Color Image Processing

Image Processing

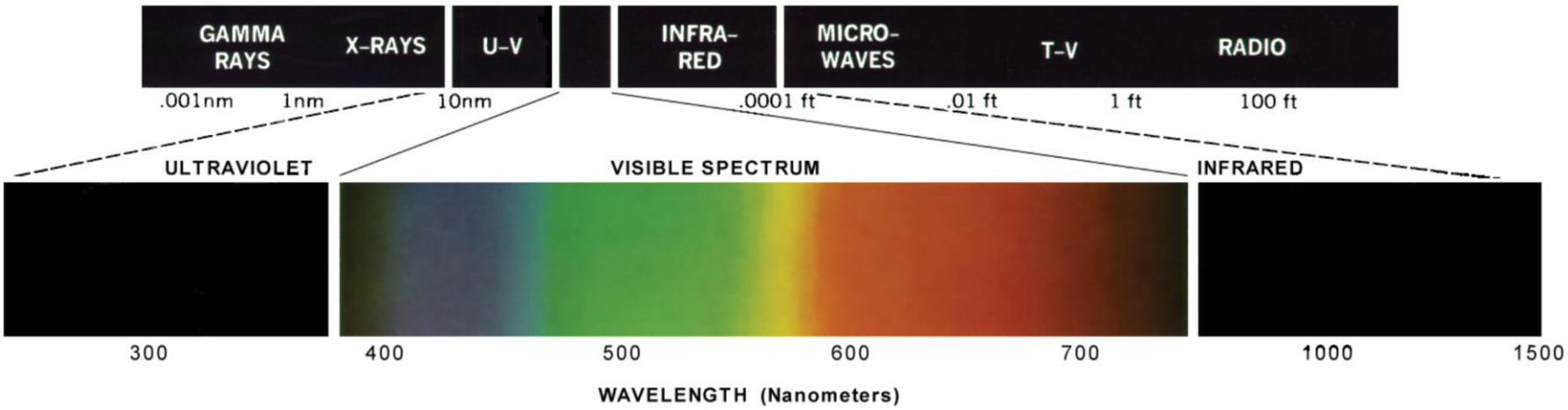
CSE 166

Lecture 9

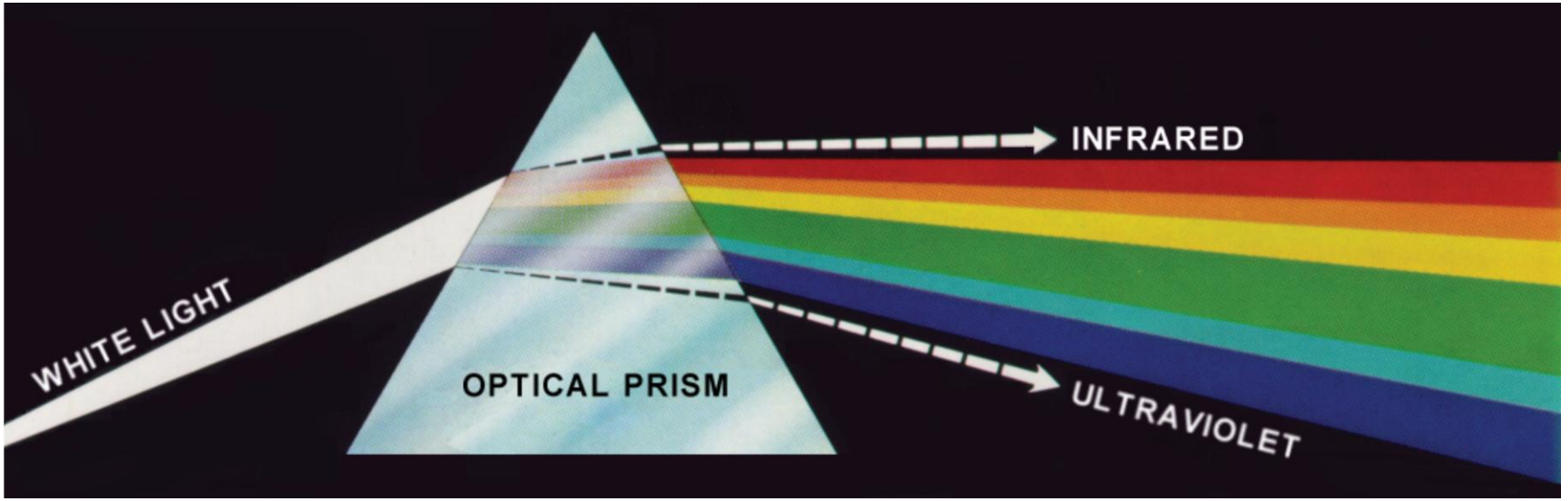
Announcements

- Assignment 3 is due today, 11:59 PM
- Midterm is May 4
- Assignment 4 will be released May 4
  - Due May 11, 11:59 PM
- Reading
  - Chapter 7: Color Image Processing
    - Sections 7.1, 7.2, 7.3, 7.4, 7.5, and 7.6

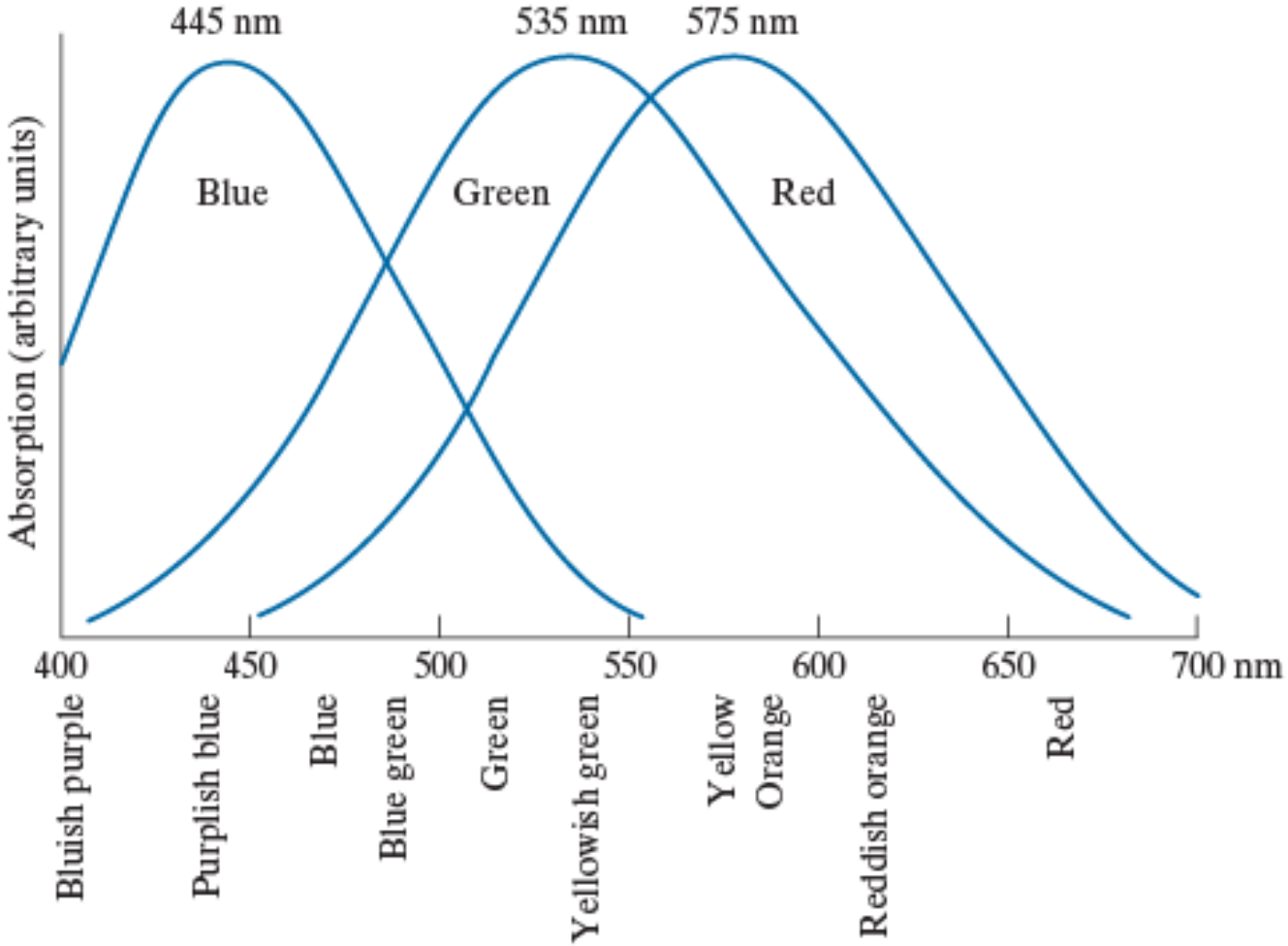
Electromagnetic spectrum



Separating visible light



Human eye cones

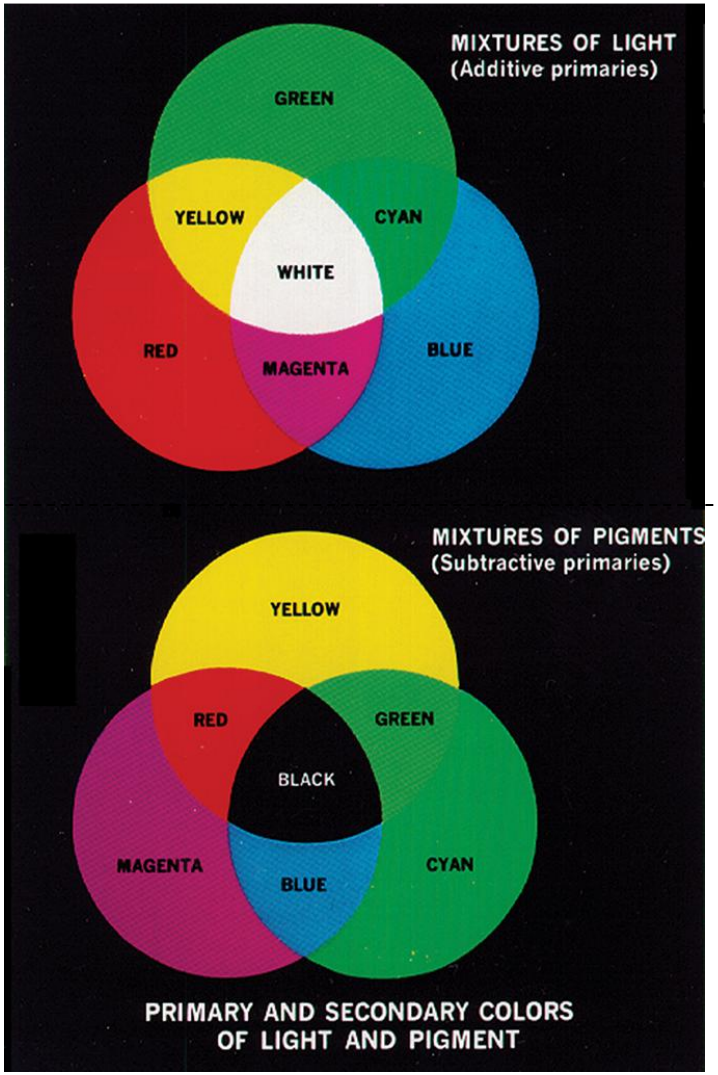


Mixing light

Light

Primary and secondary colors are swapped

Pigment



Note that green, cyan, and blue are not accurate colors in figure to the left. More accurate colors below.

