Image and Video Processing

Colour Image Processing

- **Motive**

- Color is a powerful descriptor that often simplifies object identification and extraction from a scene.

- Human can discern thousands of color shades and intensities, compared to about only two dozen shades of gray.

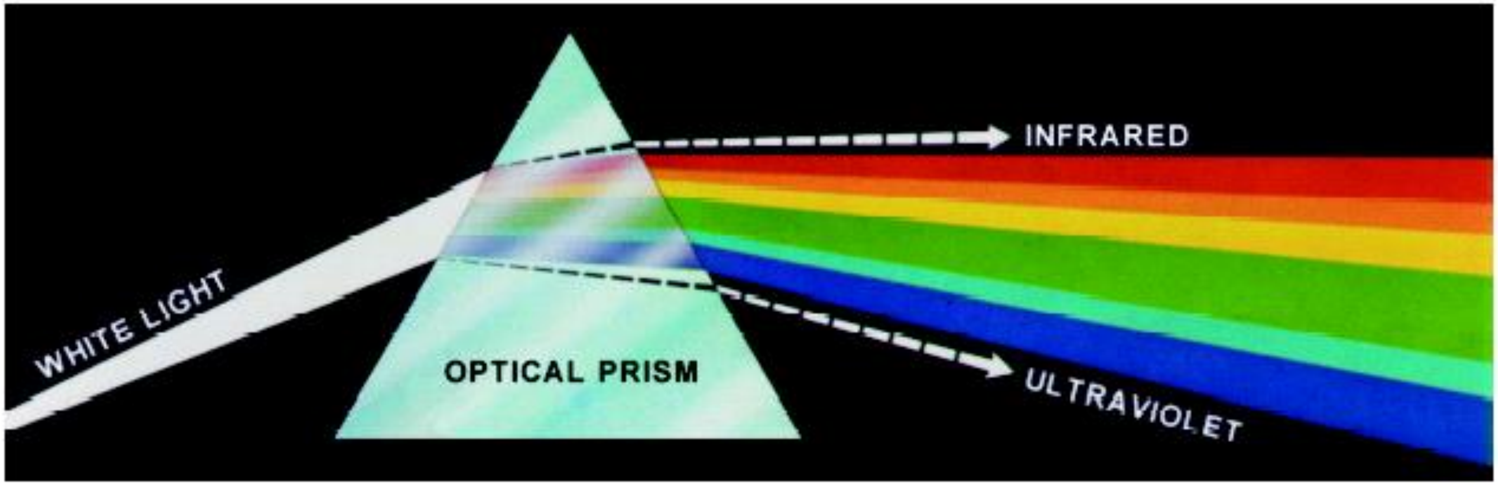
Introduction

We'll look at color image processing, covering:

- Color fundamentals and models
  - Color spectrum vs. electromagnetic spectrum
  - CIE standard, R, G, B as the primary colors
  - Chromaticity diagram
  - Color models – RGB, HSI etc.
- Color Processing
  - Grey to color - Psuedo coloring
  - Processing using RGB model vs. HSI model
  - Color Enhancement, Segmentation etc.

Color Spectrum

In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colours

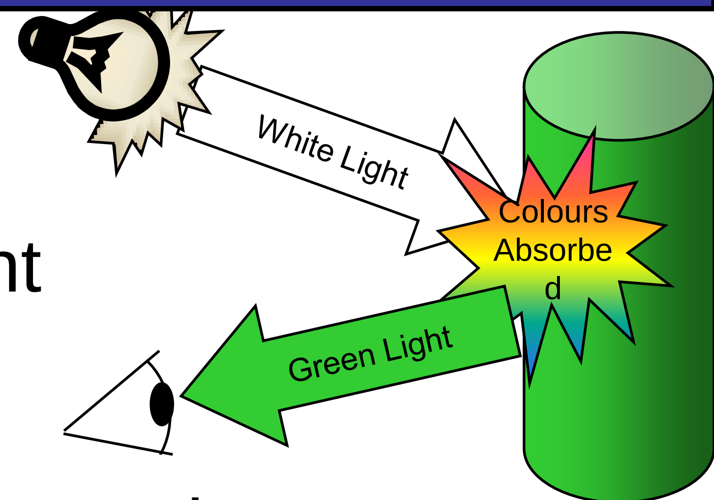


Some Questions?

