Color Image Processing

Selim Aksoy
Department of Computer Engineering
Bilkent University
saksoy@cs.bilkent.edu.tr

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.

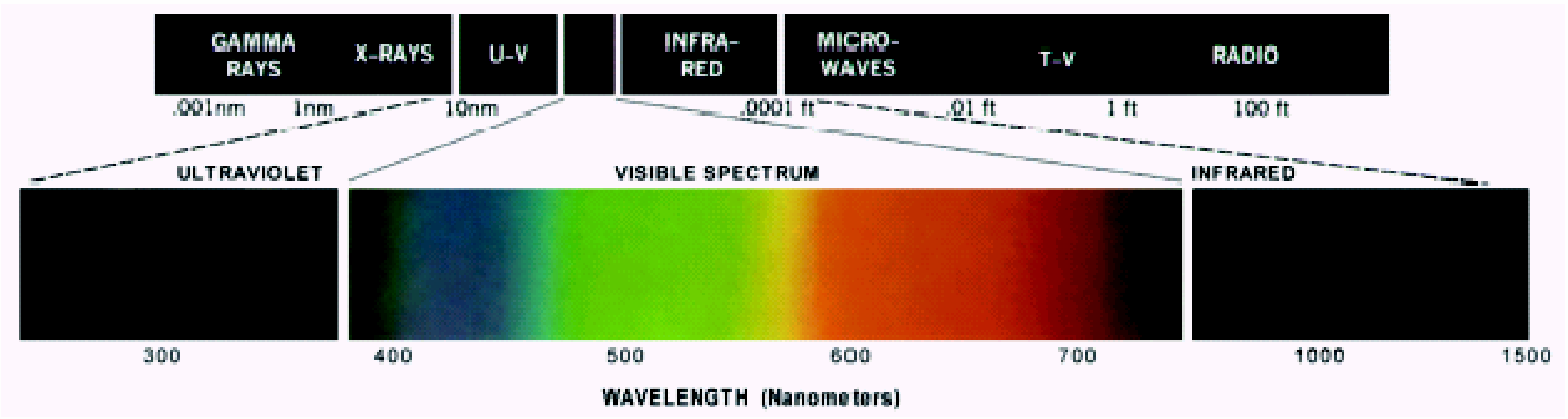
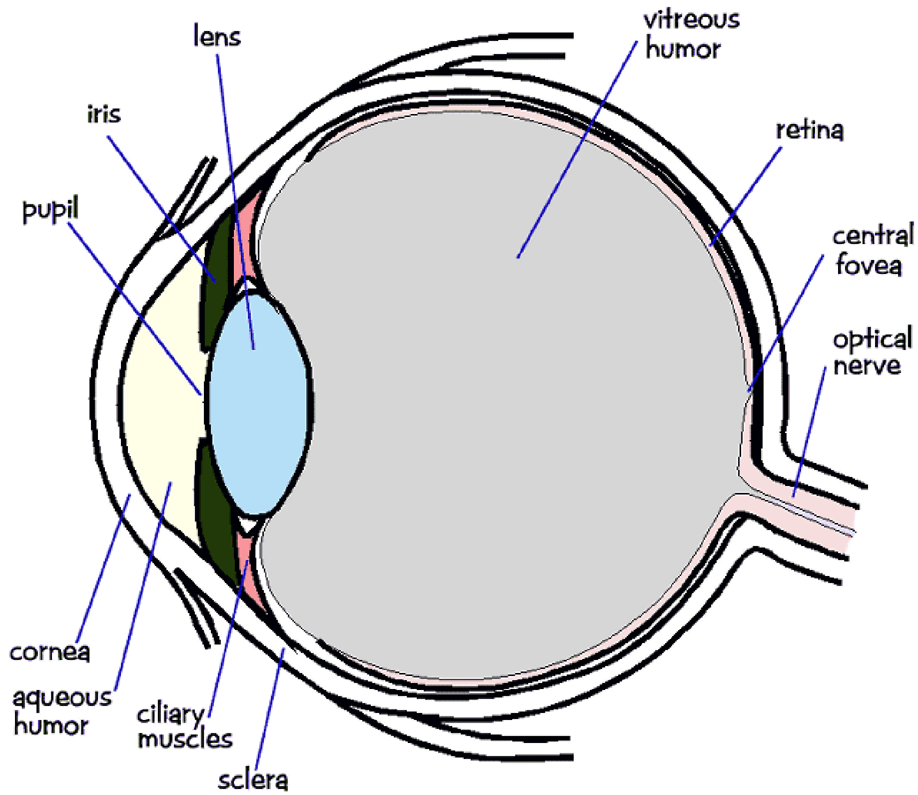