RED

YELLOW

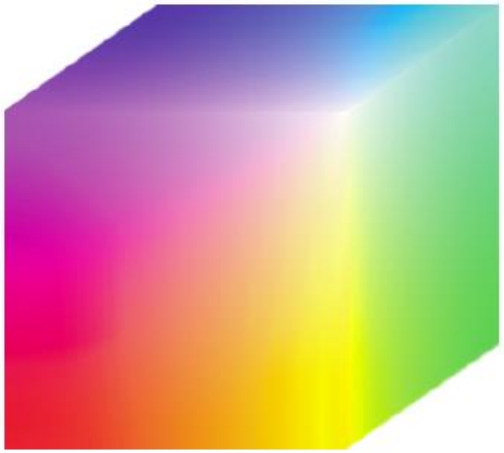
GREEN

CYAN

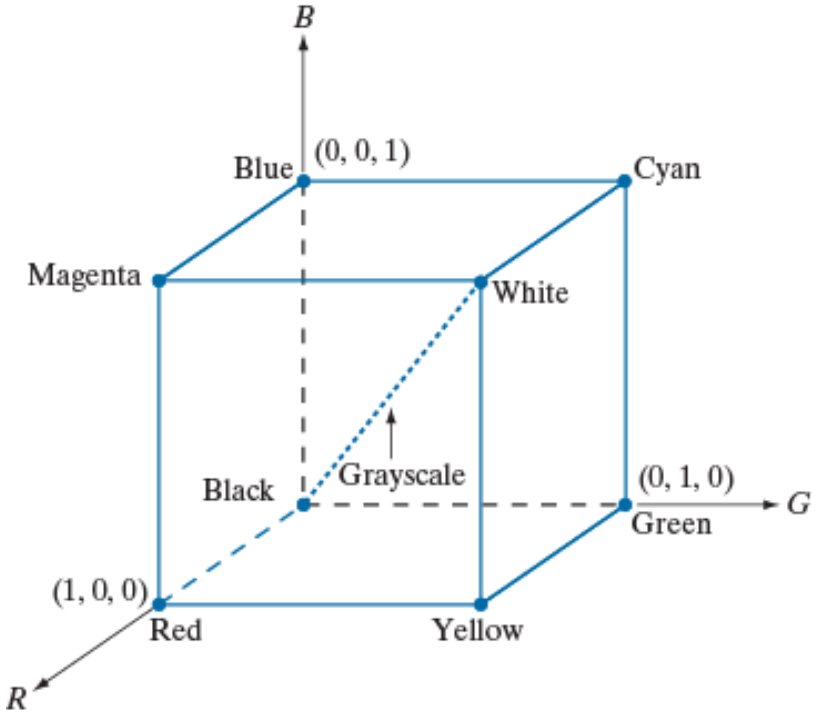
BLUE

MAGENTA

RGB color model



RGB color cube



RGB coordinates

XYZ color space

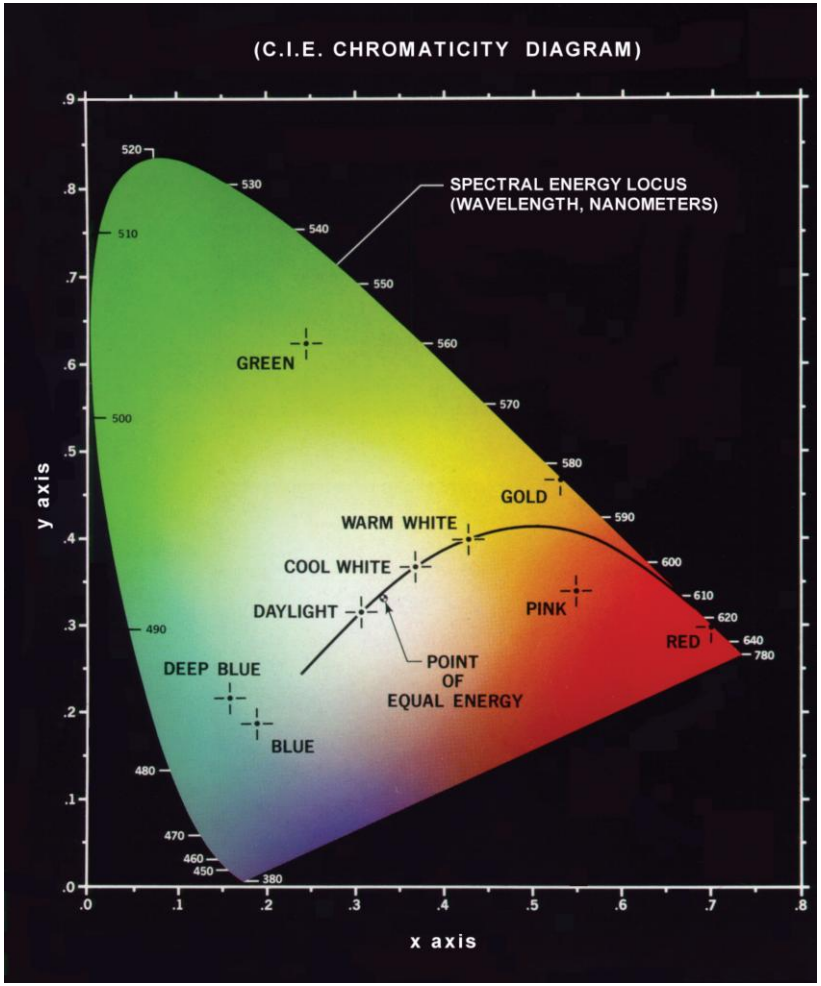
- XYZ color space
  - Encompasses all color sensations the average person can experience
  - Standard reference
    - Many other color space definitions are based on XYZ

Y is luminance (the amount of energy an observer perceives)
Z is quasi-equal to blue simulation
X is a linear combination of cone response curves chosen to be nonnegative

Chromaticity coordinates

- The plane parallel to the XZ-plane and that Y lies on contains all possible chromaticities at the luminance Y
- Typically represented using (x,y)

$$x + y + z = 1$$



Not actual locations of colors; just gives an idea

XYZ color space and chromaticity coordinates

Given X, Y, and Z

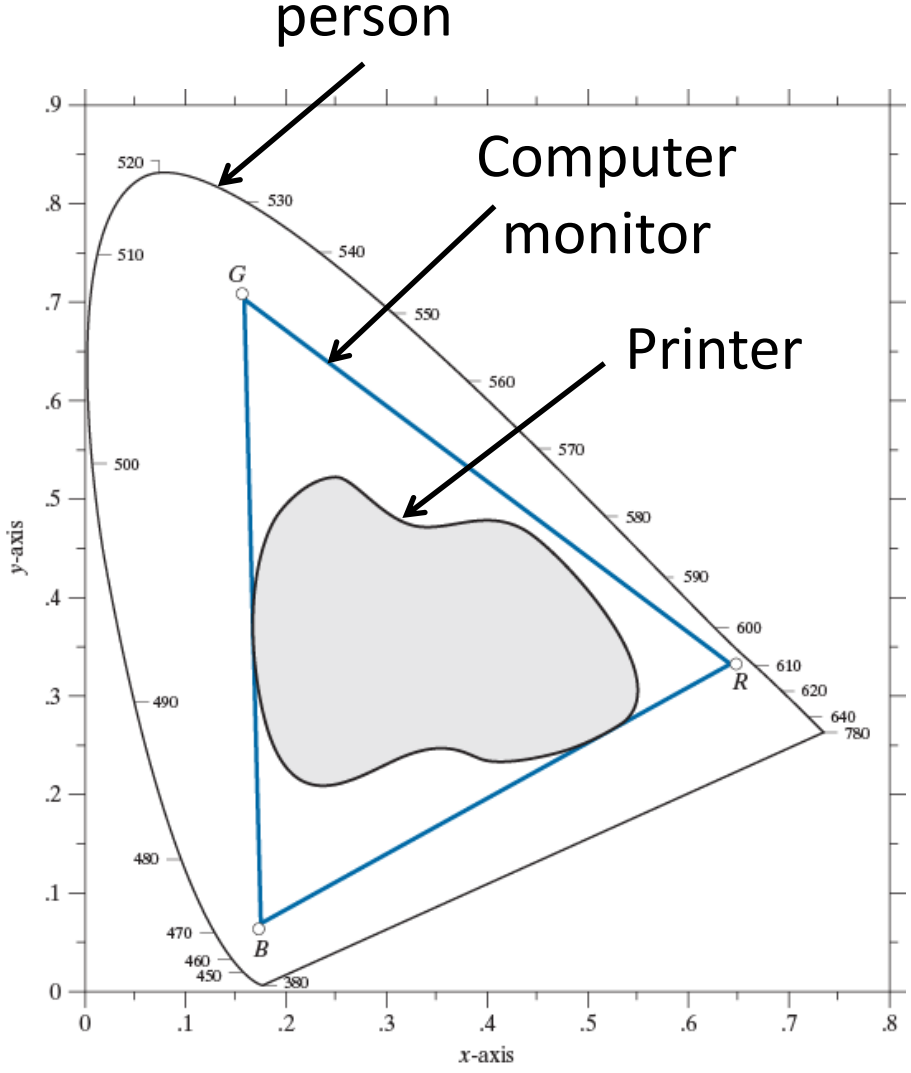
$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