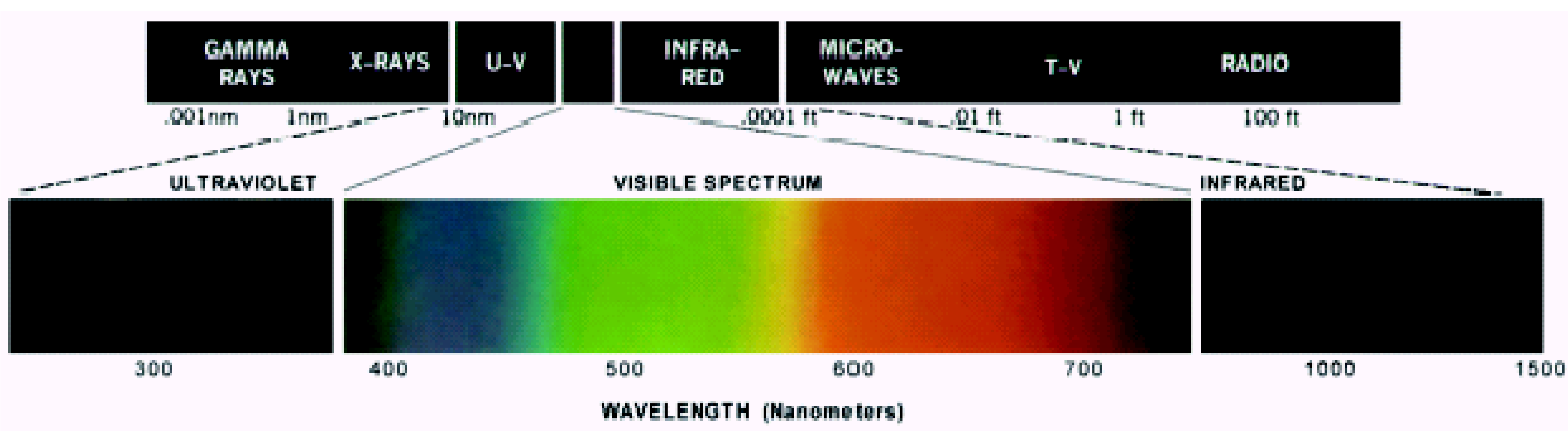
- What does it mean when we say an object is in a certain color?
- Why are the primary colors of human vision red, green, and blue?
- Is it true that different proportions of red, green, and blue can produce all the visible color?
- What kind of color model is the most suitable one to describe human vision? What is more suitable for digital processing?

Colors of human vision

The colors that humans and most animals perceive in an object are determined by the nature of the light reflected from the object



Chromatic light spans the electromagnetic spectrum from approximately 400 to 700nm



Colors of human vision (cont..)

- As we mentioned before human colour vision is achieved through 6 to 7 million cones in each eye
- Approximately 66% of these cones are sensitive to red light, 33% to green light and 3% to blue light
- For this reason, red, green, and blue are referred to as the primary colors of human vision.
- Tristimulus: the amount of R, G, B needed to form any color (X, Y, Z)
- Trichromatic coefficients: x, y, z