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Adapted from Gonzales and Woods

Human visual system

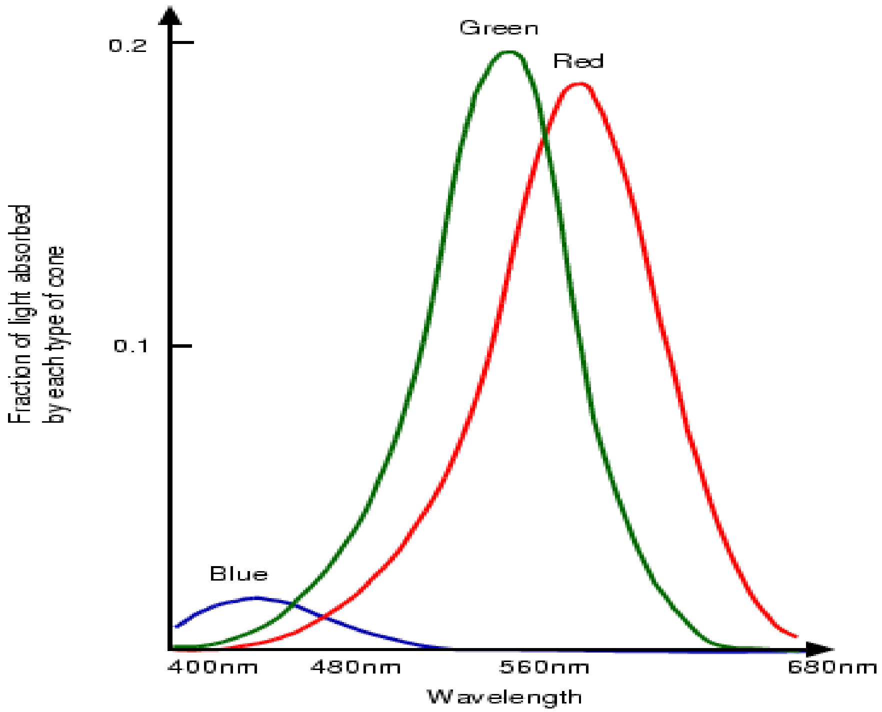


- Color perception
  - Light hits the retina, which contains photosensitive cells.
  - These cells convert the spectrum into a few discrete values.

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

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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

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Additive and subtractive colors