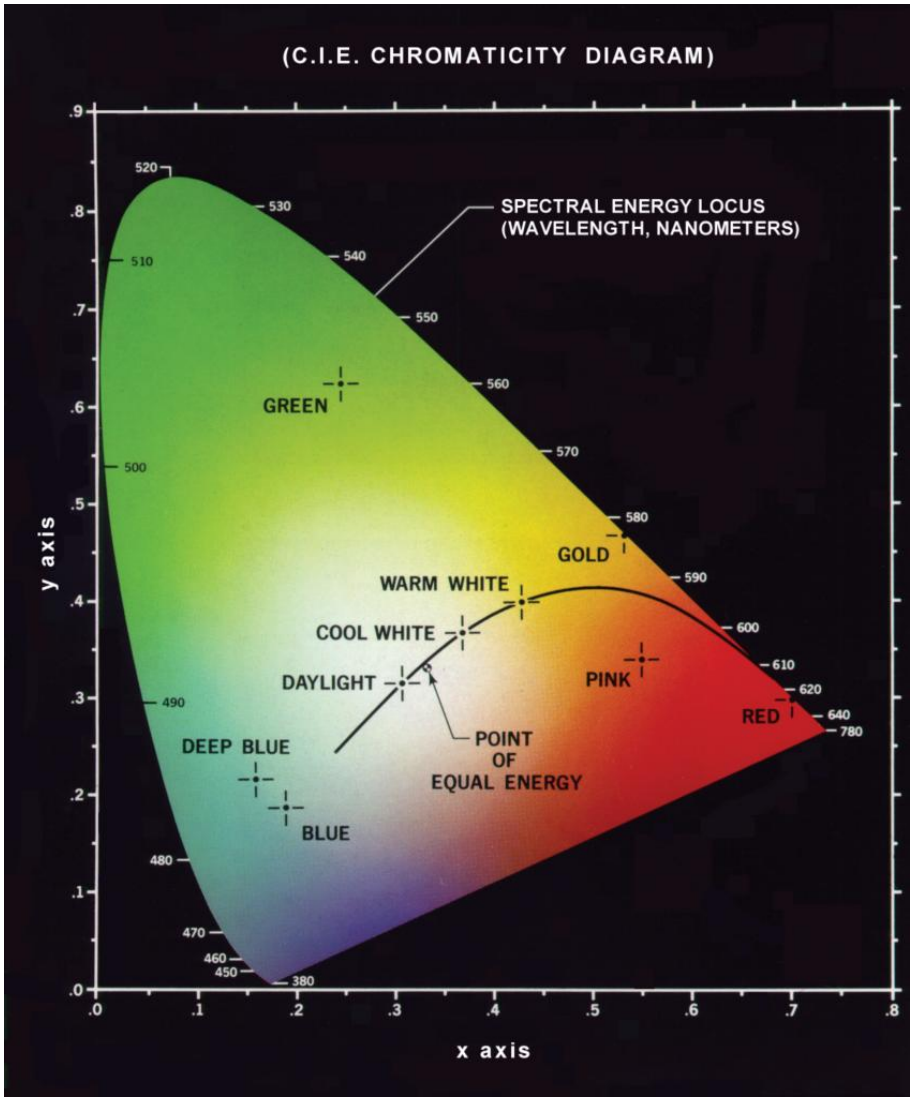
Given x, y, and Y

$$x + y + z = 1$$

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

Color gamuts





CMY color model

C is cyan
M is magenta
Y is yellow

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

CMY coordinates (1,1,1) is black, but when printed looks “muddy”.
Solution: use fourth color, black. CMYK color model, where K is black.

HSI color model

- A more familiar way to describe colors

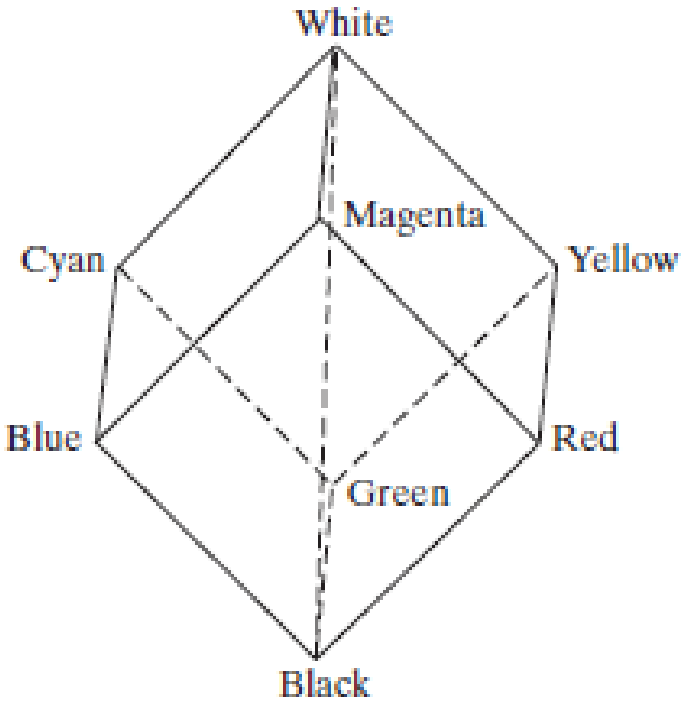
Color information

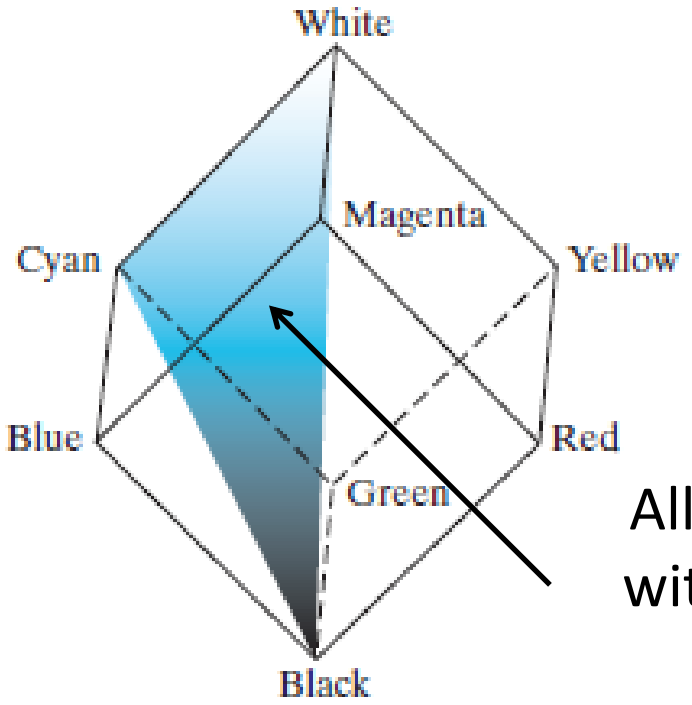
H is hue (color or shade)

S is saturation

I is intensity

HSI color model: Relationship to RGB color model

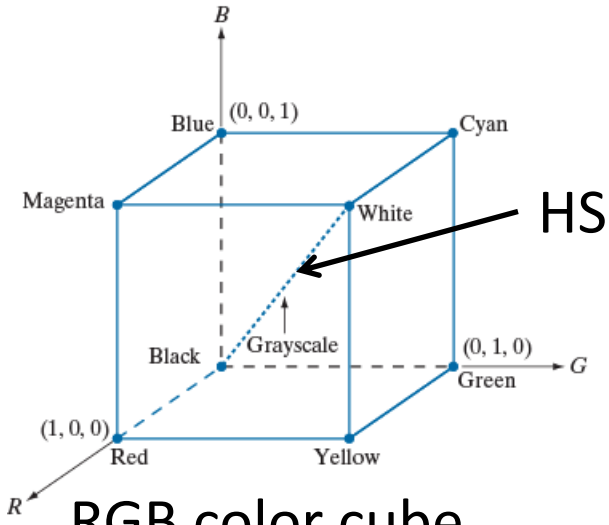




All colors with cyan hue

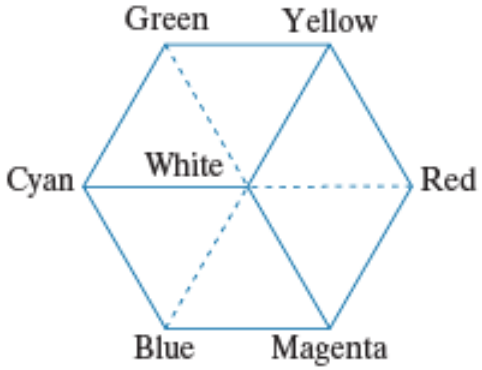
RGB color cube rotated such that line joining black and white (intensity axis) is vertical

HSI color model

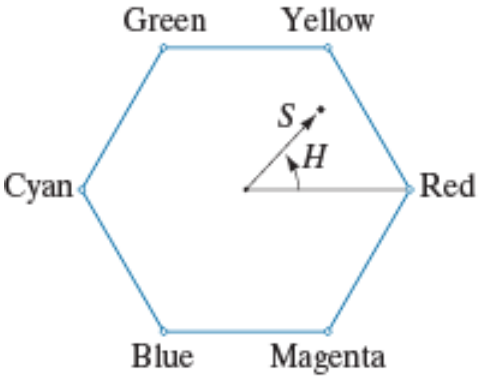


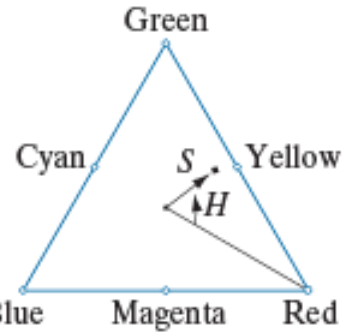
RGB color cube

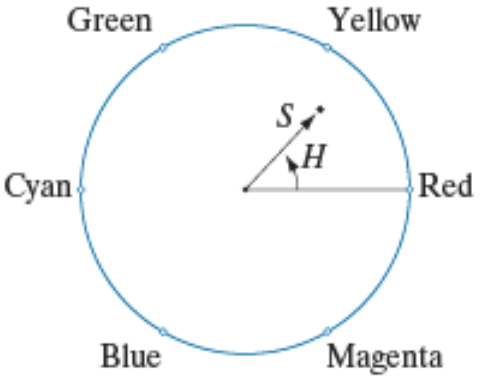
HSI intensity axis



RGB color cube rotated such that observer is on intensity axis, beyond white looking towards black