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

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

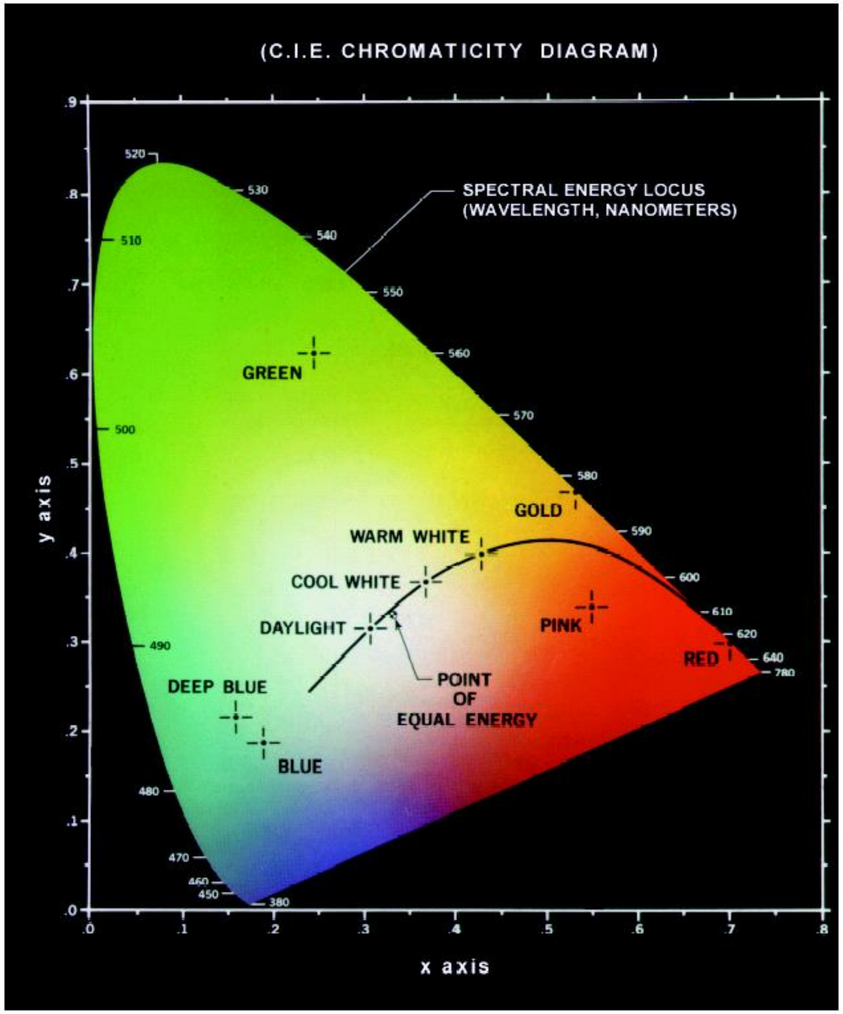
$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