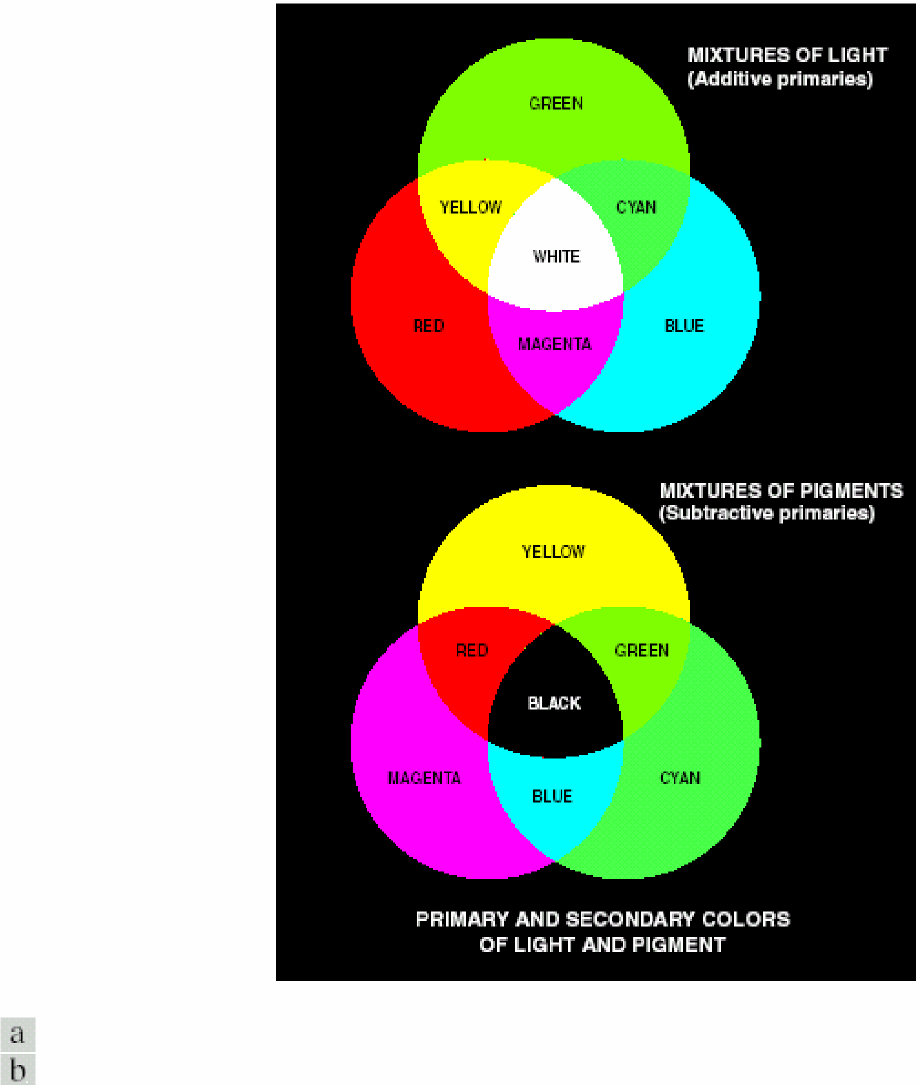

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Adapted from Gonzales and Woods

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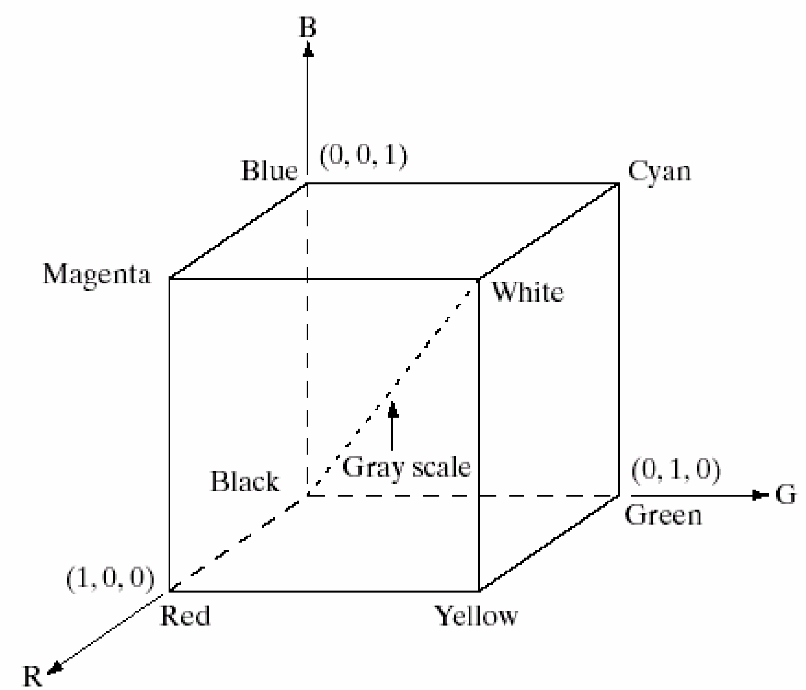
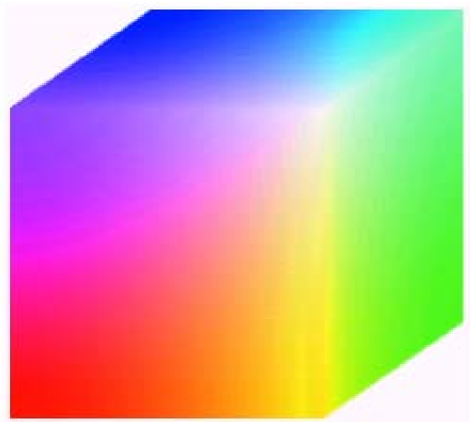
RGB model

- 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.

