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# ECG782: Multidimensional Digital Signal Processing

Color Image Processing

http://www.ee.unlv.edu/~b1morris/ecg782/

# Outline

- Color Fundamentals
- Color Models
- Full-Color Image Processing Basics
- Color Transformations
- Spatial Filtering with Color
- Image Segmentation based on Color

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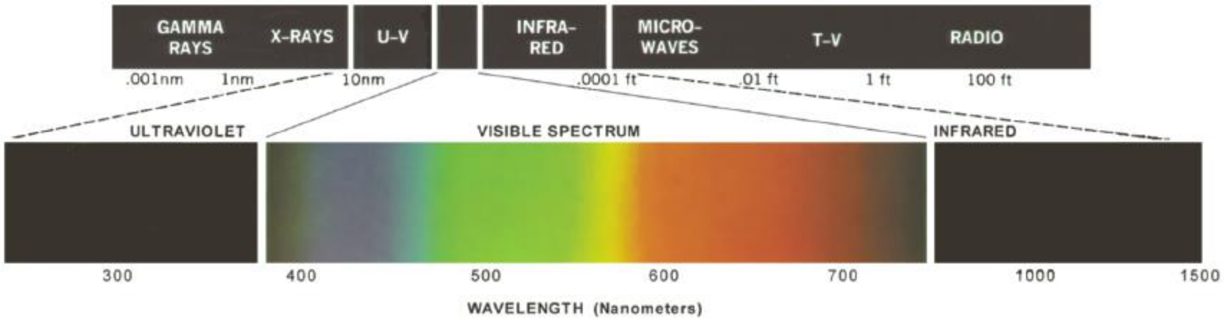
# Motivation

- Humans view the world in color
  - Can discern thousands of color shades and intensities vs. two dozen shades of gray
  - Useful for manual image analysis
- Color can be a powerful descriptor
  - Simplifies object identification and extraction

- Often, many gray scale techniques can be utilized in color (with some slight modifications)

# Color Fundamentals

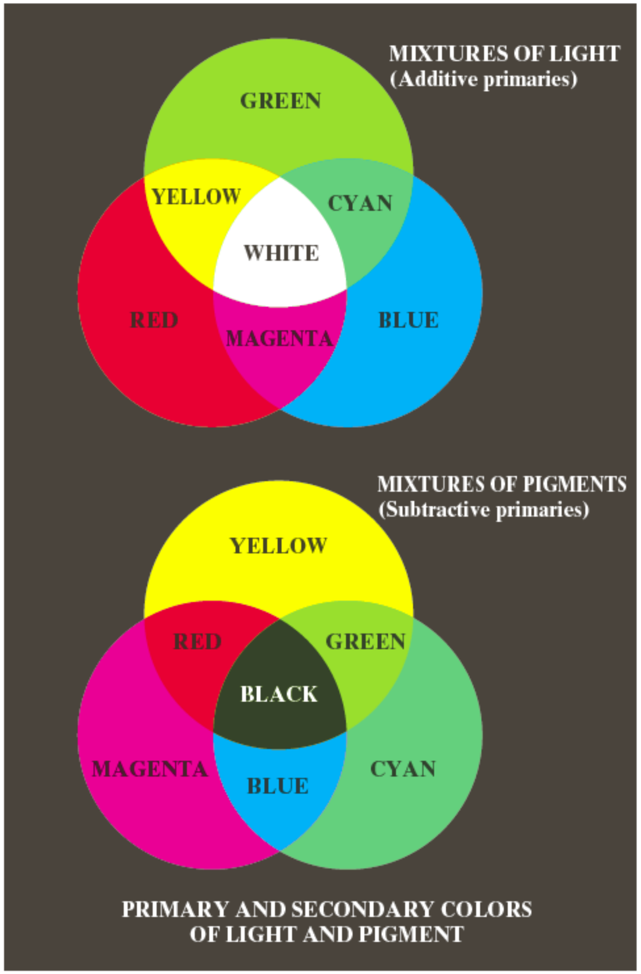
- Color is the visible spectrum of EM spectrum




  - Object color denoted by dominant reflected wavelength
- Achromatic light (void of color)
  - Intensity – only attribute and related to the gray level of image
- Chromatic light (400-700 nm)
  - Radiance – total amount of energy (Watts)
  - Luminance – amount of observed energy (lumens)
  - Brightness – related to achromatic intensity

# Primary Colors

- Cones in human eyes perceive color
  - Sensitive to Red, Green, and Blue light
- Primary colors
  - Red (700 nm), Green (546.1 nm), and Blue (435.8 nm)
  - Combination of RGB for color perception
  - Cannot be mixed to produce all visible colors
    - Must also change wavelength
- Secondary color
  - Magenta (red + blue), cyan (green + blue), yellow (red + green).
  - Used for pigments which is how a printer produces color