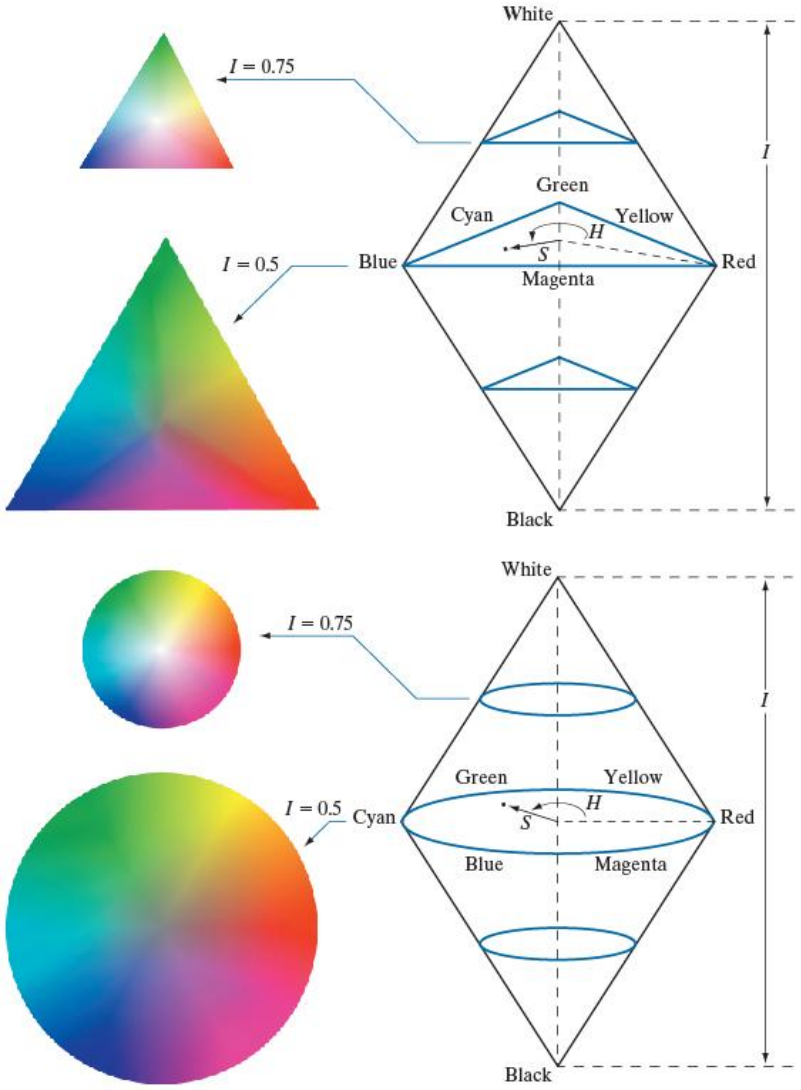




Shape does not matter, only angle from red

HSI color model

HS-plane is orthogonal to intensity axis



Shape does not matter, only angle from red

HSI color model

- RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360^\circ - \theta & \text{otherwise} \end{cases}$$

$$\text{where } \theta = \begin{cases} 90^\circ & \text{if } R = G = B \\ \cos^{-1}\left(\frac{\frac{1}{2}((R-G)+(R-B))}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right) & \text{otherwise} \end{cases}$$

$$S = \begin{cases} 0 & \text{if } R = G = B \\ 1 - \frac{3}{R+G+B}\min(R,G,B) & \text{otherwise} \end{cases}$$

$$I = \frac{1}{3}(R+G+B)$$

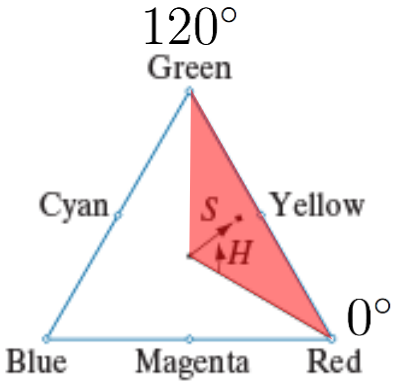
HSI color model

- HSI to RGB (3 cases)

Case 1

If $0° \le H < 120°$, then

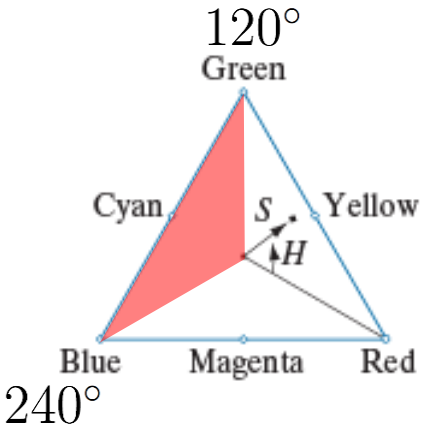
$$B = I(1 - S)$$
$$R = I\left(1 + \frac{S\cos(H)}{\cos(60° - H)}\right)$$
$$G = 3I - (R + B)$$



Case 2

else if $120° \le H < 240°$, then

$$H_{GB} = H - 120°$$
$$R = I(1 - S)$$
$$G = I\left(1 + \frac{S\cos(H_{GB})}{\cos(60° - H_{GB})}\right)$$
$$B = 3I - (R + G)$$



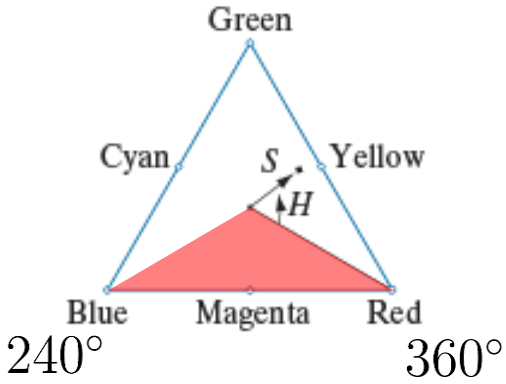
HSI color model

- HSI to RGB (3 cases)

Case 3

$\text{else } (240^\circ \le H < 360^\circ)$

$$H_{\mathrm{BR}} = H - 240^\circ$$
$$G = I(1 - S)$$
$$B = I\left(1 + \frac{S\cos(H_{\mathrm{BR}})}{\cos(60^\circ - H_{\mathrm{BR}})}\right)$$
$$R = 3I - (G + B)$$



CIELAB color space

- Designed to approximate human vision
  - Euclidean distance between points corresponds to perceptual difference
  - Includes 100% of visible color
- Also called CIE L*a*b* color space

L^* is lightness
a^* and b^* are color-opponent dimension

CIELAB color space

- XYZ to CIELAB

$$L^* = 116h\frac{Y}{Y_w} - 16$$
$$a^* = 500\left(h\frac{X}{X_w} - h\frac{Y}{Y_w}\right)$$
$$b^* = 200\left(h\frac{Y}{Y_w} - h\frac{Z}{Z_w}\right)$$

where

$$h(q) = \begin{cases} \sqrt[3]{q} & q > 0.008856 \\ 7.787q + \frac{16}{116} & \text{otherwise} \end{cases}$$

and (X_w, Y_w, Z_w) are XYZ coordinates of white point

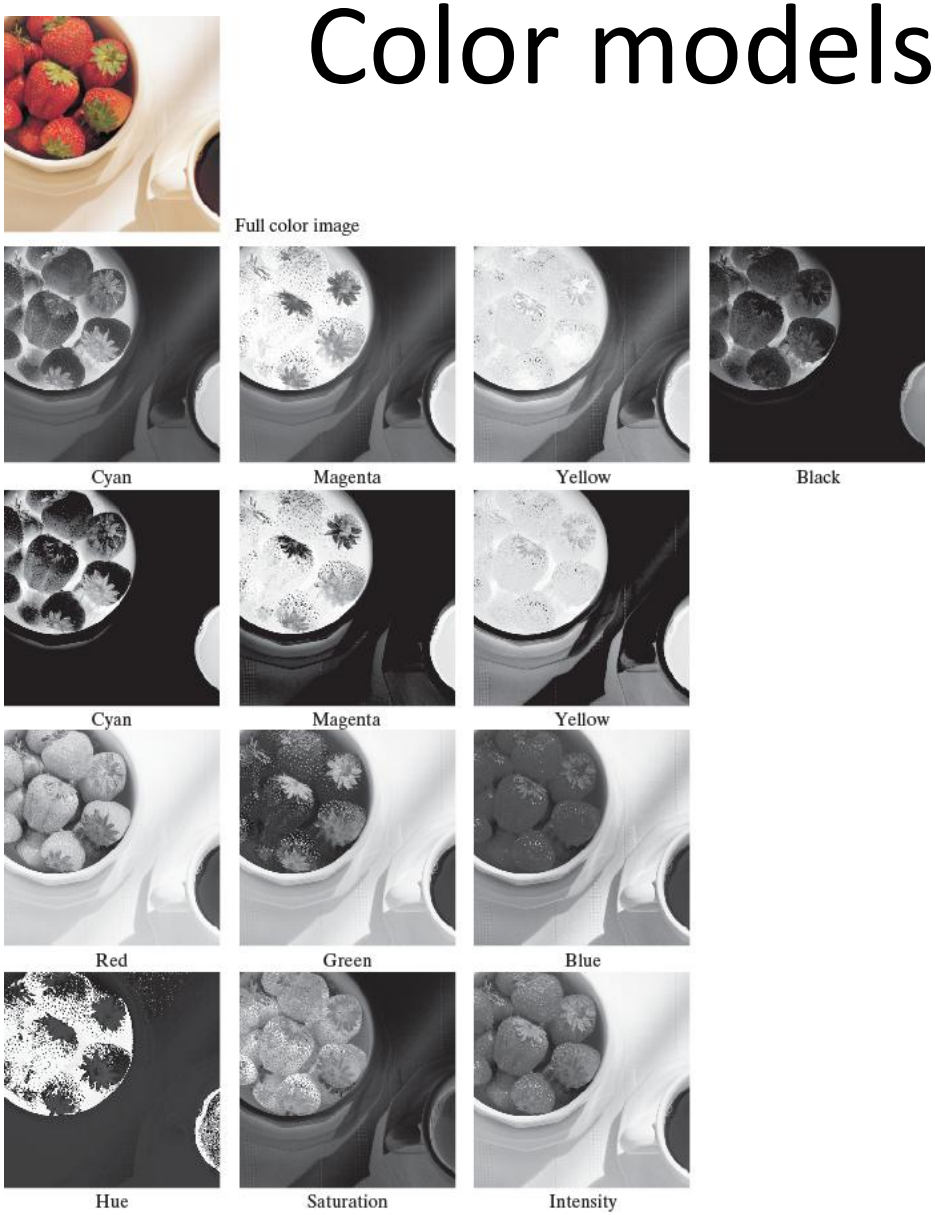
Color models

CMYK

CMY

RGB

HSI



Pseudocolor image processing

- Intensity slicing
- Intensity to color transformations

Intensity slicing

P planes perpendicular to the intensity axis at levels $l_1, l_2, \ldots, l_P$ partition the grayscale into $P + 1$ intervals $I_1, I_2, \ldots, I_{P+1}$

