Digital Image Processing
Chapter 6:
Color Image Processing

Spectrum of White Light

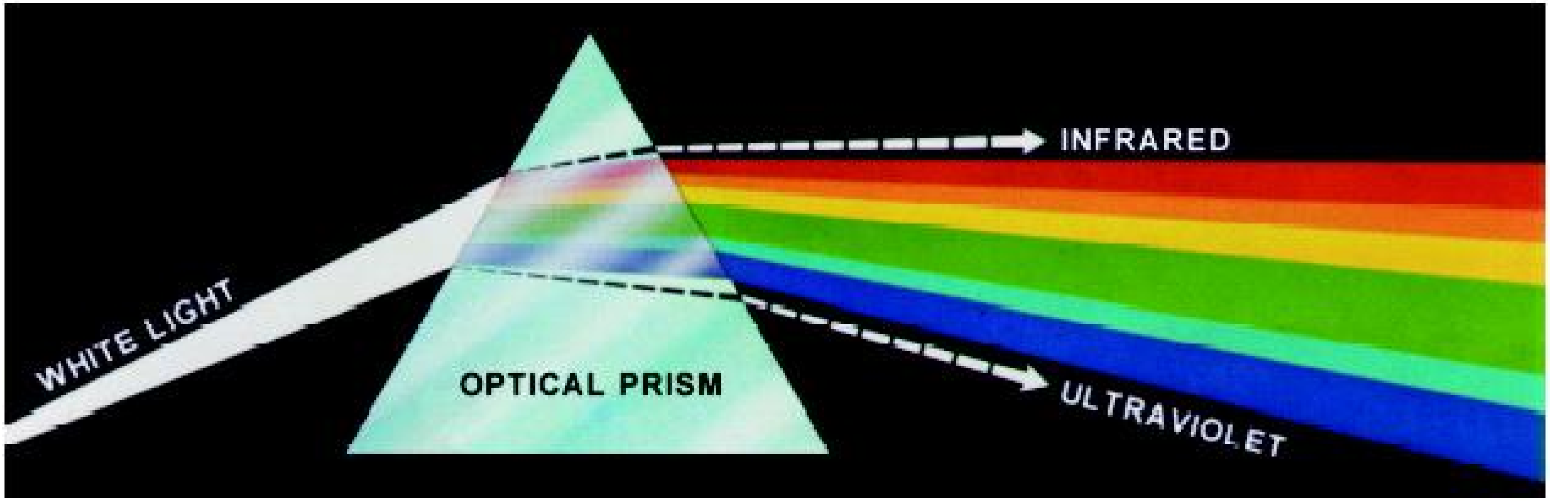
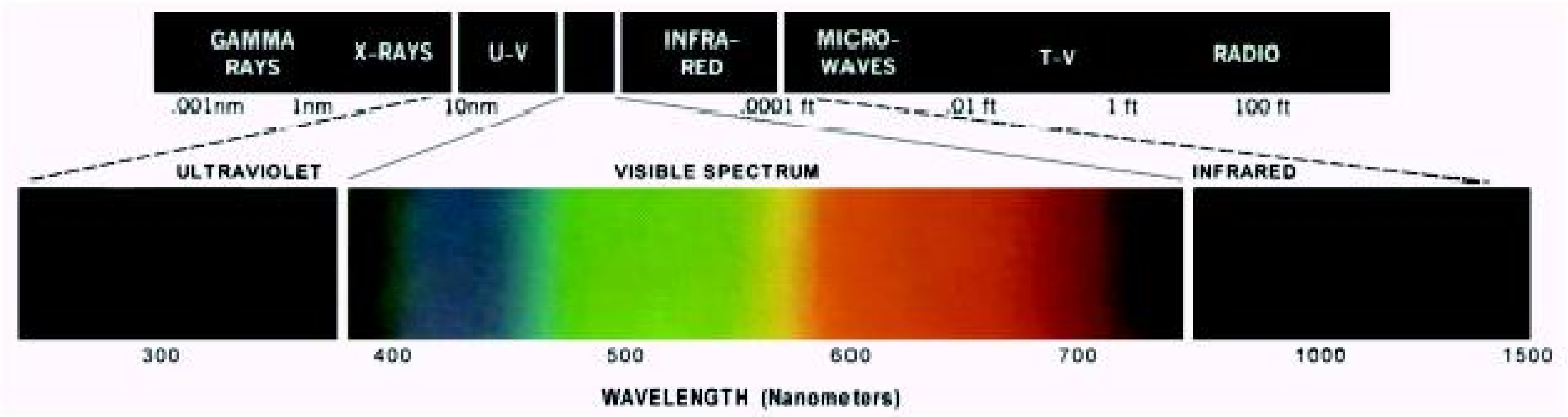


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

1666 Sir Isaac Newton, 24 year old, discovered white light spectrum.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Electromagnetic Spectrum



Visible light wavelength: from around 400 to 700 nm

1. For an achromatic (monochrome) light source, there is only 1 attribute to describe the quality: intensity

2. For a chromatic light source, there are 3 attributes to describe the quality:
   - Radiance = total amount of energy flow from a light source (Watts)
   - Luminance = amount of energy received by an observer (lumens)
   - Brightness = intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Cross section illustration

UMCP ENEE631 Slides (created by M.Wu © 2004)

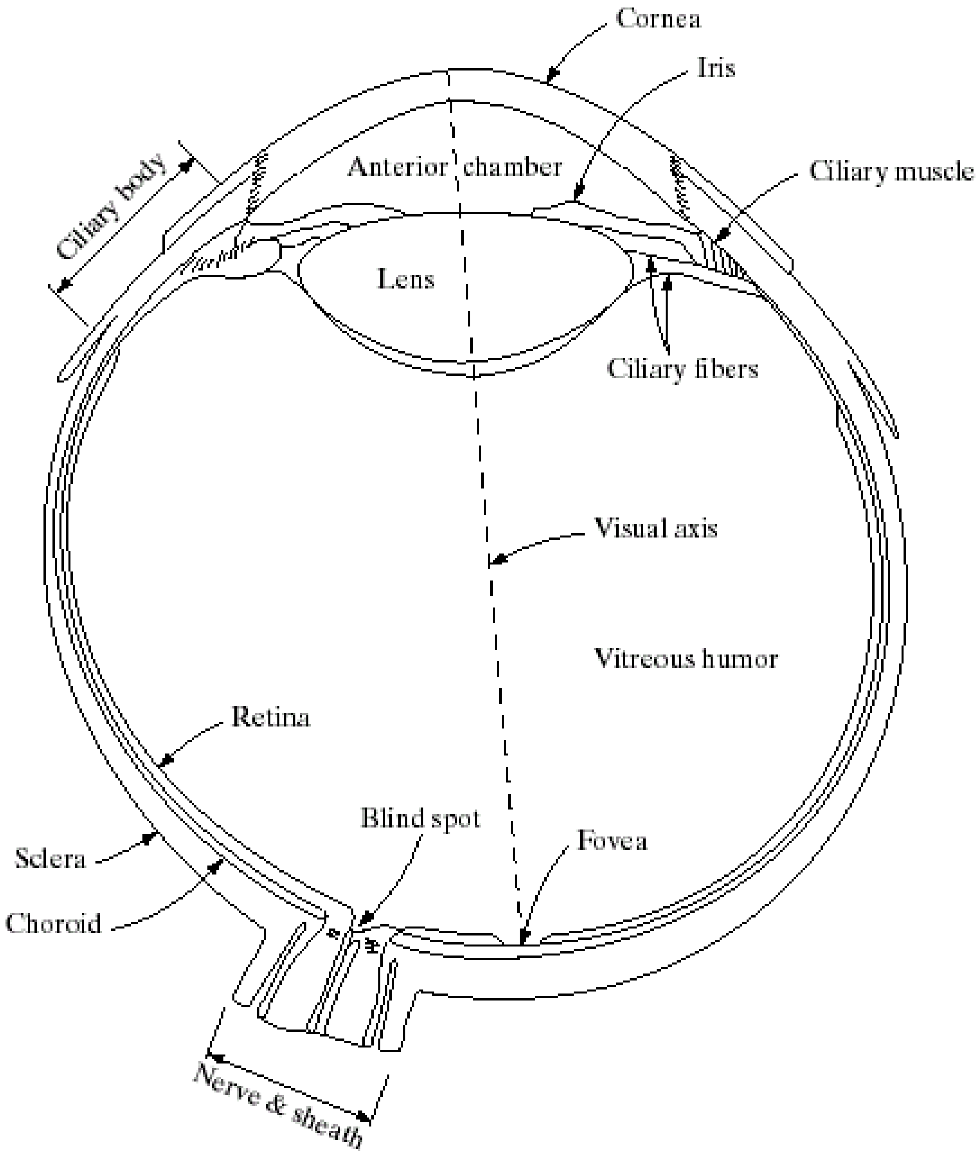


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Figure is from slides at Gonzalez/ Woods DIP book website (Chapter 2)

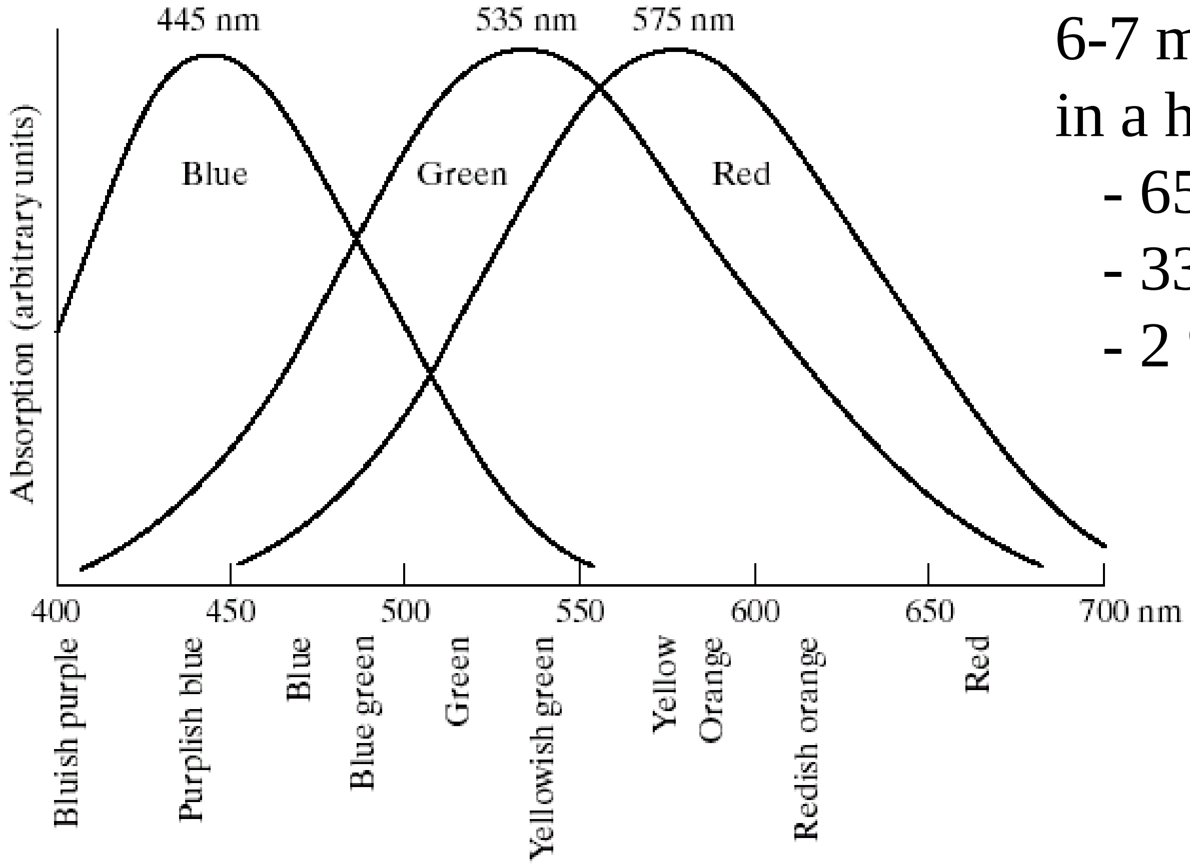
Two Types of Photoreceptors at Retina

- Rods
  - Long and thin
  - Large quantity (~ 100 million)
  - Provide ***scotopic*** vision (i.e., dim light vision or at low illumination)
  - Only extract luminance information and provide a general overall picture
- Cones
  - Short and thick, densely packed in fovea (center of retina)
  - Much fewer (~ 6.5 million) and less sensitive to light than rods
  - Provide ***photopic*** vision (i.e., bright light vision or at high illumination)
  - Help resolve fine details as each cone is connected to its own nerve end
  - Responsible for color vision

our interest
(well-lighted display)

  - Mesopic vision
    - provided at intermediate illumination by both rod and cones

Sensitivity of Cones in the Human Eye



6-7 millions cones
in a human eye
- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

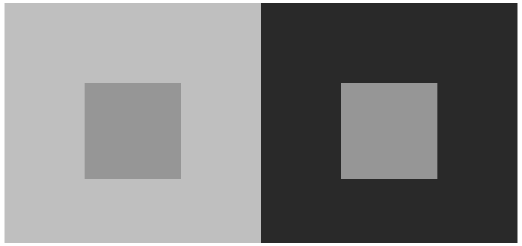
Primary colors:
Defined CIE in 1931
Red = 700 nm
Green = 546.1nm
Blue = 435.8 nm

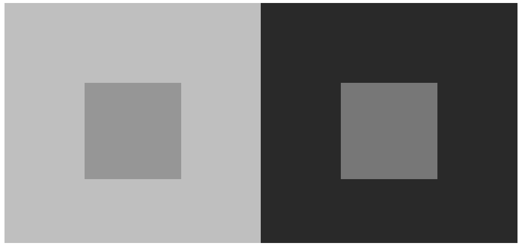
CIE = Commission Internationale de l'Eclairage
(The International Commission on Illumination)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Luminance vs. Brightness

Same lum.
Different
brightness





Different lum.
Similar
brightness

- Luminance (or intensity)
  - Independent of the luminance of surroundings

$$L(x,y) = \int_0^{inf} I(x,y,\lambda)V(\lambda)d\lambda$$

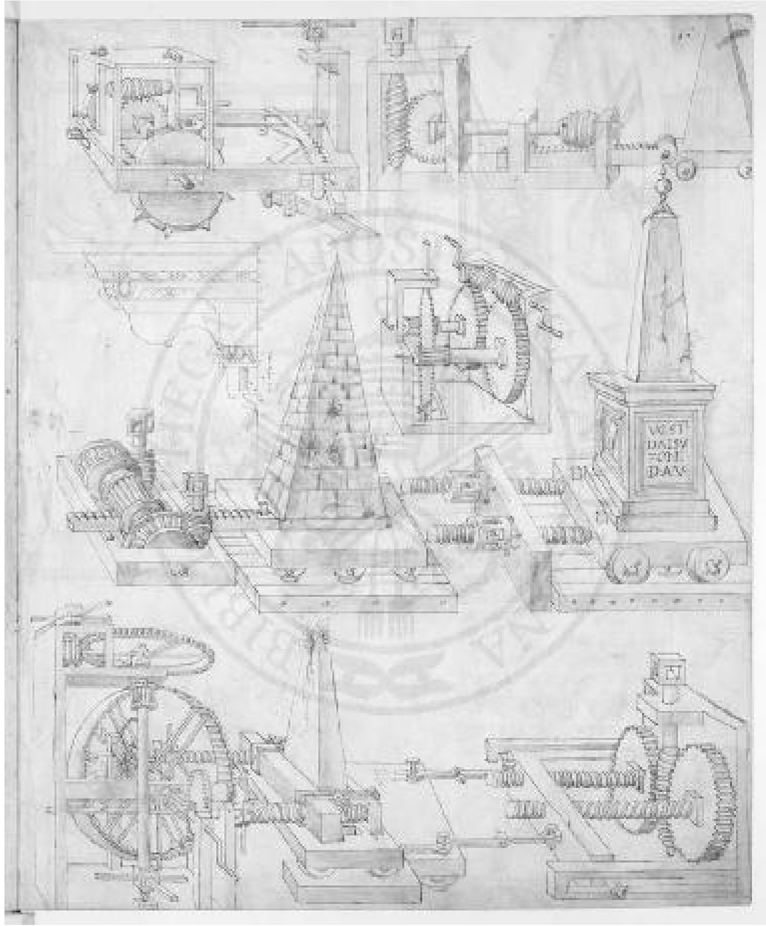
I(x,y,λ) -- spatial light distribution

V(λ) -- relative luminous efficiency func. of visual system ~ bell shape
(different for scotopic vs. photopic vision;
highest for green wavelength, second for red, and least for blue)

- Brightness
  - Perceived luminance
  - Depends on surrounding luminance

Luminance vs. Brightness (cont'd)

- Example: visible digital watermark
  - How to make the watermark appears the same graylevel all over the image?



from IBM Watson web page "Vatican Digital Library"

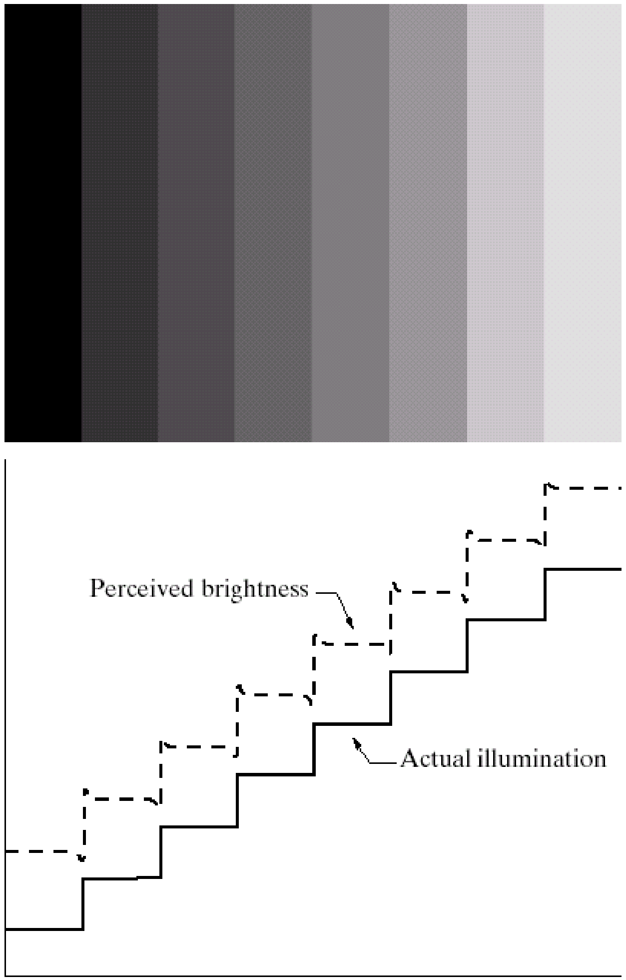
Look into Simultaneous Contrast Phenomenon

- Human perception more sensitive to luminance contrast than absolute luminance
- Weber's Law: $| L_s - L_0 | / L_0 = \text{const}$
  - Luminance of an object (L_0) is set to be just noticeable from luminance of surround (L_s)
  - For just-noticeable luminance difference ΔL:

    $$\Delta L / L \approx d(\log L) \approx 0.02 \text{ (const)}$$

    - equal increments in log luminance are perceived as equally different

- Empirical luminance-to-contrast models
  - Assume $L \in [1, 100]$, and $c \in [0, 100]$
  - $c = 50 \log_{10} L$ (logarithmic law, widely used)
  - $c = 21.9\, L^{1/3}$ (cubic root law)



a
b

FIGURE 2.7 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

Figure is from slides at Gonzalez/ Woods DIP book website (Chapter 2)

UMCP ENEE631 Slides (created by M.Wu © 2004)

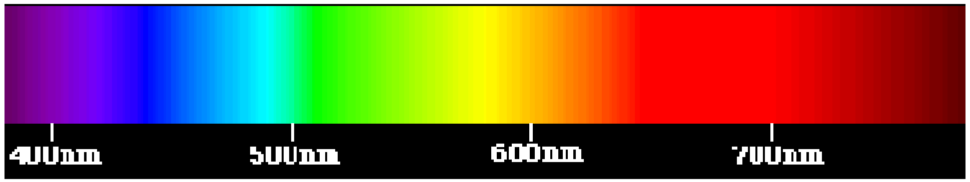
- Visual system tends to undershoot or overshoot around the boundary of regions of different intensities

è Demonstrates the perceived brightness is not a simple function of light intensity

Color of Light

UMCP ENEE408G Slides (created by M.Wu & R.Liu © 2002)

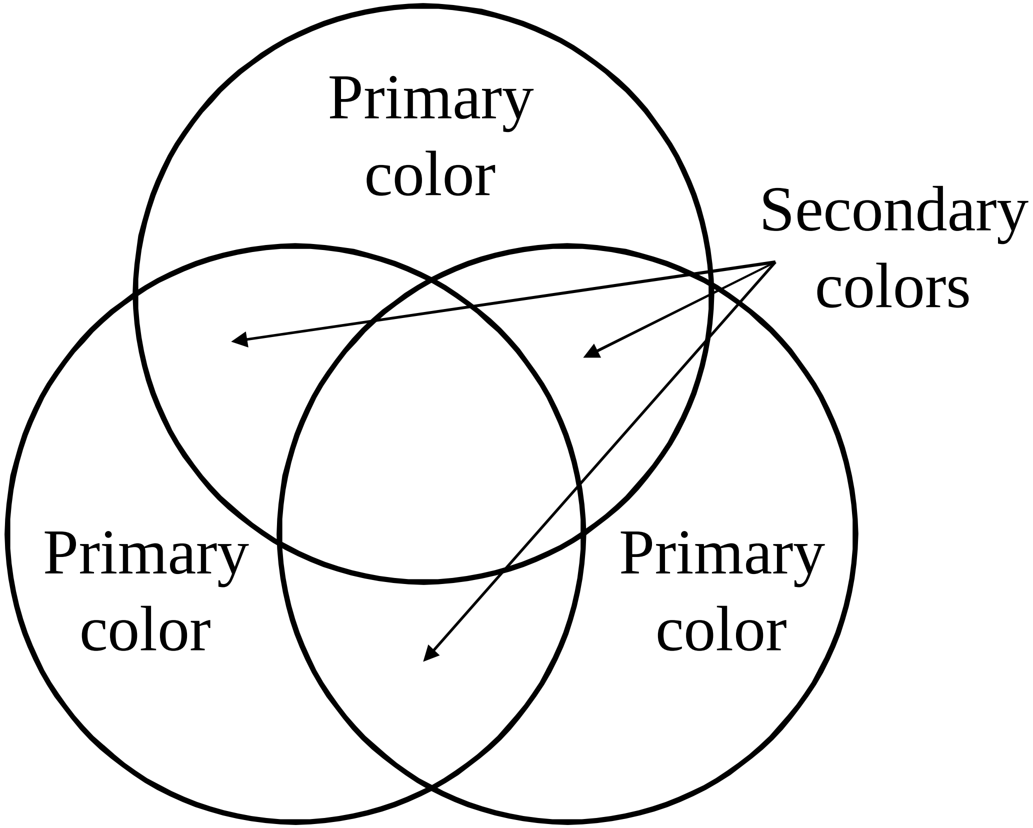
- Perceived color depends on spectral content (wavelength composition)
  - e.g., 700nm ~ red.
  - "spectral color"
    - A light with very narrow bandwidth



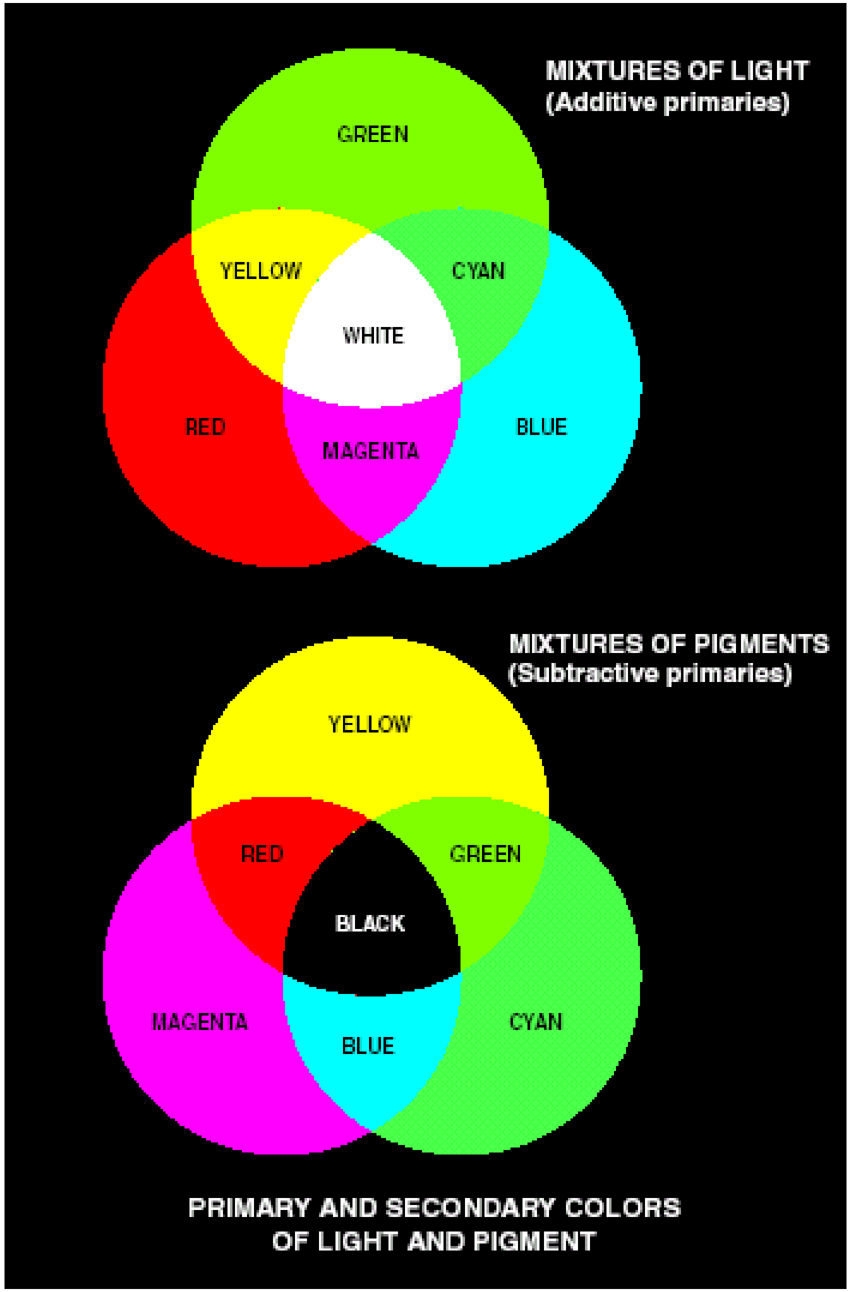
"Spectrum" from http://www.physics.sfasu.edu/astro/color.html

- A light with equal energy in all visible bands appears white

Primary and Secondary Colors



Primary and Secondary Colors (cont.)