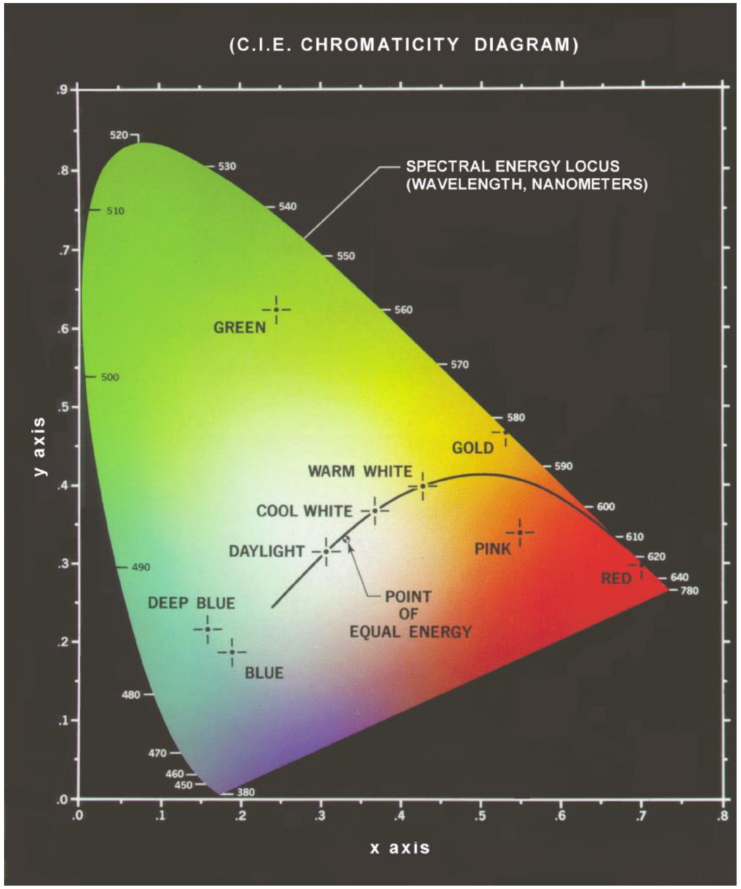


# Chromaticity

- Characteristics of color
  - Brightness – intensity
  - Hue – dominant wavelength or perceived color
  - Saturation – purity or amount of white light mixed with hue
- Chromaticity is the measure of color
  - Hue and saturation together
- Chromaticity diagram
  - Amount of RGB needed to make a particular color
  - [blue] $z = 1 - (x + y)$
  - Color gamut defines the range of colors produced

- CIE Chromaticity Diagram

green




red

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# Color Models (Color Spaces)

- Specify color in a standard form
- Popular models
  - RGB – used in monitors
  - CMY/K – used in printers
  - HSI – (hue, saturation, intensity) corresponds with human color description
- Many other models exist and are typically designed for specific purposes
  - E.g. Lab for color correction, shadow removal with YCbCr,

# RGB Color Model

- Based on Cartesian coordinate system
  - Normalized to define a unit cube
- Pixel depth – number of bits used to represent a pixel
  - 8-bits for each RGB channel for 24-bit (full-color) image
  - $(2^8)^3 = 16{,}777{,}216$ possible colors