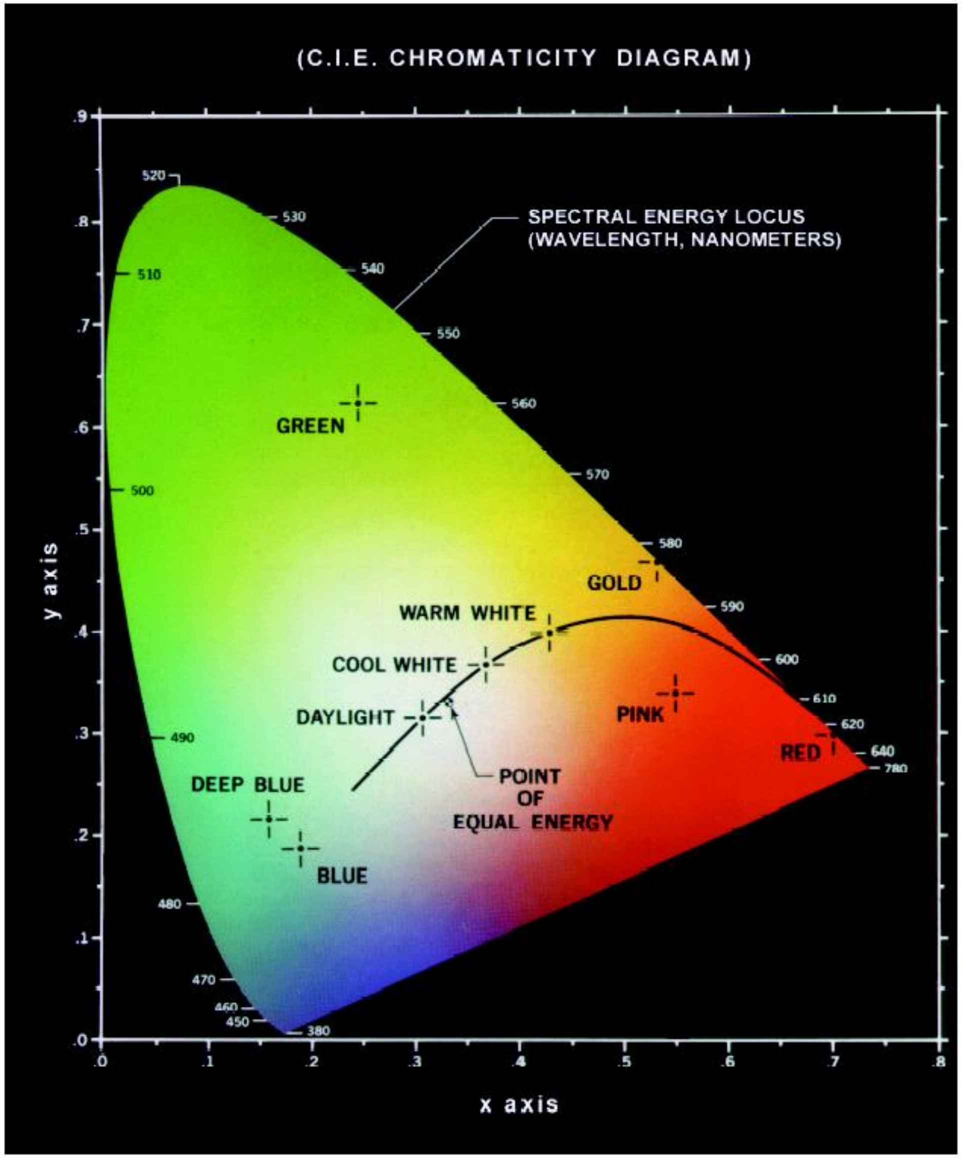
CIE Chromacity Diagram

- Specifying colors systematically can be achieved using the CIE **chromacity diagram**
- On this diagram the x-axis represents the proportion of red and the y-axis represents the proportion of red used
- The proportion of blue used in a color is calculated as:

$$z = 1 - (x + y)$$



CIE Chromacity Diagram (cont…)



Green: 62% green, 25% red and 13% blue

Red: 32% green, 67% red and 1% blue

CIE Chromacity Diagram (cont…)