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

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CIE chromaticity model

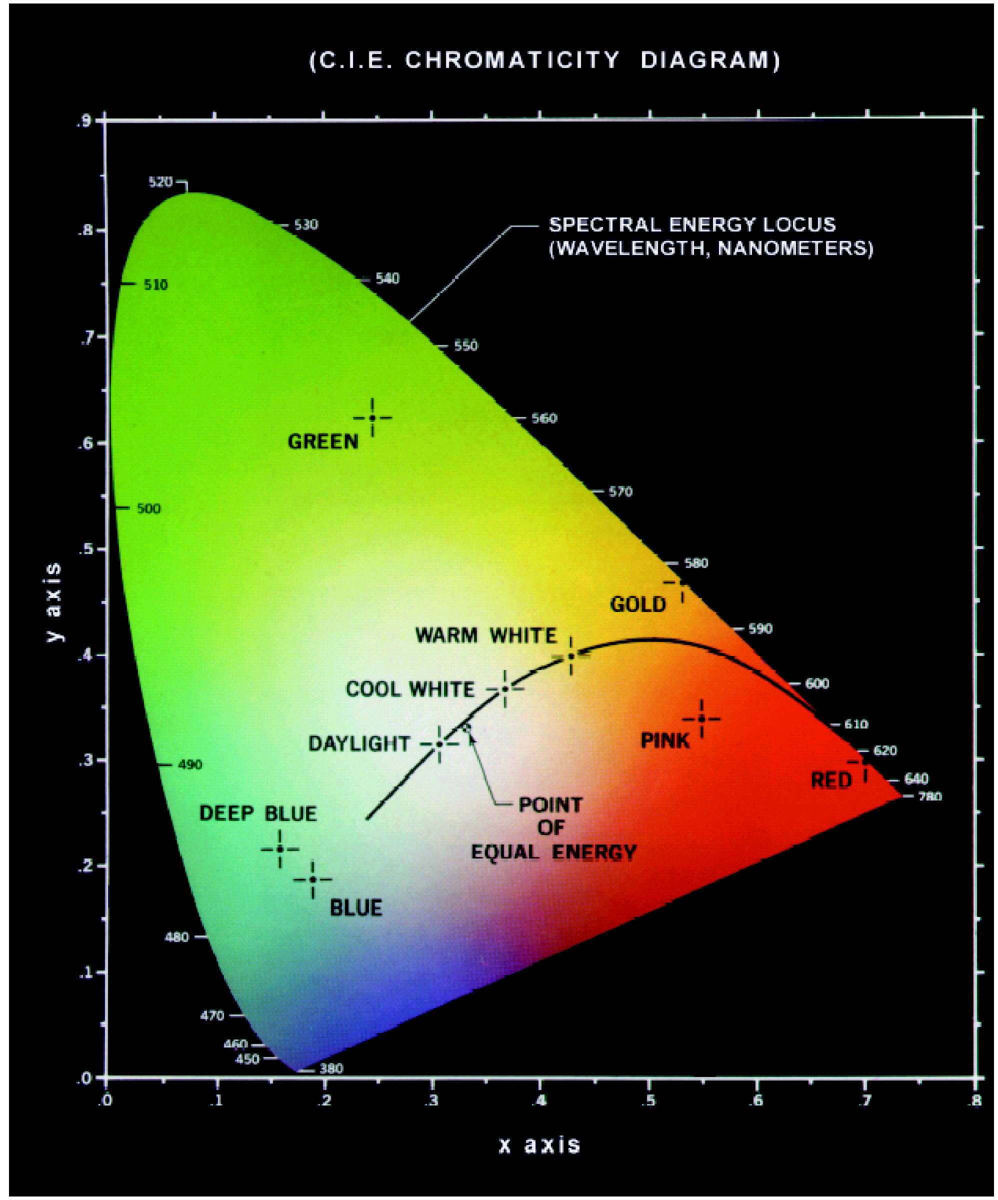
- The Commission Internationale de l'Eclairage defined 3 standard primaries: X, Y, Z that can be added to form all visible colors.
- Y was chosen so that its color matching function matches the sum of the 3 human cone responses.