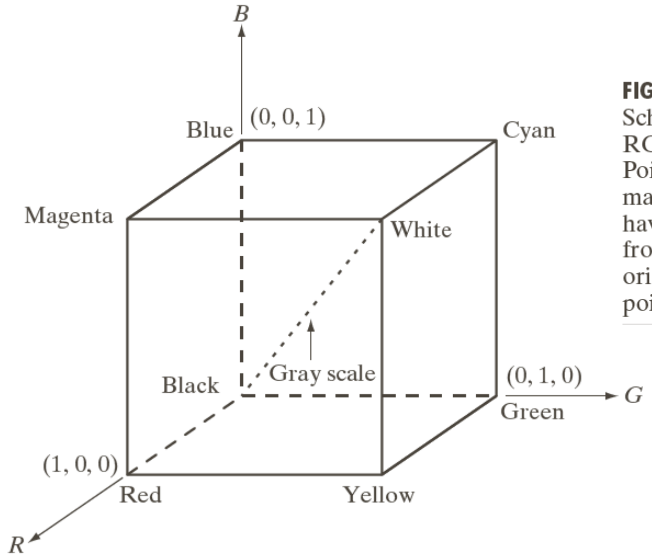



**FIGURE 6.7** Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

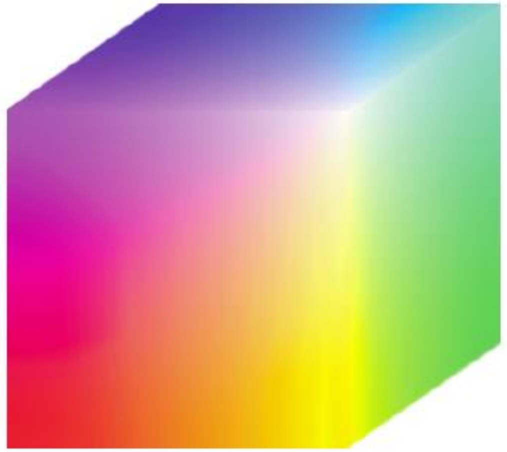


**FIGURE 6.8** RGB 24-bit color cube.

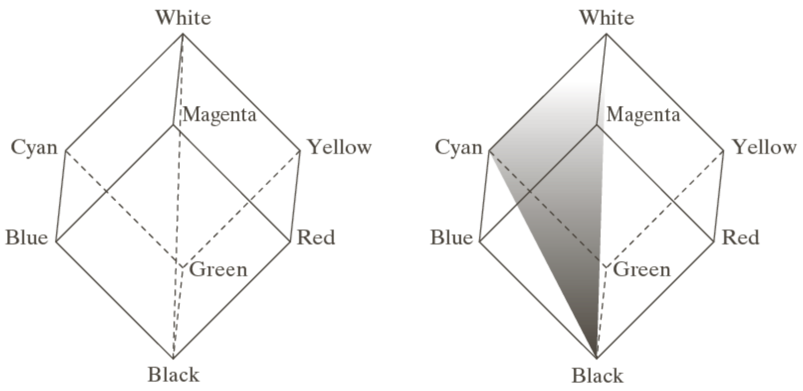
# CMY/K Color Models

- Useful for devices that deposit colored pigments (printers)
  - Cyan (green + blue) pigments illuminated with white light does not reflect red
  - K (black) used since combination of CMY does not produce good black
- Very simple transformation from RGB to CMY color space

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

# HSI Color Model

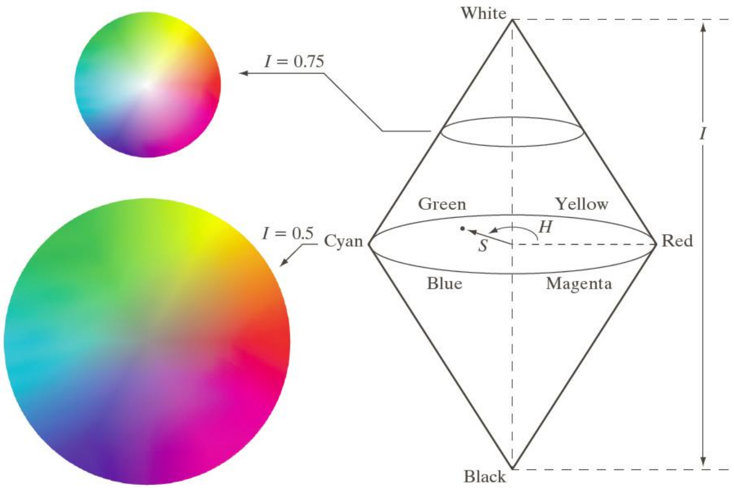
- More natural way to describe color than RGB
  - Decouples color intensity from color-carrying information (chromaticity)
  - Useful tool for image processing using human color descriptions

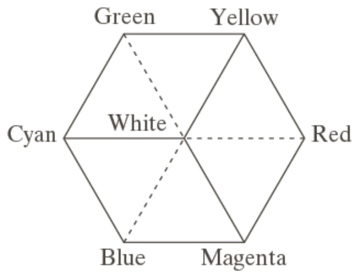


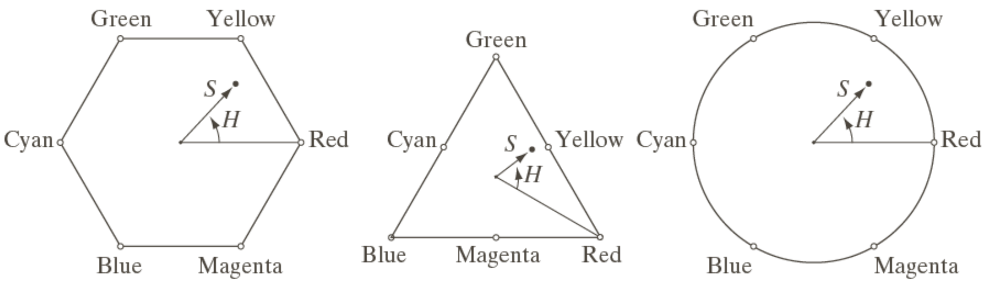

- Intensity – line between black and white in RGB cube
- Saturation – distance from intensity line
- Hue – plane contained by black, white, and color

# HSI Color Model II

- Color as a point in HSI space
  - Hue – denoted by the angle from Red
  - Saturation – denoted by length of vector
- Arbitrary shape  for HS space
  - Transform  between hexagon and circle
- Intensity is a vertical height
  - Maps out a “cone” color space
  - High intensity has little color
  - Low intensity has little color



# HSI-RGB Conversion

- RGB to HSI
  - Normalized RGB values
  - Hue angle wrt Red axis
- $H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases}$
  - $\theta = \cos^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\}$
- $S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$
- $I = \frac{1}{3}(R + G + B)$
- Matlab: `rgb2hsv.m`

- HIS to RGB
  - Conversion depends on $H$ value (3 cases)
- RG sector ($0° \leq H < 120°$)
  - $B = I(1 - S)$
  - $R = I\left[1 + \frac{S \cos H}{\cos(60° - H)}\right]$
  - $G = 3I - (R + B)$
- Similar formulas exist for the other two sectors
- Matlab: `hsv2rgb.m`

