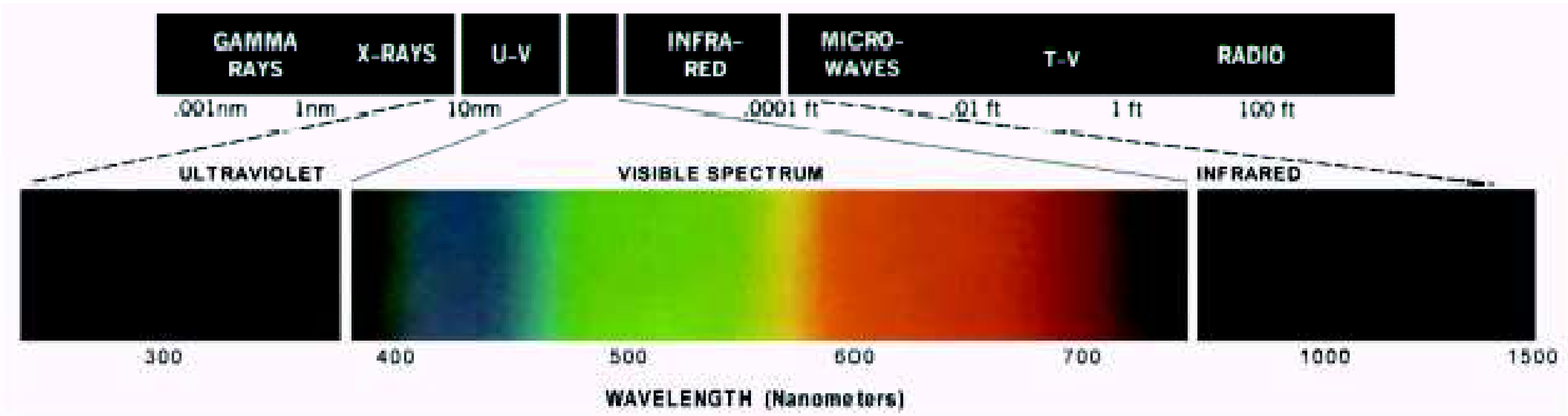
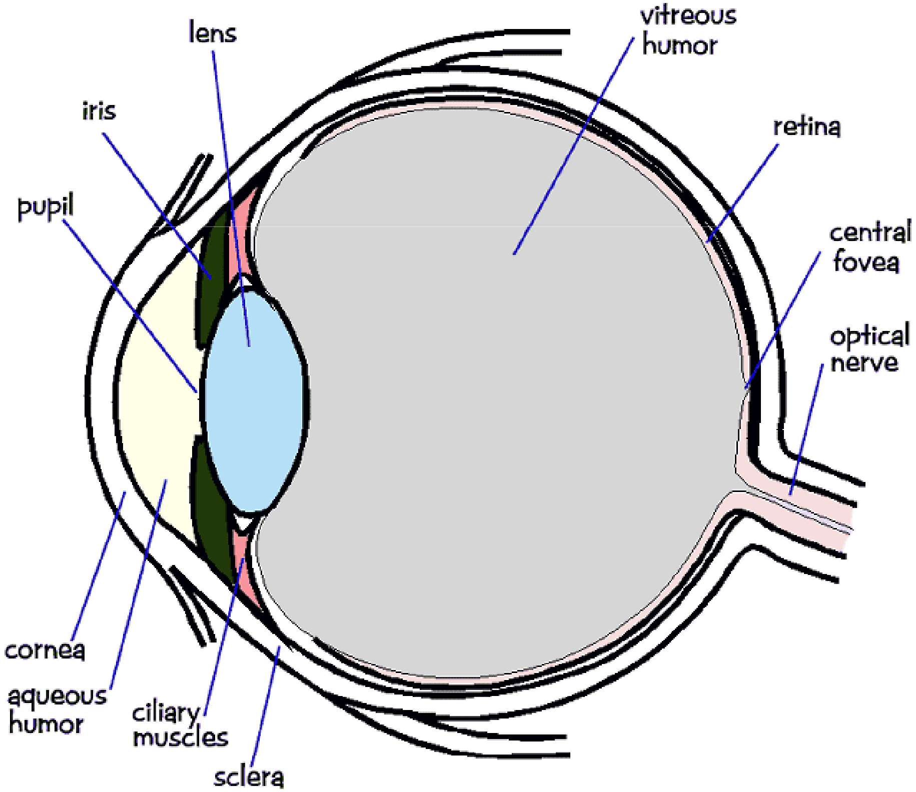


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Adapted from Gonzales and Woods

Human visual system

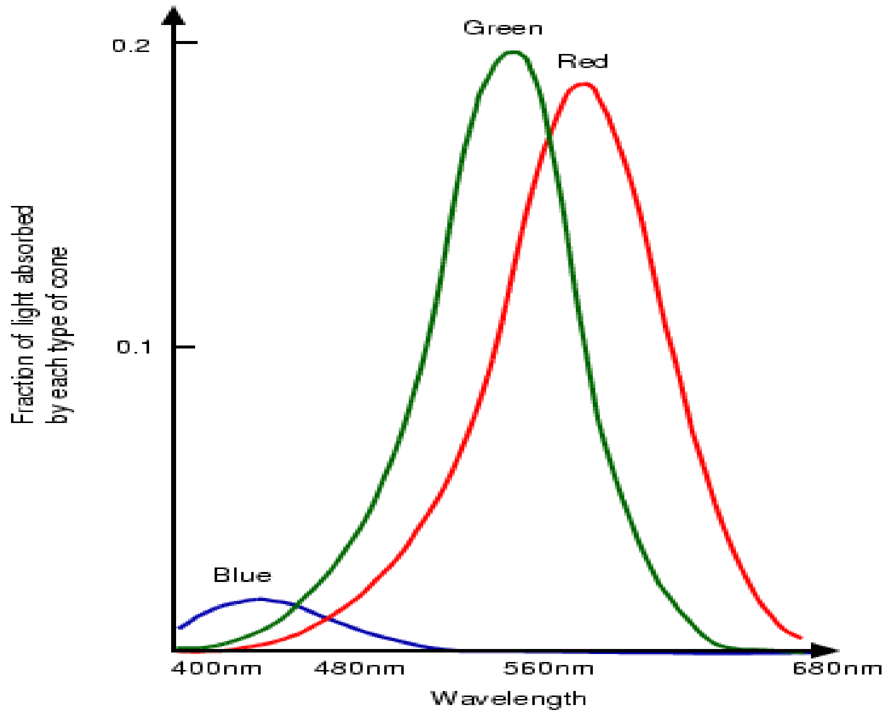


- Color perception
  - Light hits the retina, which contains photosensitive cells.
  - These cells convert the spectrum into a few discrete values.

Adapted from Steve Seitz, U of Washington

Human visual system

- There are two types of photosensitive cells:
  - Cones
    - Sensitive to colored light, but not very sensitive to dim light.
  - Rods
    - Sensitive to achromatic light.
- We perceive color using three different types of cones.
  - Each one is sensitive in a different region of the spectrum.
    - 440 nm (BLUE)
    - 545 nm (GREEN)
    - 580 nm (RED)
  - They have different sensitivities (we are more sensitive to green than red).



