Digital Image Processing
Chapter 6:
Color Image Processing

Spectrum of White Light

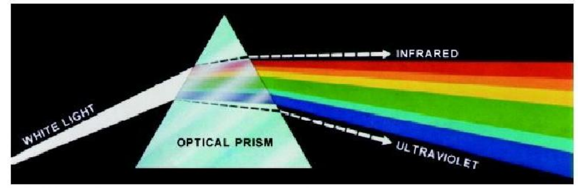
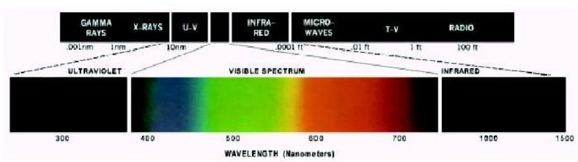


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

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

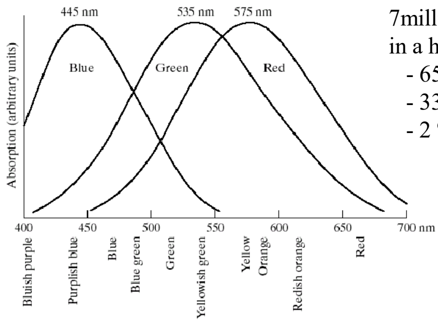
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

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



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

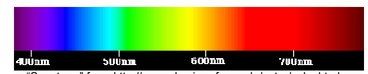
Primary colors:
Defined CIE in 1931
Red = 700 nm
Green = 546.1nm
Blue = 435.8 nm

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.

Color of Light

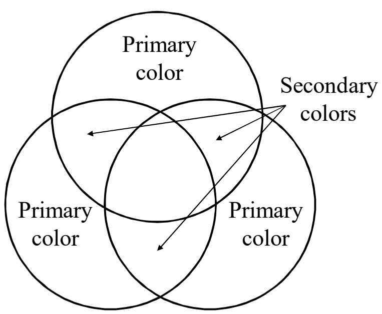
- Perceived color depends on spectral content (wavelength composition)
  - e.g., 700nm ~ red.
  - "spectral color"
    - A light with very narrow bandwidth



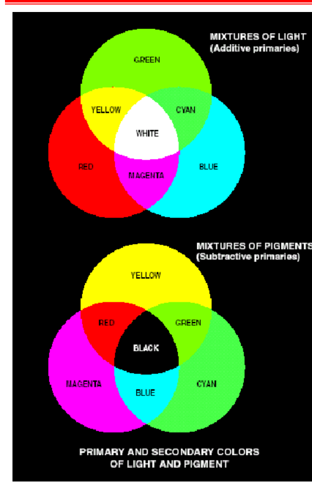
"Spectrum" from http://www.physics.sfasu.edu/astro/color.html

- 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.

Example: Seeing Yellow Without Yellow

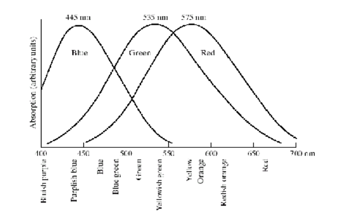
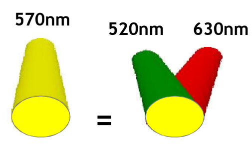


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



mix green and red light to obtain perception of yellow, 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 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)

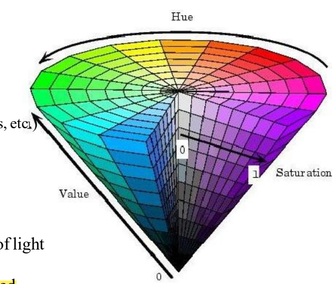
Brightness: Intensity

Hue
Saturation
} Chromaticity

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

Perceptual Attributes of Color

- 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 ☐ HSV Conversion ~ *nonlinear*



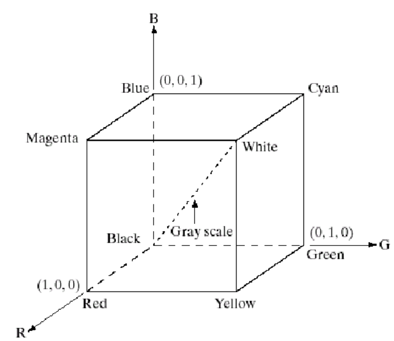
HSV circular cone is from online documentation of Matlab image processing toolbox