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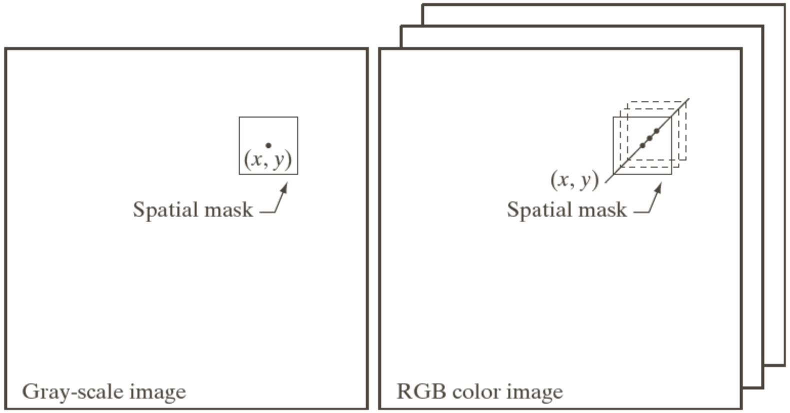
# Full-Color Image Processing Basics

- Two main processing techniques:
  - Process each component (color channel) separately
    - Each channel is a gray-level image
  - Manipulate color pixels directly
    - $c(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B\ (x,y) \end{bmatrix}$



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# Color Transformations

- Same concept as gray-level transform
  - Operate only on a single color channel
- $g(x, y) = T[f(x, y)]$
  - Transform color image (operate on color pixels)
- Simple color transforms
  - $s_i = T_i(r_1, r_2, \dots, r_n) \qquad i = 1,2, \dots, n$
  - E.g. RGB-space $n = 3$
  - Will generally operate on each color channel separately