Adapted from Octavia Camps, Penn State

Factors that affect perception

- Light: the spectrum of energy that illuminates the object surface.
- Reflectance: ratio of reflected light to incoming light.
- Specularity: highly specular (shiny) vs. matte surface.
- Distance: distance to the light source.
- Angle: angle between surface normal and light source.
- Sensitivity: how sensitive is the sensor.

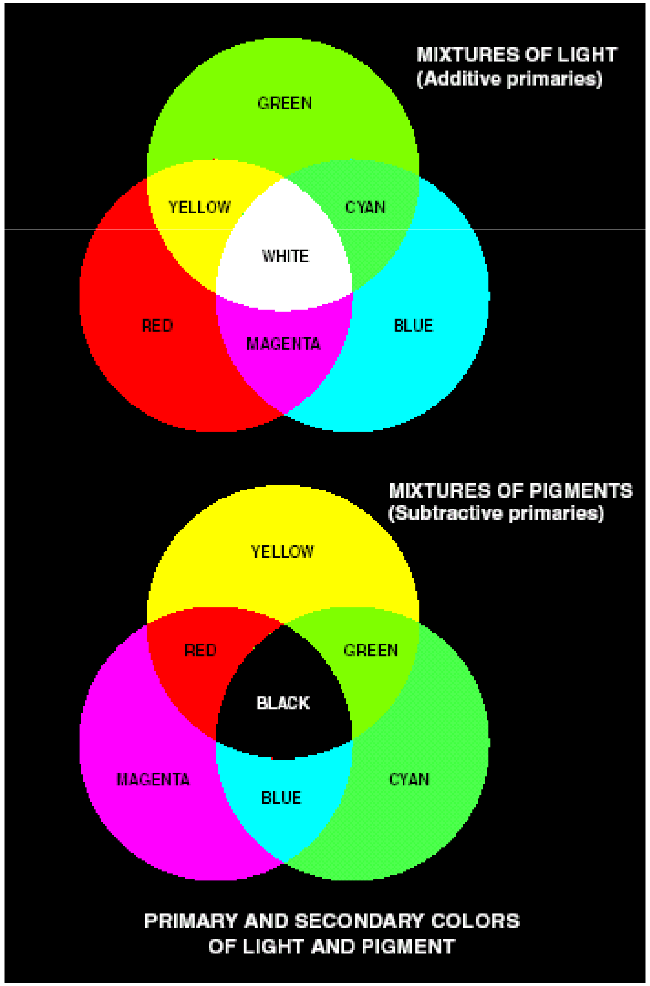
Adapted from Linda Shapiro, U of Washington

Color models

- They provide a standard way of specifying a particular color using a 3D coordinate system.
- Hardware oriented
  - RGB: additive system (add colors to black) used for displays.
  - CMY: subtractive system used for printing.
  - YIQ: used for TV and is good for compression.
- Image processing oriented
  - HSV: good for perceptual space for art, psychology and recognition.

Adapted from Octavia Camps, Penn State

Additive and subtractive colors



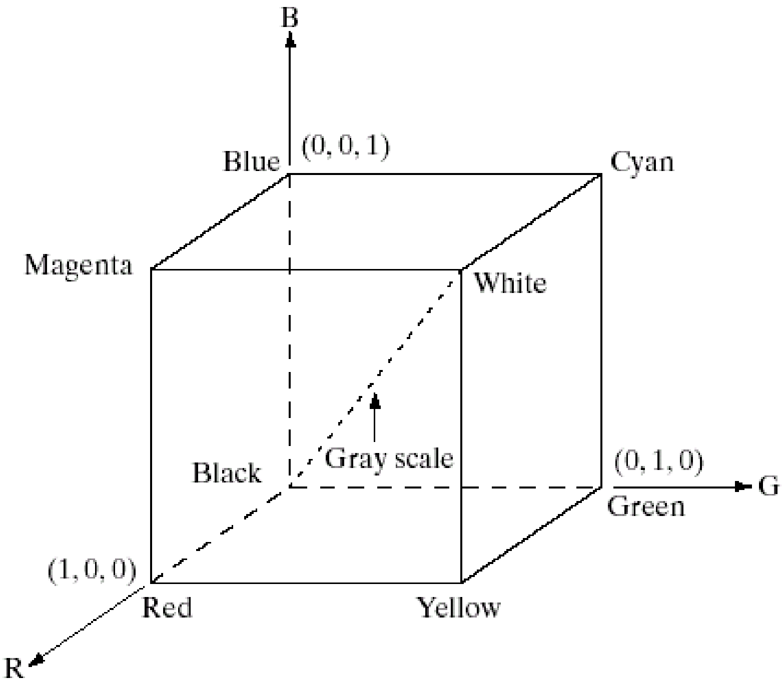
a
b

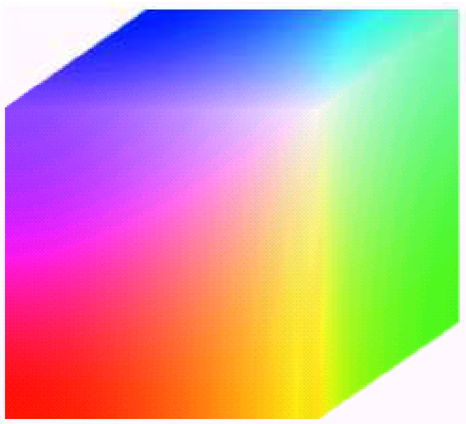
FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Adapted from Gonzales and Woods

RGB model

- Additive model.
- An image consists of 3 bands, one for each primary color.
- Appropriate for image displays.





Adapted from Gonzales and Woods

CMY model

- Cyan-Magenta-Yellow is a subtractive model which is good to model absorption of colors.
- Appropriate for paper printing.