$$g(x, y) = c_k \text{ if } f(x, y) \in I_k$$

Output image

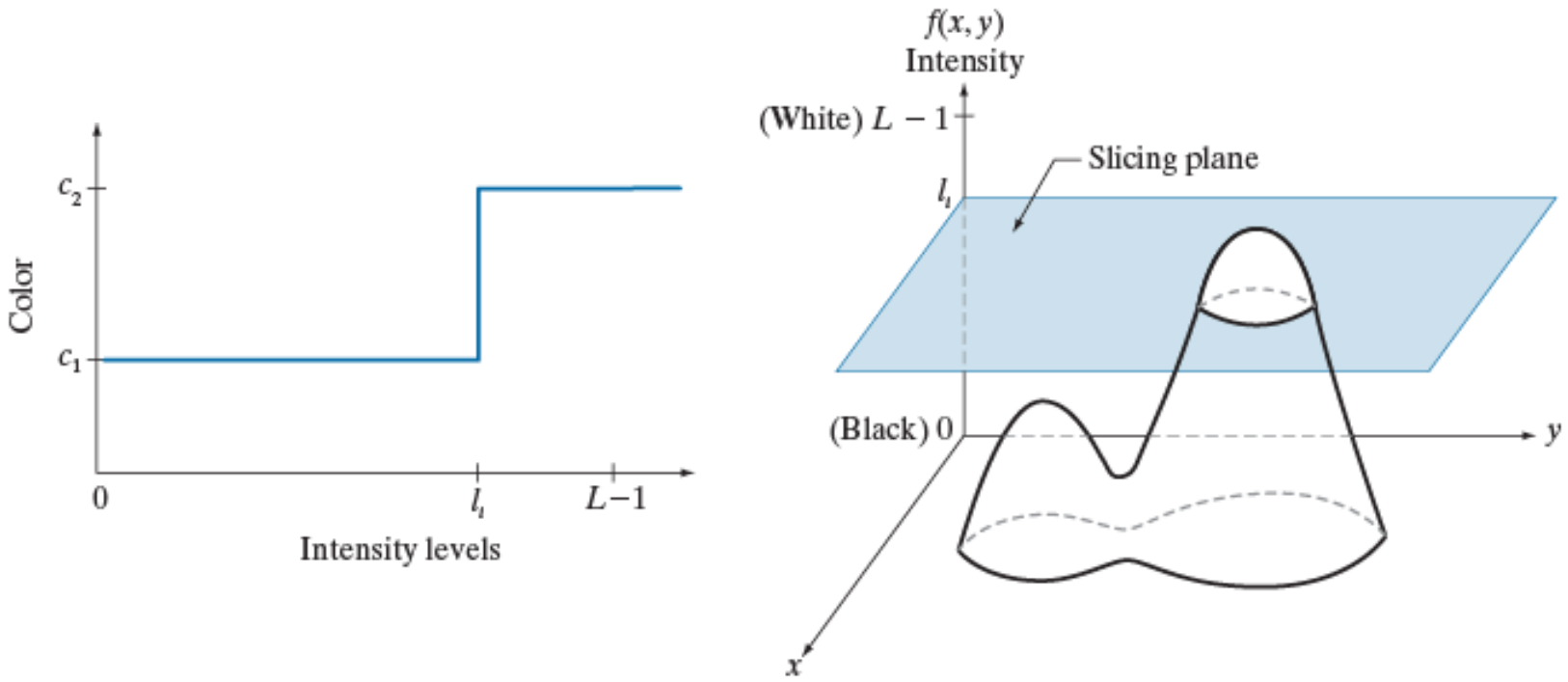
k-th intensity interval

Input image

Color associated with k-th intensity interval

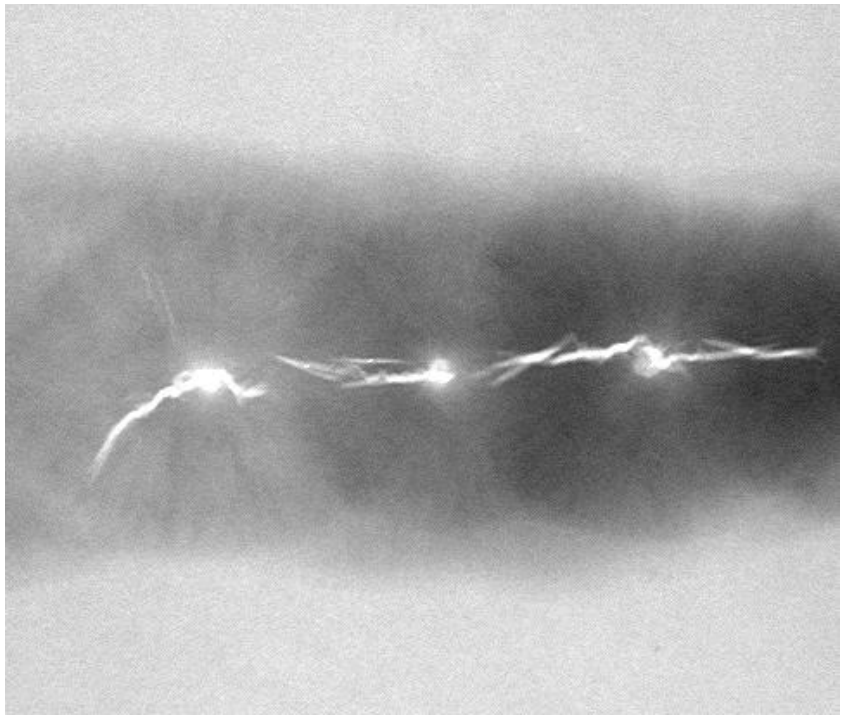
Intensity slicing

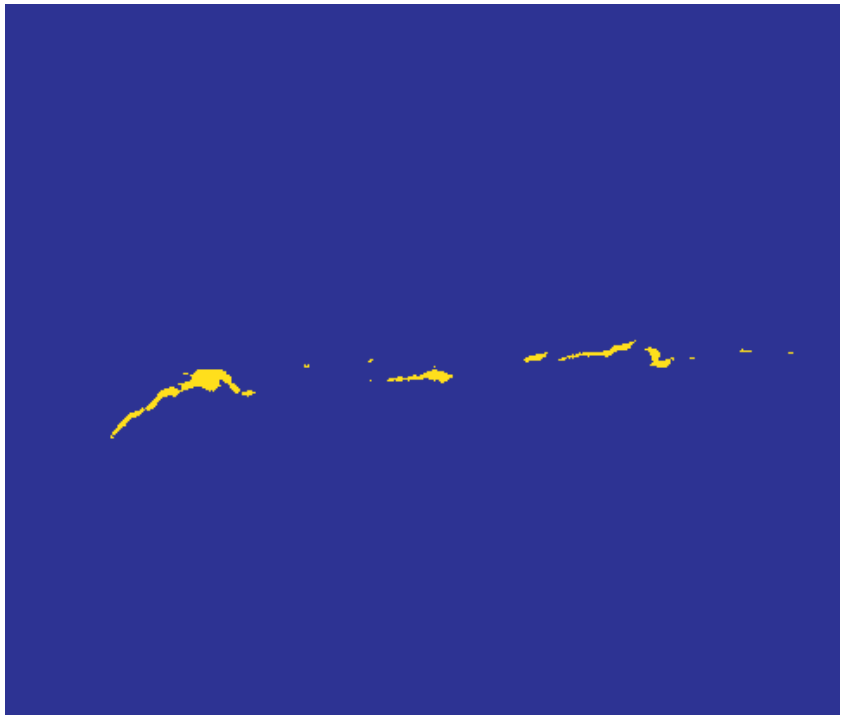
- Example: grayscale to 2 colors



Intensity slicing

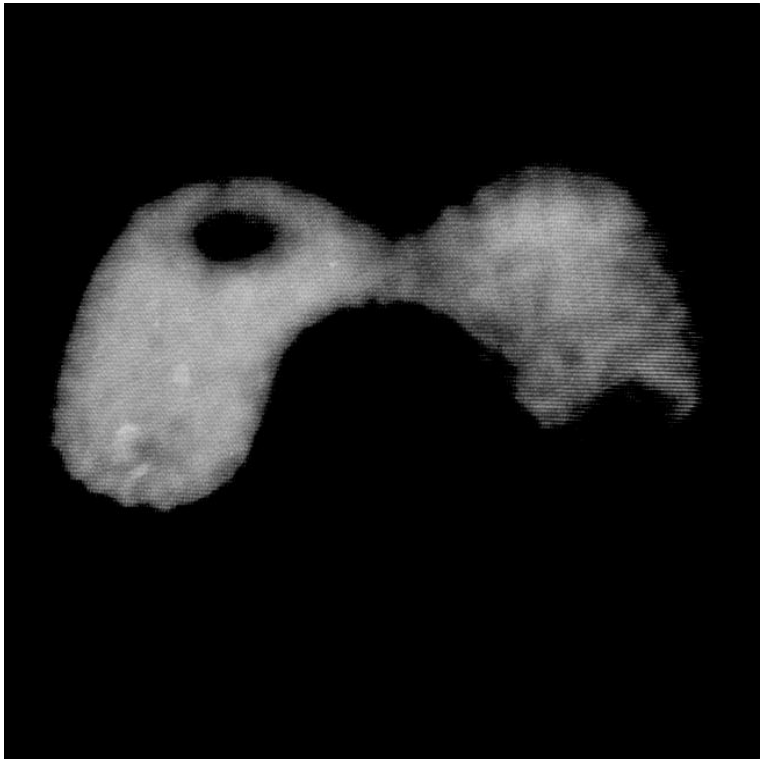