# Colorspace Example

Remember: light is high value and low is dark

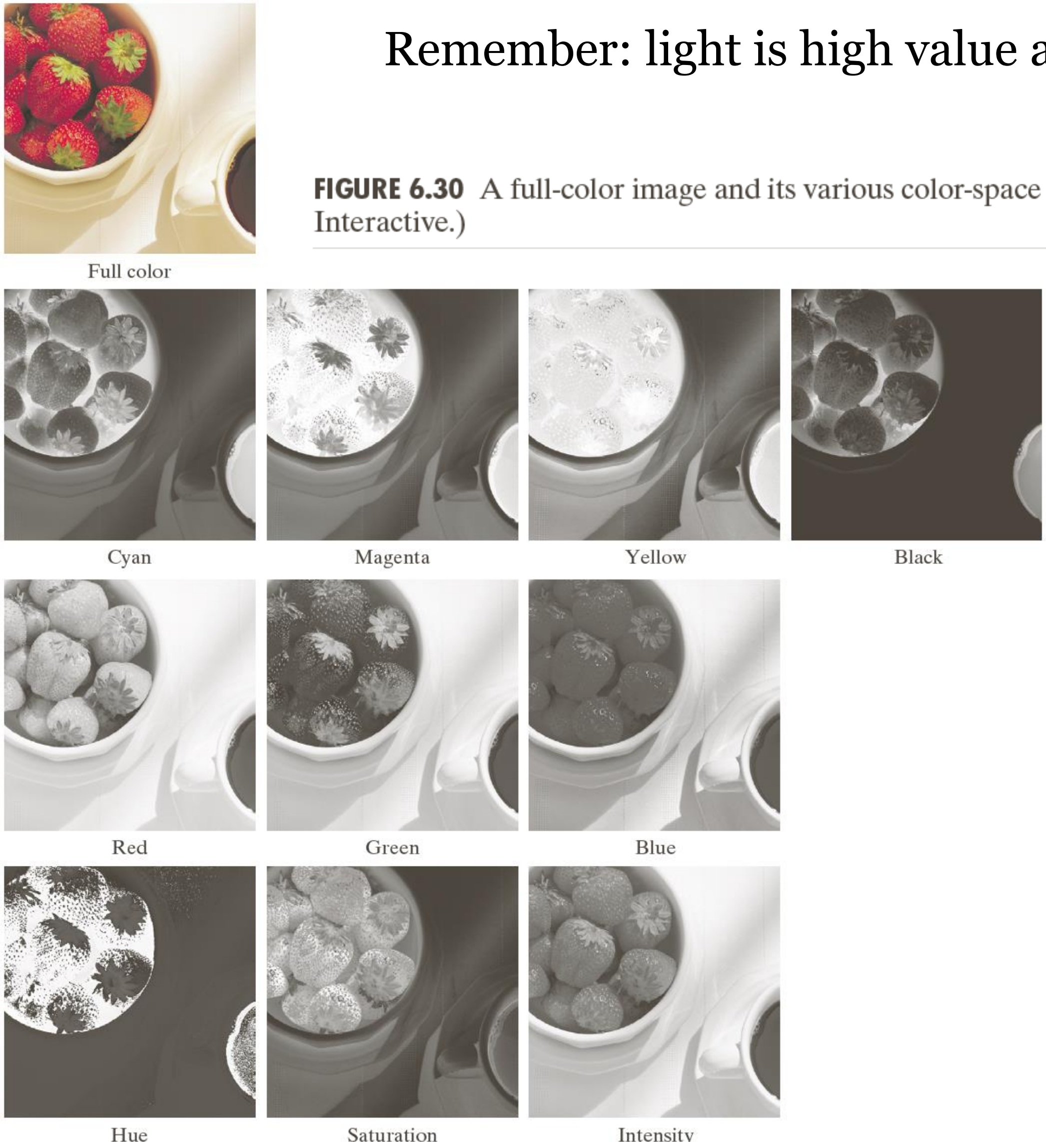



**FIGURE 6.30** A full-color image and its various color-space components. Interactive.)

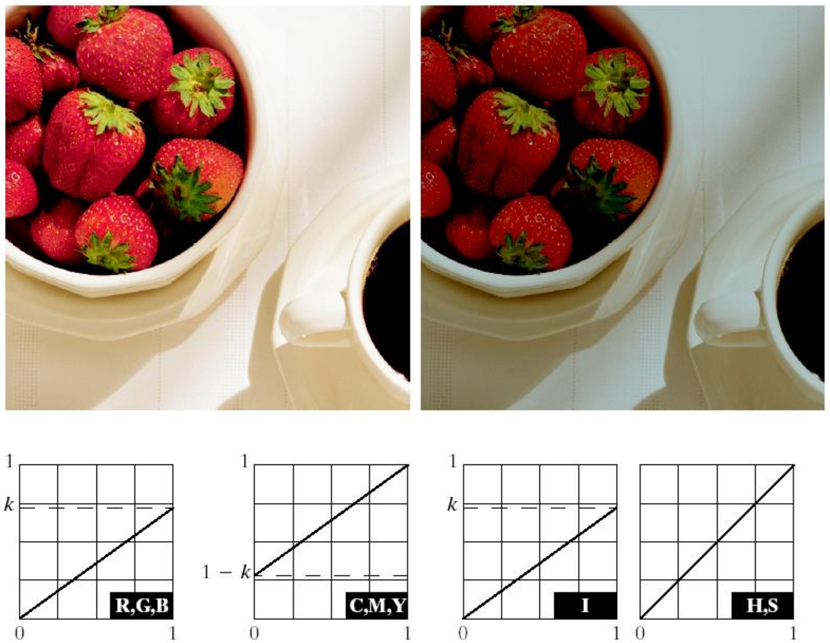
Red = 0, or 1

# Colorspace Example II

- Adjust intensity of image
  - Probably easiest to work in HSI space
  - $s_3 = kr_3$
    - $i = 3$ for the intensity channel
  - CMYK
    - $s_i = kr_i + (1 - k)$ $\qquad i = 1,2,3$

a b
c d e

**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.)



# Tone and Color Correction

- Use CIE L*a*b* (CIELAB) colorspace
  - Colorimetric – matching colors encoded identically
  - Perceptually uniform – color differences between hues are perceived uniformly
  - Device independent color model
- Decouples intensity from chromaticity
  - L* - lightness (intensity)
  - a* - red minus green
  - b* - green minus blue