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

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

CIE chromaticity model

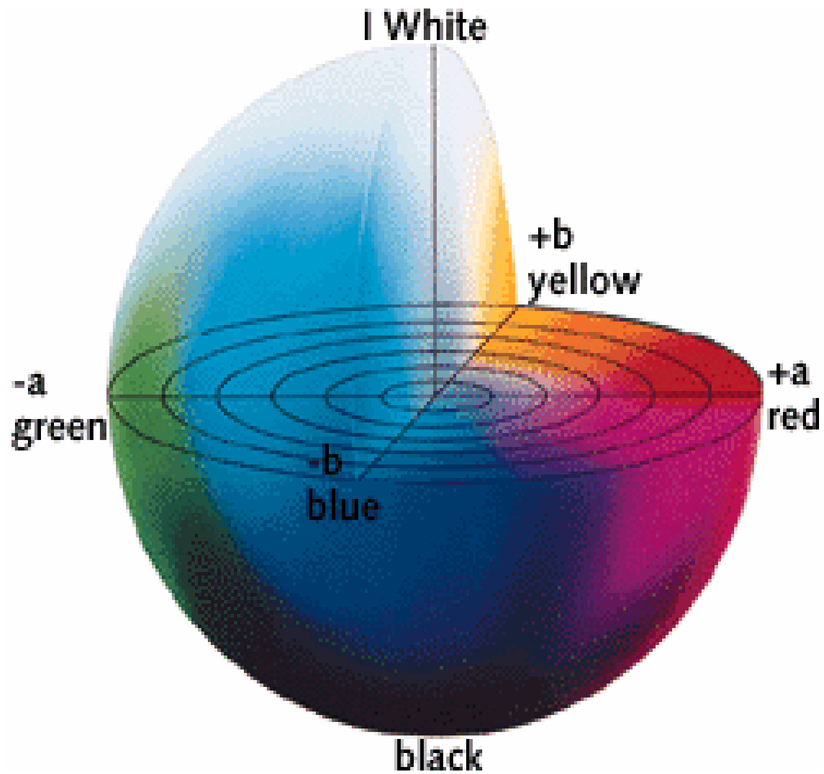
- x, y, z normalize X, Y, Z such that
  $$x + y + z = 1.$$
- Actually only x and y are needed because
  $$z = 1 - x - y.$$
- Pure colors are at the curved boundary.
- White is (1/3, 1/3, 1/3).



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.

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

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HSV model

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

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

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

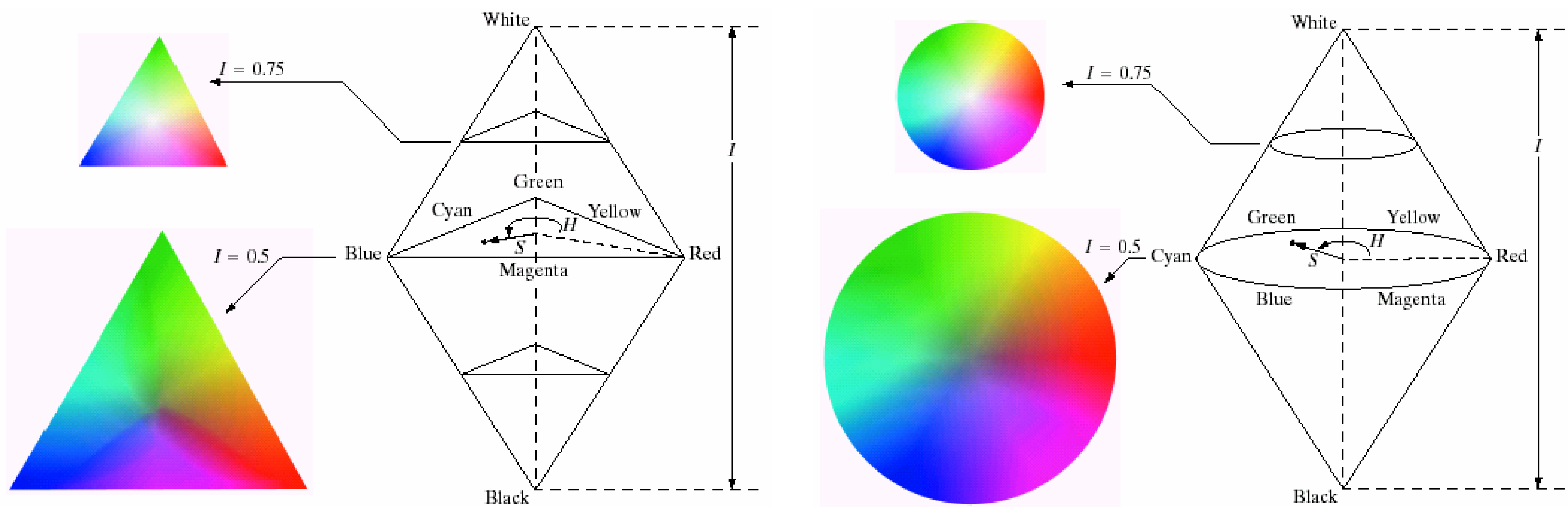
$$H = \cos^{-1}\left\{ \frac{1/2[(R-G)+(R-B)]}{\sqrt{\left[(R-G)^2 + (R-B)(G-B)\right]}} \right\} \text{if} \quad B<G$$