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

Adapted from Octavia Camps, Penn State

CIE chromaticity model

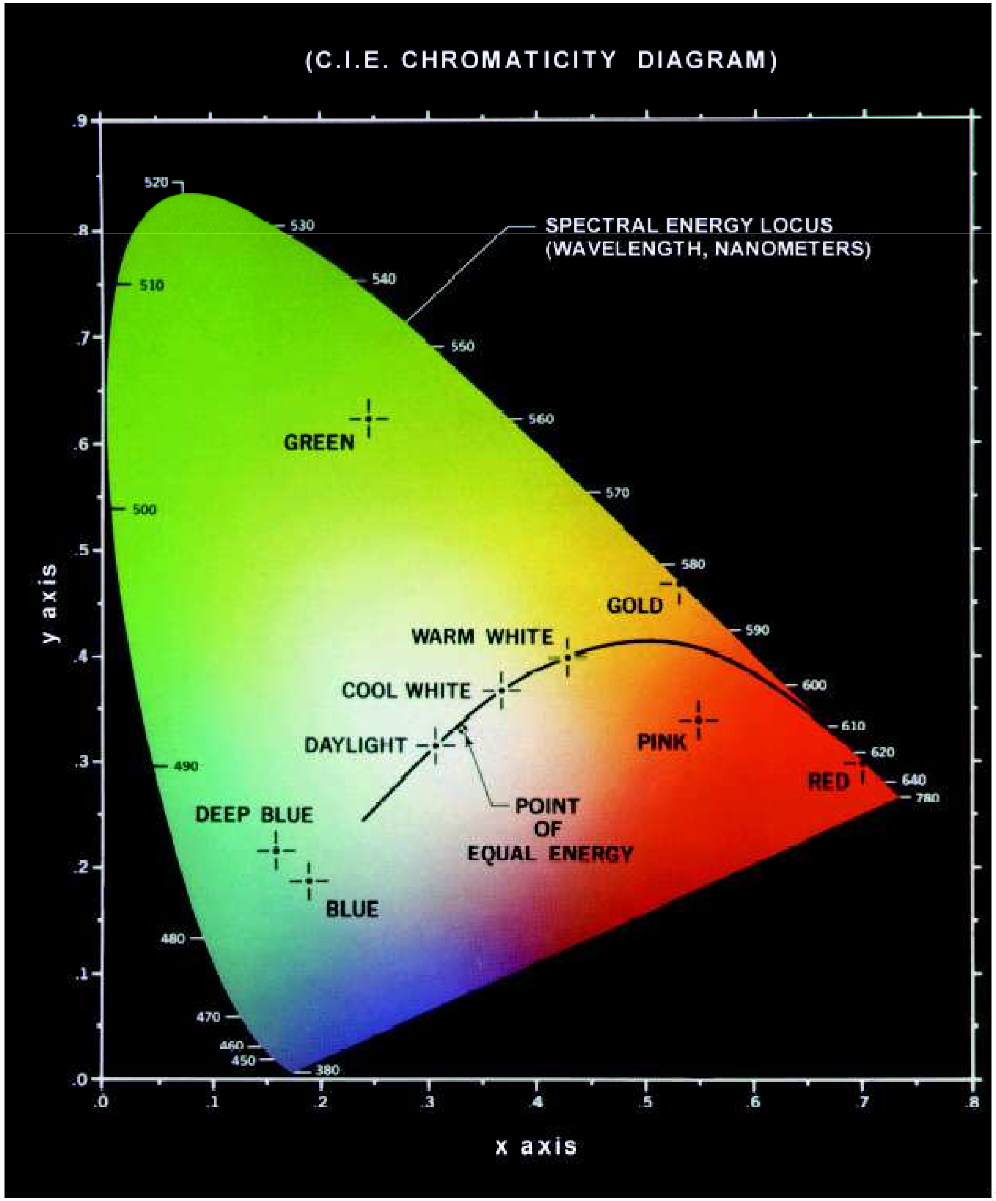
- The Commission Internationale de l'Eclairage defined 3 standard primaries: X, Y, Z that can be added to form all visible colors.
- Y was chosen so that its color matching function matches the sum of the 3 human cone responses.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.6067 & 0.1736 & 0.2001 \\ 0.2988 & 0.5868 & 0.1143 \\ 0.0000 & 0.0661 & 1.1149 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.9107 & -0.5326 & -0.2883 \\ -0.9843 & 1.9984 & -0.0283 \\ 0.0583 & -0.1185 & 0.8986 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

CIE chromaticity model

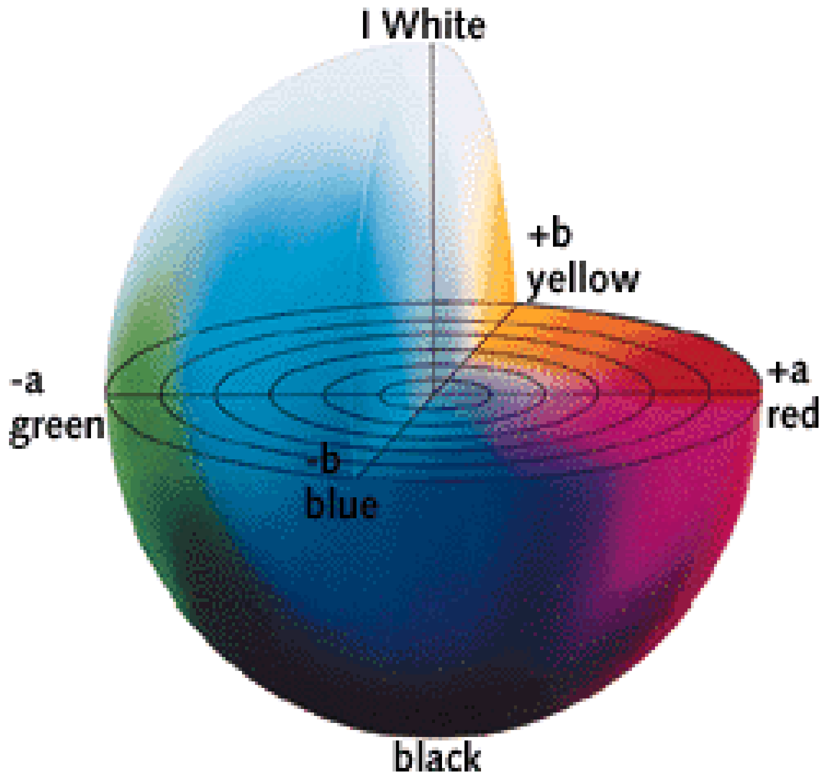
- x, y, z normalize X, Y, Z such that
  $$x + y + z = 1.$$
- Actually only x and y are needed because
  $$z = 1 - x - y.$$
- Pure colors are at the curved boundary.
- White is (1/3, 1/3, 1/3).



Adapted from Octavia Camps, Penn State

CIE Lab (L*a*b) model

- One luminance channel (L) and two color channels (a and b).
- In this model, the color differences which you perceive correspond to Euclidian distances in CIE Lab.
- The a axis extends from green (-a) to red (+a) and the b axis from blue (-b) to yellow (+b). The brightness (L) increases from the bottom to the top of the 3D model.



http://www.fho-emden.de/~hoffmann/cielab03022003.pdf

Adapted from Linda Shapiro, U of Washington

YIQ model

- Have better compression properties.
- Luminance Y is encoded using more bits than chrominance values I and Q (humans are more sensitive to Y than I and Q).
- Luminance used by black/white TVs.
- All 3 values used by color TVs.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.532 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Adapted from Octavia Camps, Penn State

HSV model

- HSV: Hue, saturation, value are non-linear functions of RGB.
- Hue relations are naturally expressed in a circle.