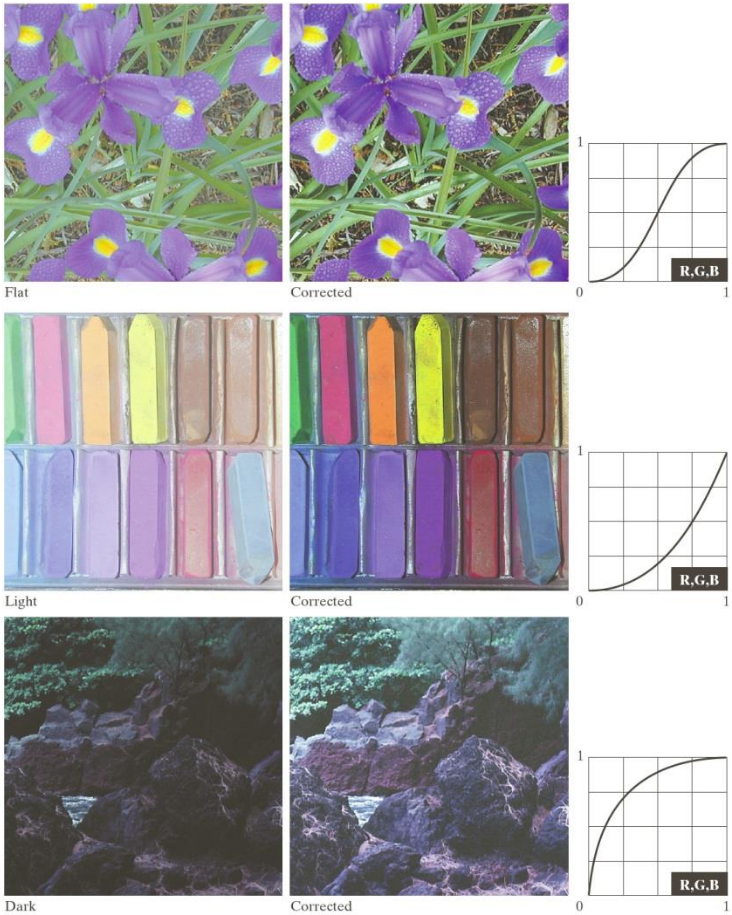



**FIGURE 6.35** Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

# Color Balancing

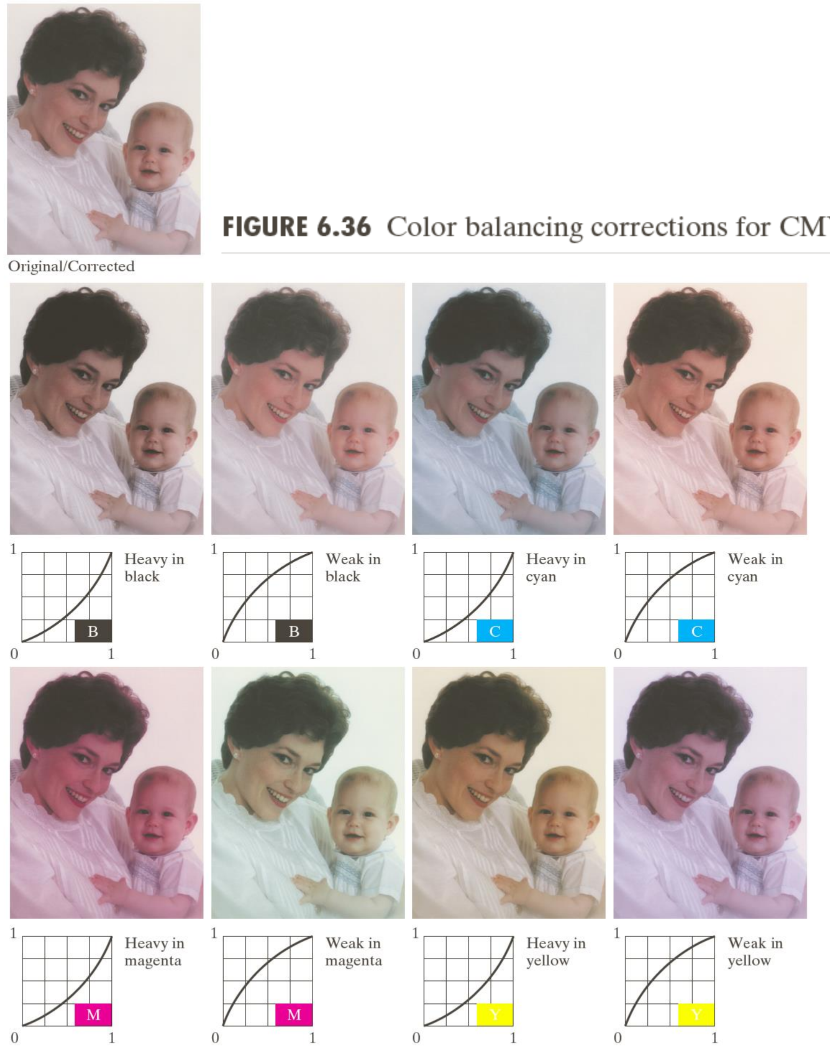
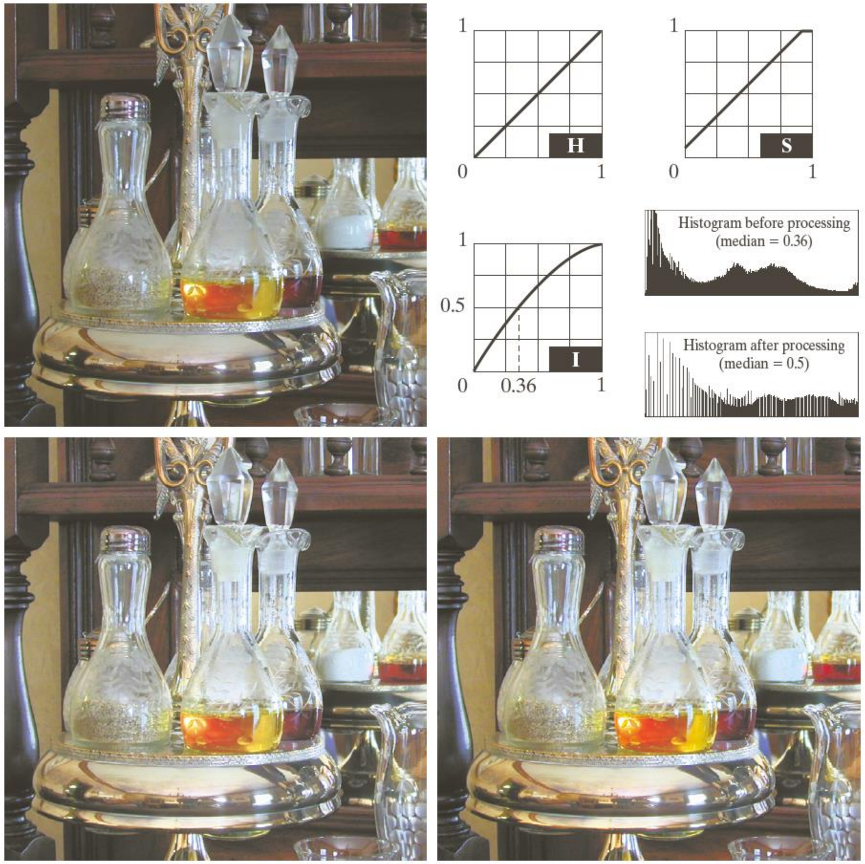