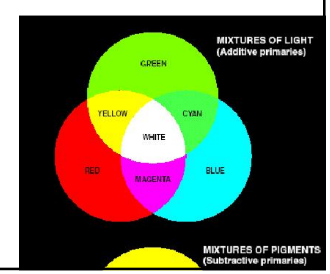
http://www.mathworks.com/access/helpdesk/help/toolbox/images/color10.shtml

RGB Color Model

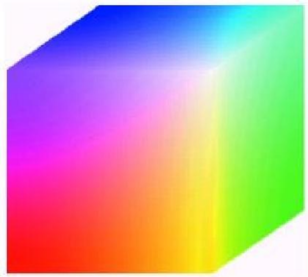
Purpose of color models: to facilitate the specification of colors in some standard

RGB color models:
- based on cartesian coordinate system



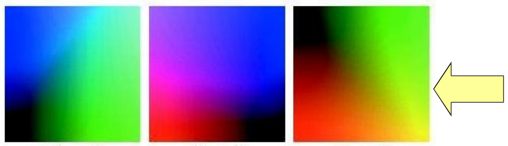


RGB Color Cube



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

Color depth 24 bits = 16777216 colors

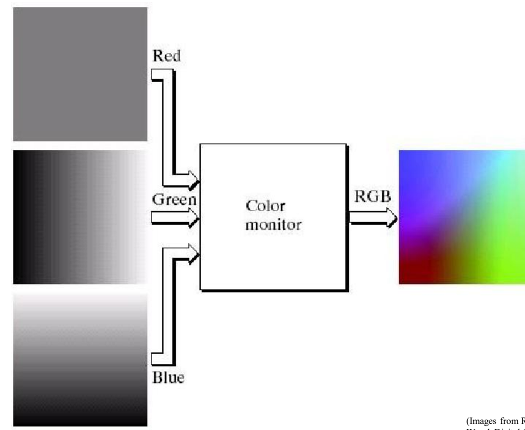


(R = 0) (G = 0) (B = 0)

Hidden faces of the cube

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

RGB Color Model (cont.)

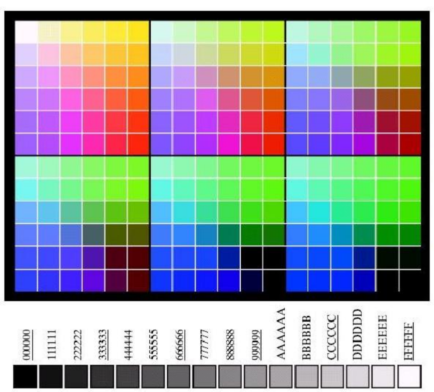


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



a
b

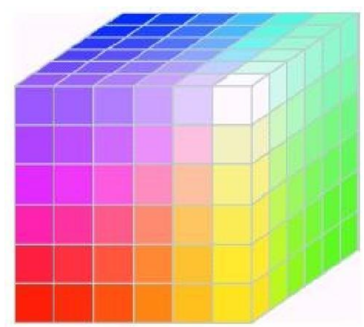
FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

(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.

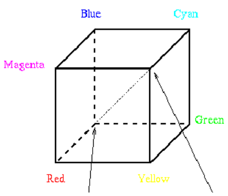
However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

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

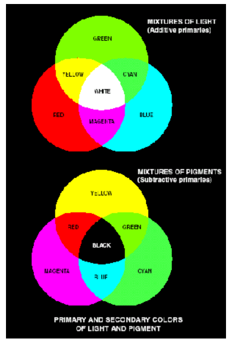
CMY and CMYK Color Models

- 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

C = Cyan
M = Magenta
Y = Yellow
K = 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

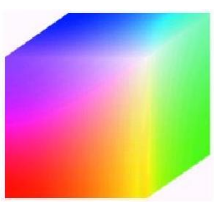
Saturation: Relative purity (inversely proportional to amount of white light added)