- Example: grayscale to 2 colors

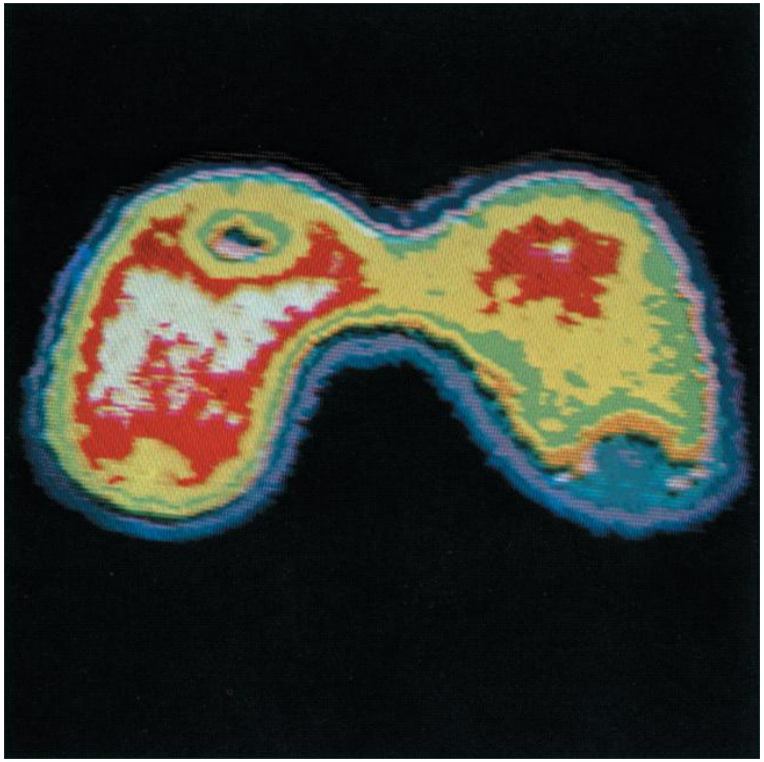




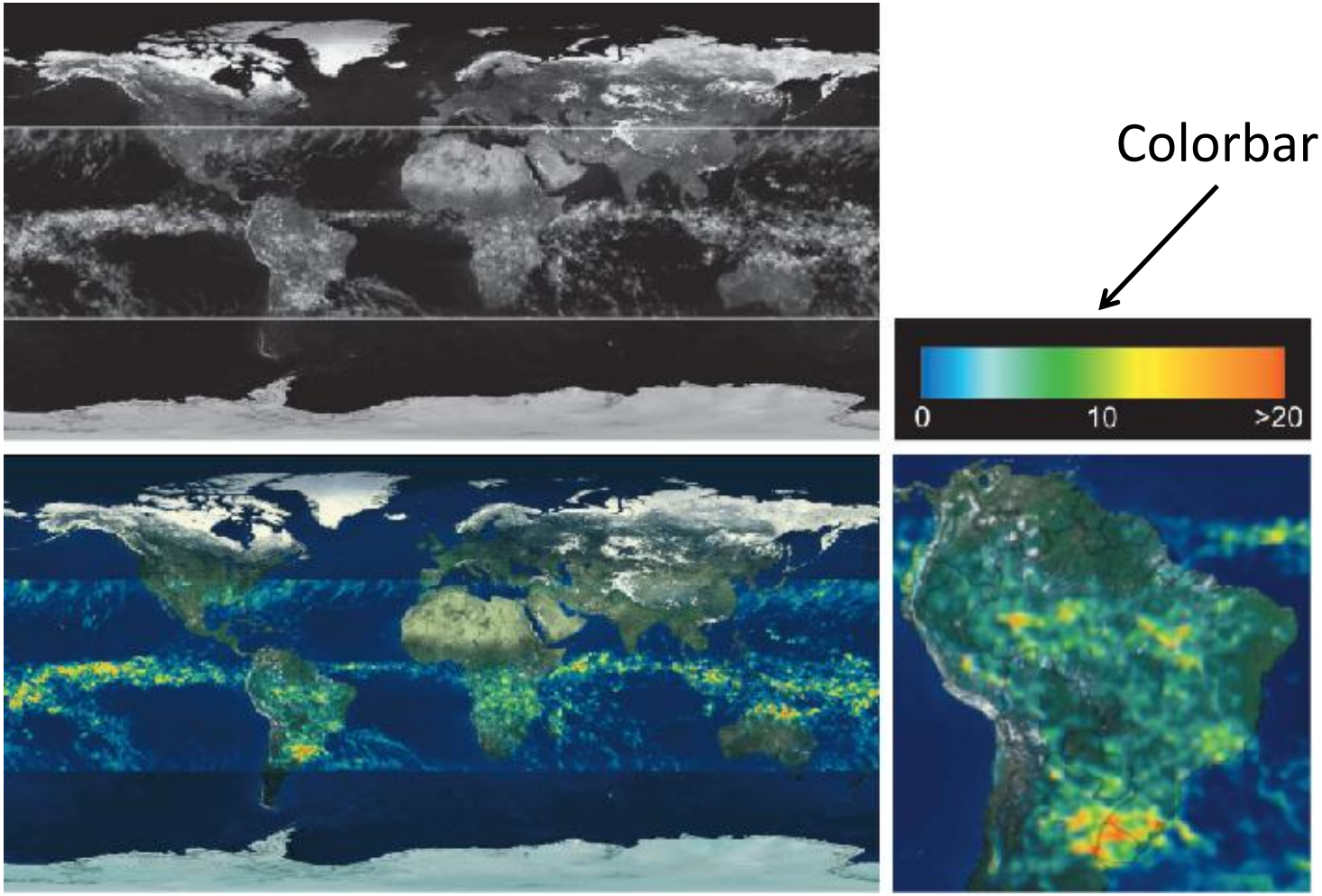
Intensity slicing

- Example: grayscale to 8 colors





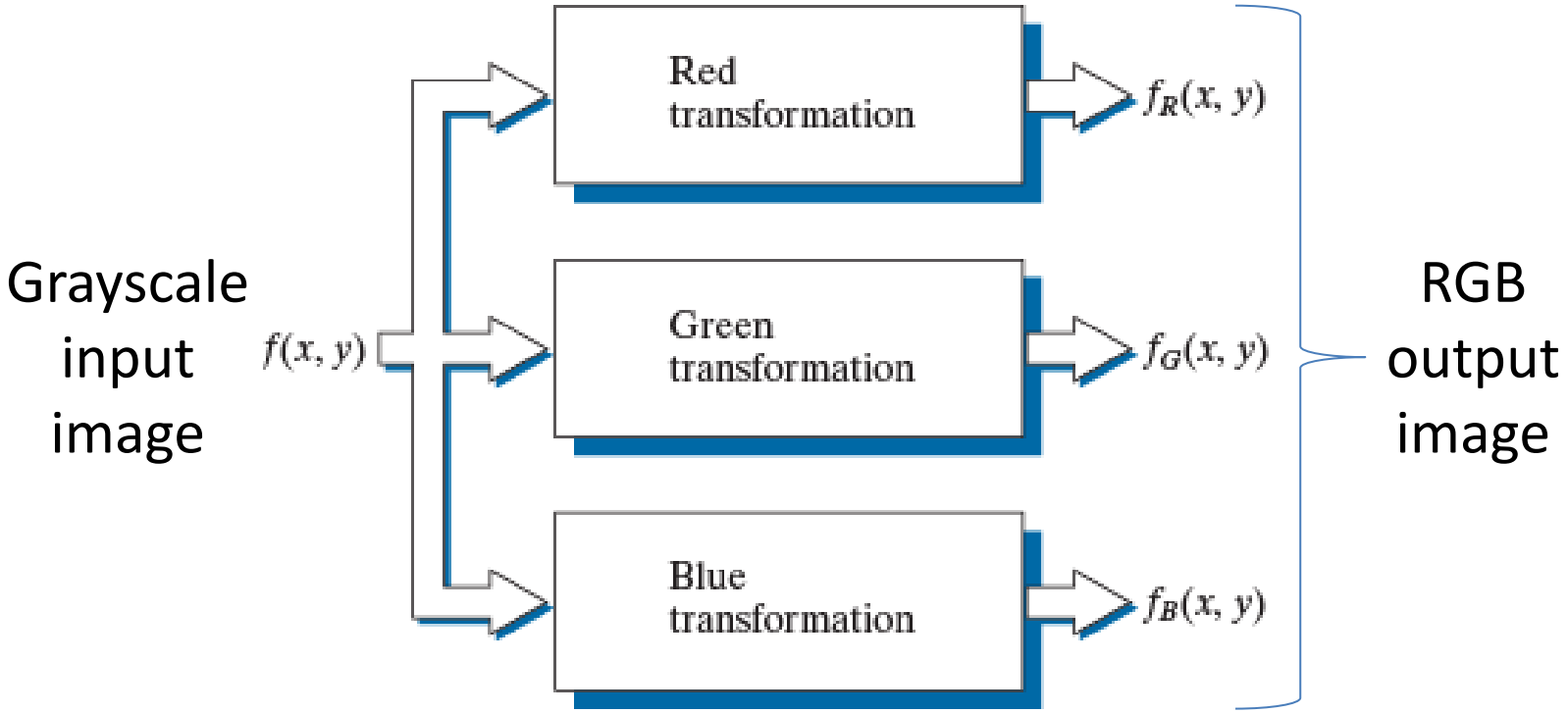
Intensity slicing



Example: grayscale to 256 colors

Intensity to color transformations

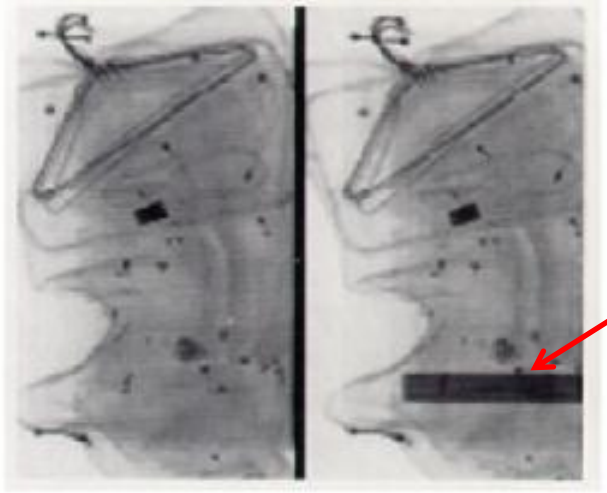
- More general than intensity slicing
  - Single input image