**FIGURE 6.36** Color balancing corrections for CMYK color images.

# Color Histogram Processing

- Do not want to operate on all channels separately
  - Results in erroneous color outputs
- Generally operate on intensity separately and leave colors (hue) unchanged
  - HSI is well suited
- Intensity normalization improves overall contrast
- Use saturation adjustment due to "lighter" image




a b
c d

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

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# Spatial Filtering with Color

- Operate on RGB color channels separately
  - Filter each channel separately and combine
- Operate on HSI intensity channel alone
  - Well suited for gray-level processing techniques
  - Efficient filtering with only one channel
    - Overhead associated with colorspace conversion

# Smoothing Example

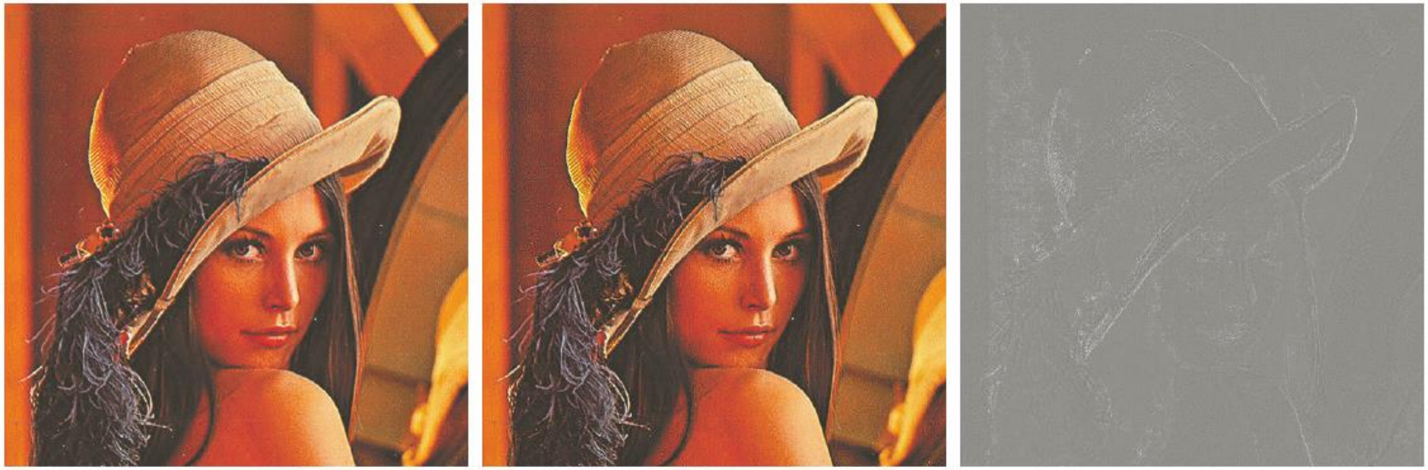
- Very similar output perceptually for RGB and HSI processing
  - With HSI colors do not change
  - Differences magnified with greater filter size

a b c

**FIGURE 6.40** Image smoothing with a $5 \times 5$ 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.

# Sharpening Example

- Very similar output perceptually for RGB and HSI processing



a b c

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

Very famous image processing image: “Lena”

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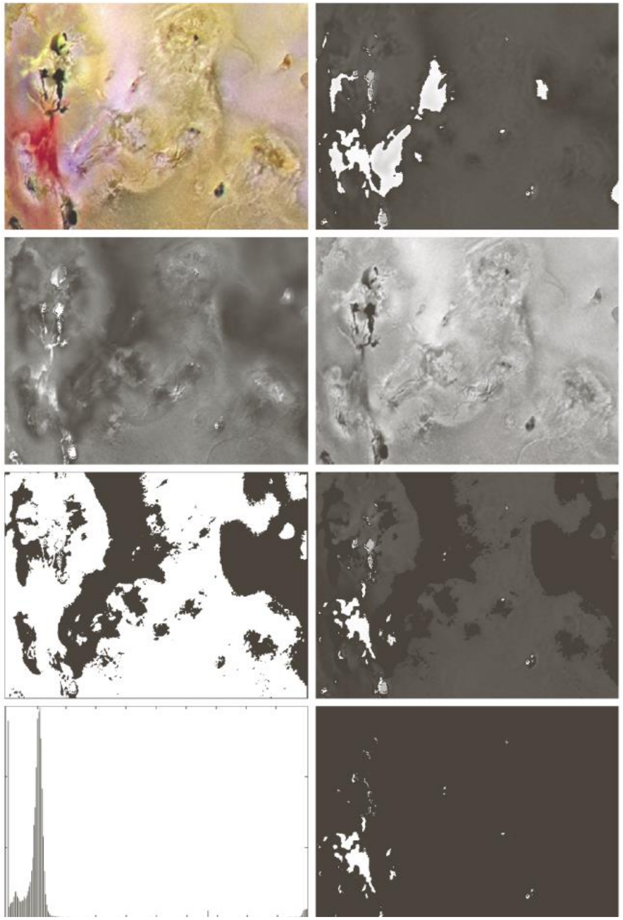
# Color Segmentation