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

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

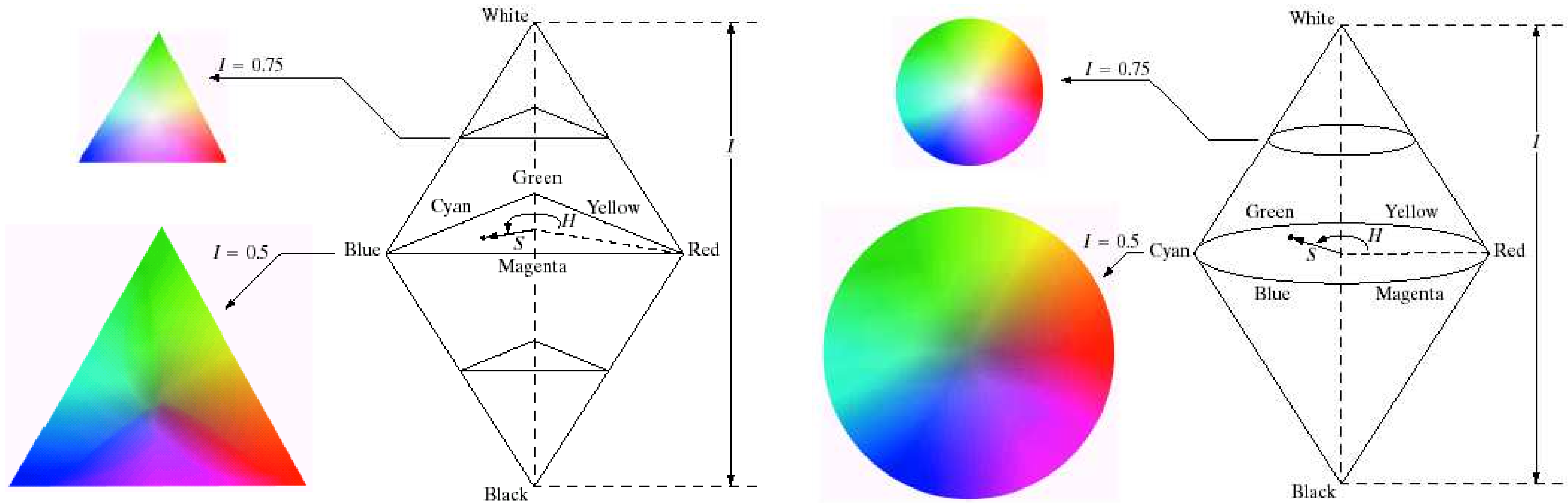
$$H = \cos^{-1}\left\{ \frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2 + (R-B)(G-B)]}} \right\} \text{if } B<G$$

$$H = 360 - \cos^{-1}\left\{ \frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2 + (R-B)(G-B)]}} \right\} \text{if } B>G$$

Adapted from Octavia Camps, Penn State

HSV model

- Uniform: equal (small) steps give the same perceived color changes.
- Hue is encoded as an angle (0 to 2π).
- Saturation is the distance to the vertical axis (0 to 1).
- Intensity is the height along the vertical axis (0 to 1).



Adapted from Gonzales and Woods

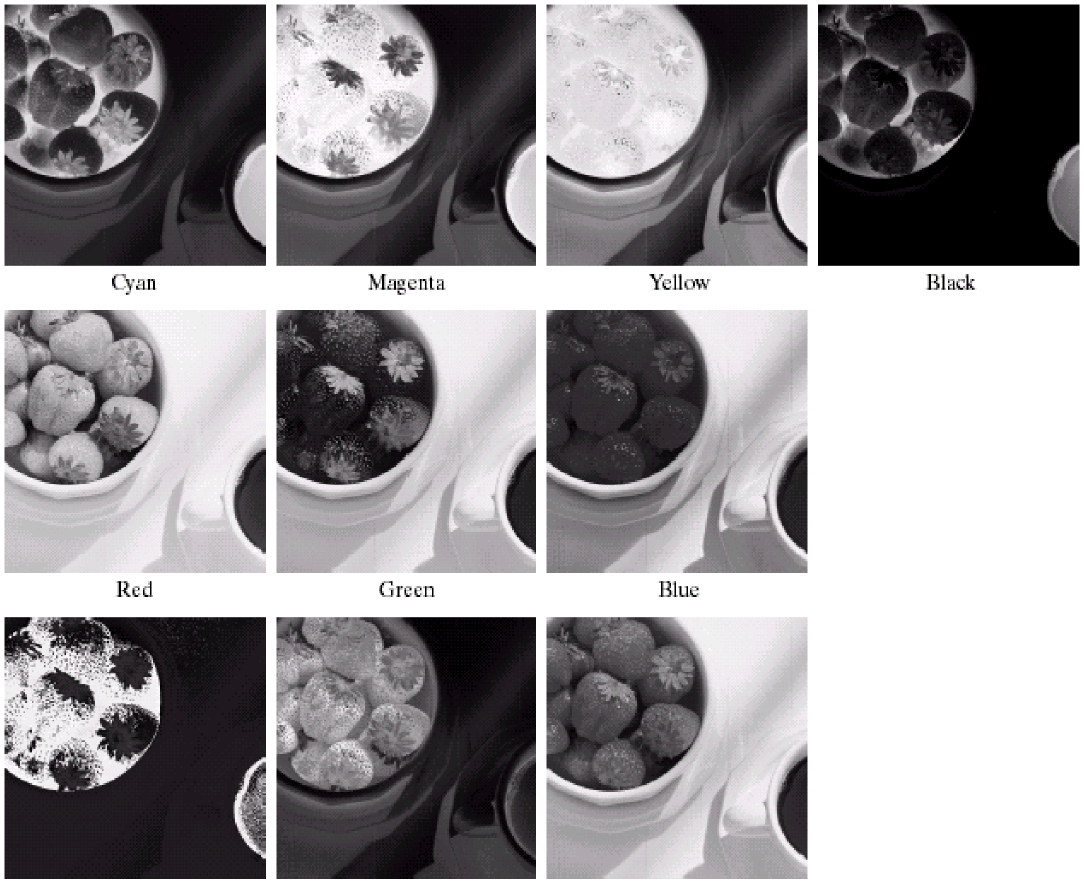
HSV model

(Left) Image of food originating from a digital camera.
(Center) Saturation value of each pixel decreased 20%.
(Right) Saturation value of each pixel increased 40%.