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

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

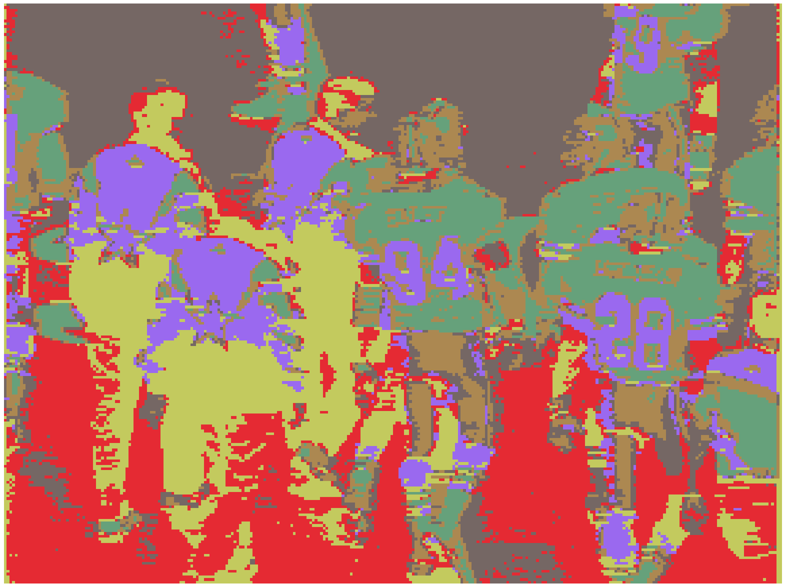
HSV

Adapted from Gonzales and Woods

Examples: segmentation

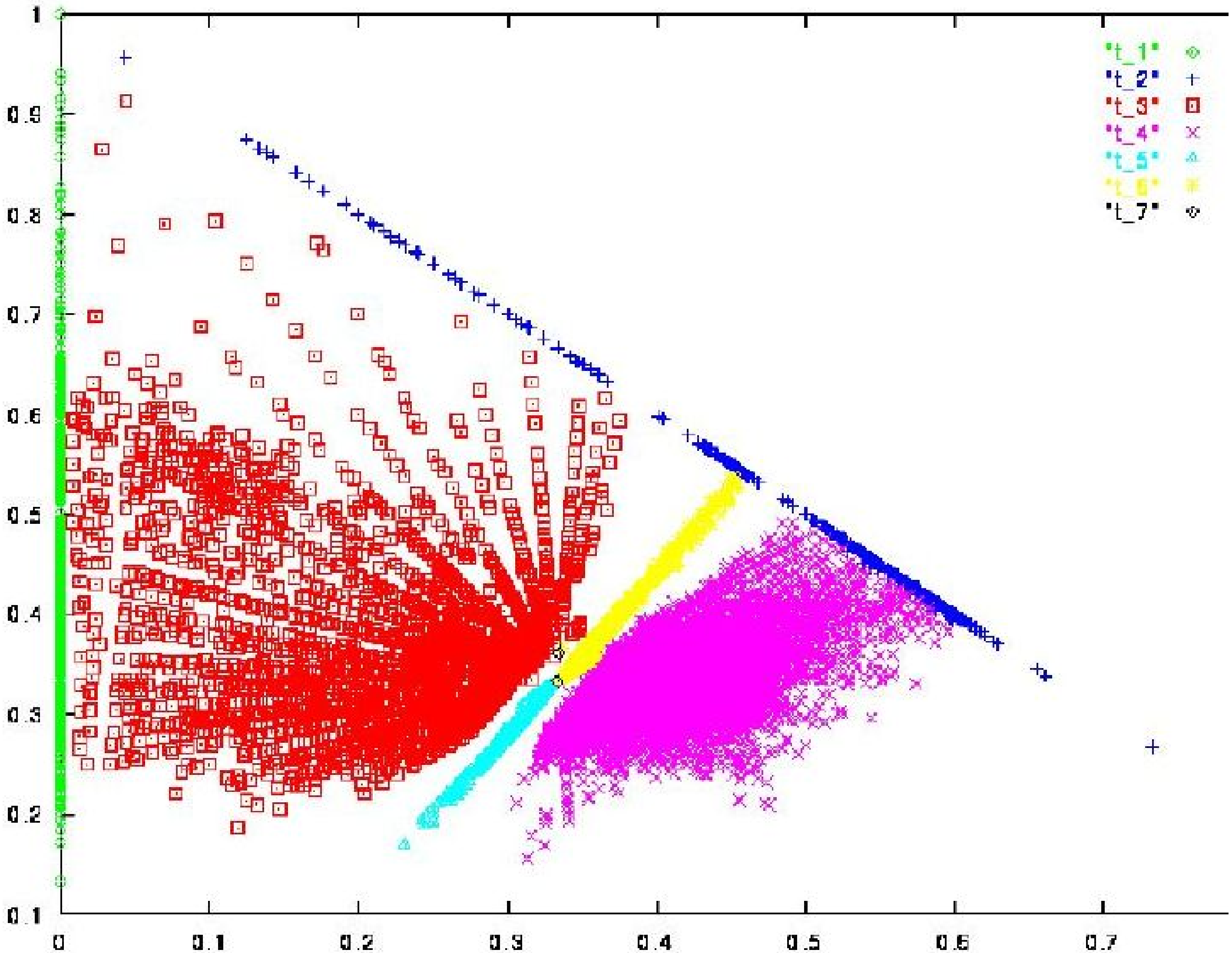
- Can cluster on color values and pixel locations.
- Can use connected components and an approximate color criteria to find regions.
- Can train an algorithm to look for certain colored regions – for example, skin color.