- HSI is a natural colorspace choice
  - Hue used to select colors of interest
  - Saturation used as a “mask”
    - Retain high saturation (pure) colors

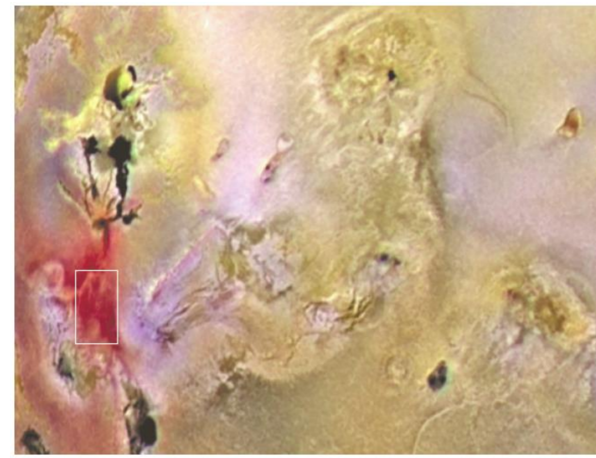


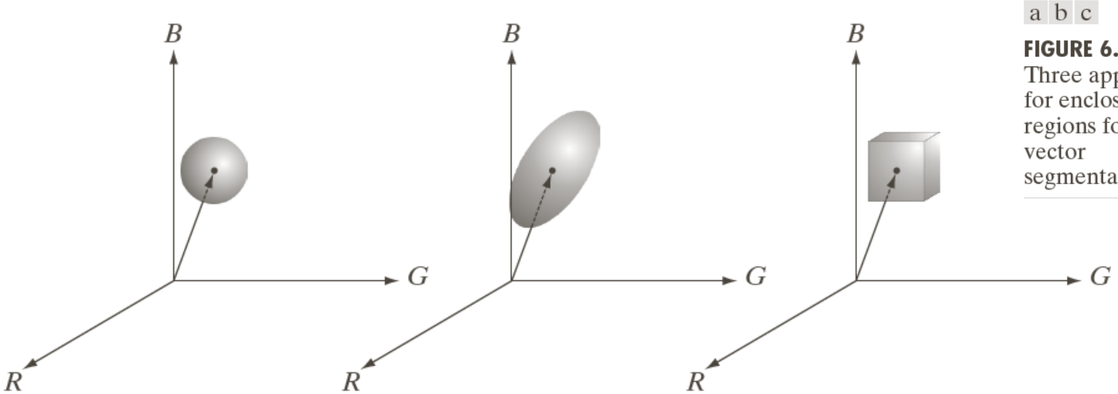
a b
c d
e f
g h

**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).

# RGB Color Segmentation

- Generally better segmentation results in RGB
  - Utilize a generic notion of distance in RGB space
  - $D(z, a) = \|z - a\|_C$
  - $D(z, a) = \left[(z - a)^T C^{-1} (z - a)\right]^{\frac{1}{2}}$
    - $C$ – covariance matrix of sample color points



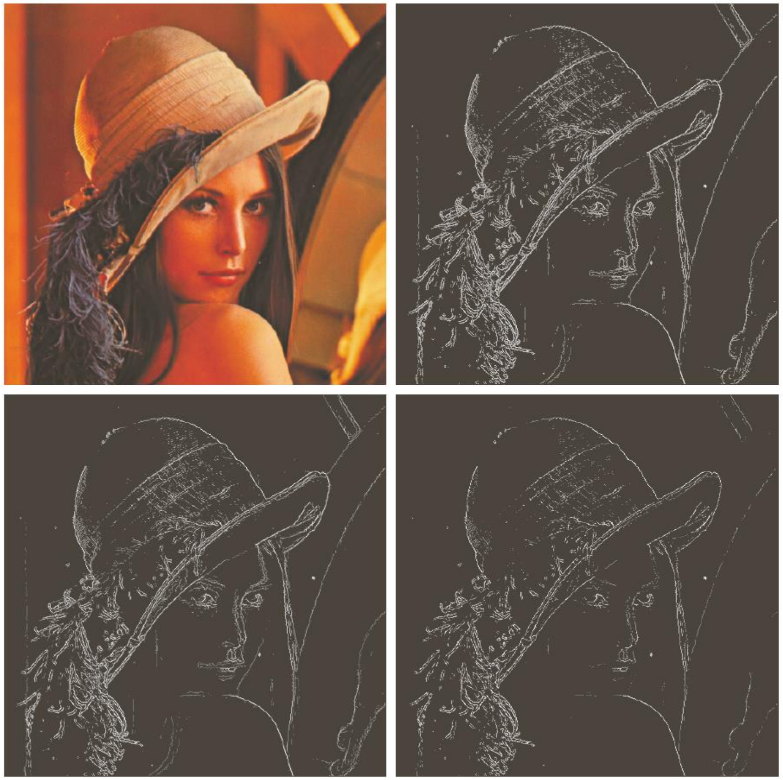



a b c

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

# Color Edge Detection

- Individual channel gradient information not directly applicable to color edges
  - Use vector gradient formulation (see book)



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).