(Hue and Saturation:) Color carrying information

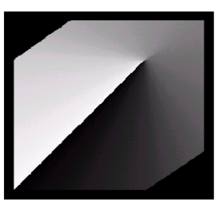
Intensity: Brightness

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

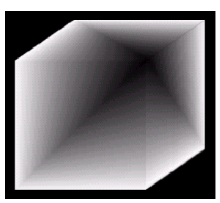
Example: HSI Components of RGB Cube



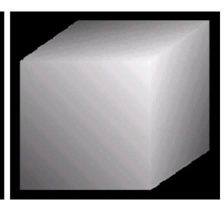
RGB Cube



Hue



Saturation



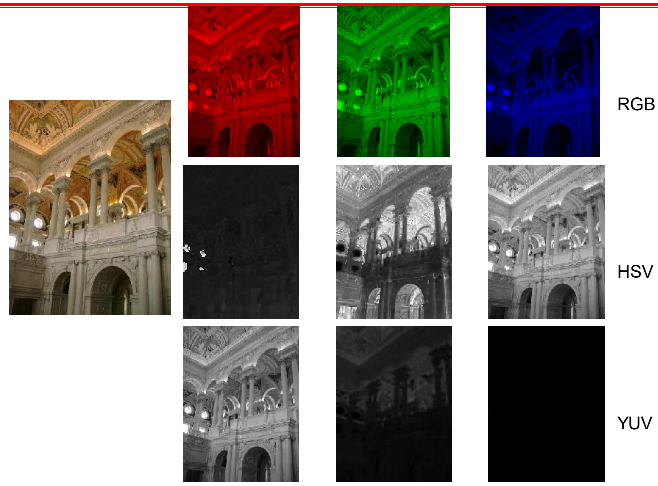
Intensity

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

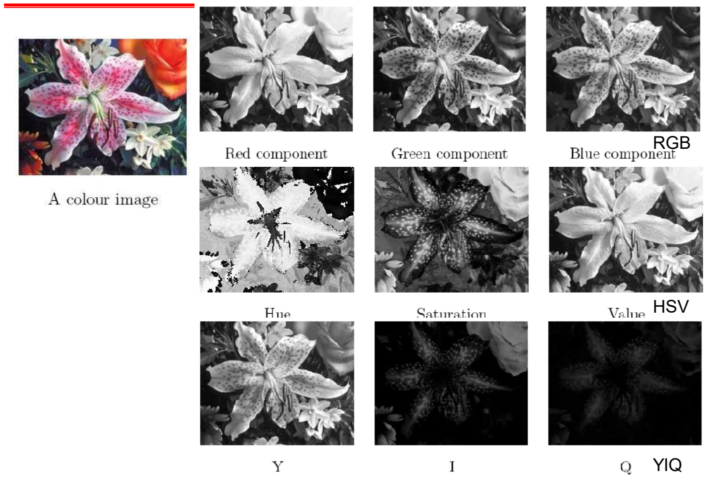
Color Coordinates

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

Examples



Examples



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

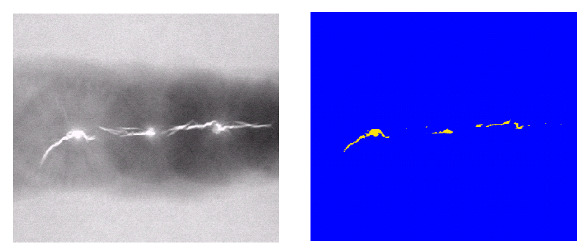
2. Full color image process: The process to manipulate real color images such as color photographs.

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.



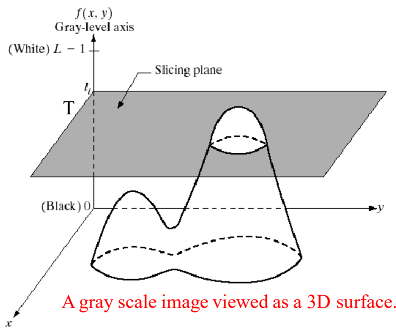
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Intensity Slicing or Density Slicing

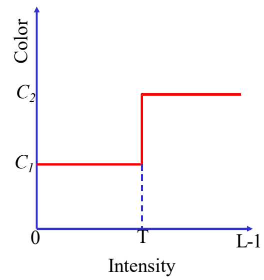
Formula:

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

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

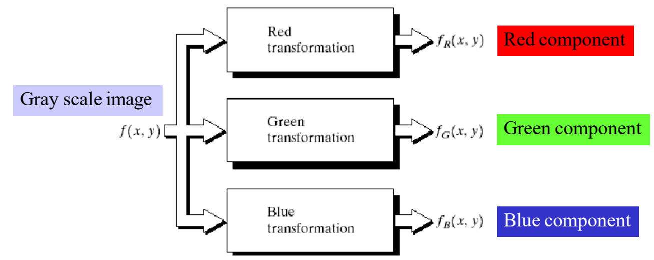


A gray scale image viewed as a 3D surface.