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.

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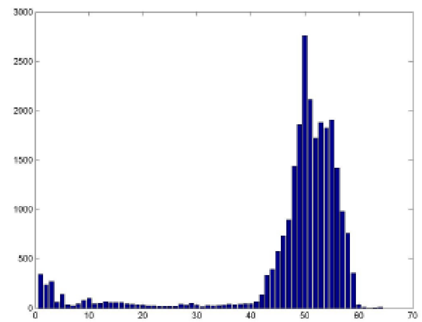
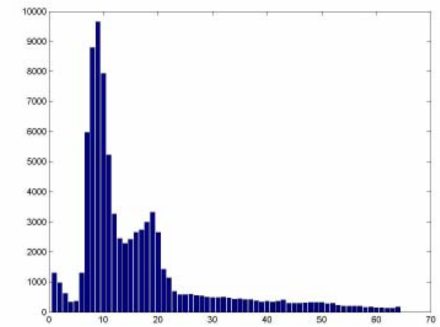
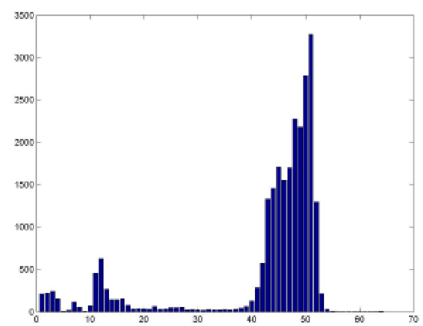
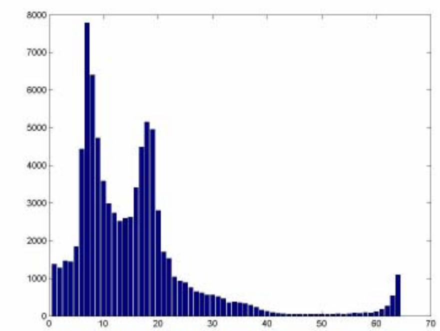
Examples: histogram