Additive primary colors: RGB use in the case of light sources such as color monitors

RGB add together to get white

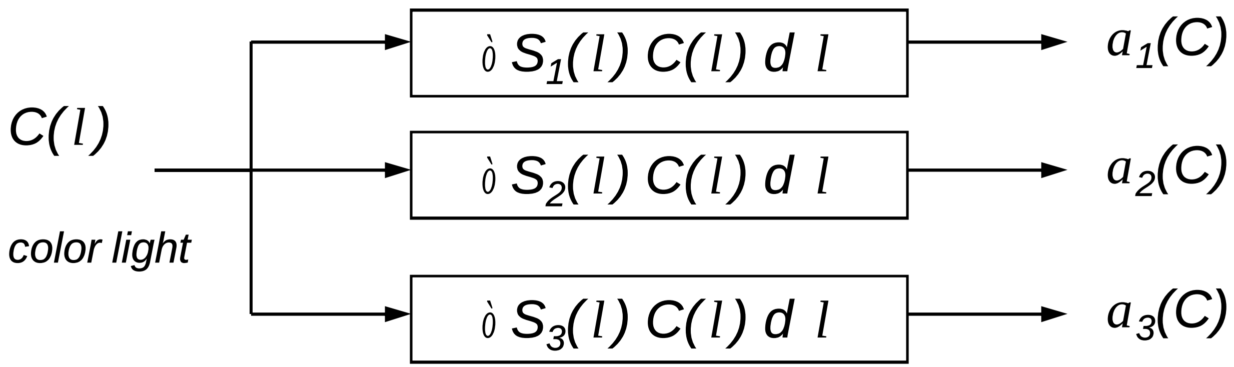
Subtractive primary colors: CMY use in the case of pigments in printing devices

White subtracted by CMY to get Black

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Representation by Three Primary Colors

- Any color can be reproduced by mixing an appropriate set of three primary colors (Thomas Young, 1802)
- Three types of cones in human retina
  - Absorption response $S_i(\lambda)$ has peaks around 450nm (blue), 550nm (green), 620nm (yellow-green)
  - Color sensation depends on the spectral response $\{\alpha_1(C), \alpha_2(C), \alpha_3(C)\}$ rather than the complete light spectrum $C(\lambda)$



Identically perceived colors if $\alpha_i(C_1) = \alpha_i(C_2)$

Example: Seeing Yellow Without Yellow

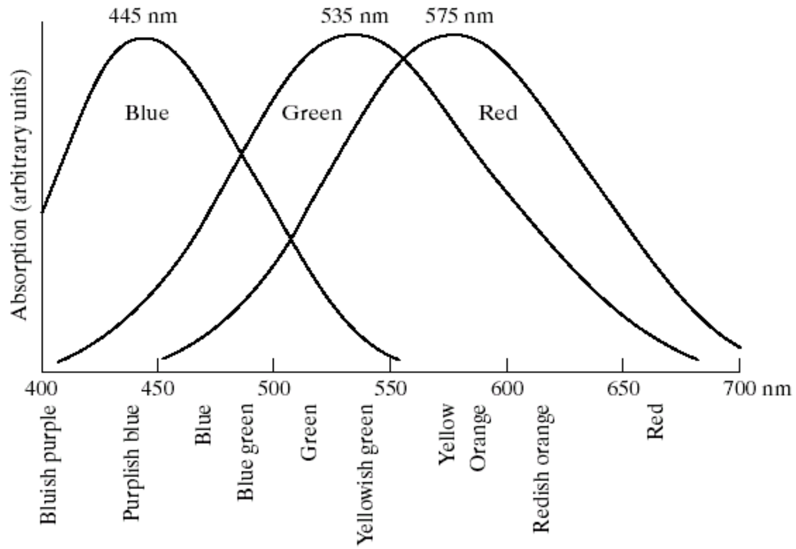
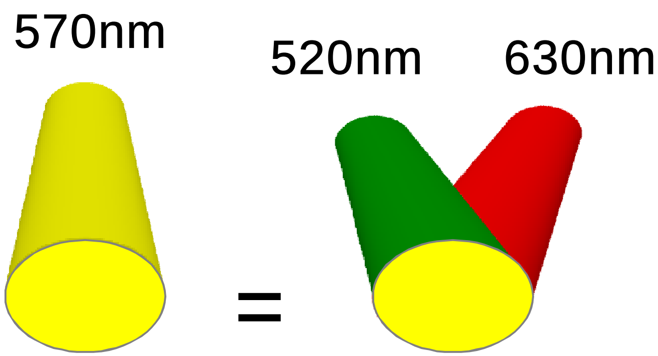


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



mix <u>green and red</u> light to obtain perception of <u>yellow</u>, without shining a single yellow photon

"Seeing Yellow" figure is from B.Liu ELE330 S'01 lecture notes @ Princeton;
R/G/B cone response is from slides at Gonzalez/ Woods DIP book website

Color Matching and Reproduction

- Mixture of three primaries: $C = Sum(b_k P_k(l))$
- To match a given color C_1
  - adjust b_k such that $a_i(C_1) = a_i(C)$, $i = 1,2,3$.

- Tristimulus values $T_k(C)$
  - $T_k(C) = b_k / w_k$

    w_k – *the amount of* k^{th} *primary to match the reference white*
- Chromaticity $t_k = T_k / (T_1+T_2+T_3)$
  - $t_1+t_2+t_3 = 1$
  - *visualize* (t_1, t_2) *to obtain chromaticity diagram*

Color Characterization

Hue: dominant color corresponding to a dominant wavelength of mixture light wave

Saturation: Relative purity or amount of white light mixed with a hue (inversely proportional to amount of white light added)

Brightness: Intensity

Hue

Saturation

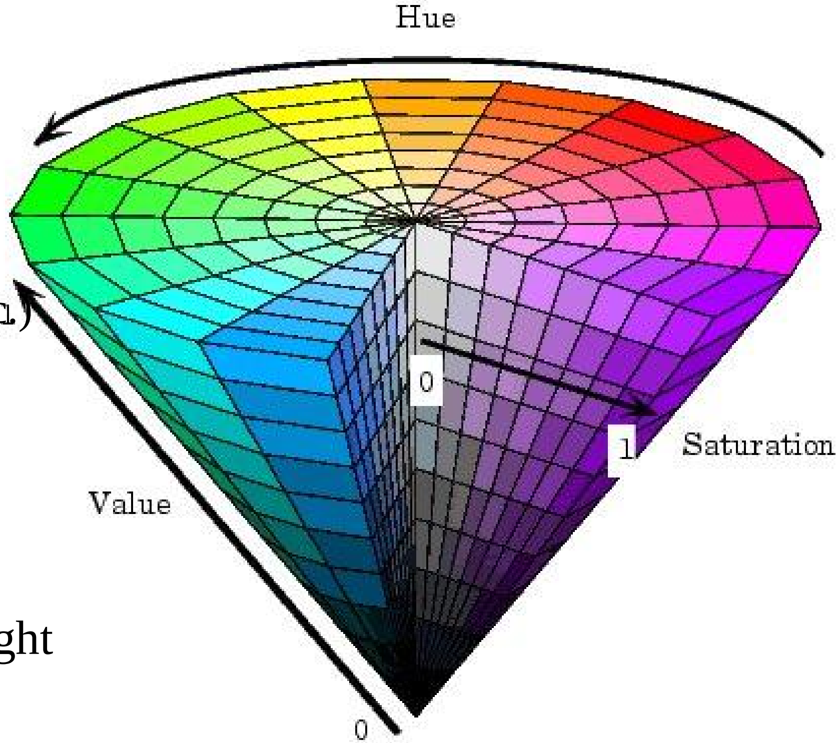
Chromaticity

amount of red (X), green (Y) and blue (Z) to form any particular color is called *tristimulus.*

Perceptual Attributes of Color

UMCP ENEE408G Slides (created by M.Wu & R.Liu © 2002)

- Value of Brightness (perceived luminance)
- Chrominance
  - **Hue**
    - specify color tone (redness, greenness, etc.)
    - depend on peak wavelength
  - **Saturation**
    - describe how pure the color is
    - depend on the spread (bandwidth) of light spectrum
    - reflect how much white light is added
- RGB ó HSV Conversion ~ *nonlinear*

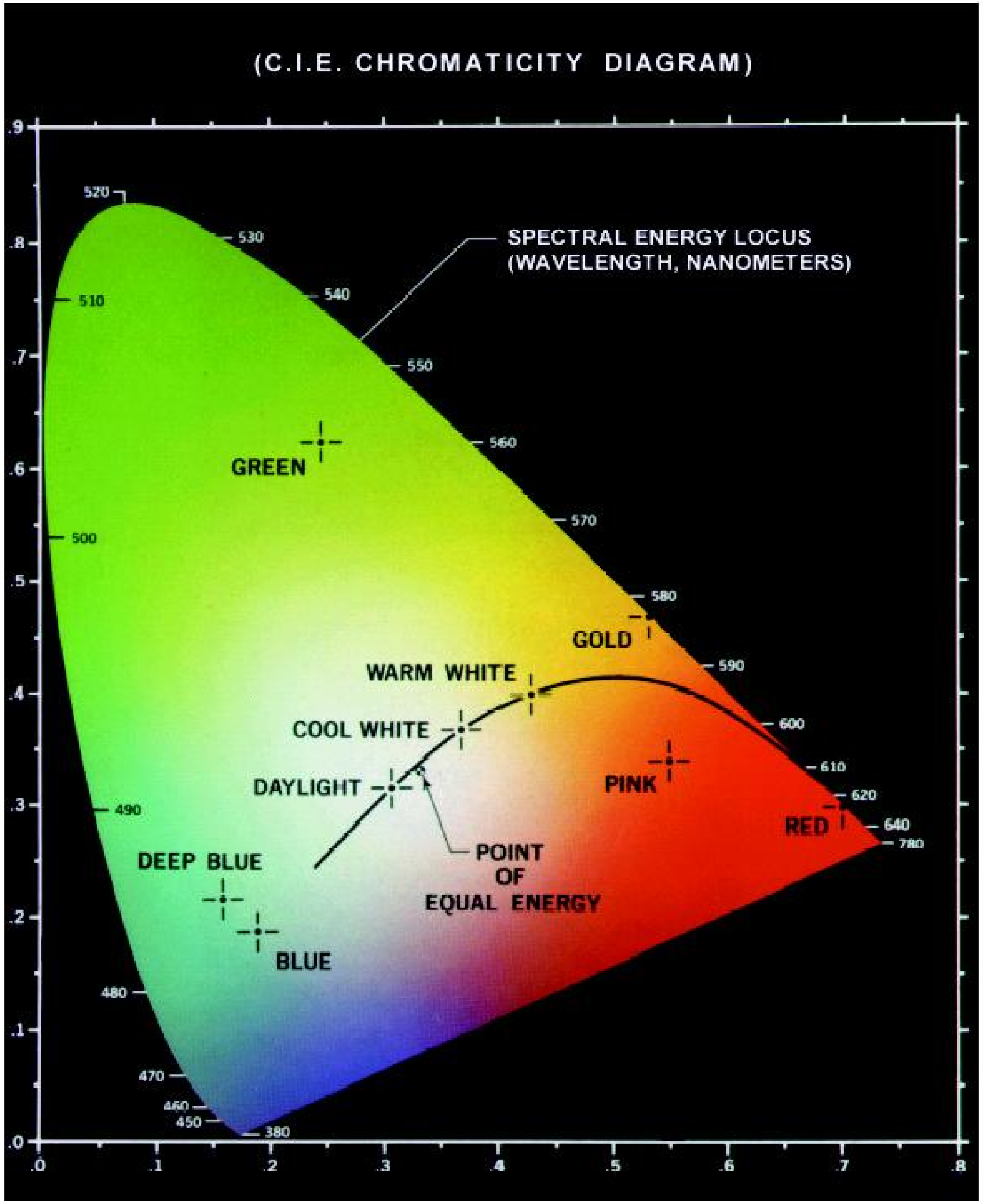


HSV circular cone is from online documentation of Matlab image processing toolbox

http://www.mathworks.com/access/helpdesk/help/toolbox/images/color10.shtml

CIE Chromaticity Diagram

y



x

Trichromatic coefficients:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

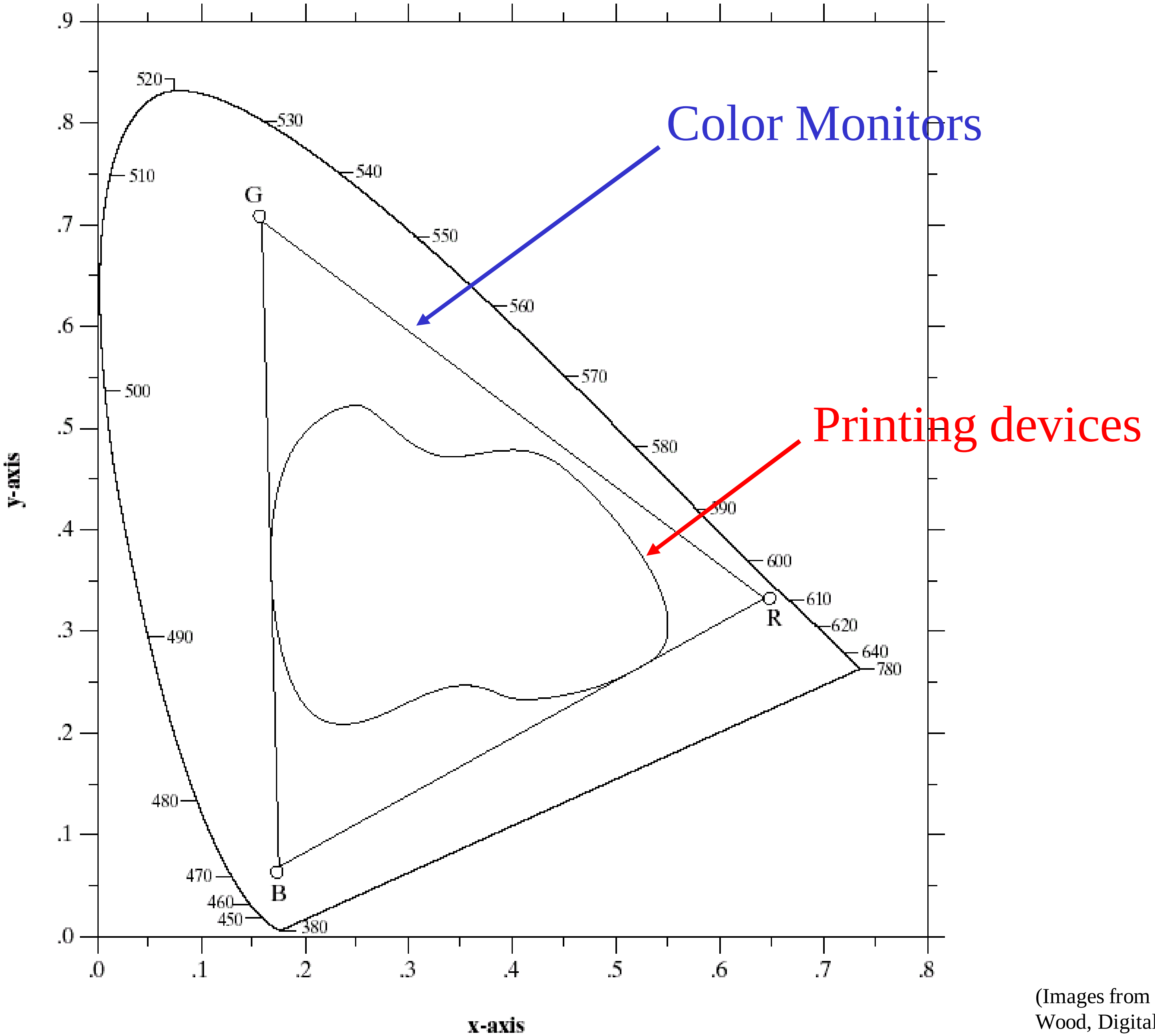
$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Points on the boundary are fully saturated colors

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Gamut of Color Monitors and Printing Devices



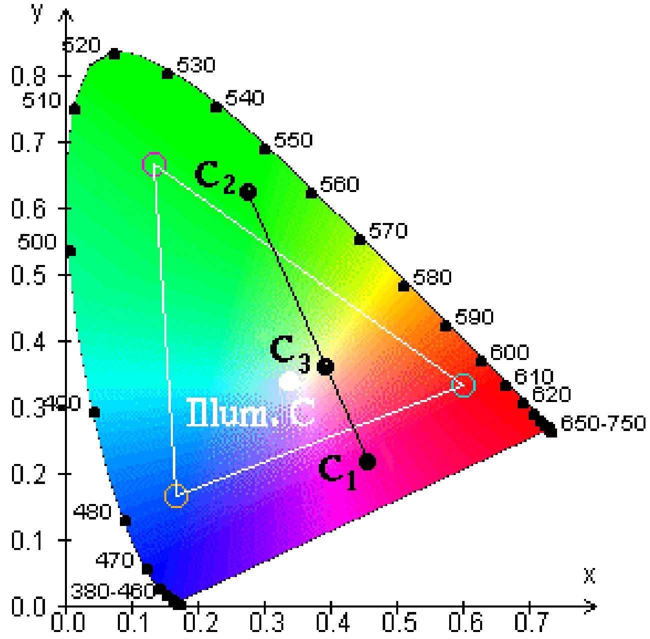
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

CIE Color Coordinates (cont'd)

- CIE XYZ system

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

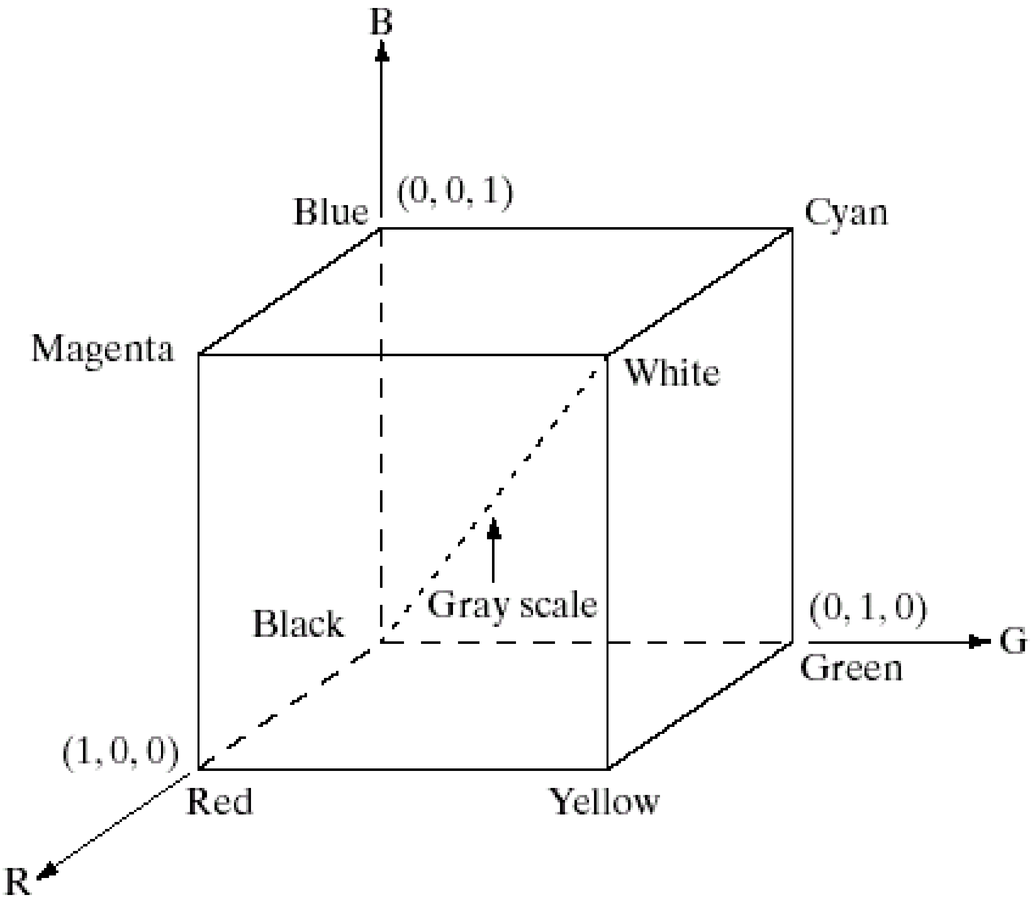
  – hypothetical primary sources to yield all-positive spectral tristimulus values
  – Y ~ luminance
- Color gamut of 3 primaries
  – Colors on line C1 and C2 can be produced by linear mixture of the two
  – Colors inside the triangle gamut can be reproduced by three primaries



From http://www.cs.rit.edu/~ncs/color/t_chroma.html

RGB Color Model

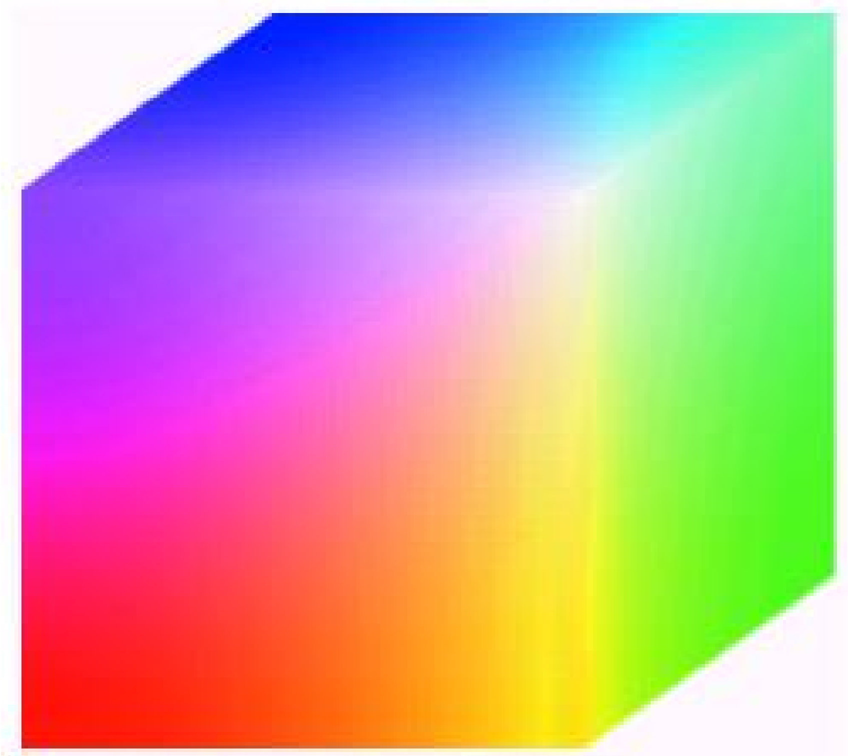
Purpose of color models: to facilitate the specification of colors in some standard



RGB color models:
- based on cartesian coordinate system

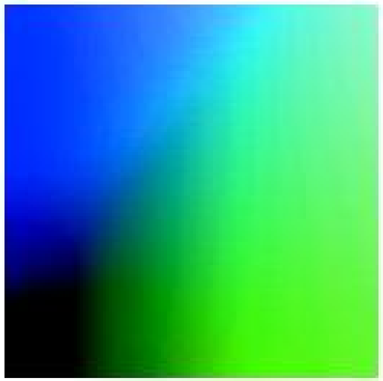
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Cube