Intensity to color transformations

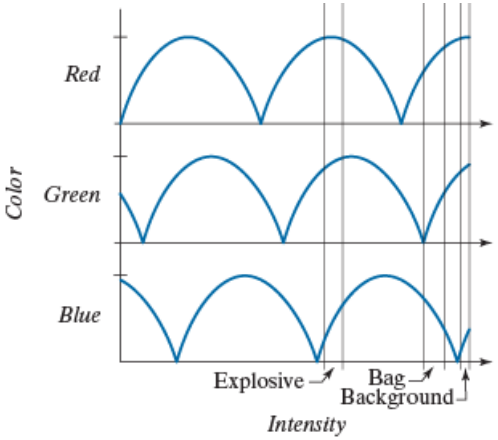
X-ray grayscale input image

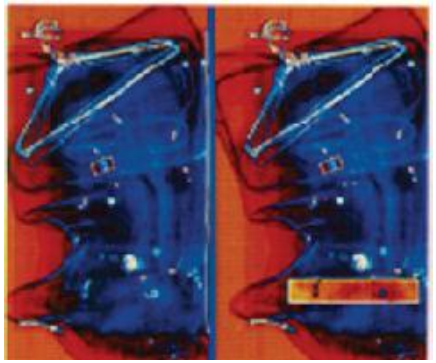
Without explosive



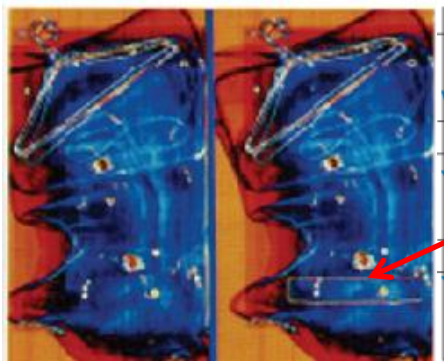
With explosive

RGB output images

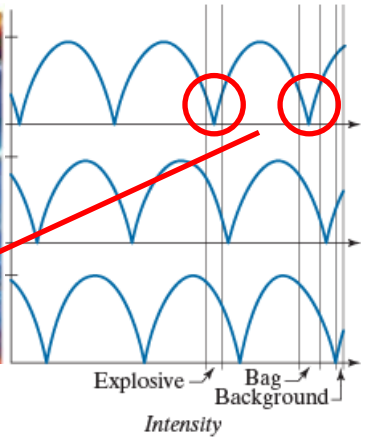




Explosive

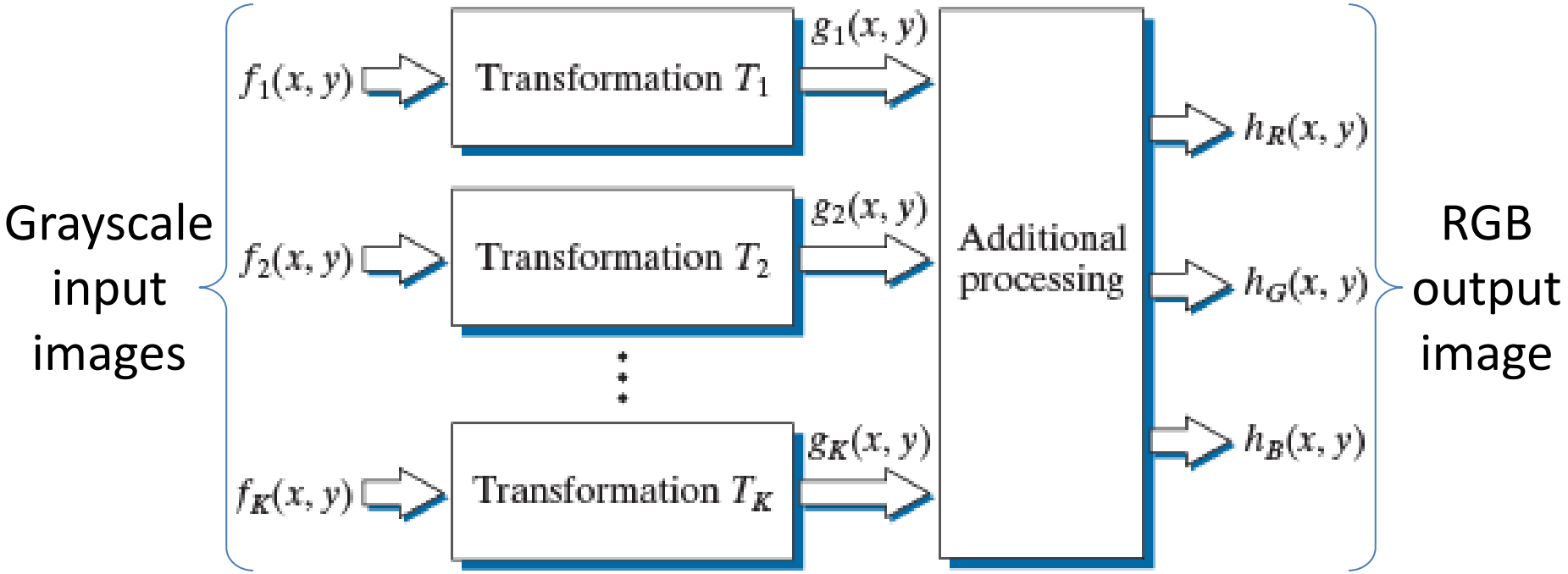


Misses explosive

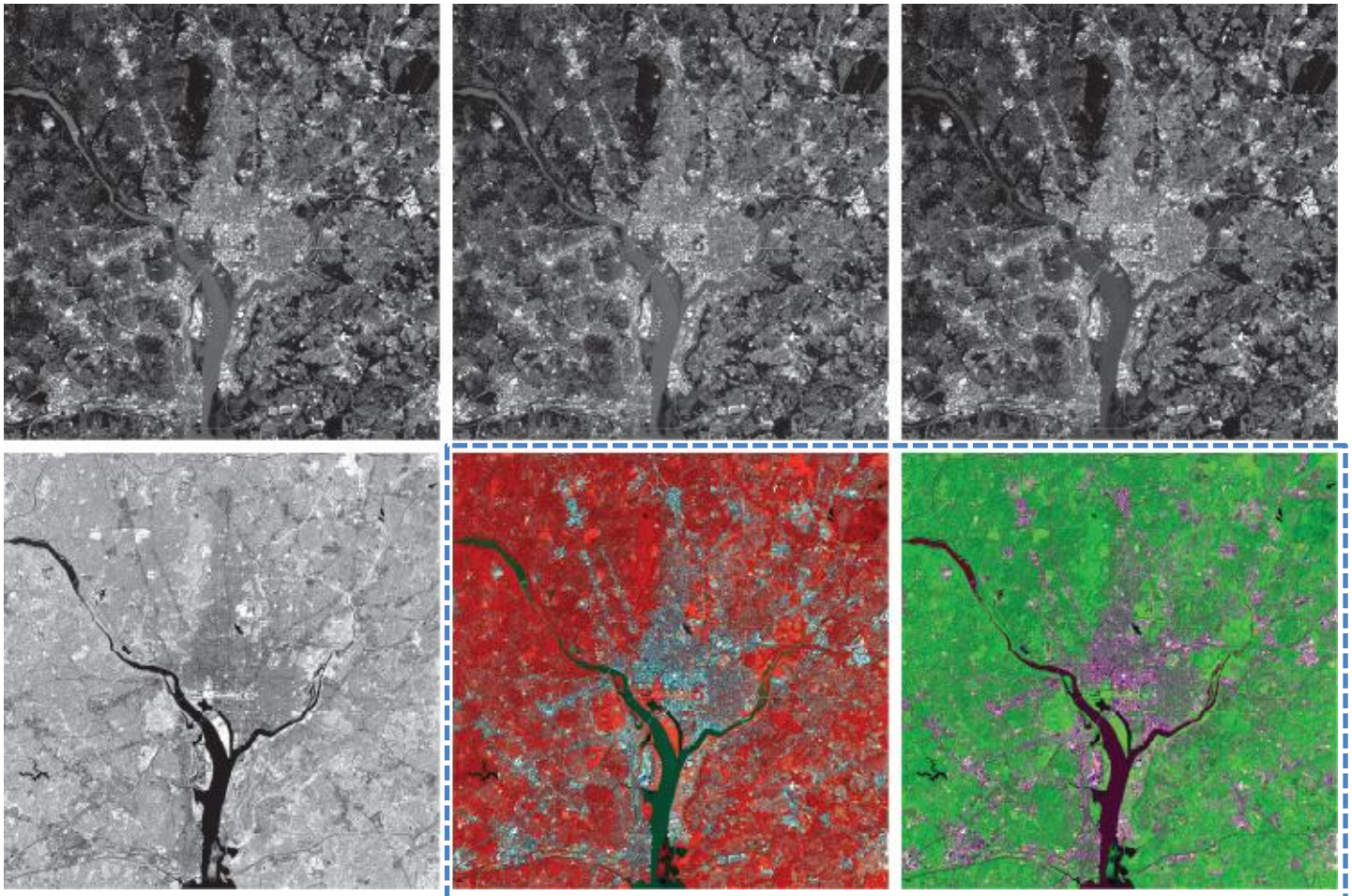


Intensity to color transformations

- More general than intensity slicing
  - Multiple input images



Intensity to color transformations

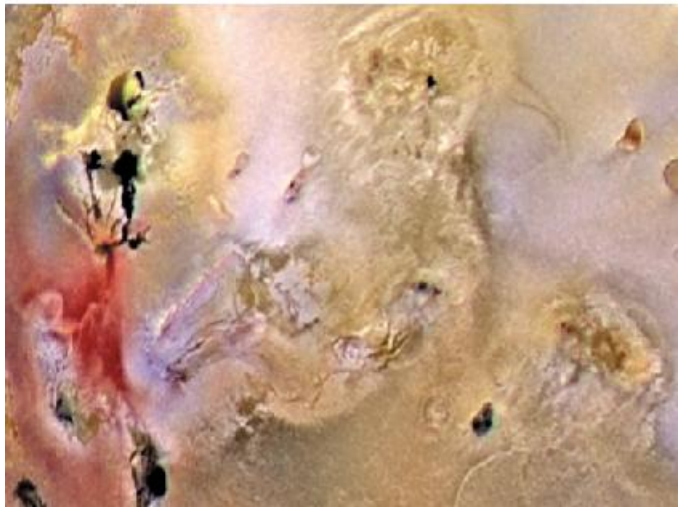


Intensity to color transformations

Multiple grayscale input images, some outside of visible spectrum



RGB output image



Close up

Intensity to color transformations

- NASA James Webb Space Telescope
  - Multiple grayscale input images, outside of visible spectrum