Adapted from Linda Shapiro, U of Washington

Color models

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



CMYK

RGB

HSV

Adapted from Gonzales and Woods

Examples: pseudocolor

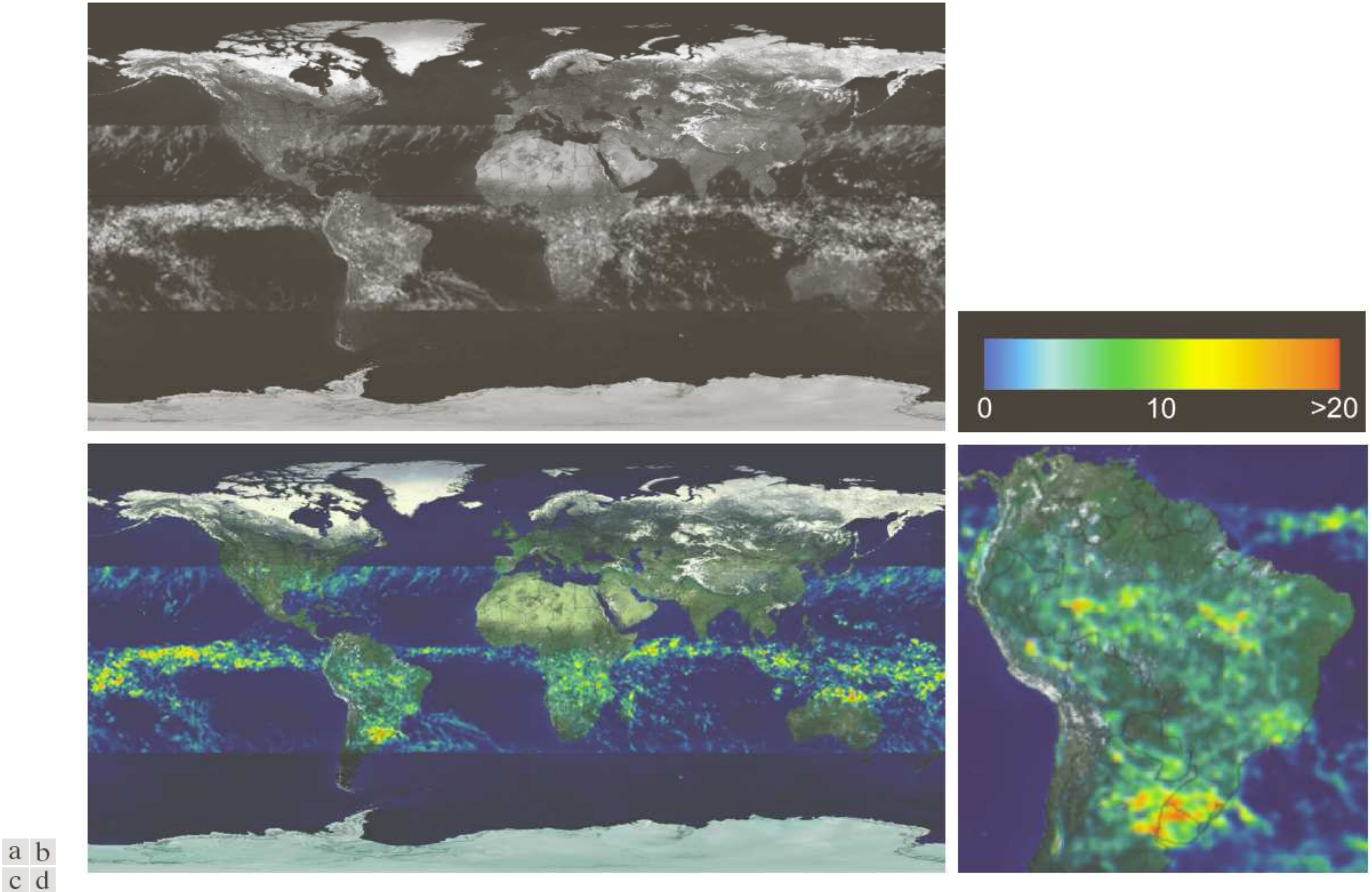
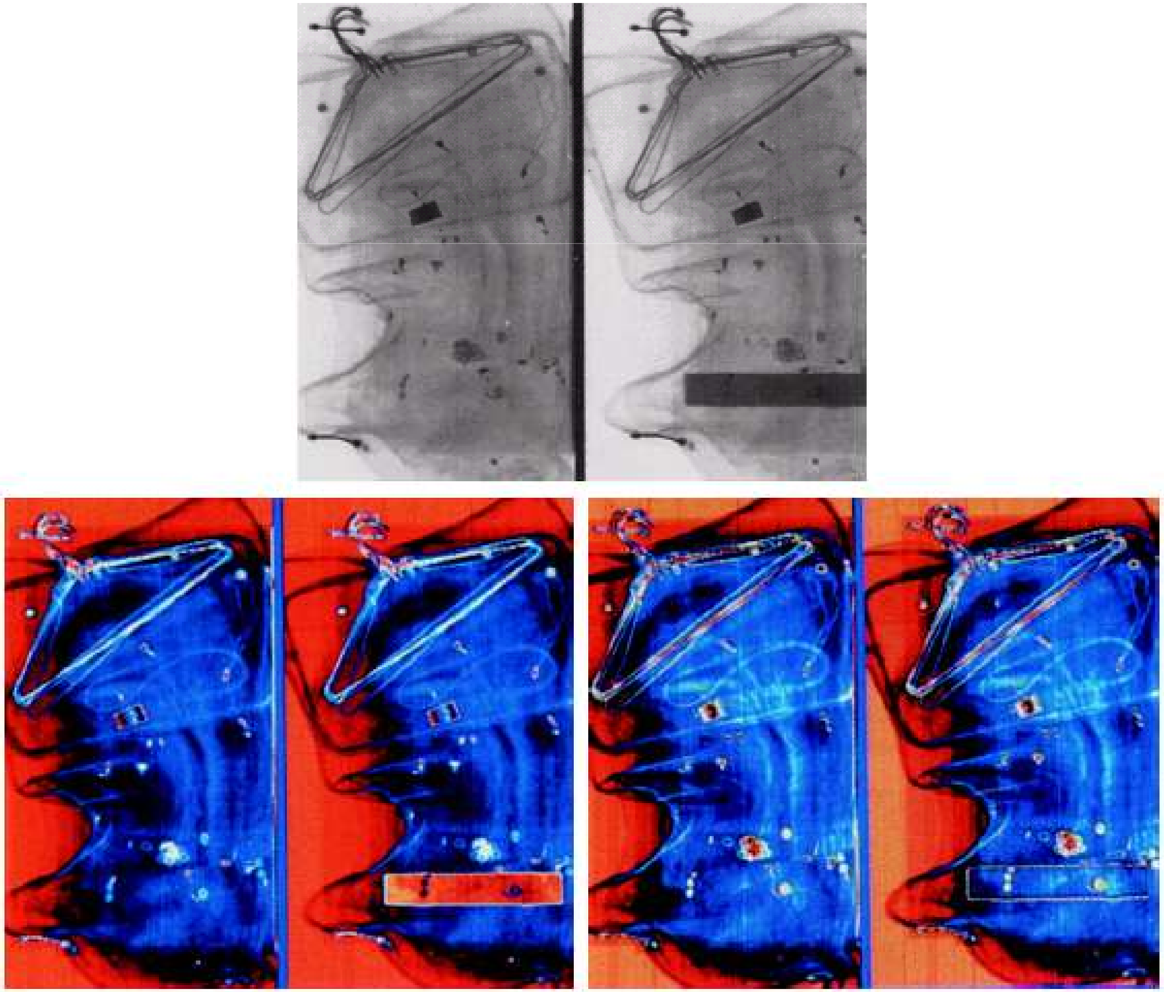
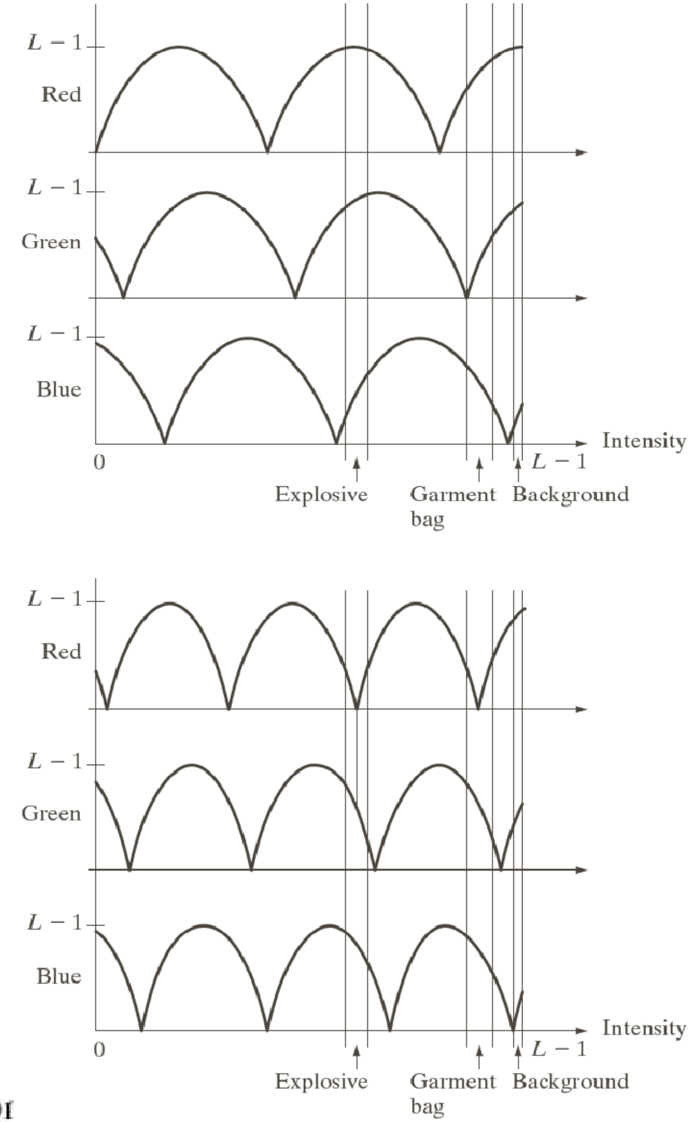


FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

Examples: pseudocolor





a
b c

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

Examples: pseudocolor

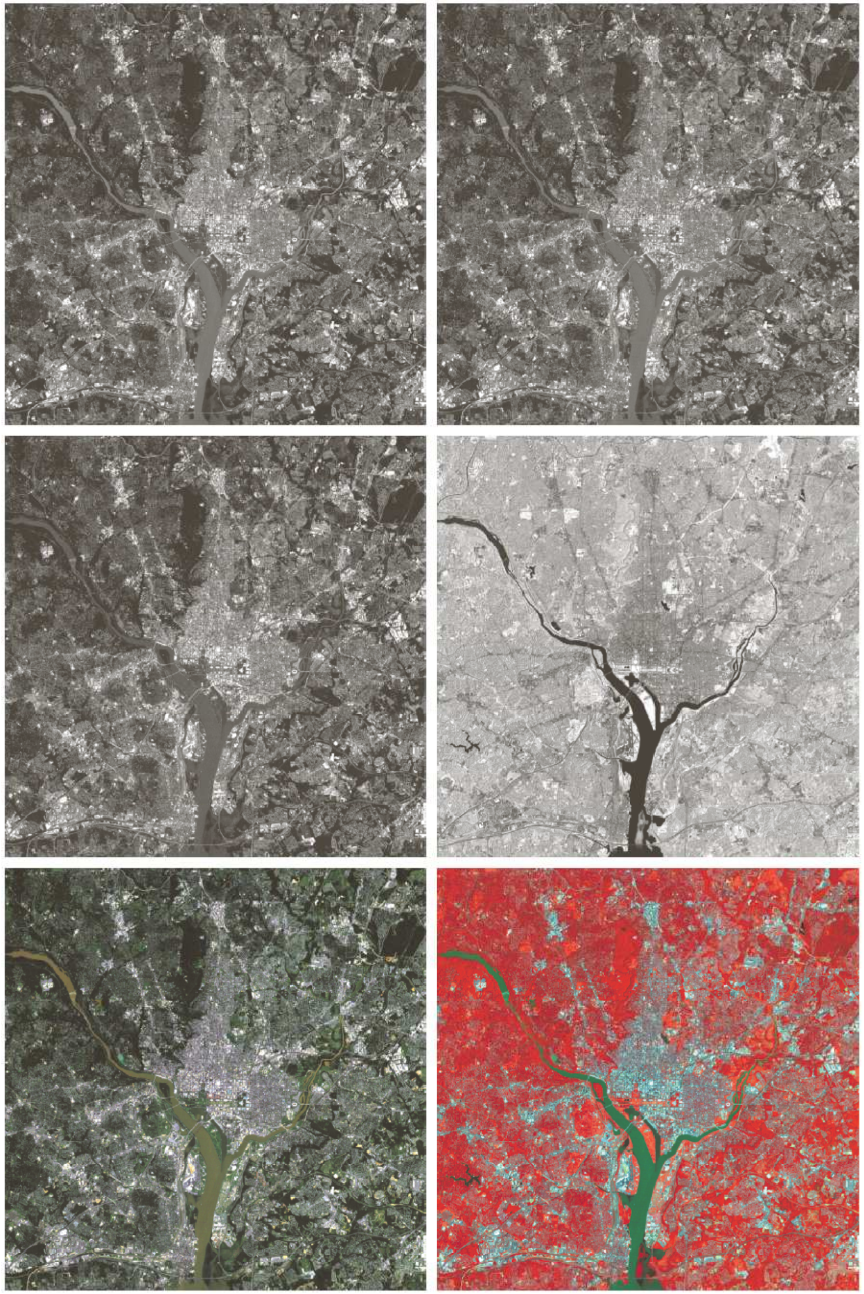


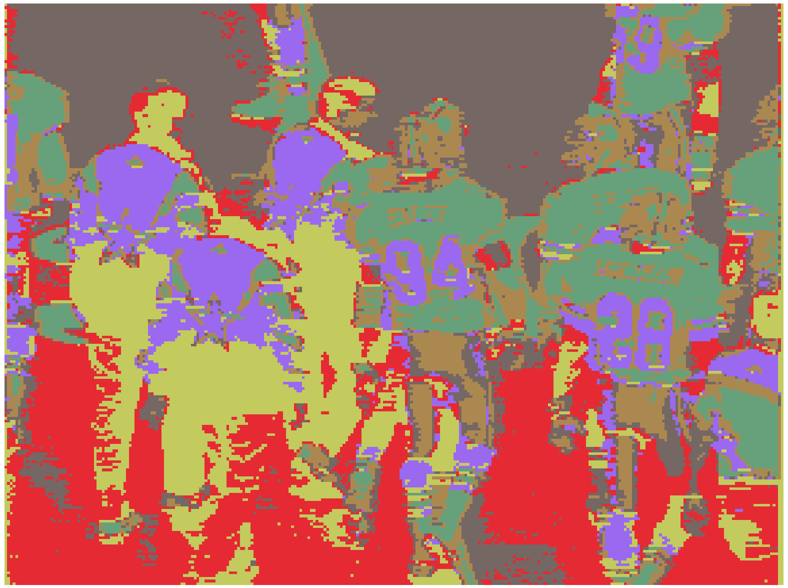
FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral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