Gray Level to Color Transformation

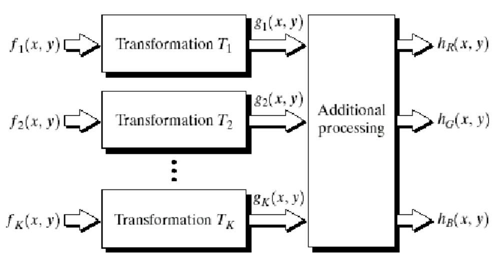
Assigning colors to gray levels based on specific mapping functions



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

Pseudocolor Coding

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

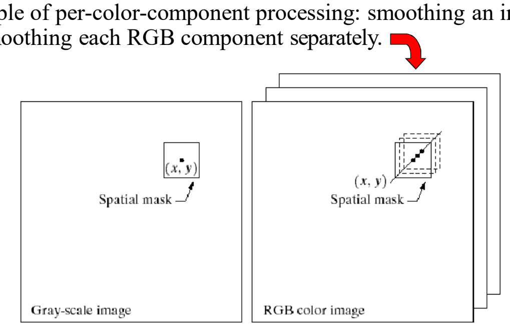


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Basics of Full-Color Image Processing

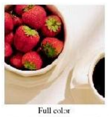
2 Methods:
1. Per-color-component processing: process each component separately.
2. Vector processing: treat each pixel as a vector to be processed.

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

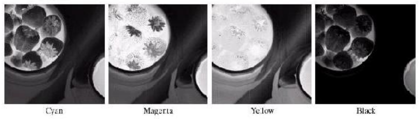


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

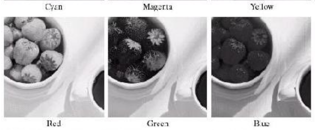
Example: *Full-Color Image and Variouis Color Space Components*



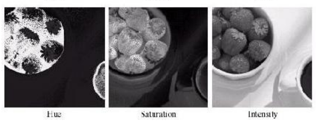
Color image



CMYK components



RGB components



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:

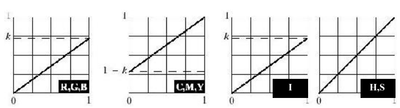
$$s_R(x,y) = kr_R(x,y)$$
$$s_G(x,y) = kr_G(x,y)$$
$$s_B(x,y) = kr_B(x,y)$$

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.

Histogram Equalization of a Full-Color Image

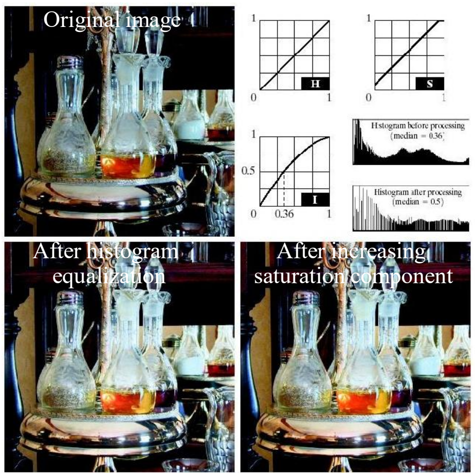
❖Histogram equalization of a color image can be performed by adjusting color intensity uniformly while leaving color unchanged.

❖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

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

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.)

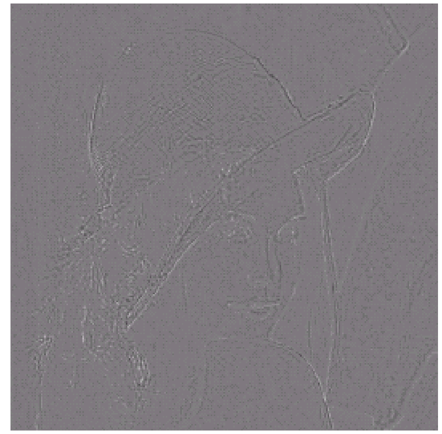
Smooth all RGB components

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.

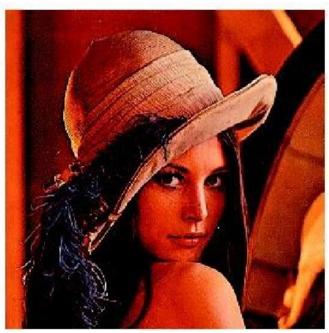
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

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.