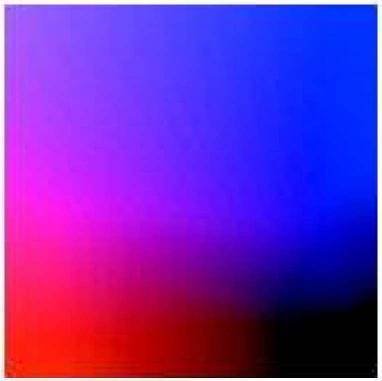


R = 8 bits
G = 8 bits
B = 8 bits

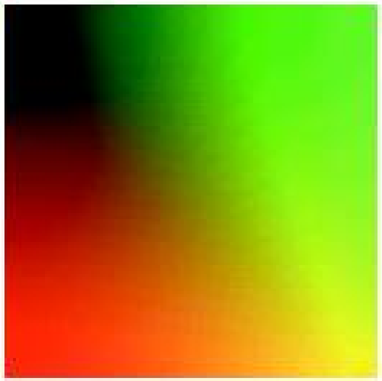
Color depth 24 bits
= 16777216 colors



$(R = 0)$



$(G = 0)$

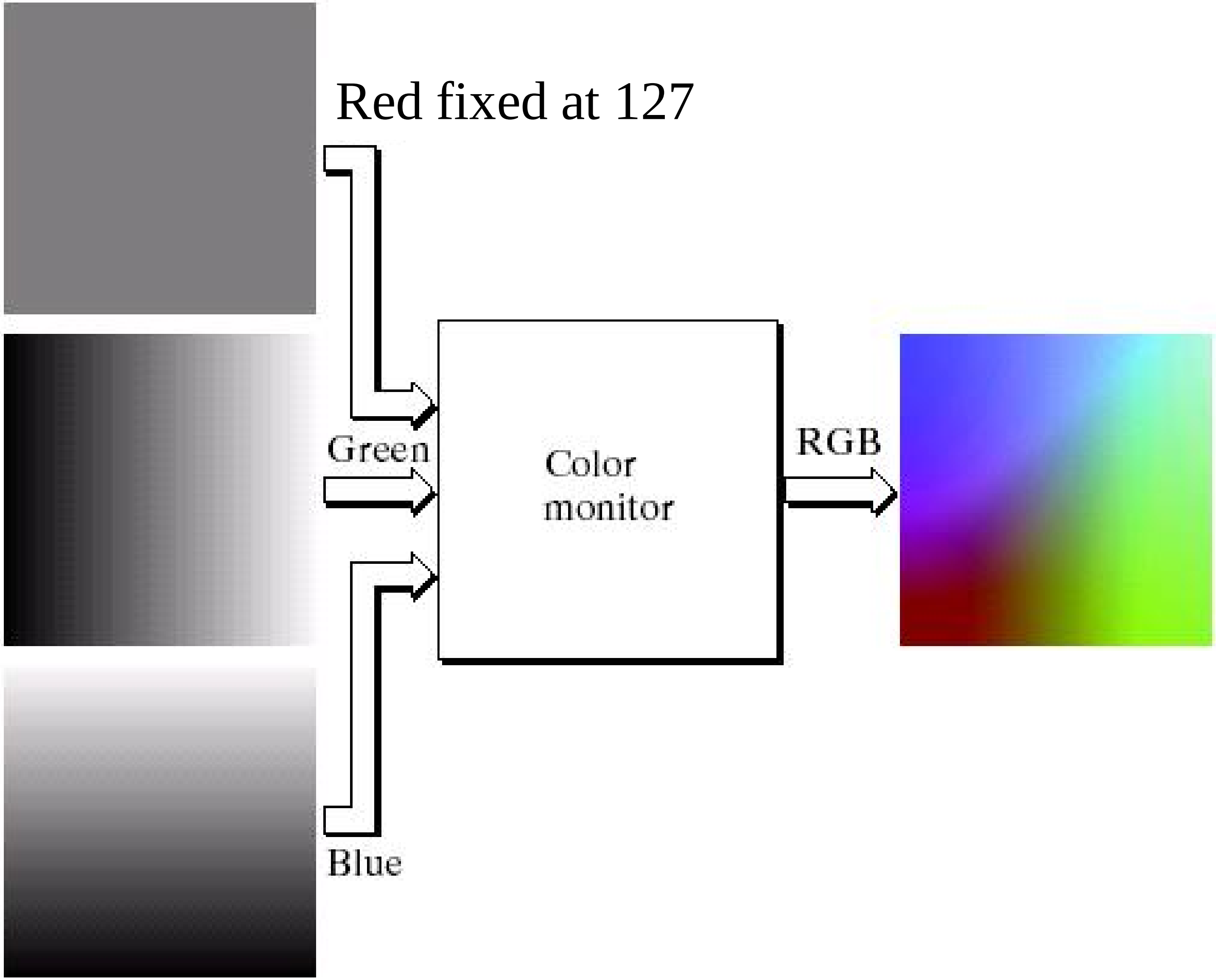


$(B = 0)$

Hidden faces
of the cube

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Model (cont.)

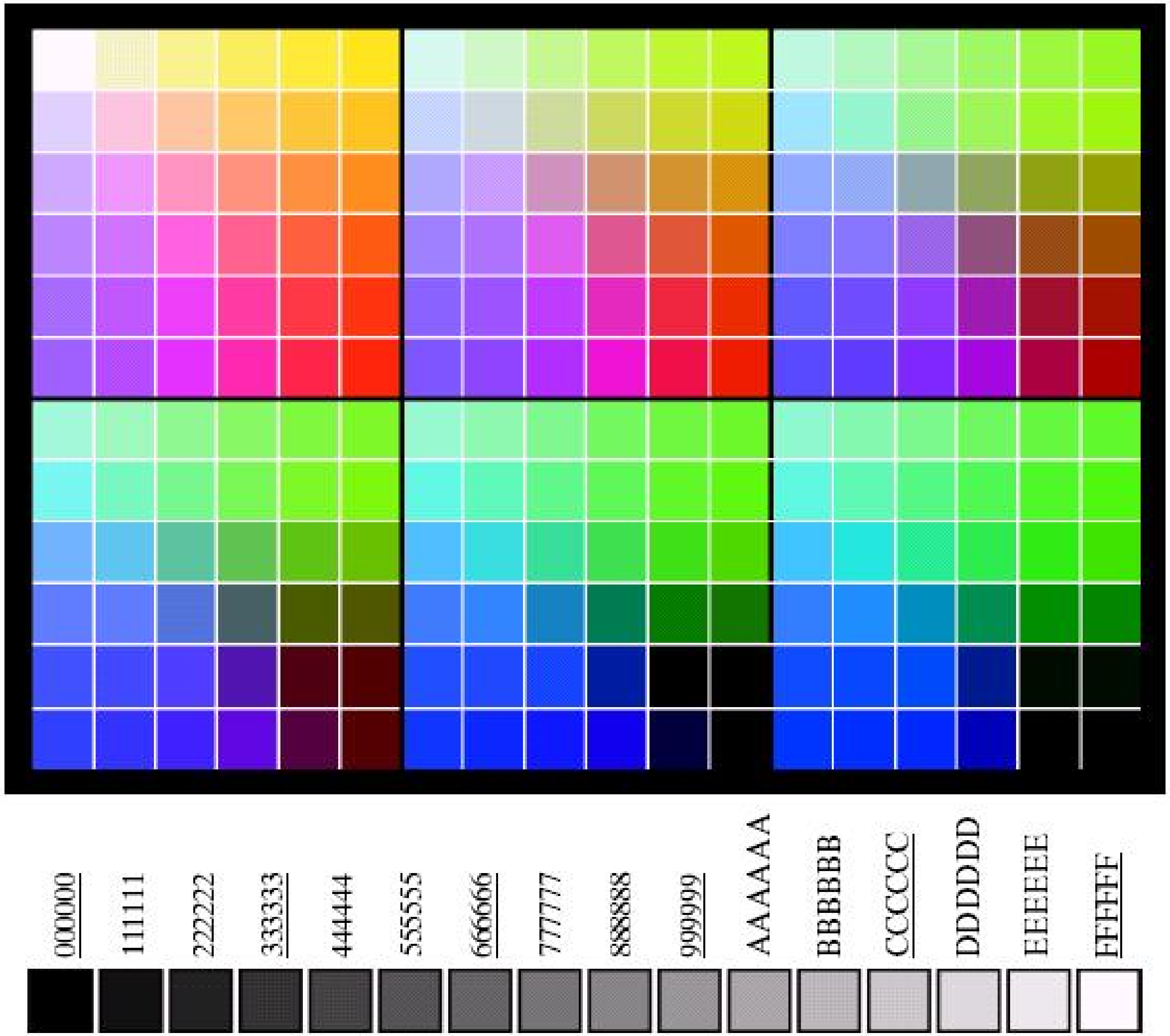


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



a
b

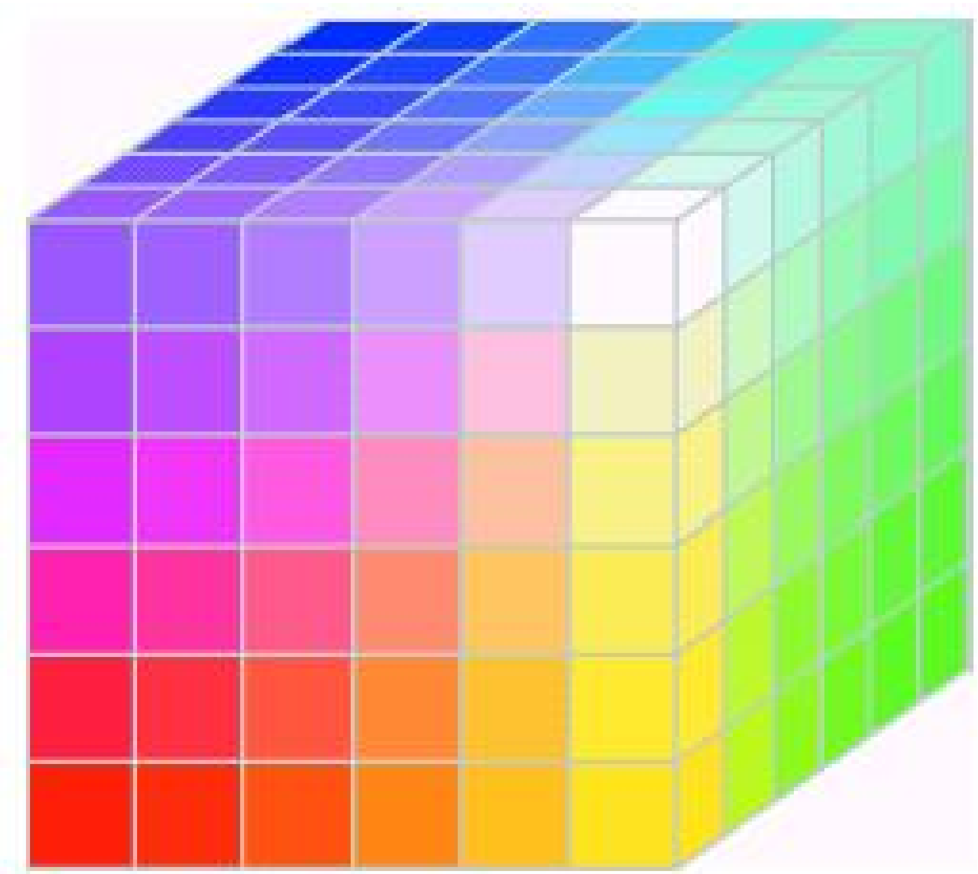
FIGURE 6.10
(a) The 216 safe RGB colors.
(b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Safe-color Cube

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.



The RGB Cube is divided into 6 intervals on each axis to achieve the total $6^3 = 216$ common colors.

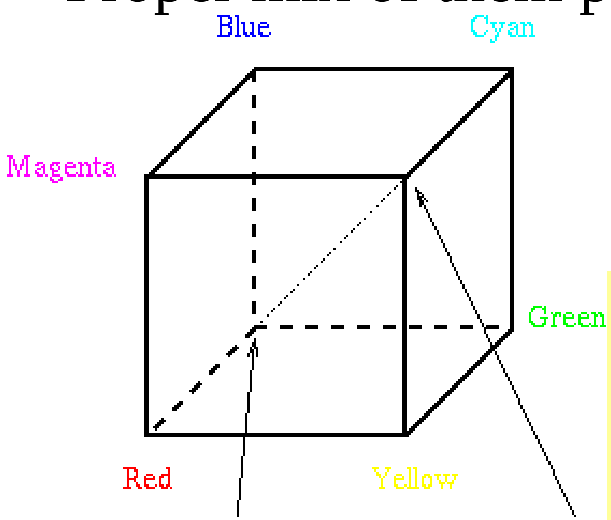
However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

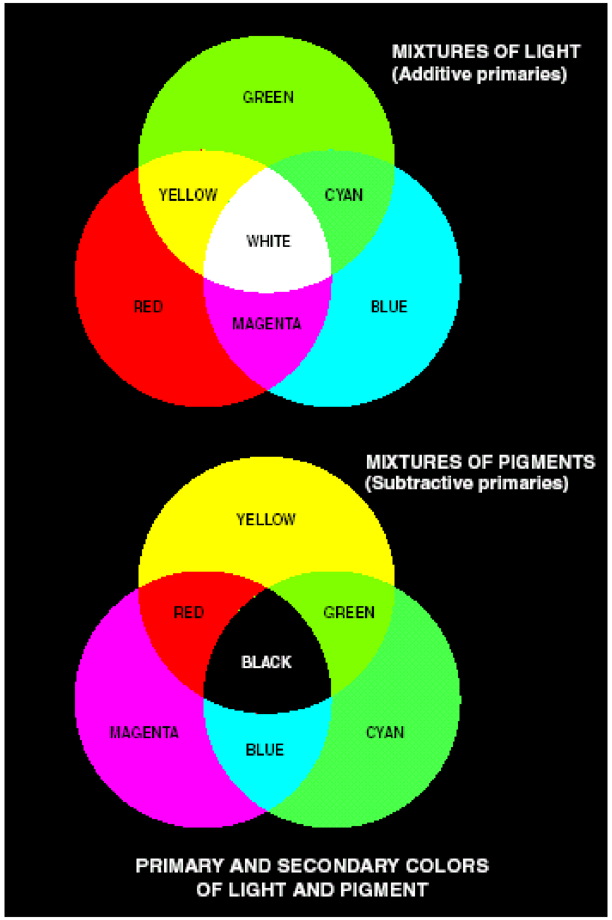
CMY and CMYK Color Models

C = Cyan
M = Magenta
Y = Yellow
K = Black

- Primary colors for pigment
  - Defined as one that subtracts/absorbs a primary color of light & reflects the other two
- CMY – Cyan, Magenta, Yellow
  - Complementary to RGB
  - Proper mix of them produces black



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



HSI Color Model

RGB, CMY models are not good for human interpreting

HSI Color model:

Hue: Dominant color

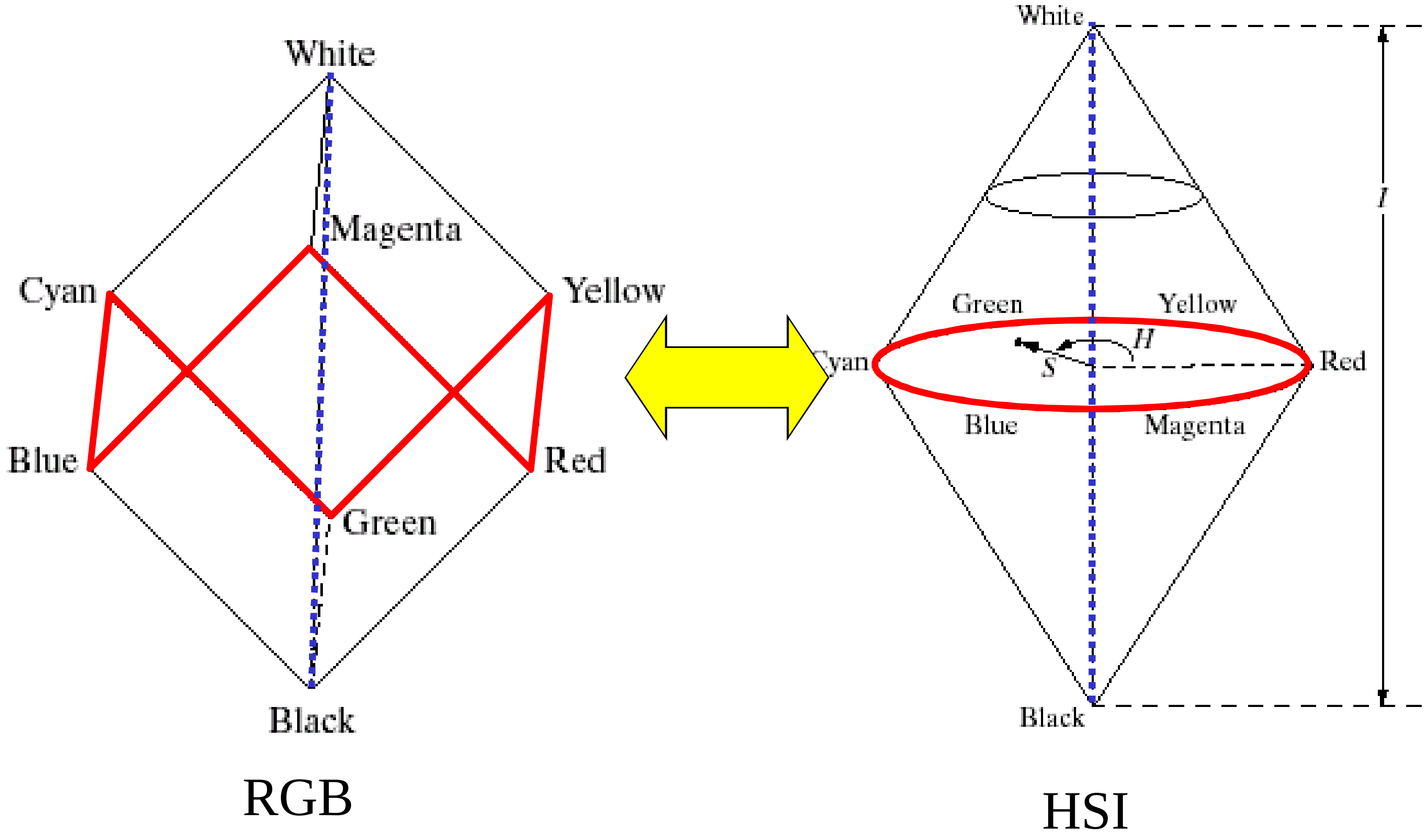
Saturation: Relative purity (inversely proportional to amount of white light added)

Color carrying information

Intensity: Brightness

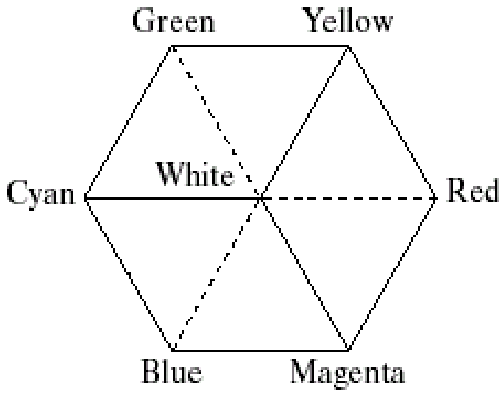
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

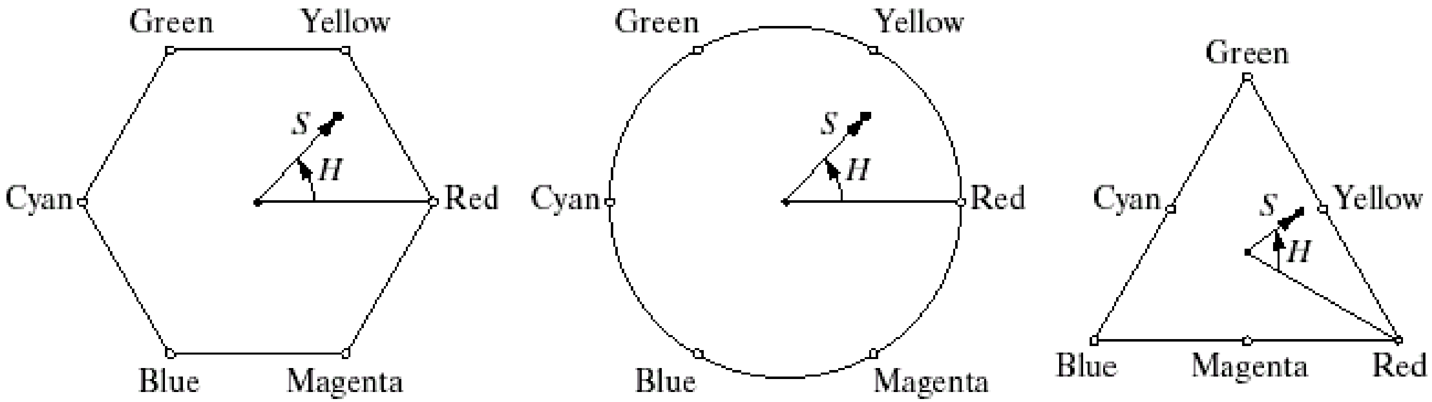
Relationship Between RGB and HSI Color Models



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

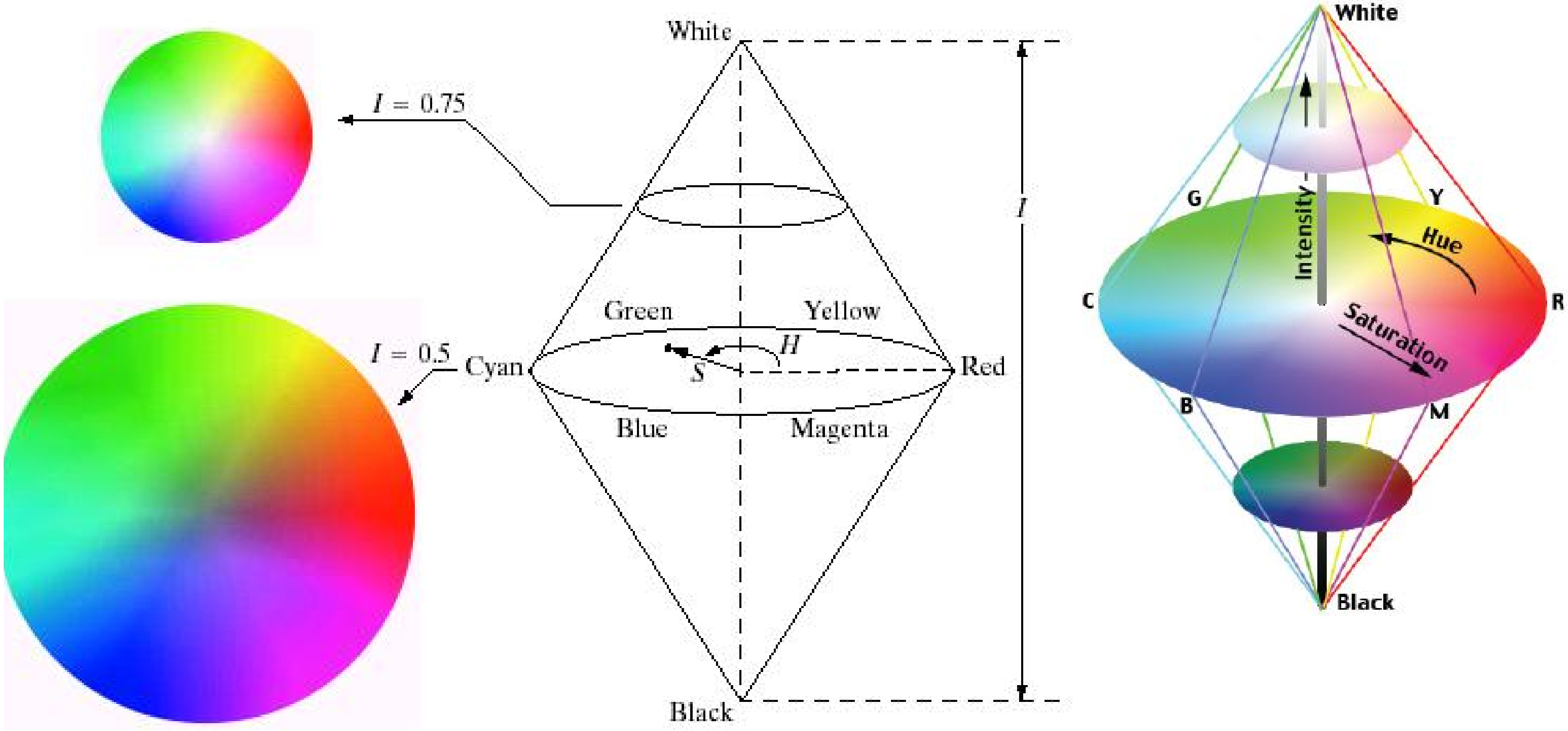
Hue and Saturation on Color Planes





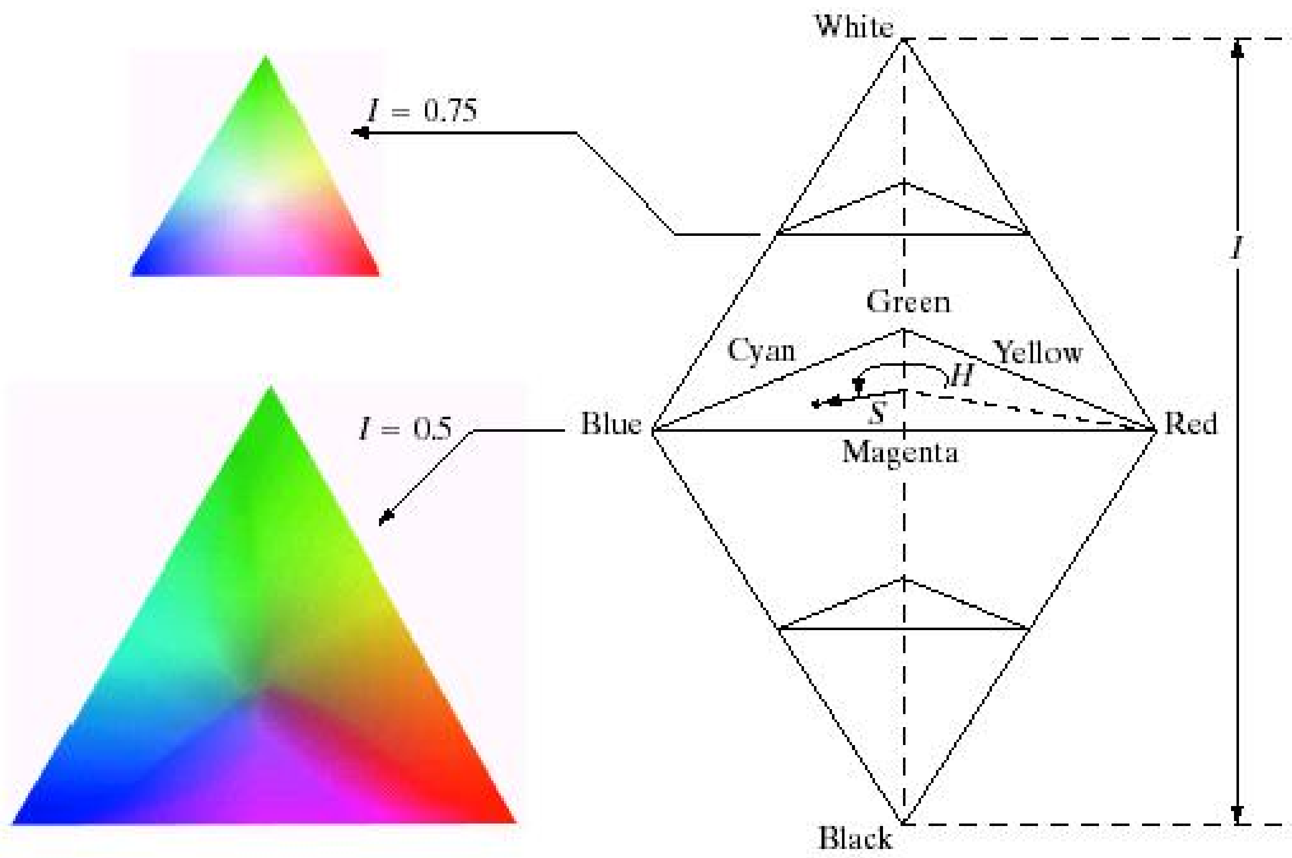
1. A dot is the plane is an arbitrary color
2. Hue is an angle from a red axis.
3. Saturation is a distance to the point.