a b
c d
e f

Examples: segmentation

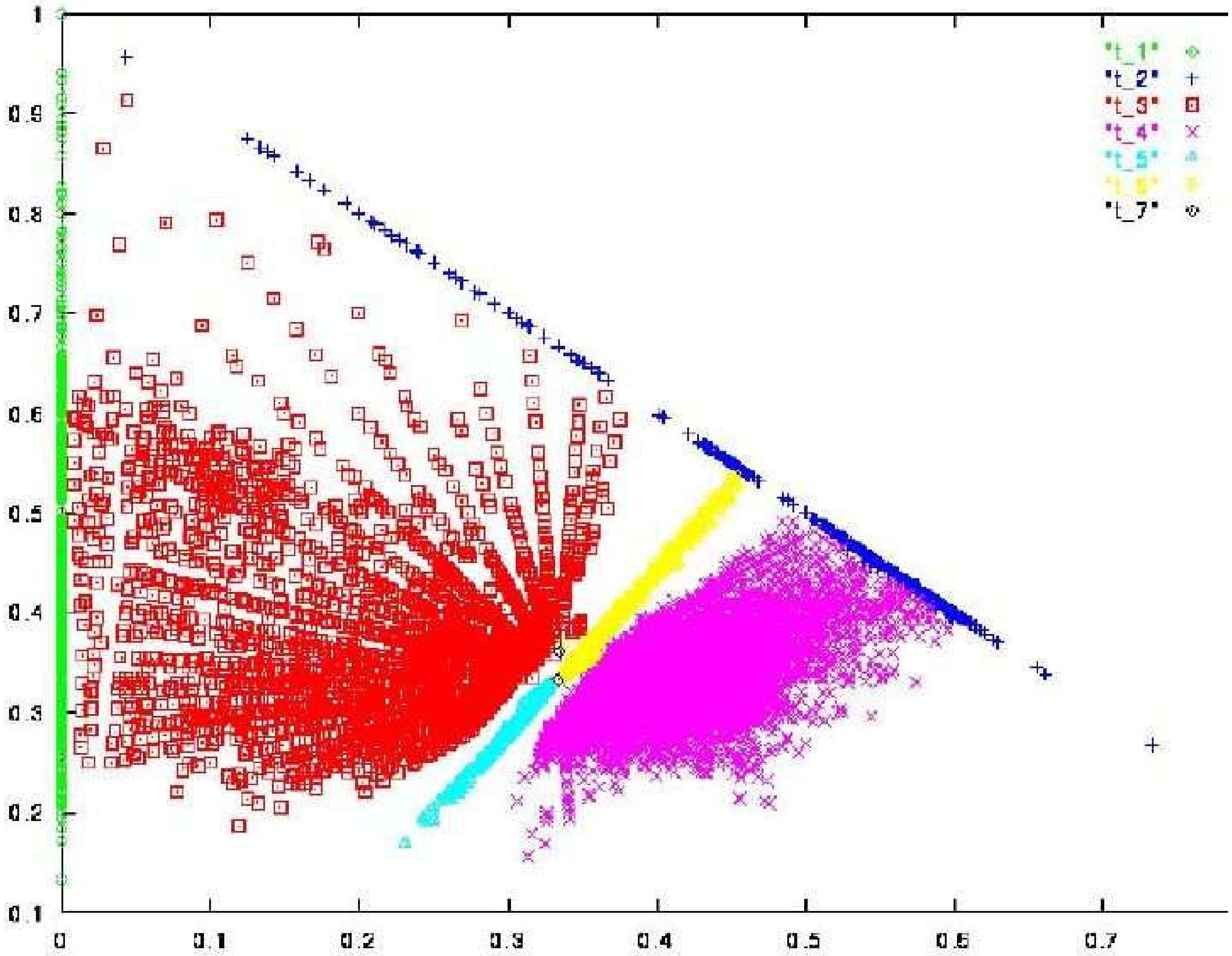
- Can cluster on color values and pixel locations.
- Can use connected components and an approximate color criteria to find regions.
- Can train an algorithm to look for certain colored regions – for example, skin color.

Original RGB image



Color clusters by k-means

Examples: segmentation

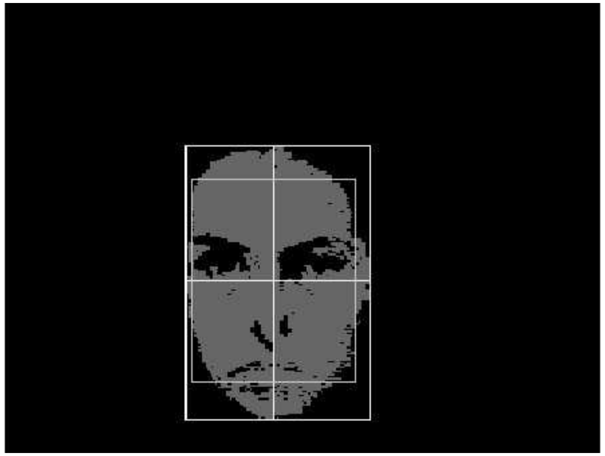


Skin color in RGB space:

Purple region shows skin color samples from several people. Blue and yellow regions show skin in shadow or behind a beard.

Adapted from Linda Shapiro, U of Washington

Examples: segmentation

(Left) Input video frame.

(Center) Pixels classified according to RGB space.

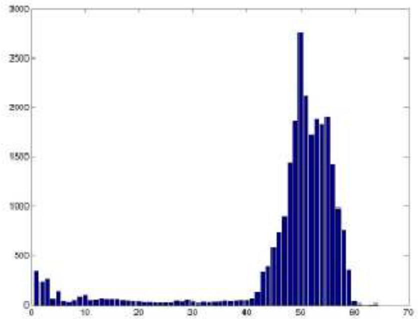
(Right) Largest connected component with aspect similar to a face.