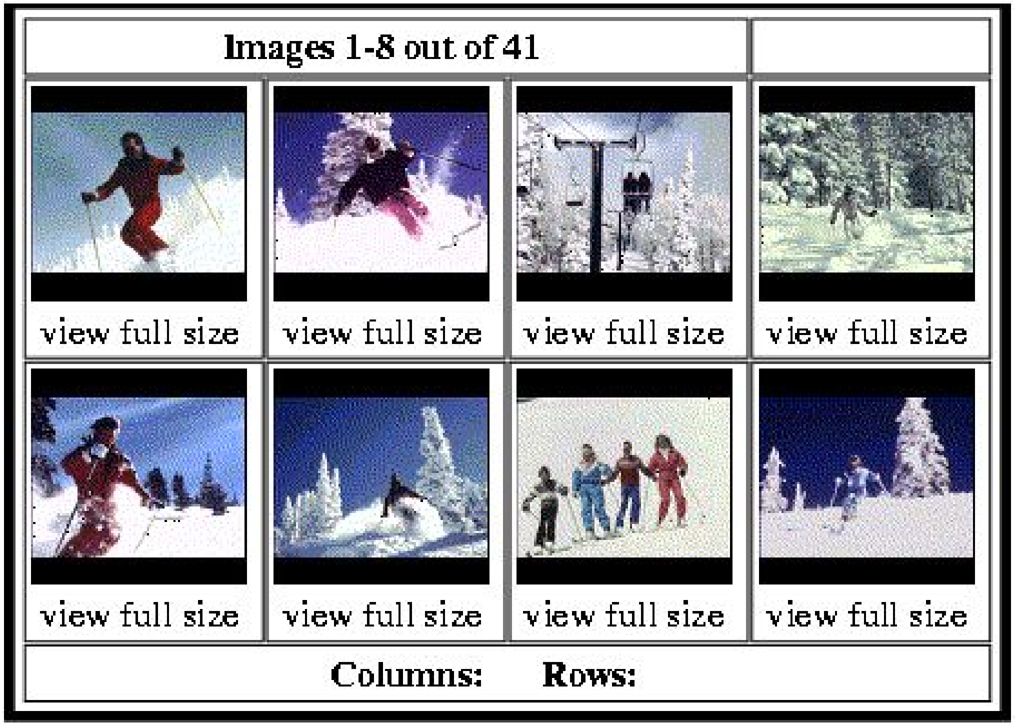








Examples: image retrieval



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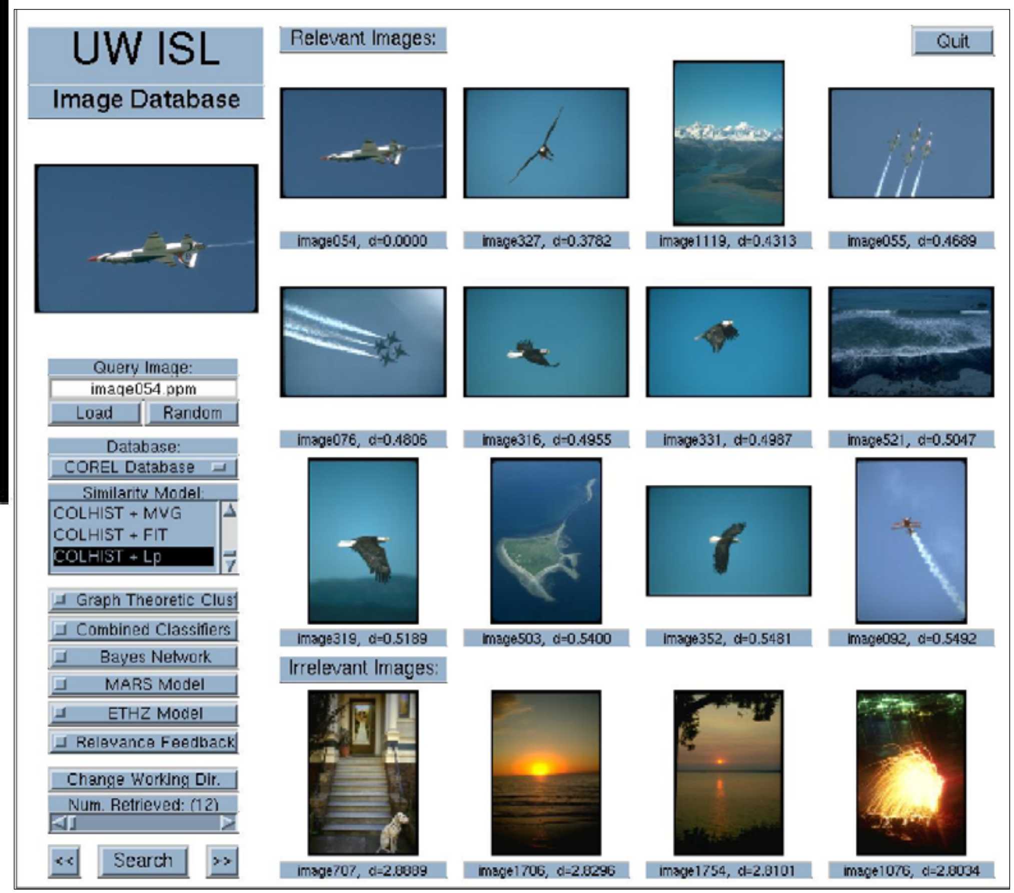

Summary

- 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

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