HSI Color Model (cont.)



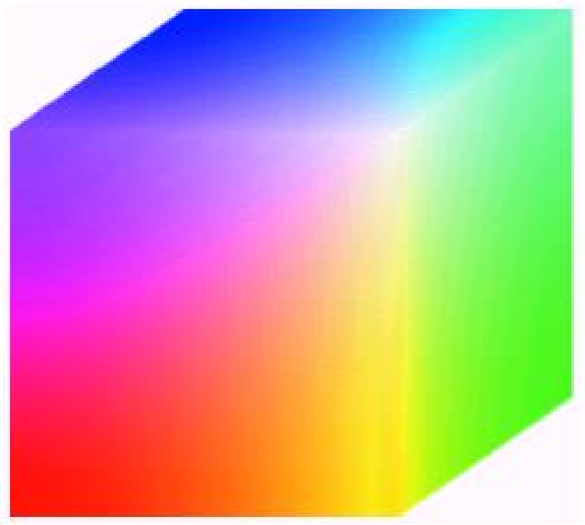
Intensity is given by a position on the vertical axis.

HSI Color Model

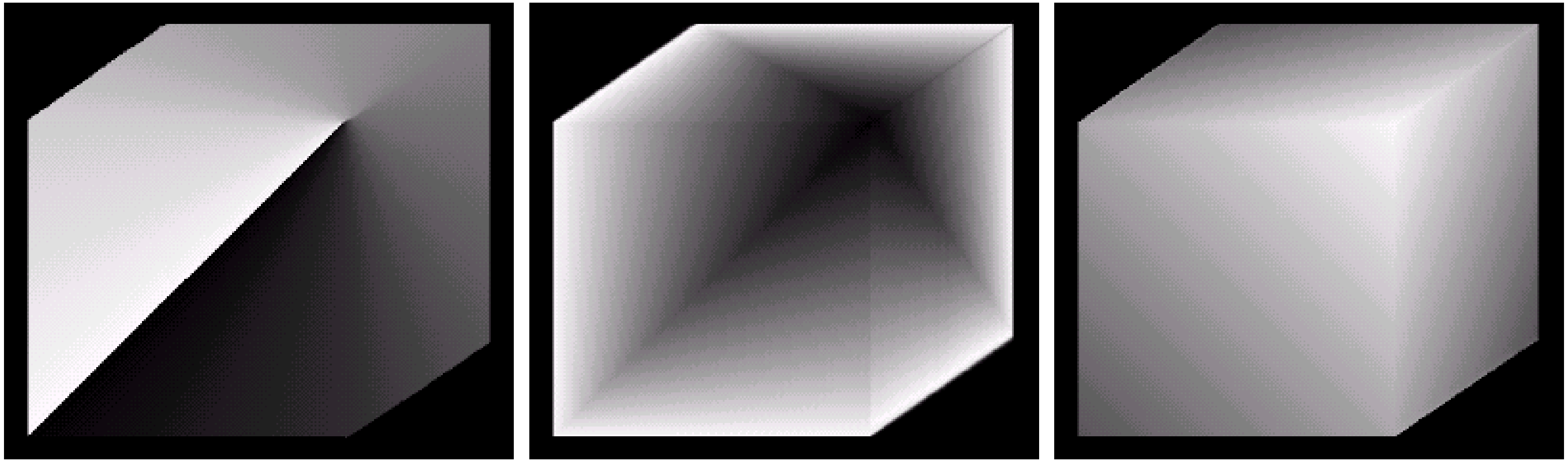


Intensity is given by a position on the vertical axis.

Example: HSI Components of RGB Cube



RGB Cube



Hue Saturation Intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Converting Colors from RGB to HSI

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

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

$$S = 1 - \frac{3}{R+G+B}$$

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

Converting Colors from HSI to RGB

RG sector: $0 \le H < 120$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^{0} - H)}\right]$$

$$B = I(1 - S)$$

$$G = 1 - (R + B)$$

GB sector: $120 \le H < 240$

$$H = H - 120$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^{0} - H)}\right]$$

$$B = 1 - (R + G)$$

BR sector: $240 \le H \le 360$

$$H = H - 240$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^{0} - H)}\right]$$

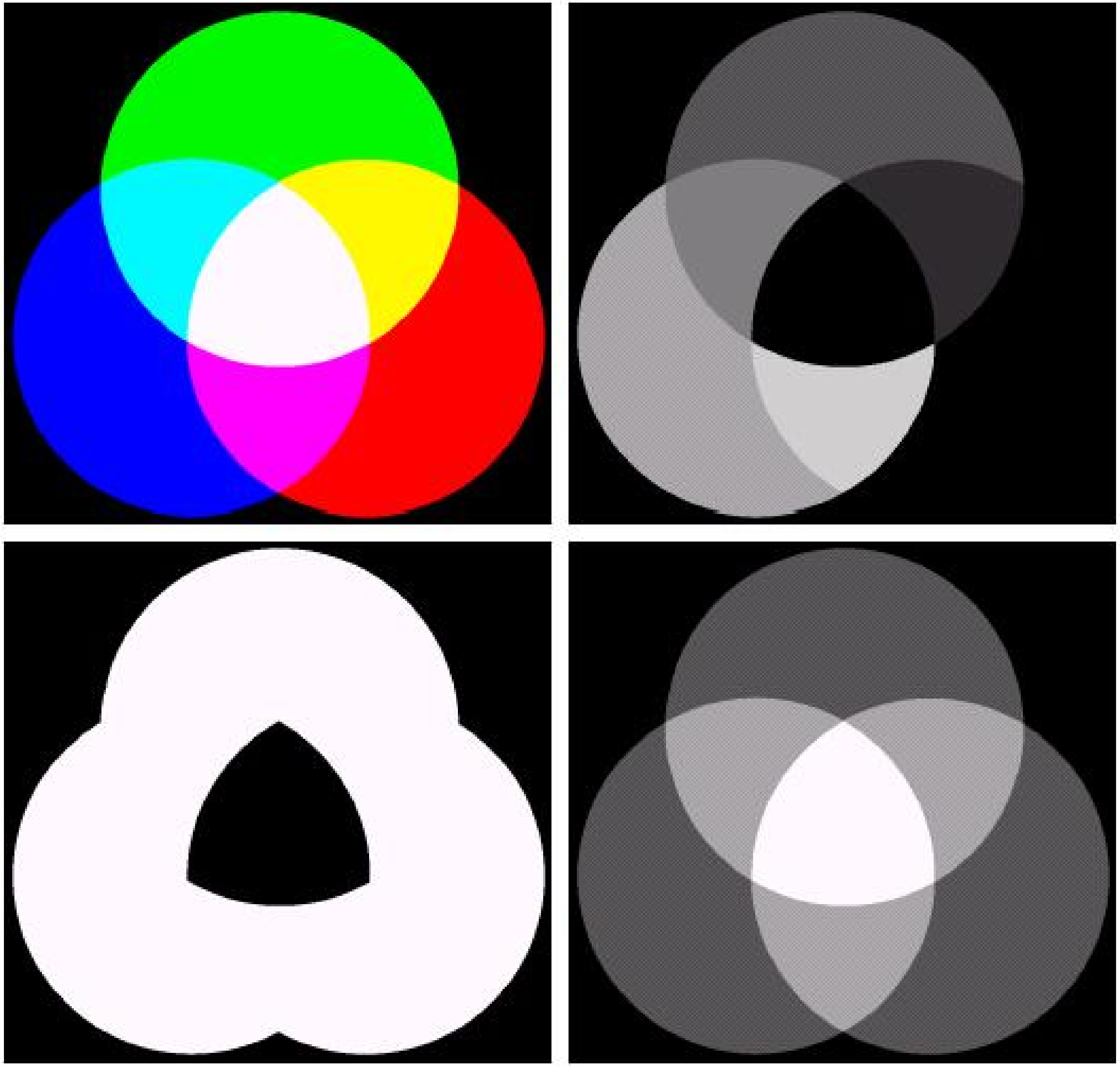
$$G = I(1 - S)$$

$$R = 1 - (G + B)$$

Example: HSI Components of RGB Colors

RGB Image

Hue

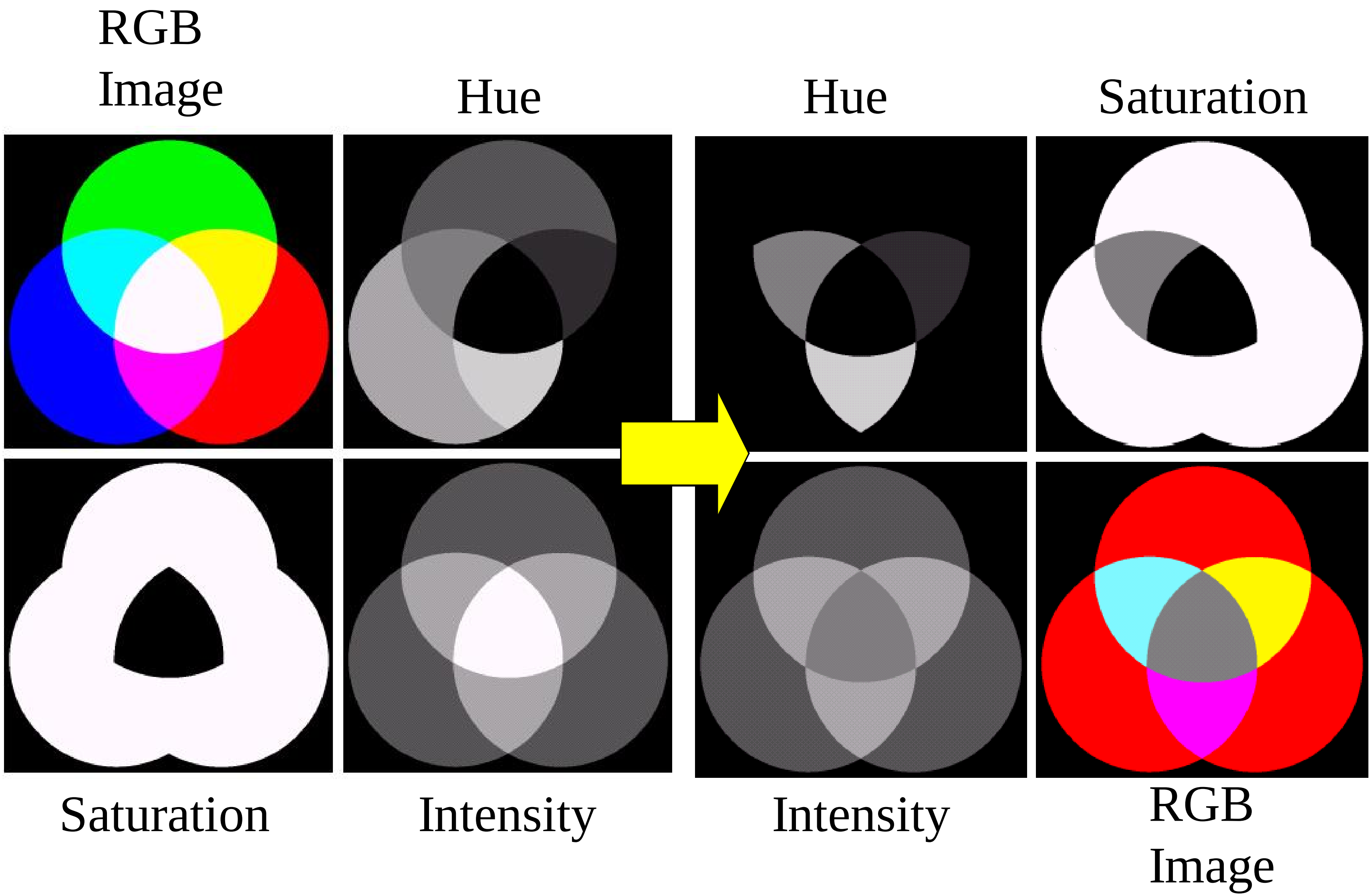


Saturation

Intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: Manipulating HSI Components



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Coordinates Used in TV Transmission

- Facilitate sending color video via 6MHz mono TV channel
- YIQ for NTSC (National Television Systems Committee) transmission system
  - Use receiver primary system (R_N, G_N, B_N) as TV receivers standard
  - Transmission system use (Y, I, Q) color coordinate
    - Y ~ luminance, I & Q ~ chrominance
    - I & Q are transmitted in through orthogonal carriers at the same freq.

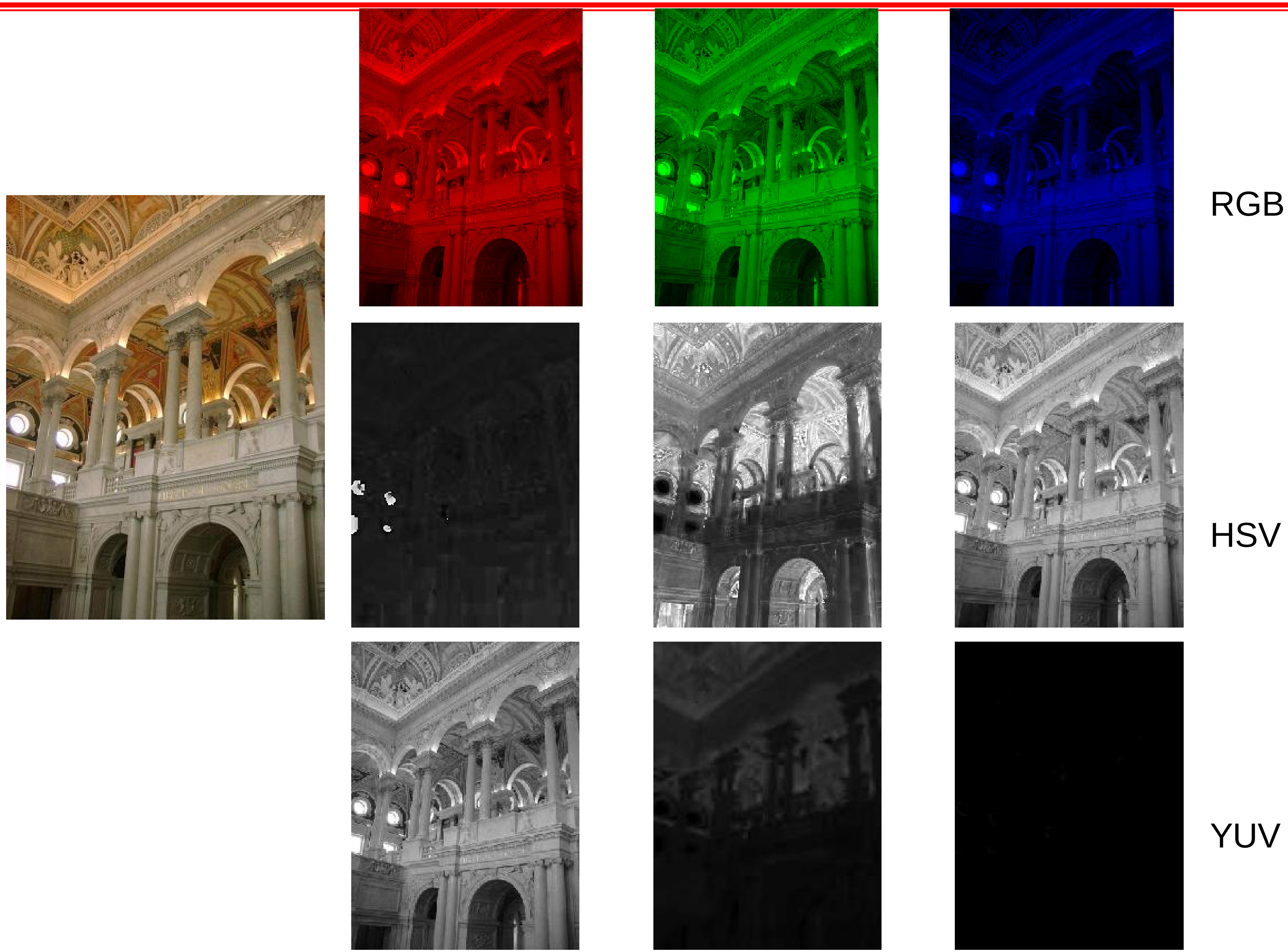
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix}. \qquad \begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R_P \\ G_P \\ B_P \end{bmatrix}.$$

- YUV (YCbCr) for PAL and digital video
  - Y ~ luminance, Cb and Cr ~ chrominance

Color Coordinates

- RGB of CIE
- XYZ of CIE
- RGB of NTSC
- YIQ of NTSC
- YUV (YCbCr)
- CMY

Examples



Examples

A colour image

Red component

Green component

Blue component

RGB

Hue

Saturation

Value

HSV

Y

I

Q

YIQ

Summary

UMCP ENEE631 Slides (created by M.Wu © 2004)

- Monochrome human vision
  - visual properties: luminance vs. brightness, etc.
  - image fidelity criteria
- Color
  - Color representations and three primary colors
  - Color coordinates

Color Image Processing

There are 2 types of color image processes

1. Pseudocolor image process: Assigning colors to gray values based on a specific criterion. Gray scale images to be processed may be a single image or multiple images such as multispectral images

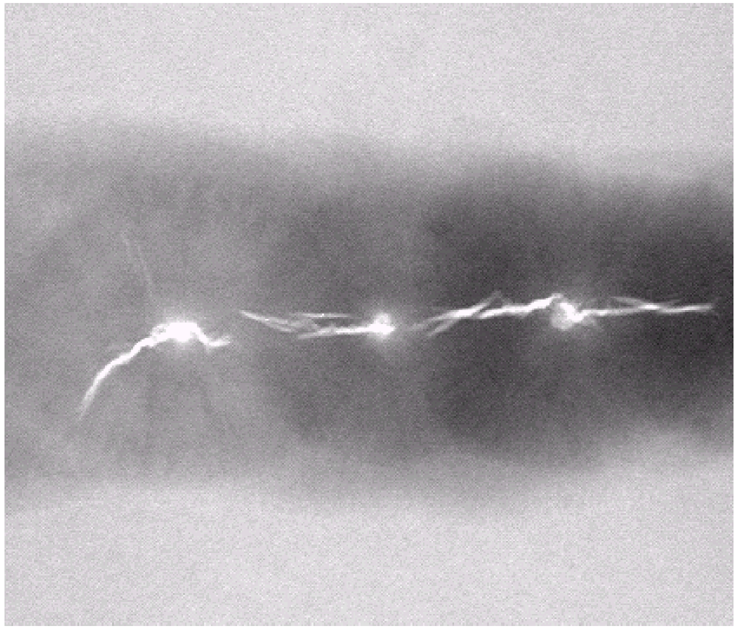
2. Full color image process: The process to manipulate real color images such as color photographs.

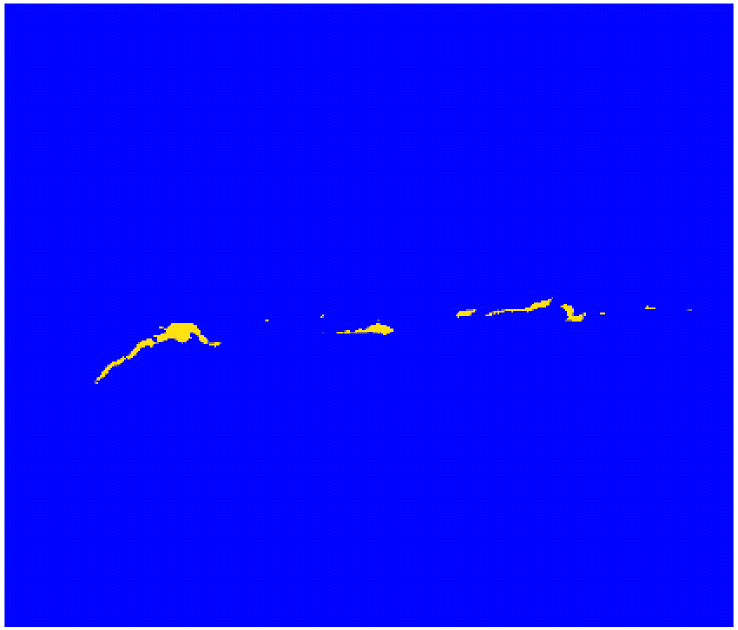
Pseudocolor Image Processing

Pseudo color = false color : In some case there is no "color" concept for a gray scale image but we can assign "false" colors to an image.

Why we need to assign colors to gray scale image?

Answer: Human can distinguish different colors better than different shades of gray.