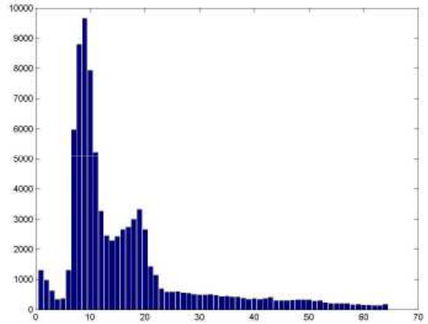
Adapted from Linda Shapiro, U of Washington

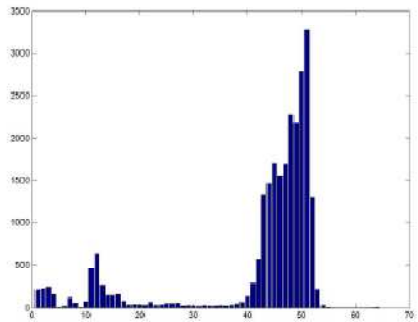
Examples: histogram

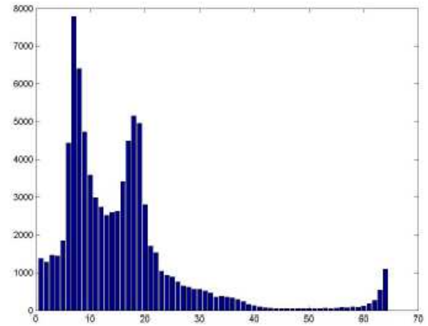
- Histogram is fast and easy to compute.
- Size can easily be normalized so that different image histograms can be compared.
- Can match color histograms for database query or classification.

Examples: histogram

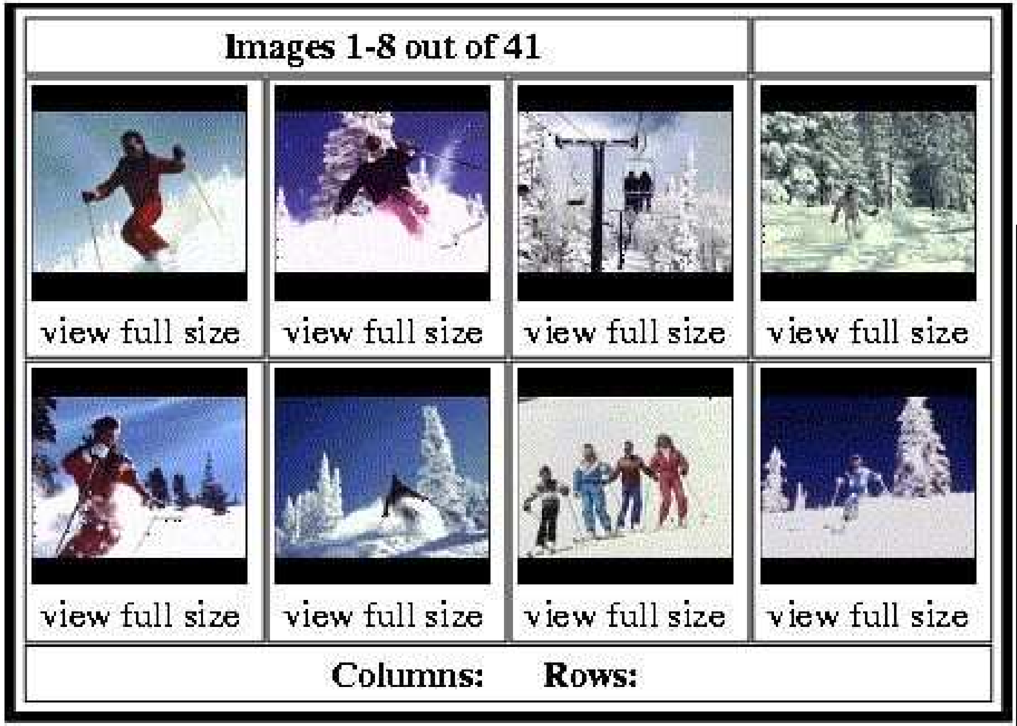





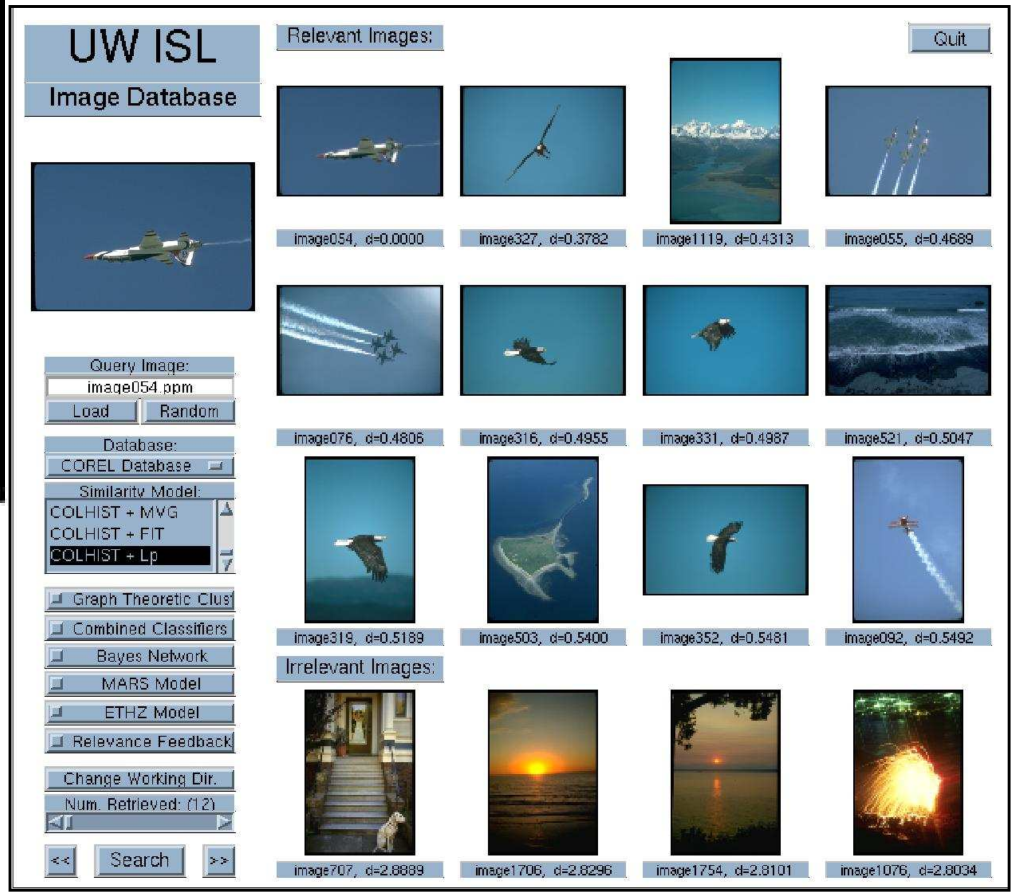




Examples: image retrieval



Adapted from Linda Shapiro, U of Washington



Summary

- To print (RGB → CMY or grayscale)
- To compress images (RGB → YUV)
  - Color information (U,V) can be compressed 4 times without significant degradation in perceptual quality.
- To compare images (RGB → CIE Lab)
  - CIE Lab space is more perceptually uniform.
  - Euclidean distance in Lab space hence meaningful.
- http://www.couleur.org/index.php?page=transformations