Intensity to color transformations

NASA James Webb Space Telescope



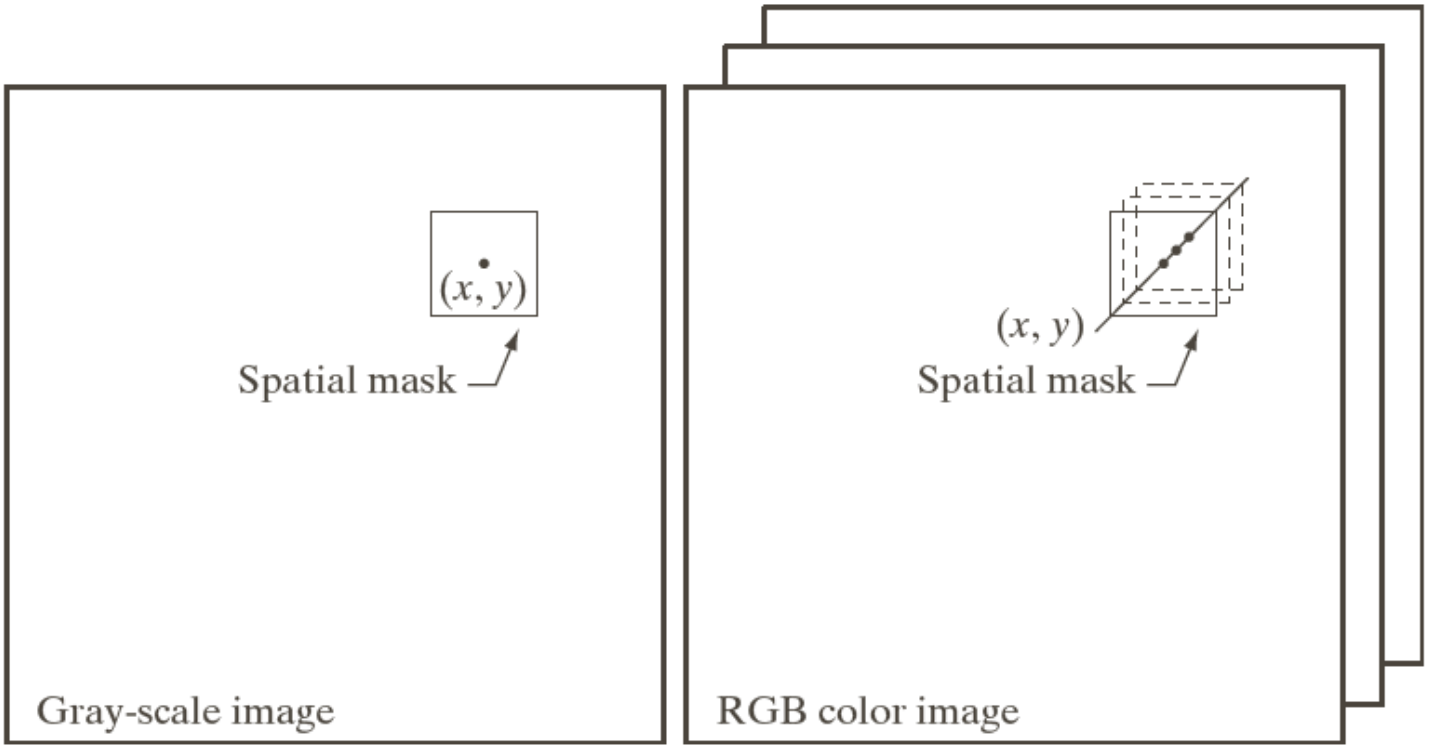
Full-color image processing

- Two approaches
  - Process each channel independently
  - Process color vector space

$$\mathbf{c}(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

Full-color image processing

Spatial filtering: process each channel independently



Full-color image processing

Spatial filtering example: image smoothing

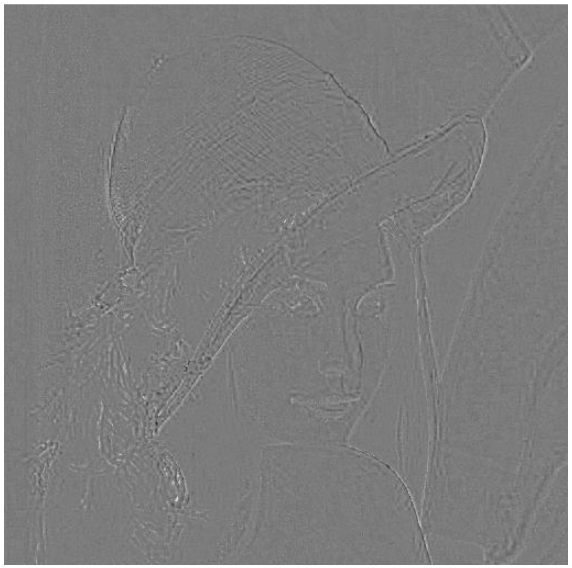
All RGB channels



HSI intensity channel only



Difference



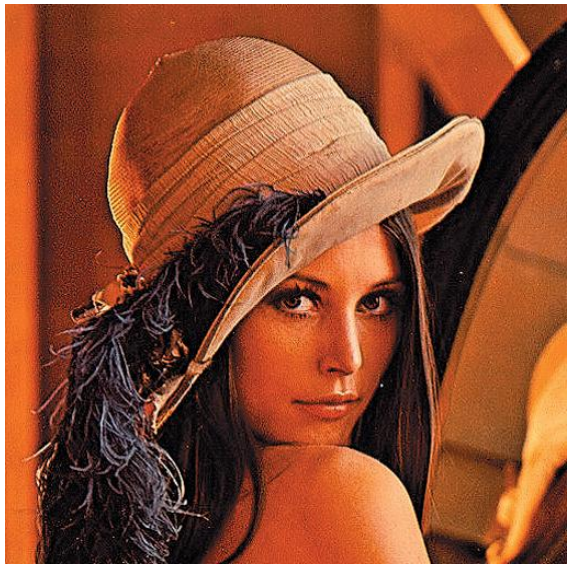
Full-color image processing

Spatial filtering example: image sharpening

All RGB channels



HSI intensity channel only

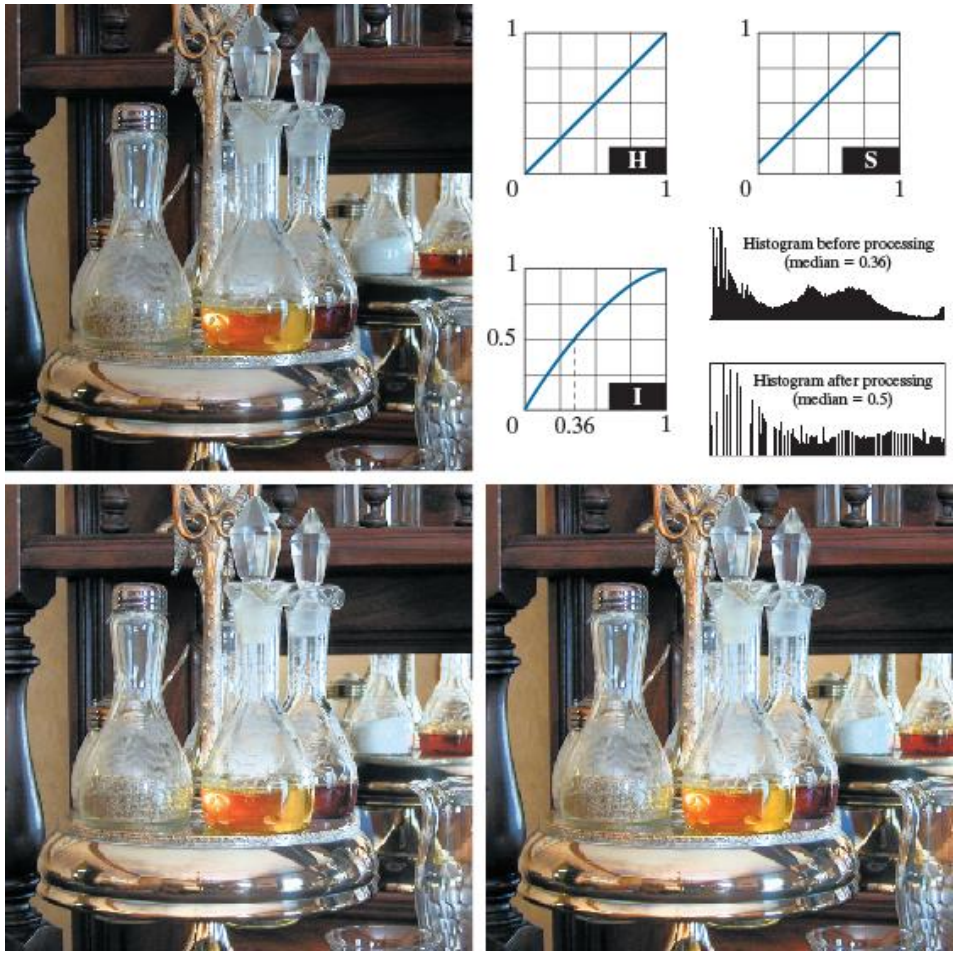


Difference



Full-color image processing

Histogram equalization: **do not** process each channel independently



1. RGB to HSI
2. Histogram equalize HSI *intensity* channel
3. HSI to RGB
4. HSI *saturation* channel adjustment

Next Lecture

- Midterm review