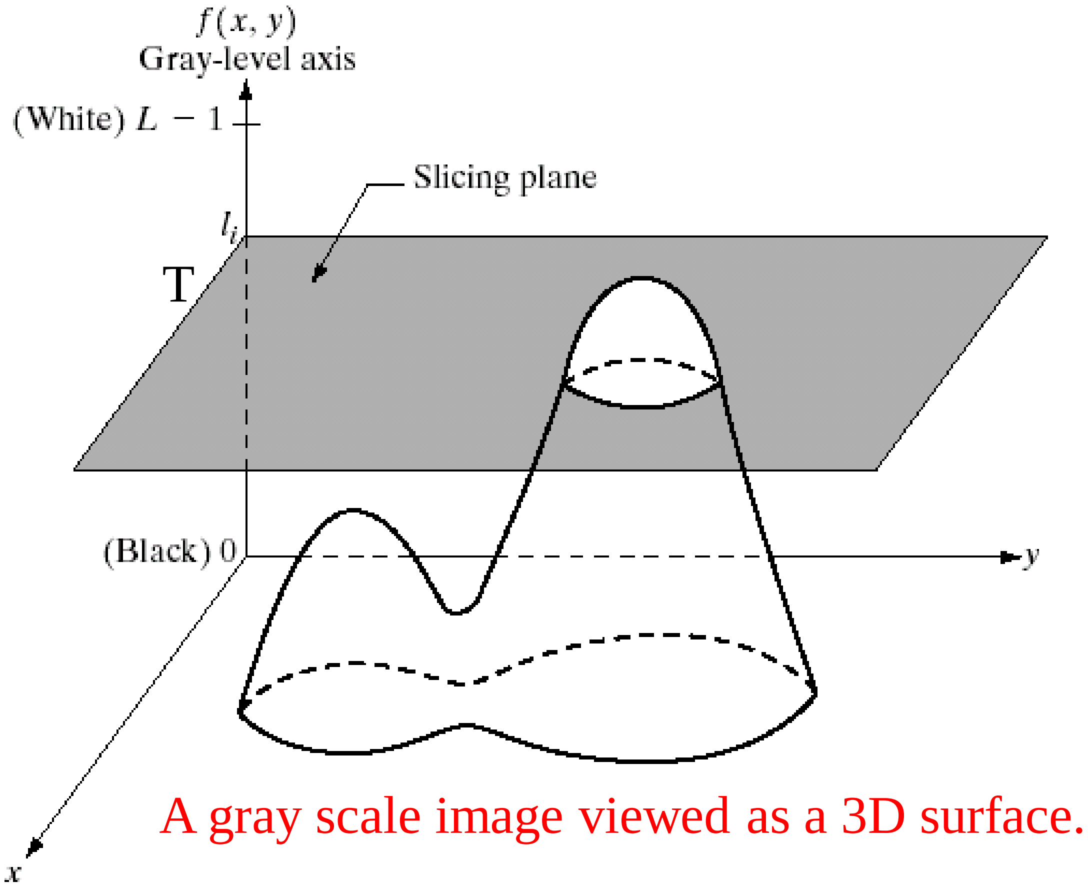
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Intensity Slicing or Density Slicing

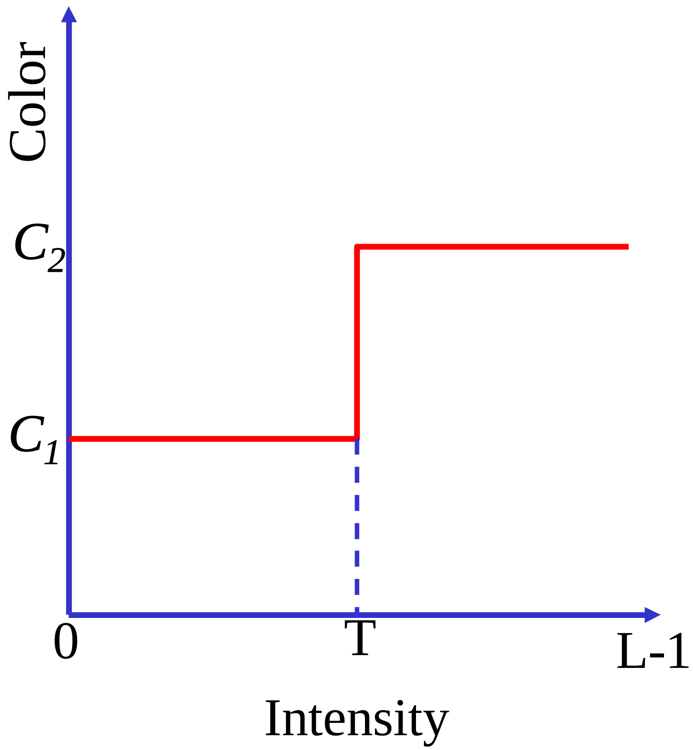
Formula:

$$g(x,y)=\begin{cases} C_1 & \text{if } f(x,y)\le T \\ C_2 & \text{if } f(x,y)>T \end{cases}$$

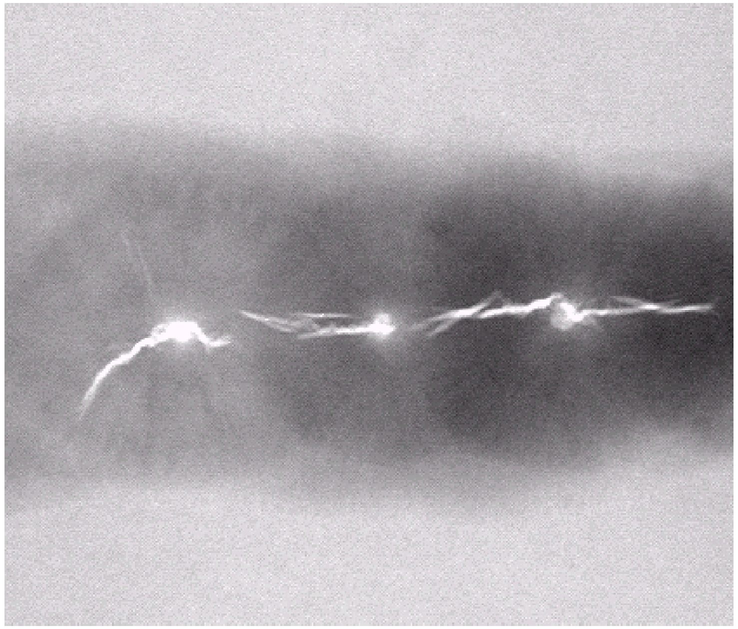
C_1 = Color No. 1
C_2 = Color No. 2



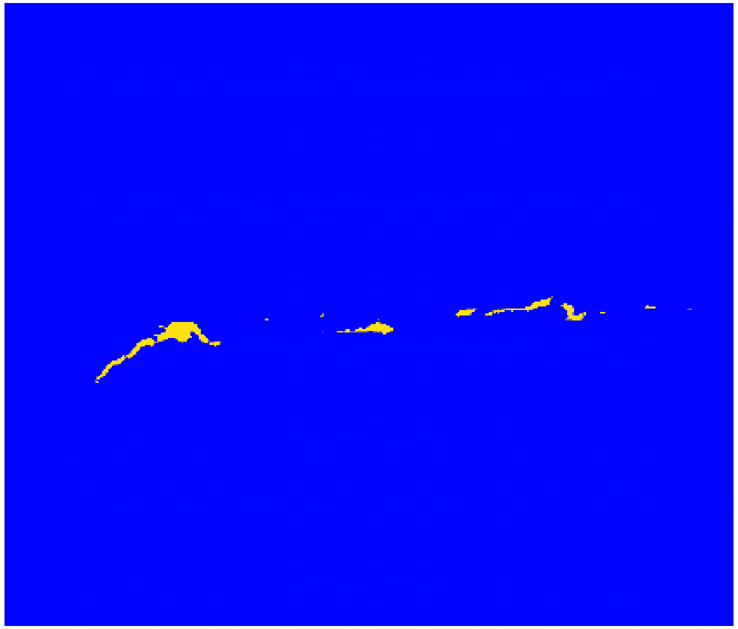
A gray scale image viewed as a 3D surface.



Intensity Slicing Example



An X-ray image of a weld with cracks



After assigning a yellow color to pixels with value 255 and a blue color to all other pixels.

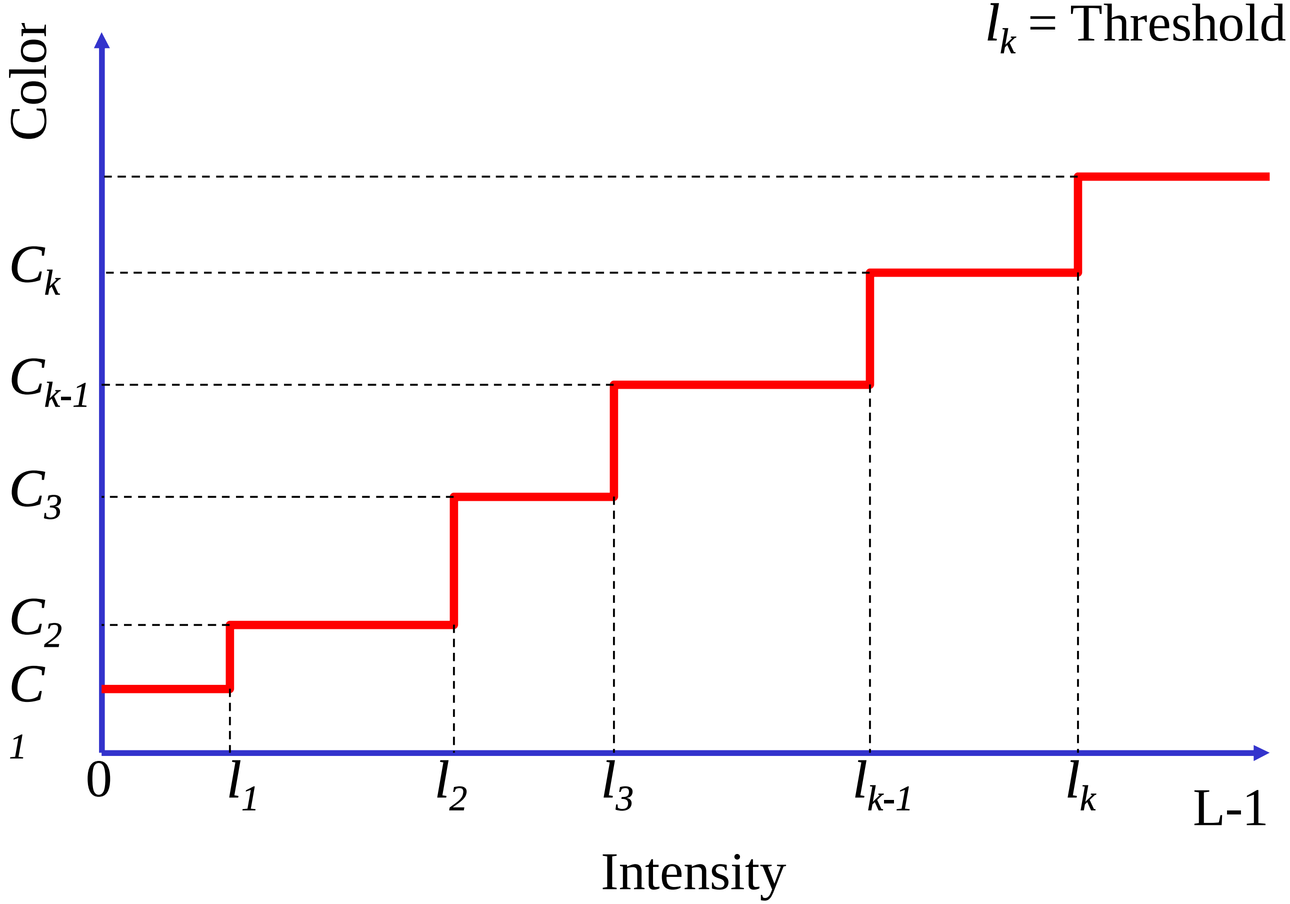
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Multi Level Intensity Slicing

$$g(x, y) = C_k \qquad \text{for } l_{k-1} < f(x, y) \le l_k$$

grey level:	0–63	64–127	128–191	192–255
colour:	blue	magenta	green	red

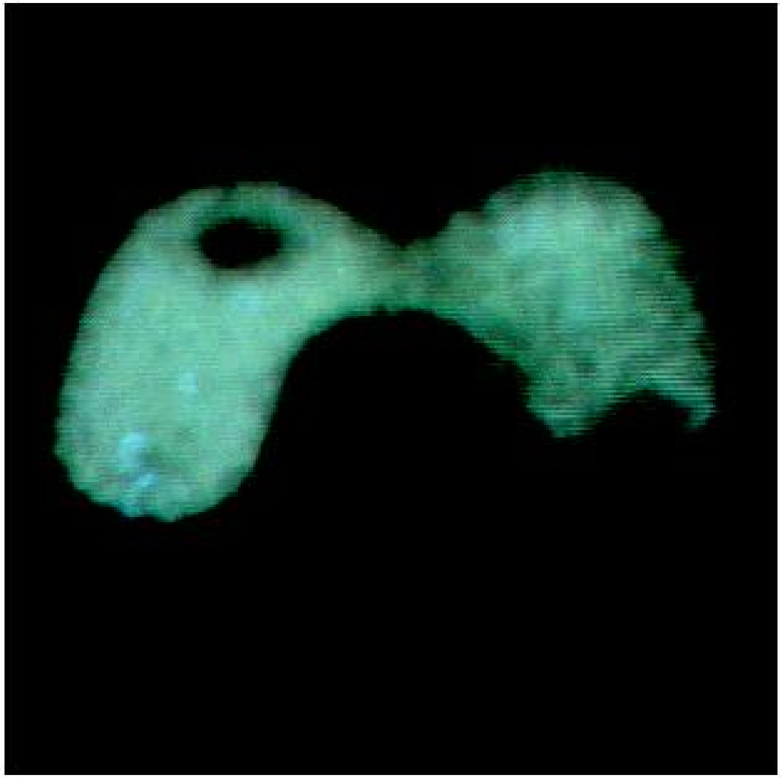
C_k = Color No. k
l_k = Threshold level k



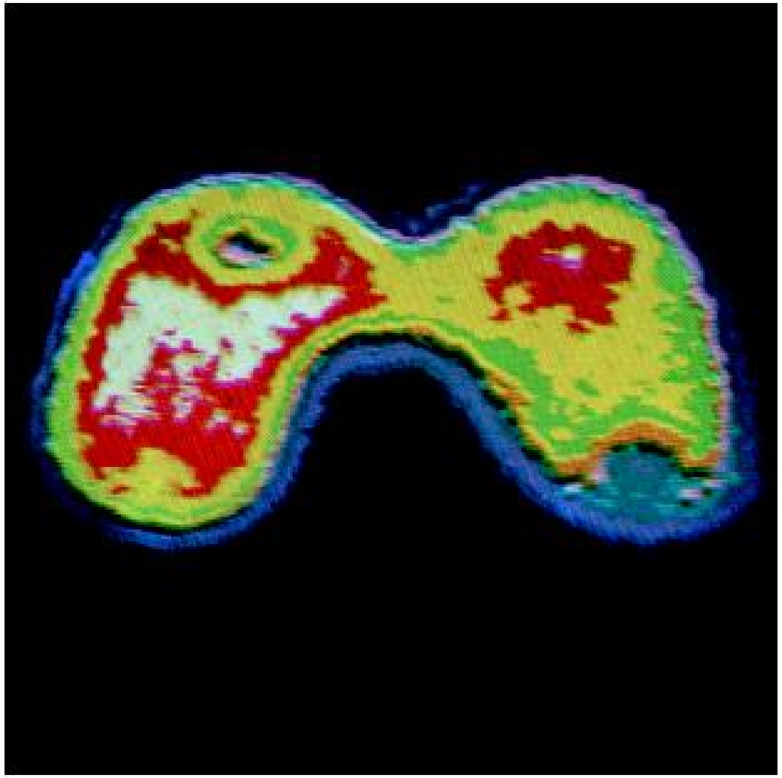
Multi Level Intensity Slicing Example

$$g(x,y) = C_k \qquad \text{for } l_{k-1} < f(x,y) \le l_k$$

C_k = Color No. k
l_k = Threshold level k



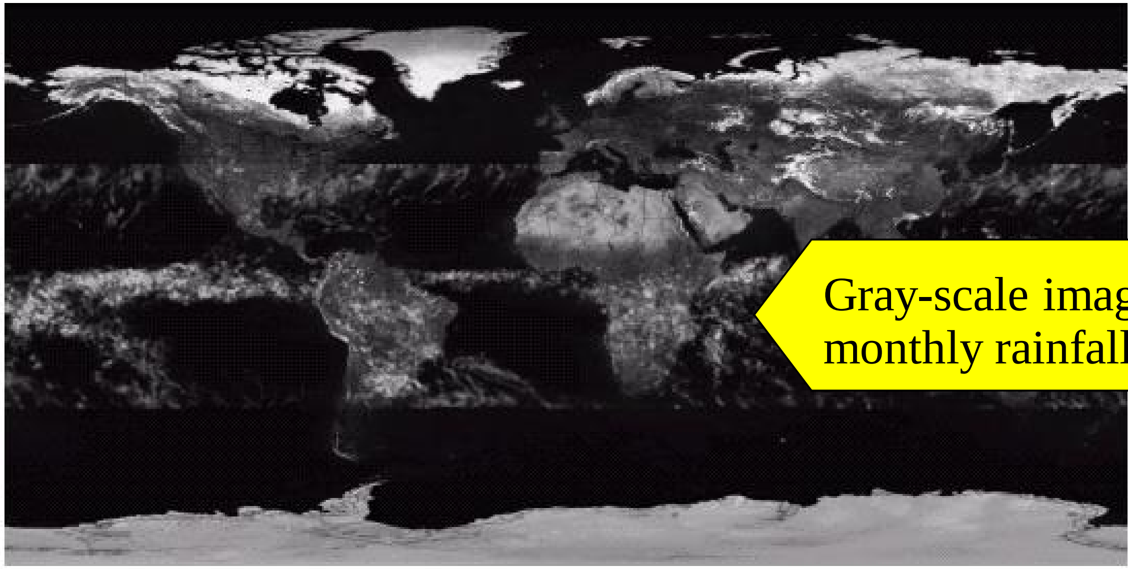
An X-ray image of the Picker Thyroid Phantom.



After density slicing into 8 colors

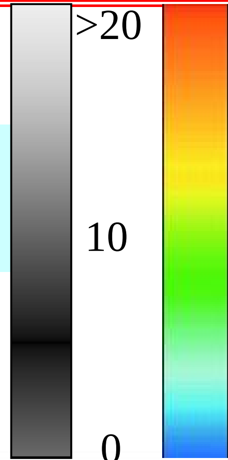
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Coding Example

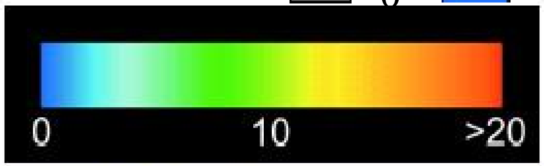


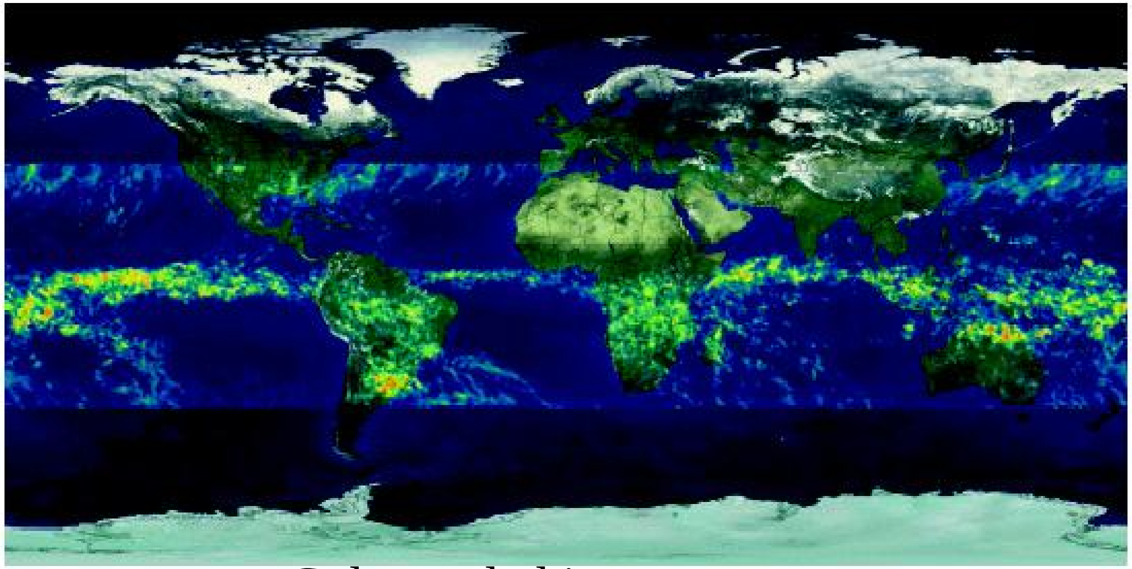
Gray-scale image of average monthly rainfall.

Gray Scale

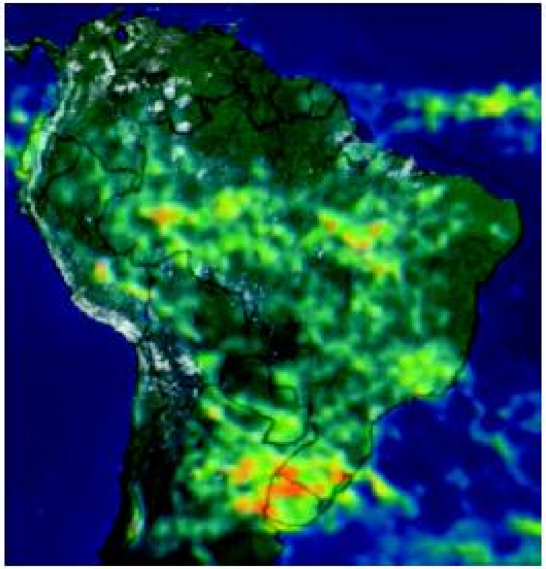


Color map





Color coded image

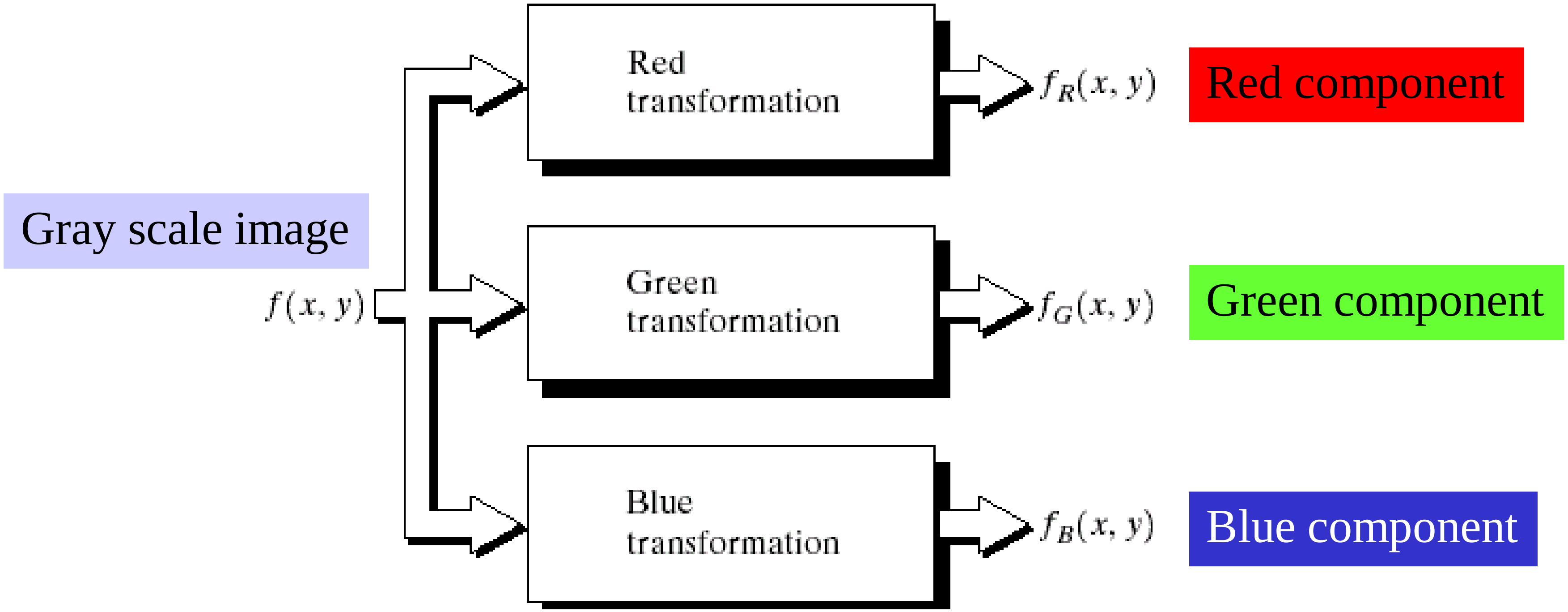


South America region

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gray Level to Color Transformation

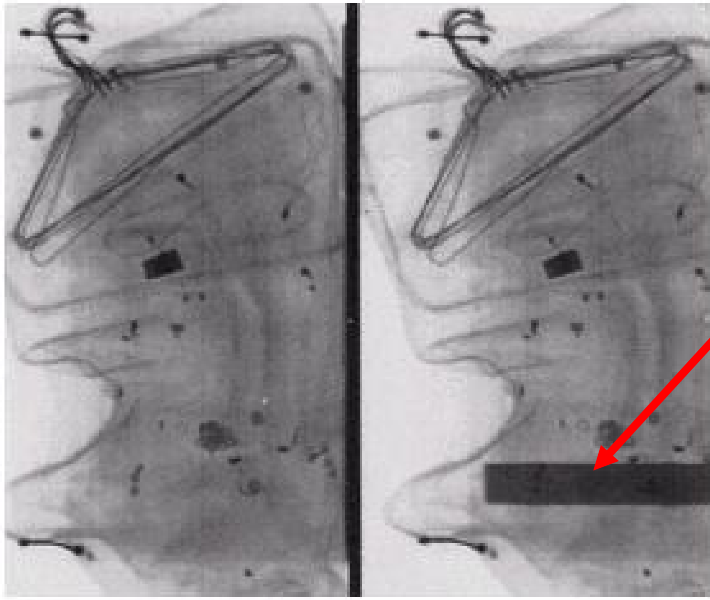
Assigning colors to gray levels based on specific mapping functions



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gray Level to Color Transformation Example

An X-ray image of a garment bag

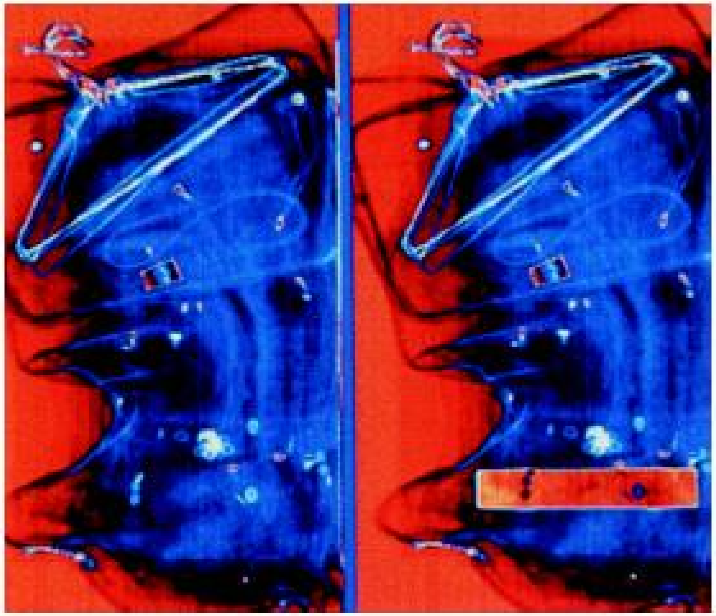


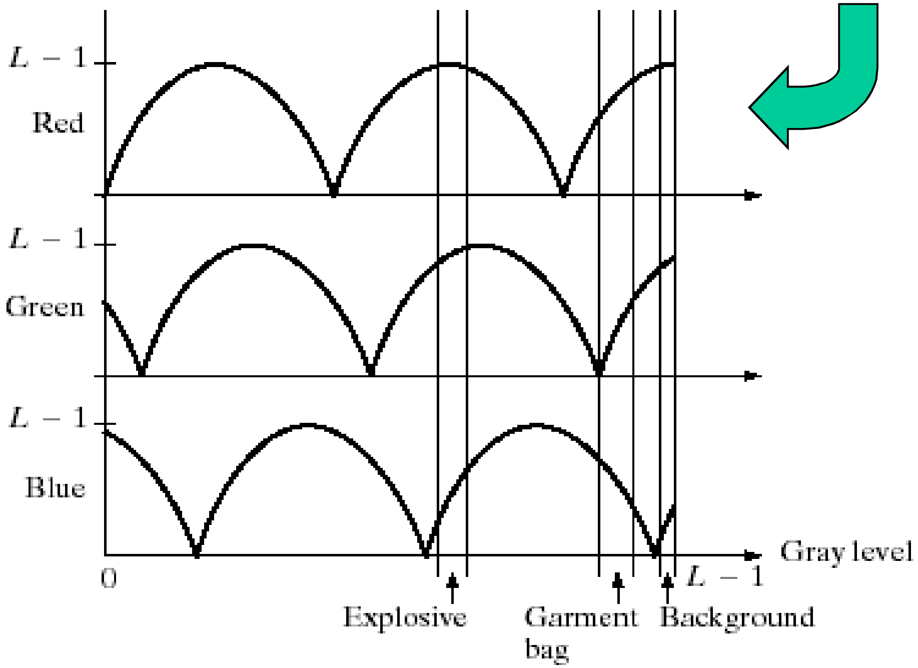
An X-ray image of a garment bag with a simulated explosive device

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.)

Transformations

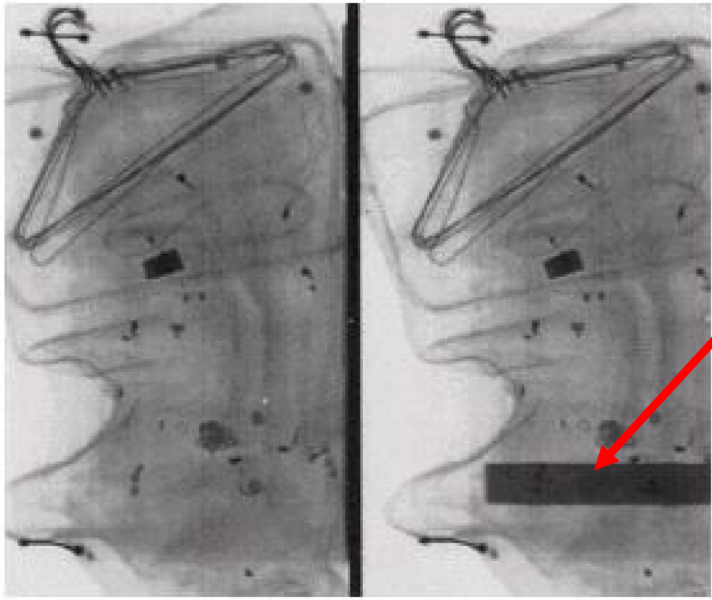
Color coded images





Gray Level to Color Transformation Example

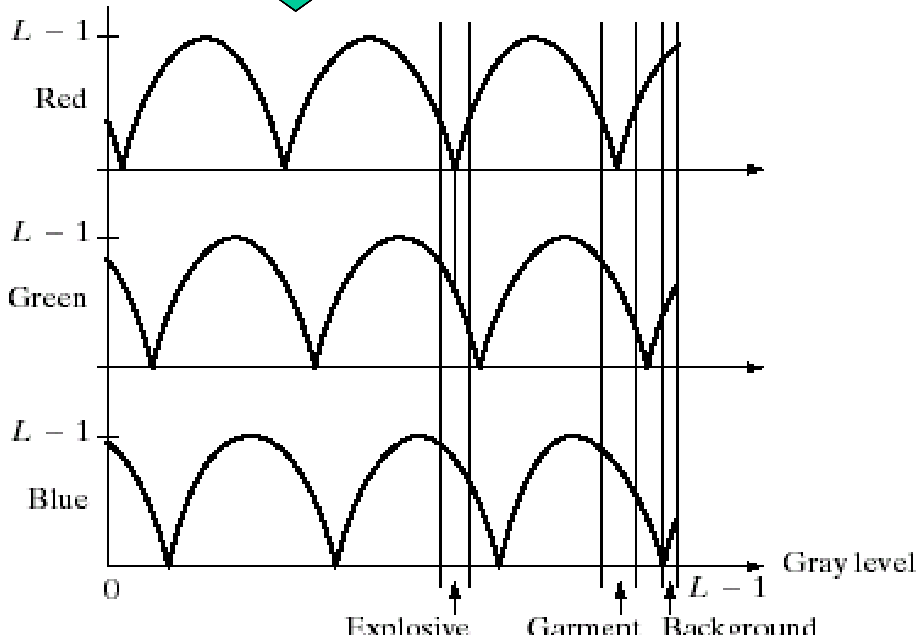
An X-ray image of a garment bag

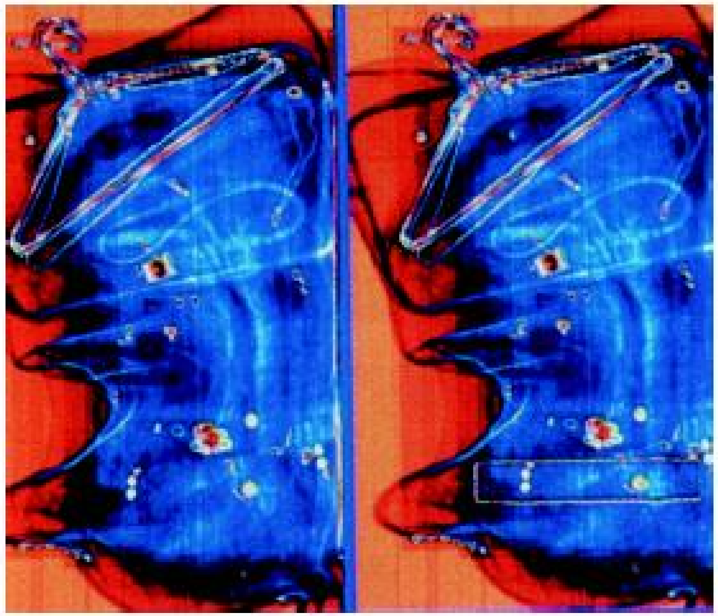


An X-ray image of a garment bag with a simulated explosive device

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.)

Transformations

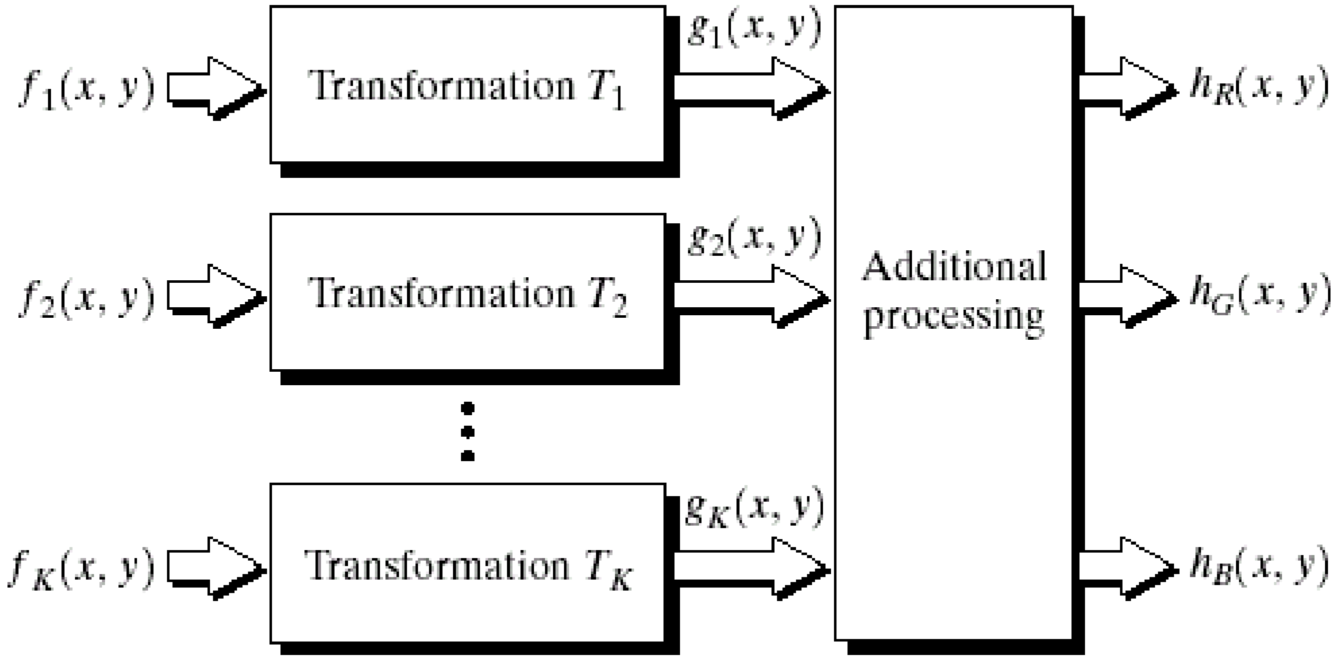




Color coded images

Pseudocolor Coding

Used in the case where there are many monochrome images such as multispectral satellite images.



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Pseudocolor Coding Example

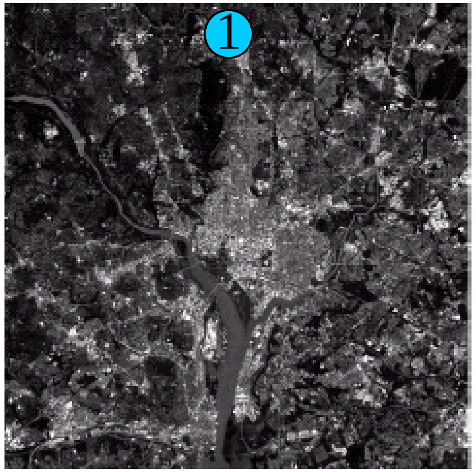
TABLE 1.1
Thematic bands in NASA's LANDSAT satellite.

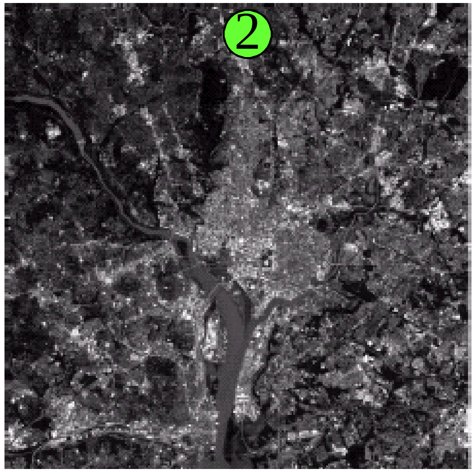
Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

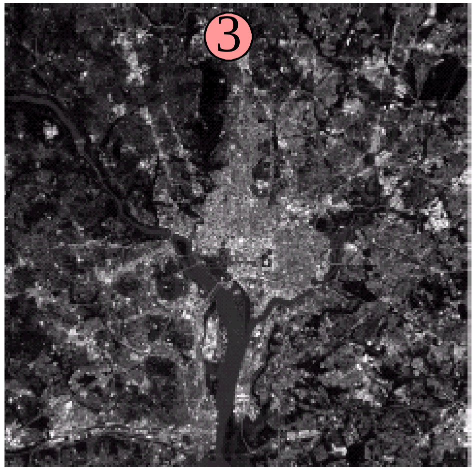
Pseudocolor Coding Example

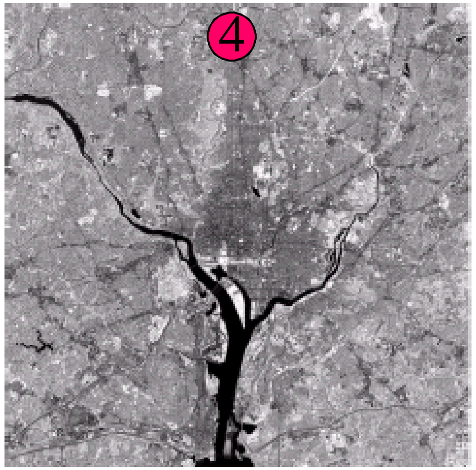
Visible blue
λ= 0.45-0.52 µm
Max water penetration

Visible green
λ= 0.52-0.60 µm
Measuring plant





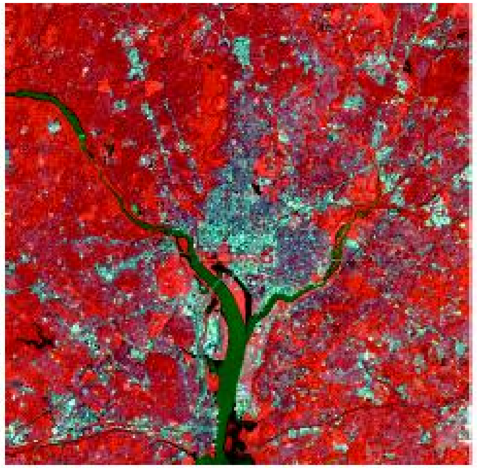




Visible red
λ= 0.63-0.69 µm
Plant discrimination

Near infrared
λ= 0.76-0.90 µm
Biomass and shoreline mapping

Color composite images



Red = 1
Green = 2
Blue = 3

Red = 1
Green = 2
Blue = 4

Better visualization à Show quite clearly the difference between biomass (red) and human-made features.

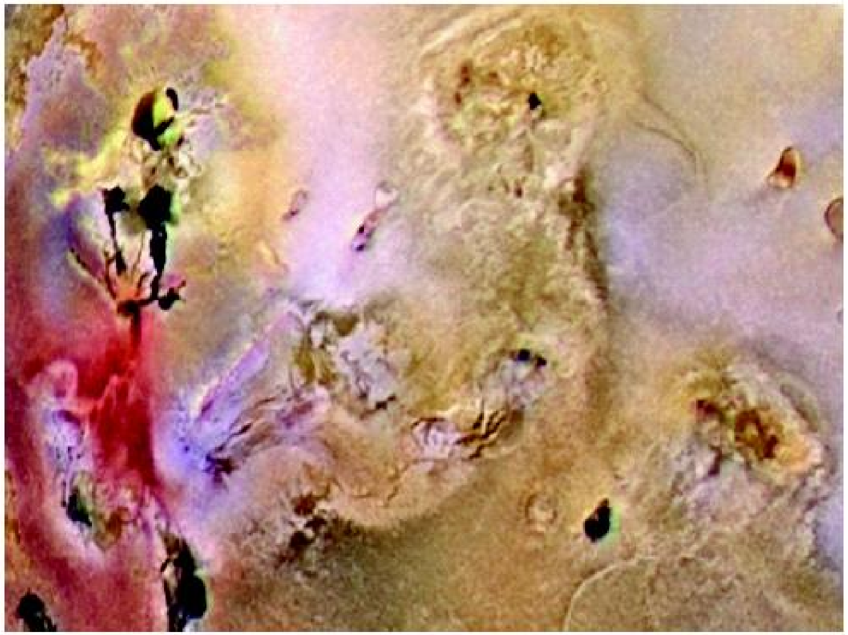
Washington D.C. area

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Pseudocolor Coding Example

Psuedocolor rendition
of Jupiter moon Io

Yellow areas = older sulfur deposits.
Red areas = material ejected from active volcanoes.



A close-up

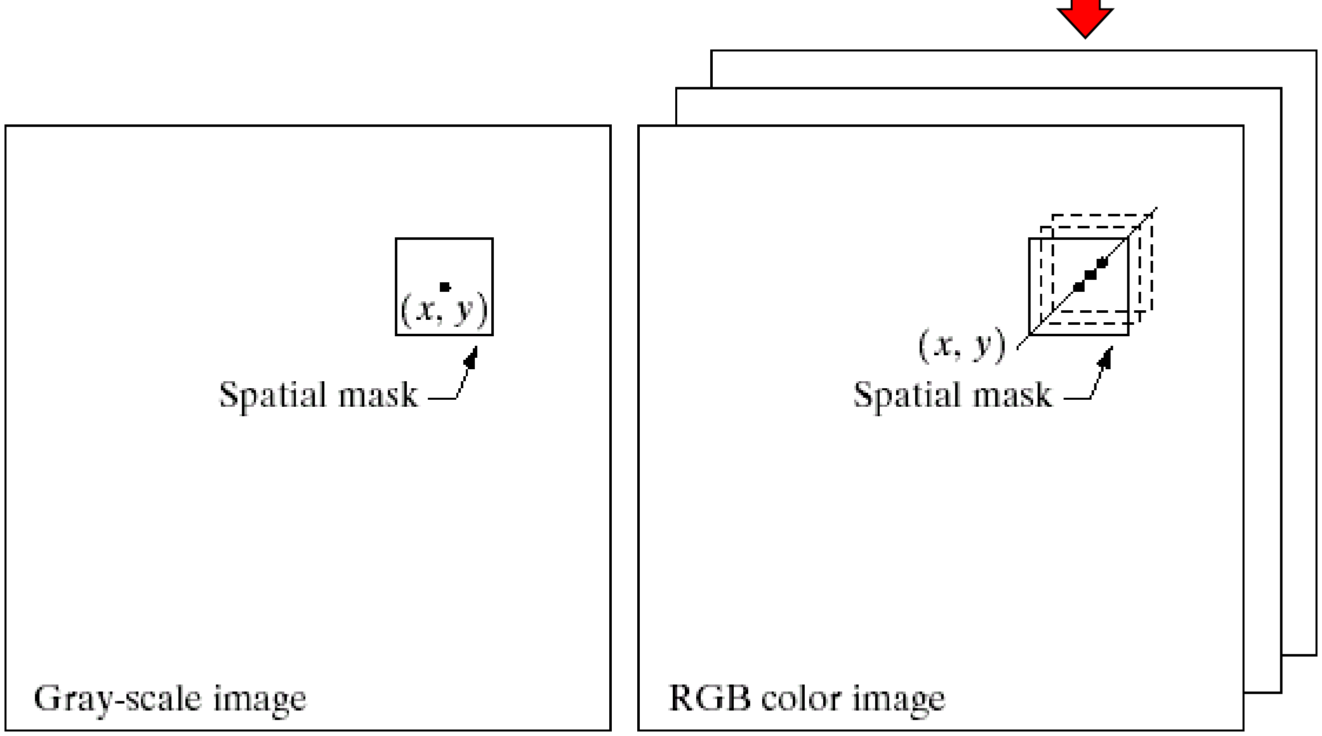
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Basics of Full-Color Image Processing

2 Methods:

1. Per-color-component processing: process each component separately.
2. Vector processing: treat each pixel as a vector to be processed.

Example of per-color-component processing: smoothing an image
By smoothing each RGB component separately.

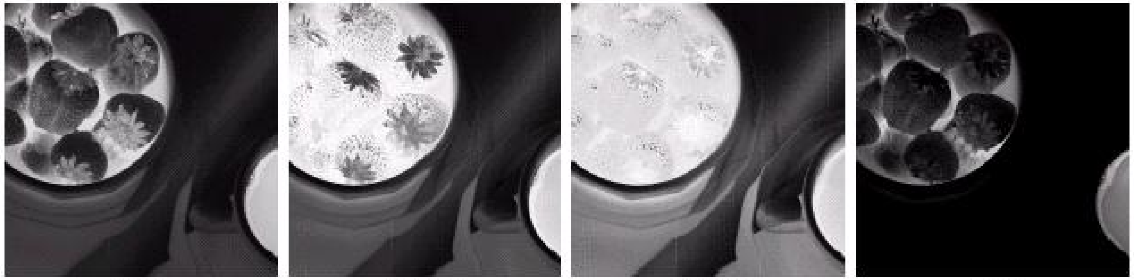


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: *Full-Color Image and Variouis Color Space Components*

Full color

Color image



Cyan Magenta Yellow Black

CMYK components

Red Green Blue

RGB components

Hue Saturation Intensity

HSI components

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Transformation

Use to transform colors to colors.

Formulation:

$$g(x,y) = T\left[f(x,y)\right]$$

$f(x,y)$ = input color image, $g(x,y)$ = output color image
T = operation on f over a spatial neighborhood of (x,y)

When only data at one pixel is used in the transformation, we can express the transformation as:

$$s_i = T_i(r_1, r_2, \ldots, r_n) \qquad i = 1, 2, \ldots, n$$

Where r_i = color component of $f(x,y)$
s_i = color component of $g(x,y)$

For RGB images, $n = 3$

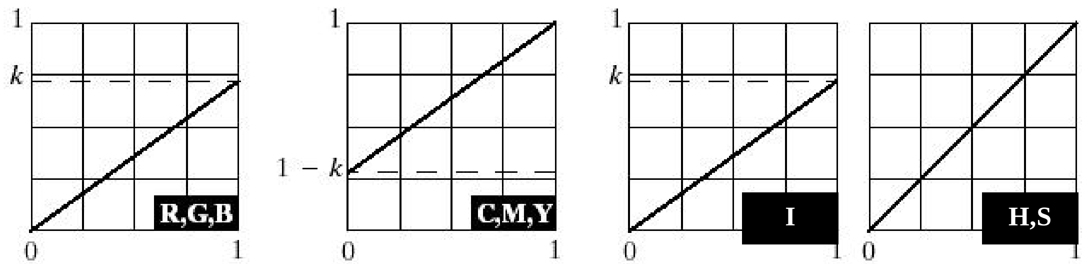
Example: Color Transformation

Formula for RGB:

$$s_R(x,y) = kr_R(x,y)$$
$$s_G(x,y) = kr_G(x,y)$$
$$s_B(x,y) = kr_B(x,y)$$

Formula for HSI:

$$s_I(x,y) = kr_I(x,y)$$



Formula for CMY:

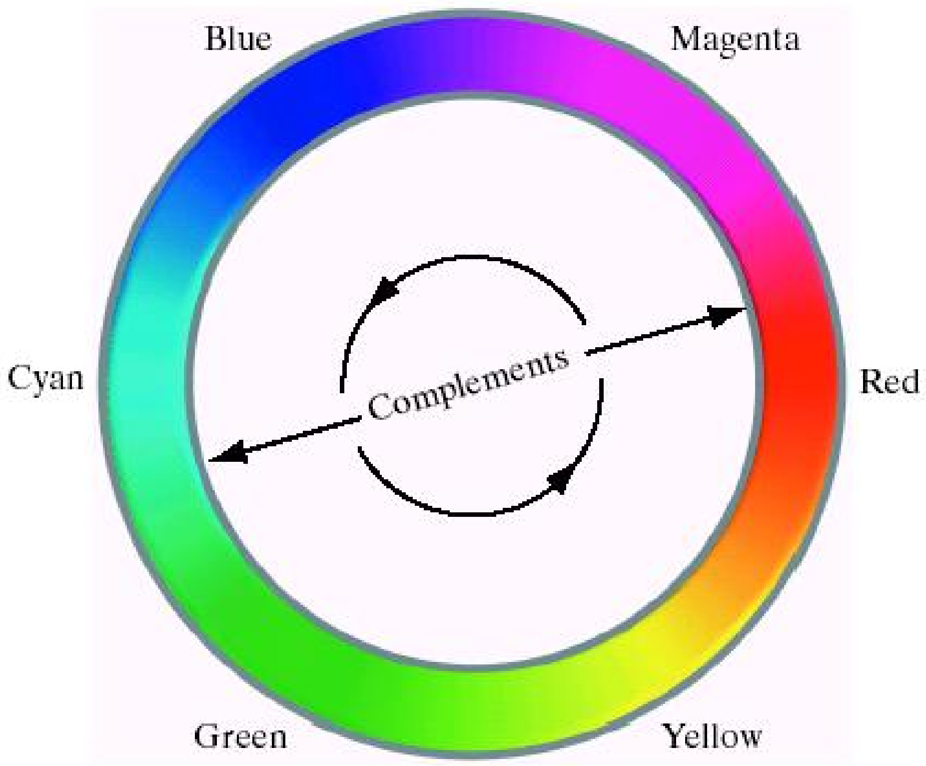
$$s_C(x,y) = kr_C(x,y) + (1-k)$$
$$s_M(x,y) = kr_M(x,y) + (1-k)$$
$$s_Y(x,y) = kr_Y(x,y) + (1-k)$$

These 3 transformations give the same results.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Complements

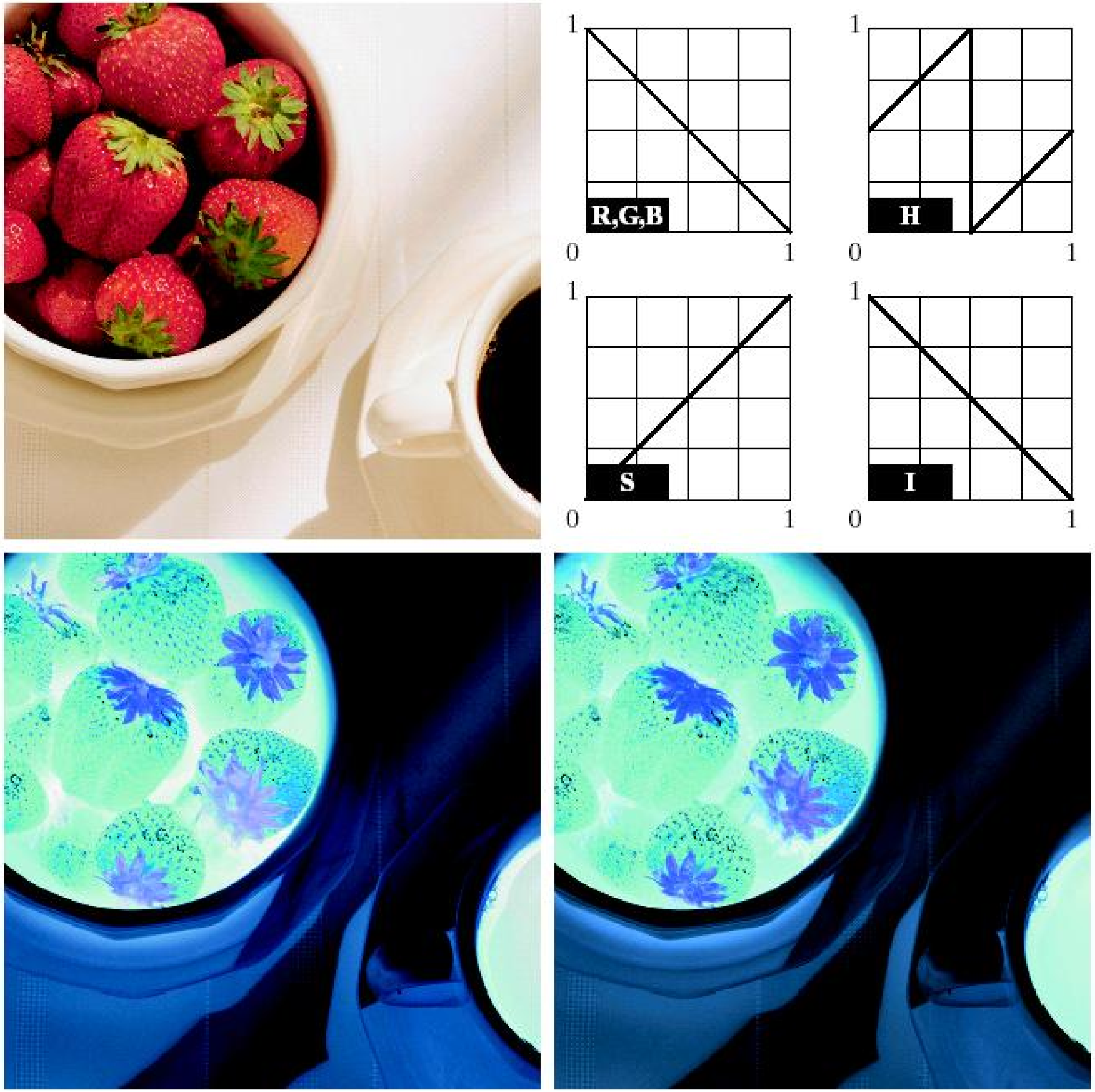
Color complement replaces each color with its opposite color in the color circle of the Hue component. This operation is analogous to image negative in a gray scale image.



Color circle

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Complement Transformation Example



a b
c d

FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Slicing Transformation

We can perform "slicing" in color space: if the color of each pixel is far from a desired color more than threshold distance, we set that color to some specific color such as gray, otherwise we keep the original color unchanged.

$$s_i = \begin{cases} 0.5 & \text{if } \left[\left| r_j - a_j \right| > \dfrac{W}{2} \right]_{any\ 1 \le j \le n} \\ r_i & \text{otherwise} \end{cases}$$

Set to gray

Keep the original color

$i = 1, 2, \ldots, n$

or

$$s_i = \begin{cases} 0.5 & \text{if } \sum_{j=1}^{n} \left(r_j - a_j \right)^2 > R_0^2 \\ r_i & \text{otherwise} \end{cases}$$

Set to gray

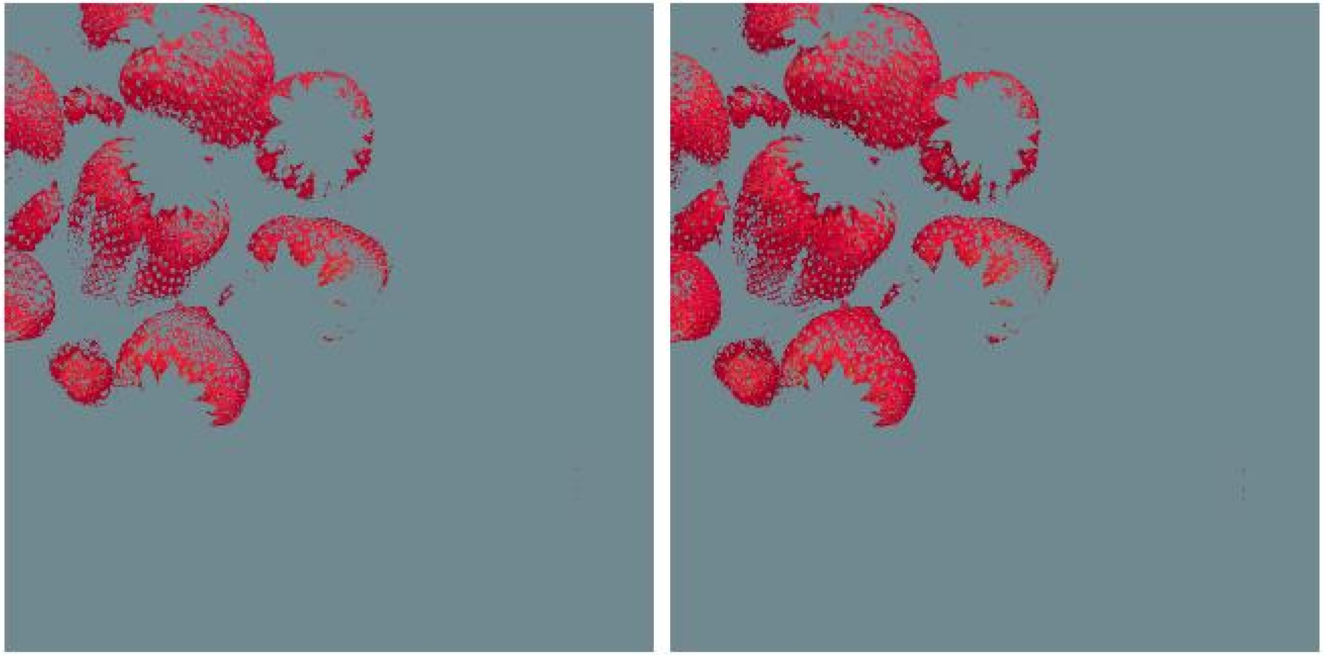
Keep the original color

$i = 1, 2, \ldots, n$

Color Slicing Transformation Example

After color slicing

Original image

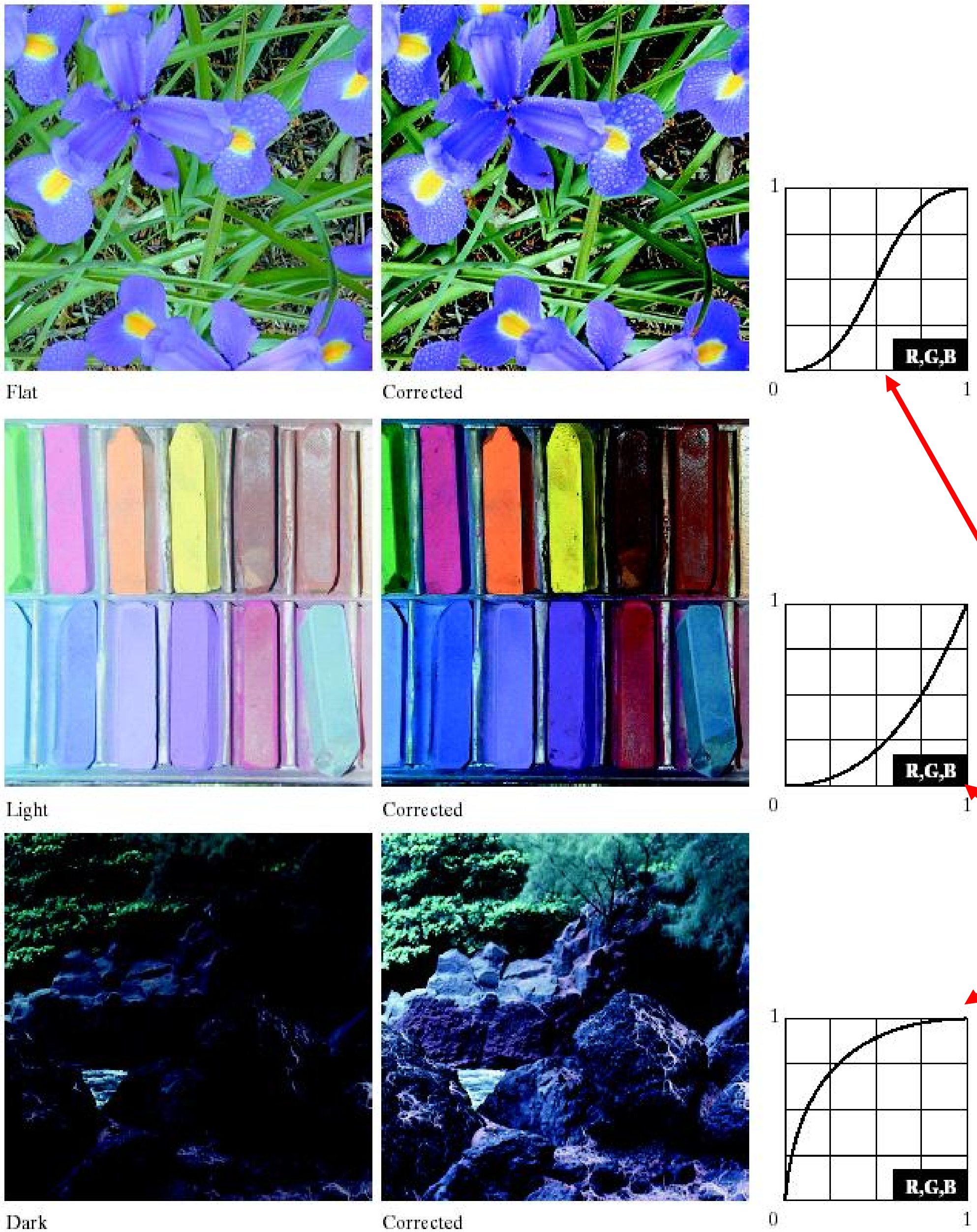


a b

FIGURE 6.34 Color slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at $(0.6863, 0.1608, 0.1922)$, and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color $(0.5, 0.5, 0.5)$.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Tonal Correction Examples



In these examples, only brightness and contrast are adjusted while keeping color unchanged.

This can be done by using the same transformation for all RGB components.

Contrast enhancement

Power law transformations

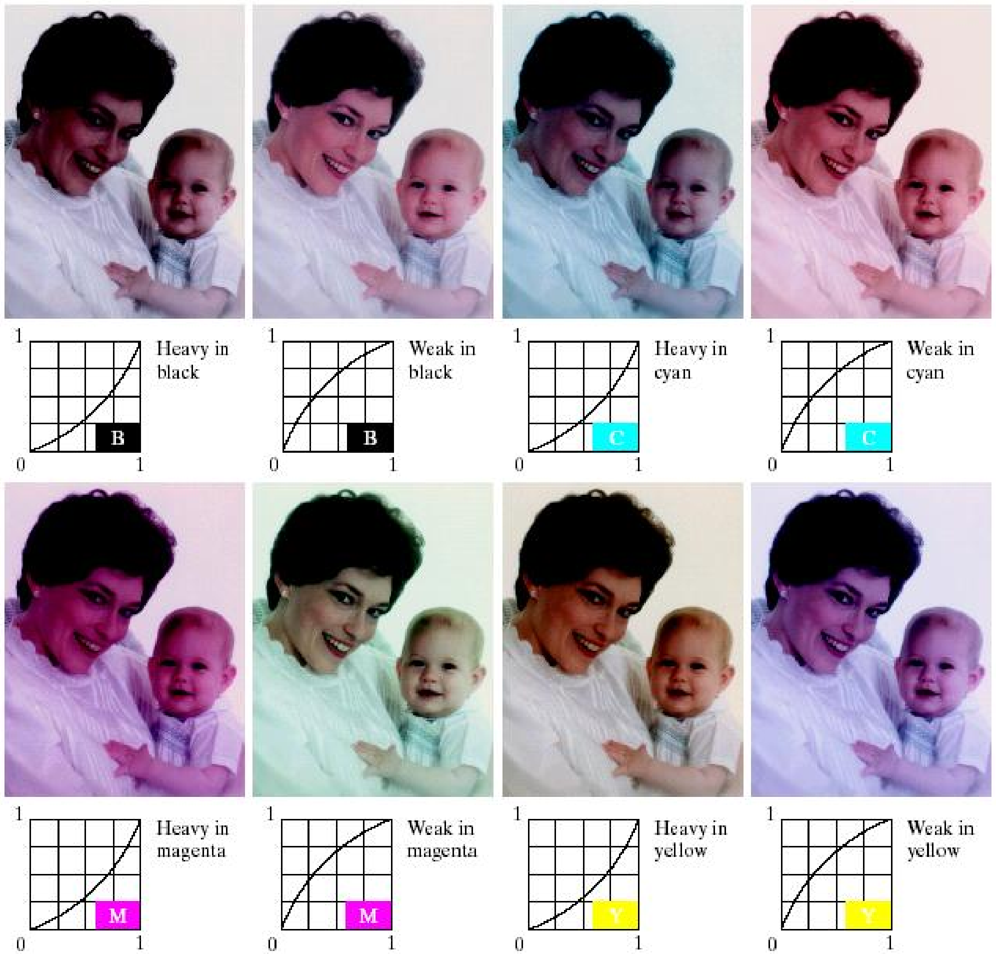
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Balancing Correction Examples

FIGURE 6.36 Color balancing corrections for CMYK color images.

Original/Corrected

Color imbalance: primary color components in white area are not balance. We can measure these components by using a color spectrometer.



Color balancing can be performed by adjusting color components separately as seen in this slide.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Histogram Equalization of a Full-Color Image

- Histogram equalization of a color image can be performed by adjusting color intensity uniformly while leaving color unchanged.

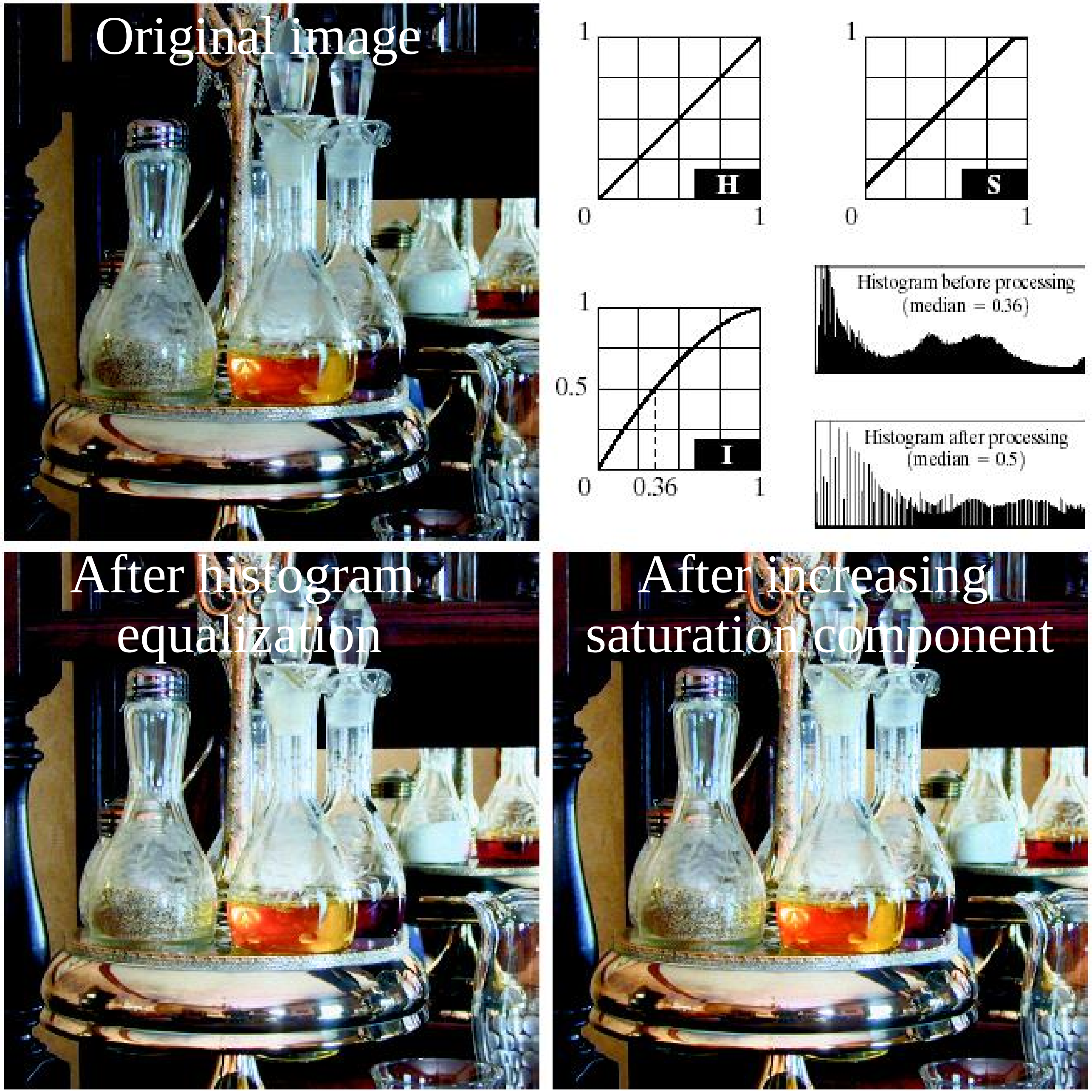
- The HSI model is suitable for histogram equalization where only Intensity (I) component is equalized.

$$s_k = T(r_k) = \sum_{j=0}^{k} p_r(r_j)$$

$$= \sum_{j=0}^{k} \frac{n_j}{N}$$

where r and s are intensity components of input and output color image.

Histogram Equalization of a Full-Color Image



a b
c d

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

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Smoothing

2 Methods:

1. Per-color-plane method: for RGB, CMY color models
   Smooth each color plane using moving averaging and the combine back to RGB

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

2. Smooth only Intensity component of a HSI image while leaving H and S unmodified.

Note: 2 methods are not equivalent.

Color Image Smoothing Example (cont.)

Color image

Red

Green

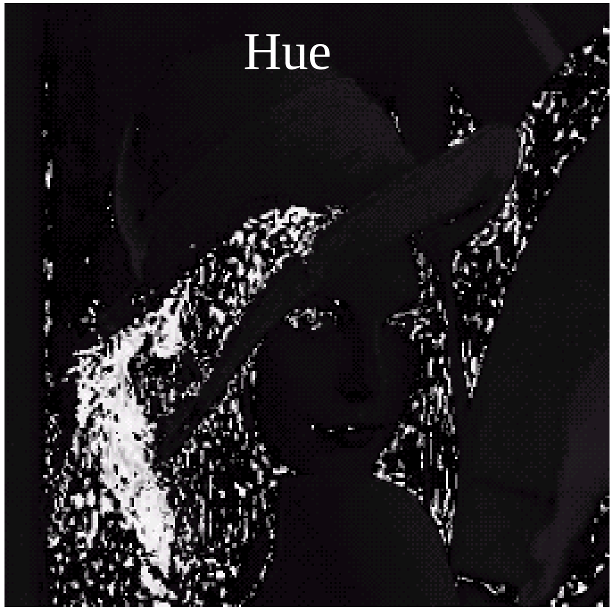
Blue

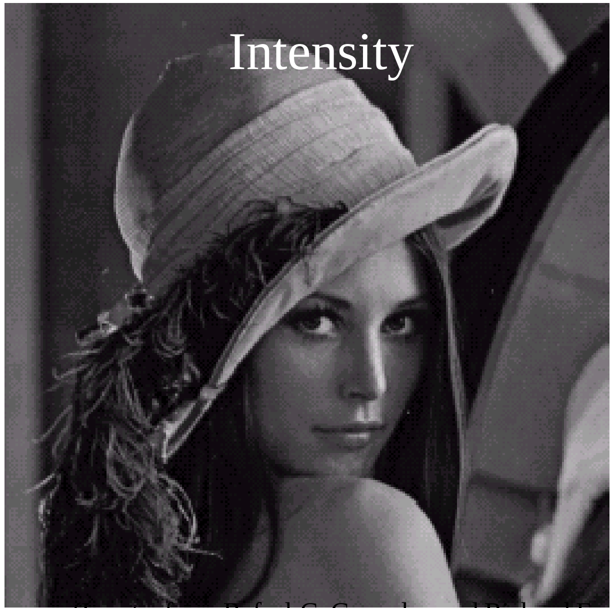
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Smoothing Example (cont.)

Color image

HSI Components





(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Smoothing Example (cont.)

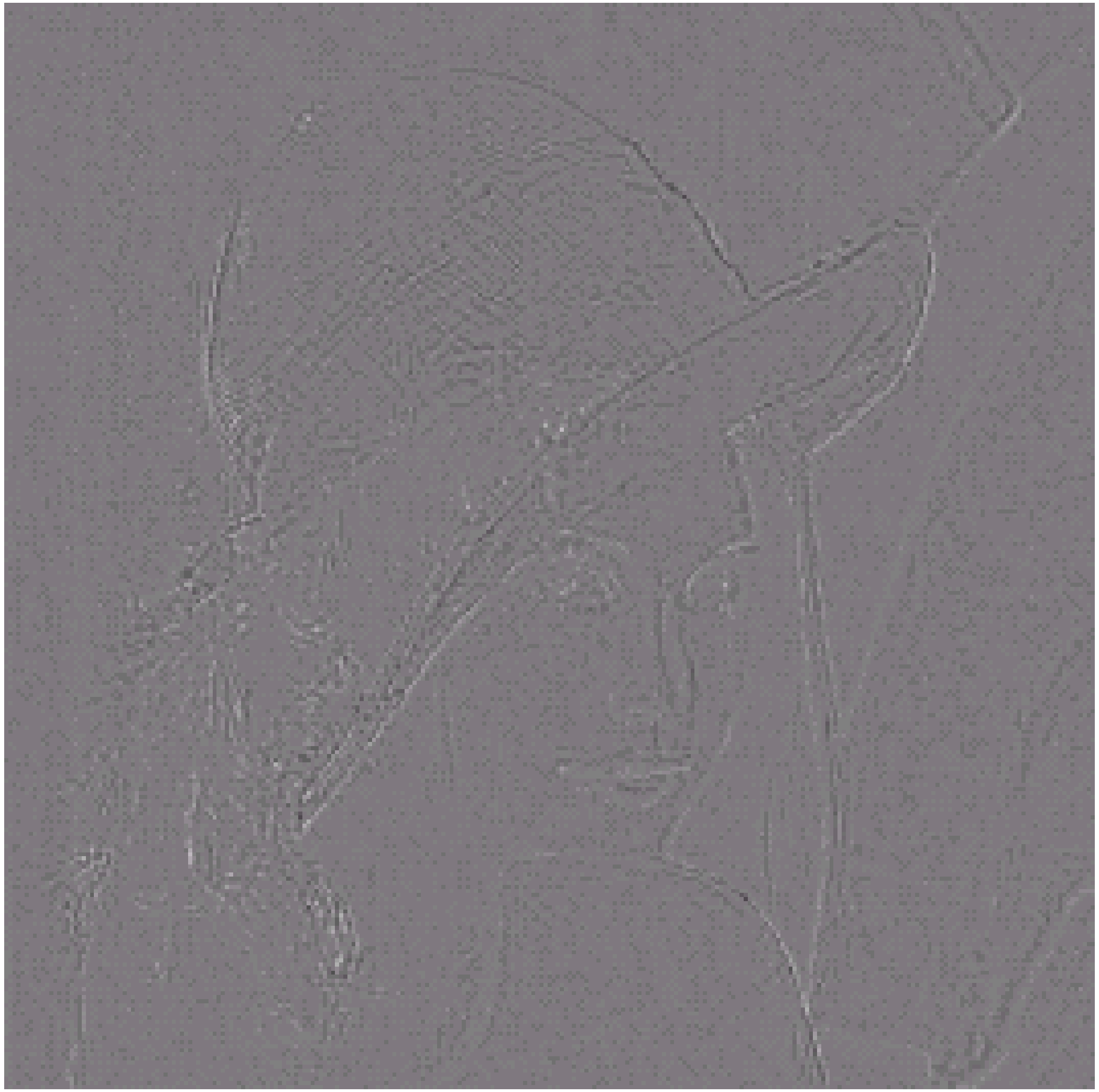
Smooth all RGB components

Smooth only I component of HSI

(faster)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Smoothing Example (cont.)



Difference between smoothed results from 2 methods in the previous slide.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Sharpening

We can do in the same manner as color image smoothing:

1. Per-color-plane method for RGB,CMY images
2. Sharpening only I component of a HSI image

Sharpening all RGB components

Sharpening only I component of HSI

Color Image Sharpening Example (cont.)

Difference between sharpened results from 2 methods in the previous slide.

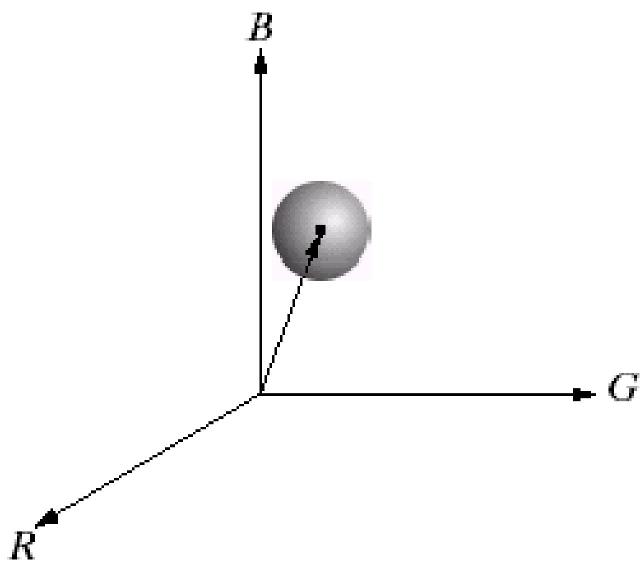
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Segmentation

2 Methods:

1. Segmented in HSI color space:
   A thresholding function based on color information in H and S Components. We rarely use I component for color image segmentation.

2. Segmentation in RGB vector space:
   A thresholding function based on distance in a color vector space.

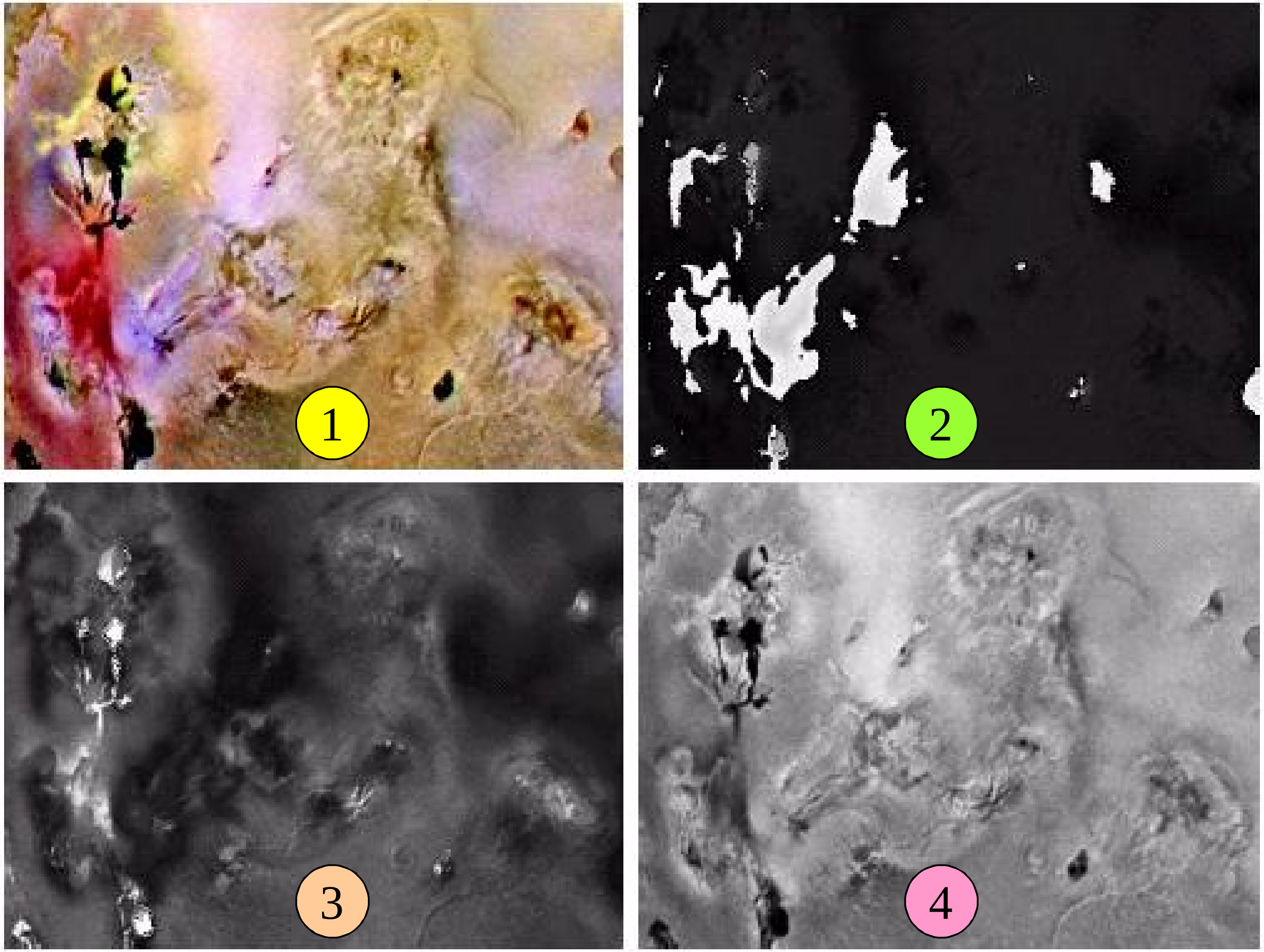


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Segmentation in HSI Color Space

Color image

Hue



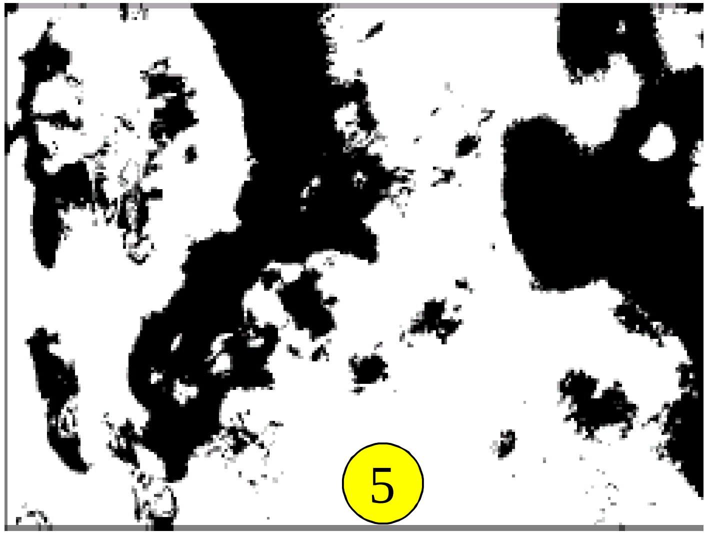
Saturation

Intensity

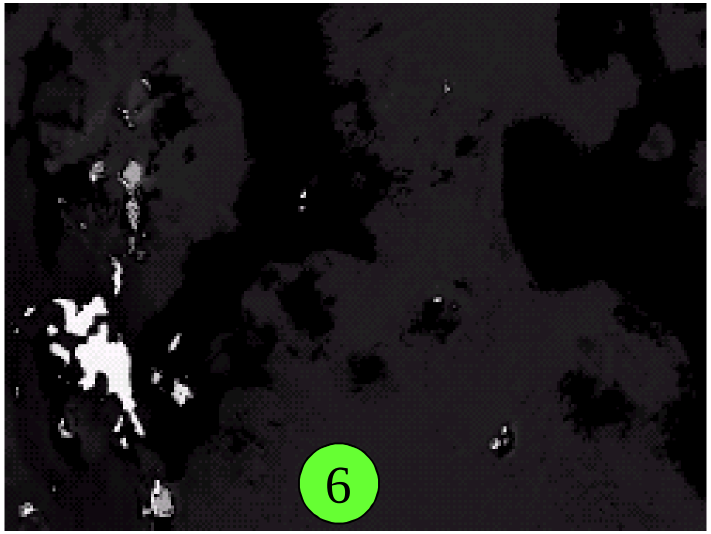
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

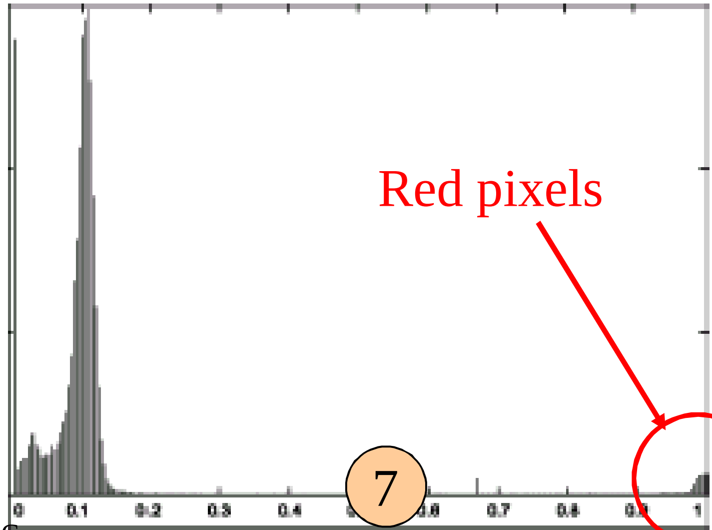
Color Segmentation in HSI Color Space (cont.)

Binary thresholding of S component with T = 10%

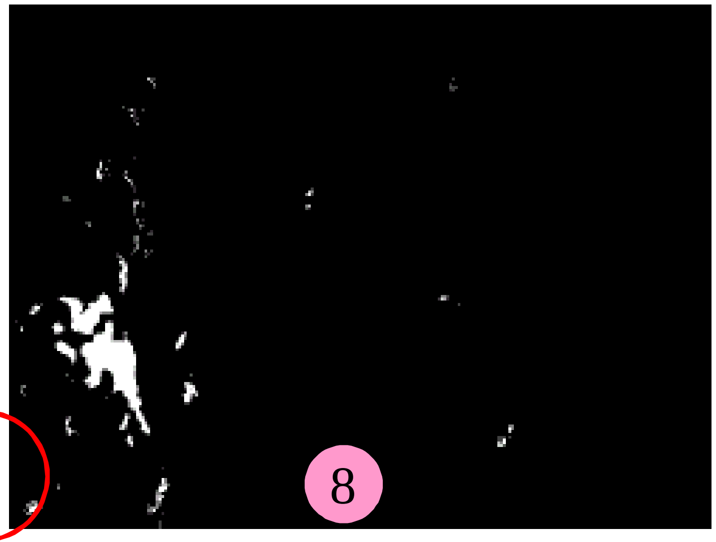


Product of 2 and 5





Histogram of 6



Segmentation of red color pixels

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.)

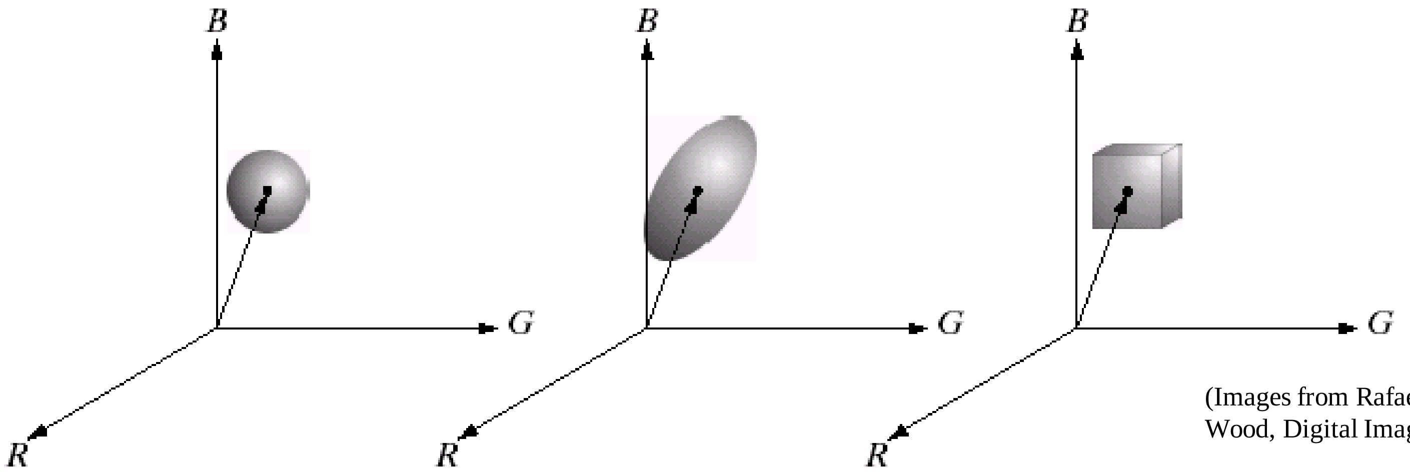
Color Segmentation in HSI Color Space (cont.)

Color image

Segmented results of red pixels

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Segmentation in RGB Vector Space



a b c

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

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

1. Each point with (R,G,B) coordinate in the vector space represents one color.
2. Segmentation is based on distance thresholding in a vector space

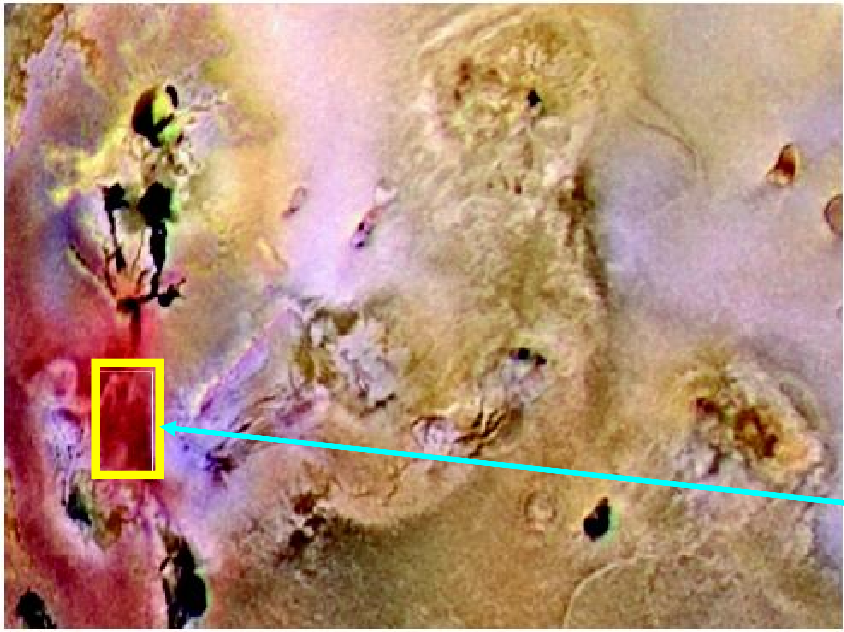
$$g(x,y)=\begin{cases}1 & \text{if } D(\mathbf{c}(x,y),\mathbf{c}_T)\le T\\ 0 & \text{if } D(\mathbf{c}(x,y),\mathbf{c}_T)> T\end{cases}$$

$D(\mathbf{u},\mathbf{v})$ = distance function

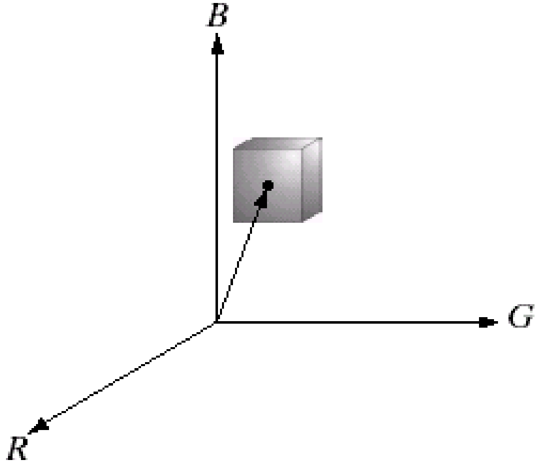
$\mathbf{c}_T$ = color to be segmented.

$\mathbf{c}(x,y)$ = RGB vector at pixel (x,y).

Example: Segmentation in RGB Vector Space



Color image



Reference color $\mathbf{c}_T$ to be segmented

$\mathbf{c}_T =$ average color of pixel in the box

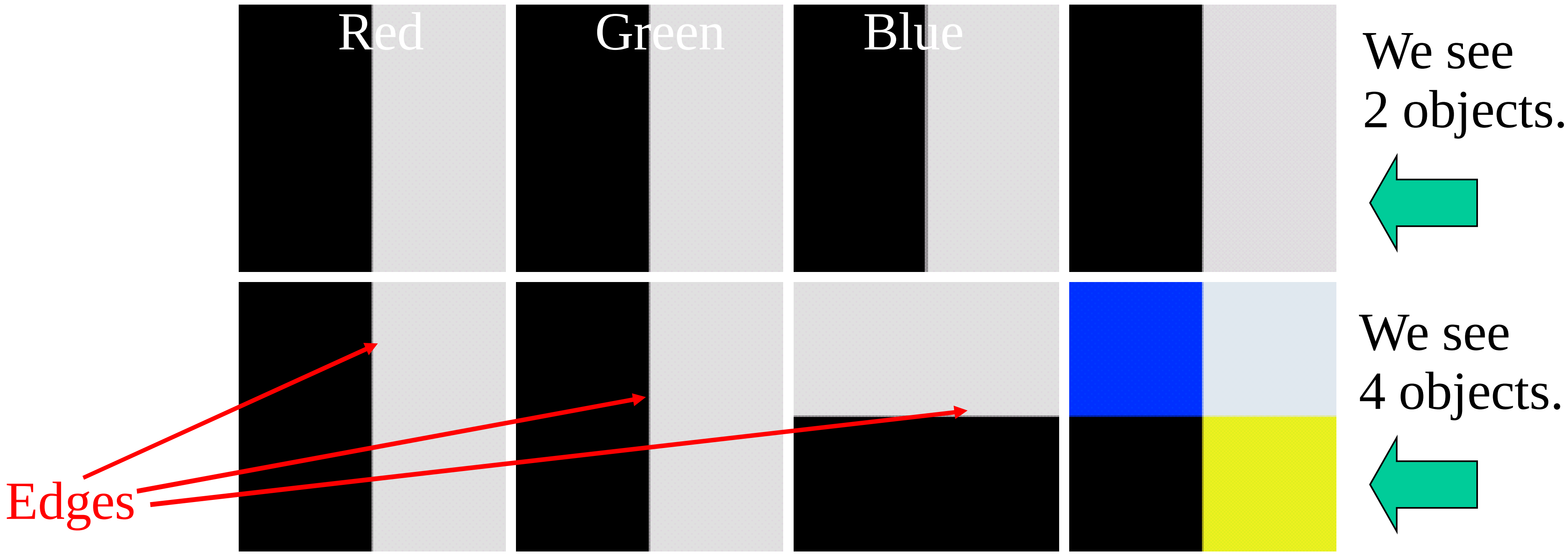
Results of segmentation in RGB vector space with Threshold value

T = 1.25 times the SD of R,G,B values In the box

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gradient of a Color Image

Since gradient is define only for a scalar image, there is no concept of gradient for a color image. We can't compute gradient of each color component and combine the results to get the gradient of a color image.



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gradient of a Color Image (cont.)

One way to compute the maximum rate of change of a color image which is close to the meaning of gradient is to use the following formula: Gradient computed in RGB color space:

$$F(q) = \left\{ \frac{1}{2} \left[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy}) \cos 2q + 2 g_{xy} \sin 2q \right] \right\}^{\frac{1}{2}}$$

$$q = \frac{1}{2} \tan^{-1} \left[\frac{2 g_{xy}}{\left(g_{xx} - g_{yy} \right)} \right]$$

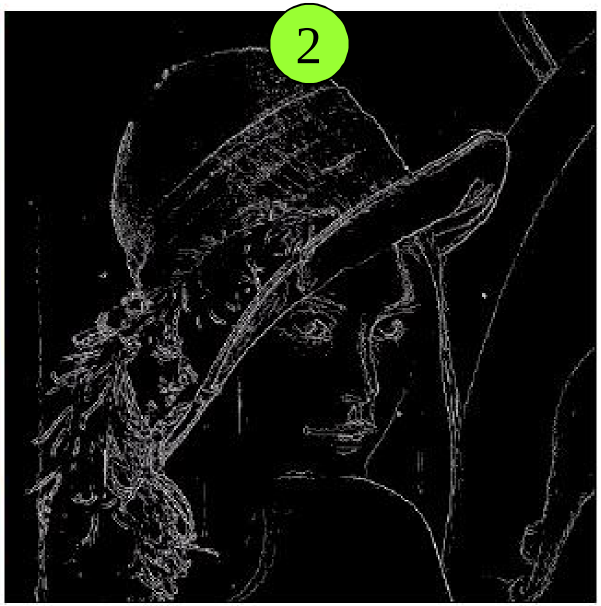
$$g_{xx} = \left| \frac{\partial R}{\partial x} \right|^2 + \left| \frac{\partial G}{\partial x} \right|^2 + \left| \frac{\partial B}{\partial x} \right|^2$$

$$g_{yy} = \left| \frac{\partial R}{\partial y} \right|^2 + \left| \frac{\partial G}{\partial y} \right|^2 + \left| \frac{\partial B}{\partial y} \right|^2$$

$$g_{xy} = \frac{\partial R}{\partial x} \frac{\partial R}{\partial y} + \frac{\partial G}{\partial x} \frac{\partial G}{\partial y} + \frac{\partial B}{\partial x} \frac{\partial B}{\partial y}$$

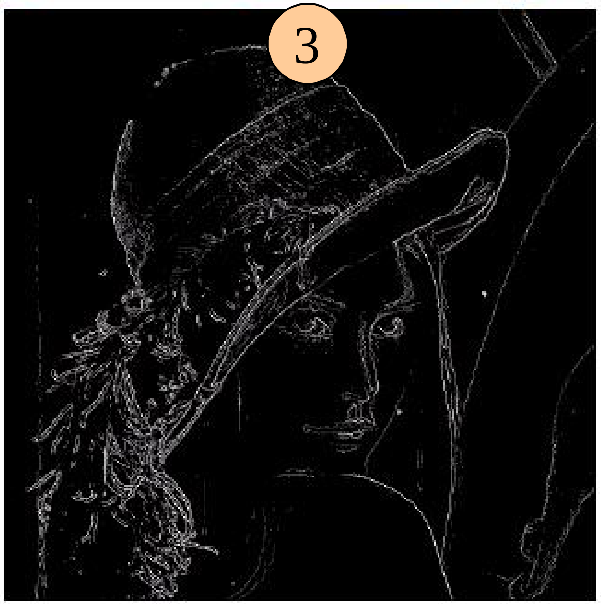
Gradient of a Color Image Example

Original image



Obtained using the formula in the previous slide

Sum of gradients of each color component



Difference between 2 and 3

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gradient of a Color Image Example

Gradients of each color component

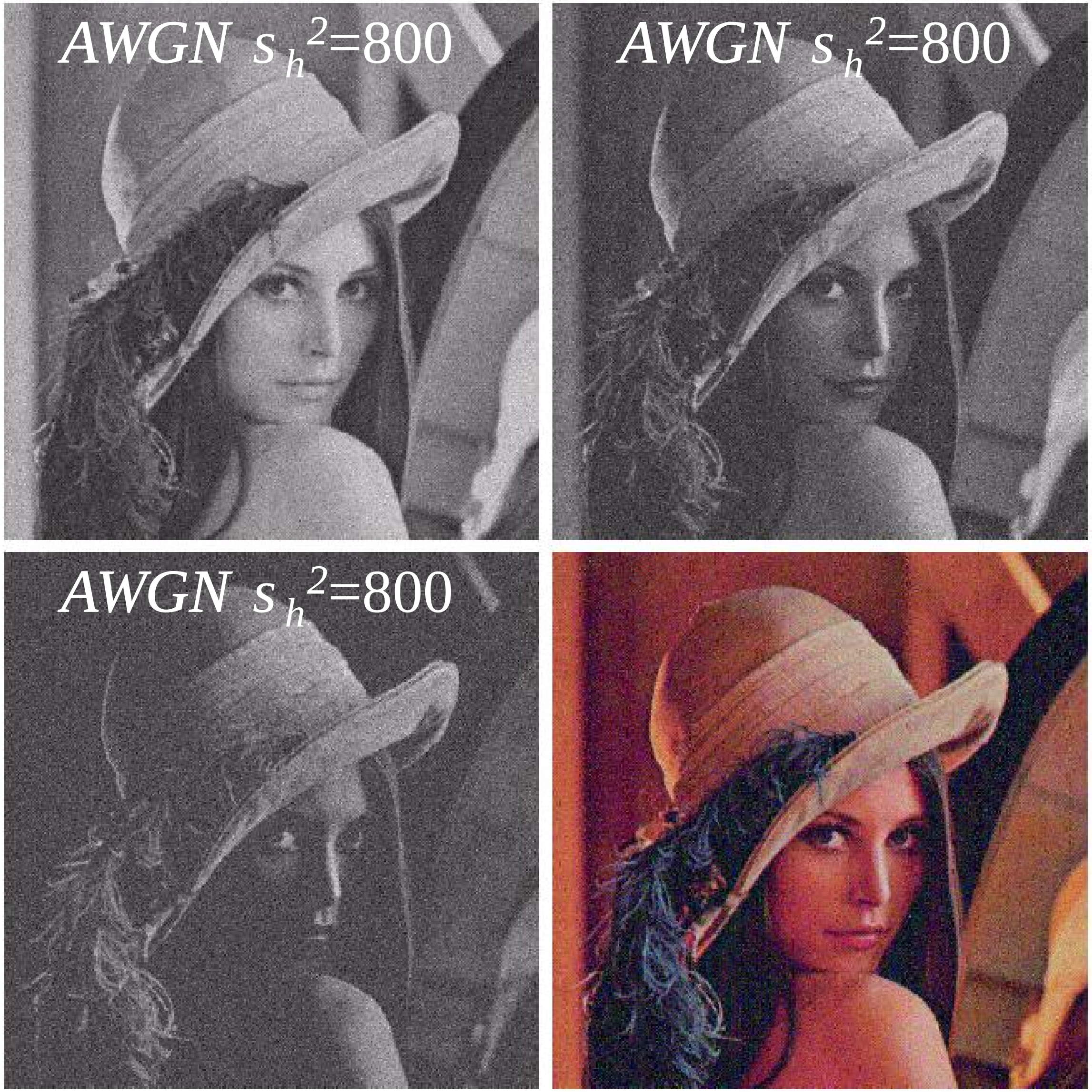
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Noise in Color Images

Noise can corrupt each color component independently.

a b
c d

FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]



Noise is less noticeable in a color image

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Noise in Color Images

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Noise in Color Images

a b
c d

FIGURE 6.50
(a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Compression

Original image

JPEG2000 File

After lossy compression with ratio 230:1

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.