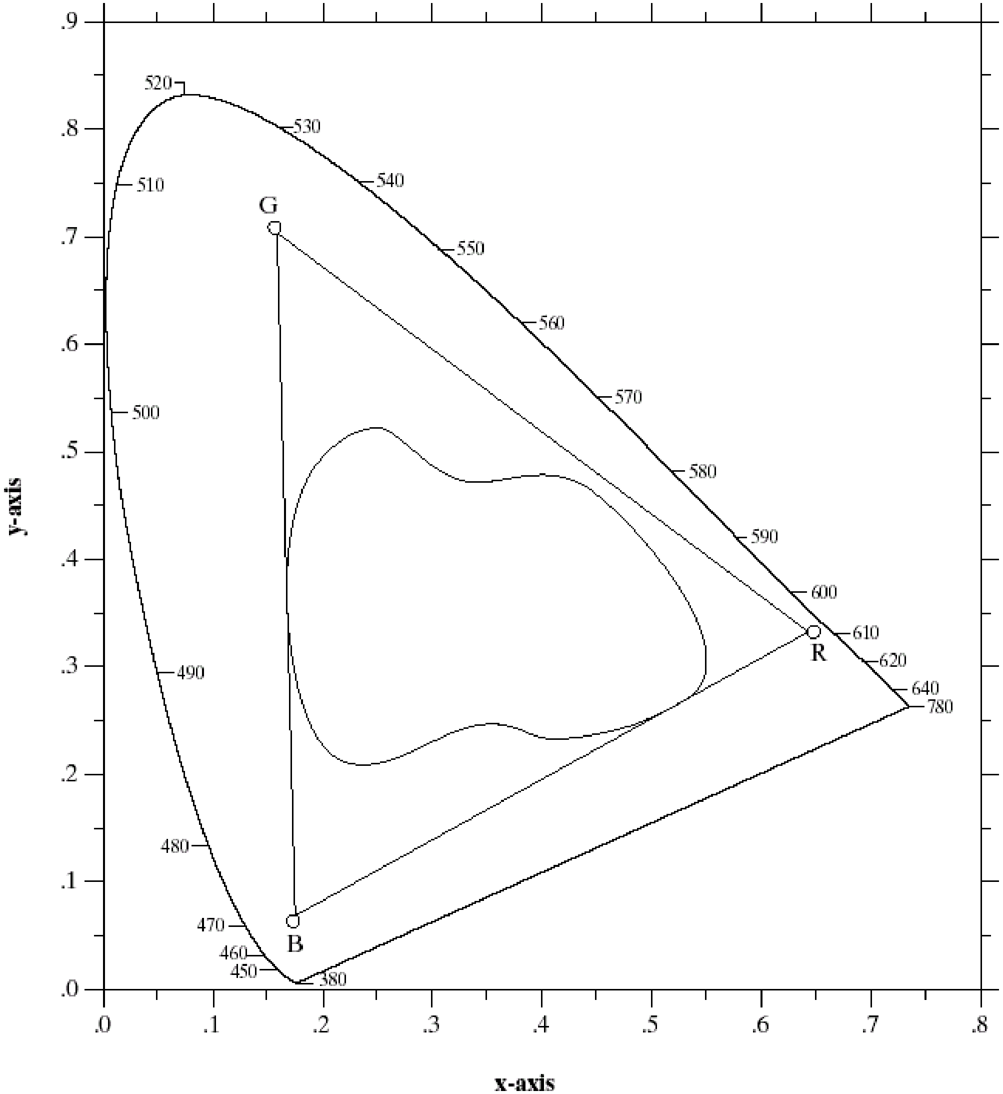
Any colour located on the boundary of the chromacity chart is fully saturated

The point of equal energy has equal amounts of each colour and is the CIE standard for pure white

Any straight line joining two points in the diagram defines all of the different colours that can be obtained by combining these two colours additively

This can be easily extended to three points

CIE Chromacity Diagram (cont…)



- This means the entire colour range cannot be displayed based on any three colours
- The triangle shows the typical colour gamut produced by RGB monitors
- The strange shape is the gamut achieved by high quality colour printers

Colour Models

From the previous discussion it should be obvious that there are different ways to model colour

We will consider two very popular models used in colour image processing:

- RGB (**R**ed **G**reen **B**lue)
- HSI (**H**ue **S**aturation **I**ntensity)

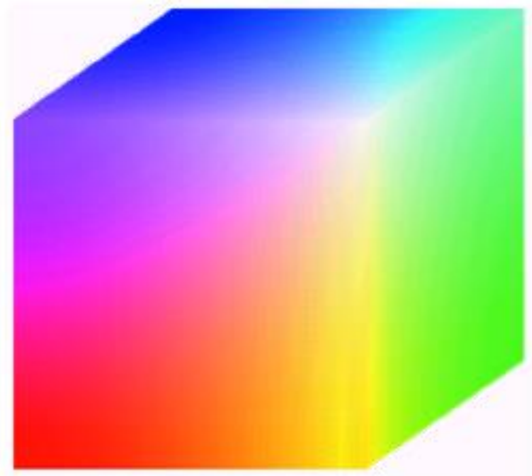
RGB

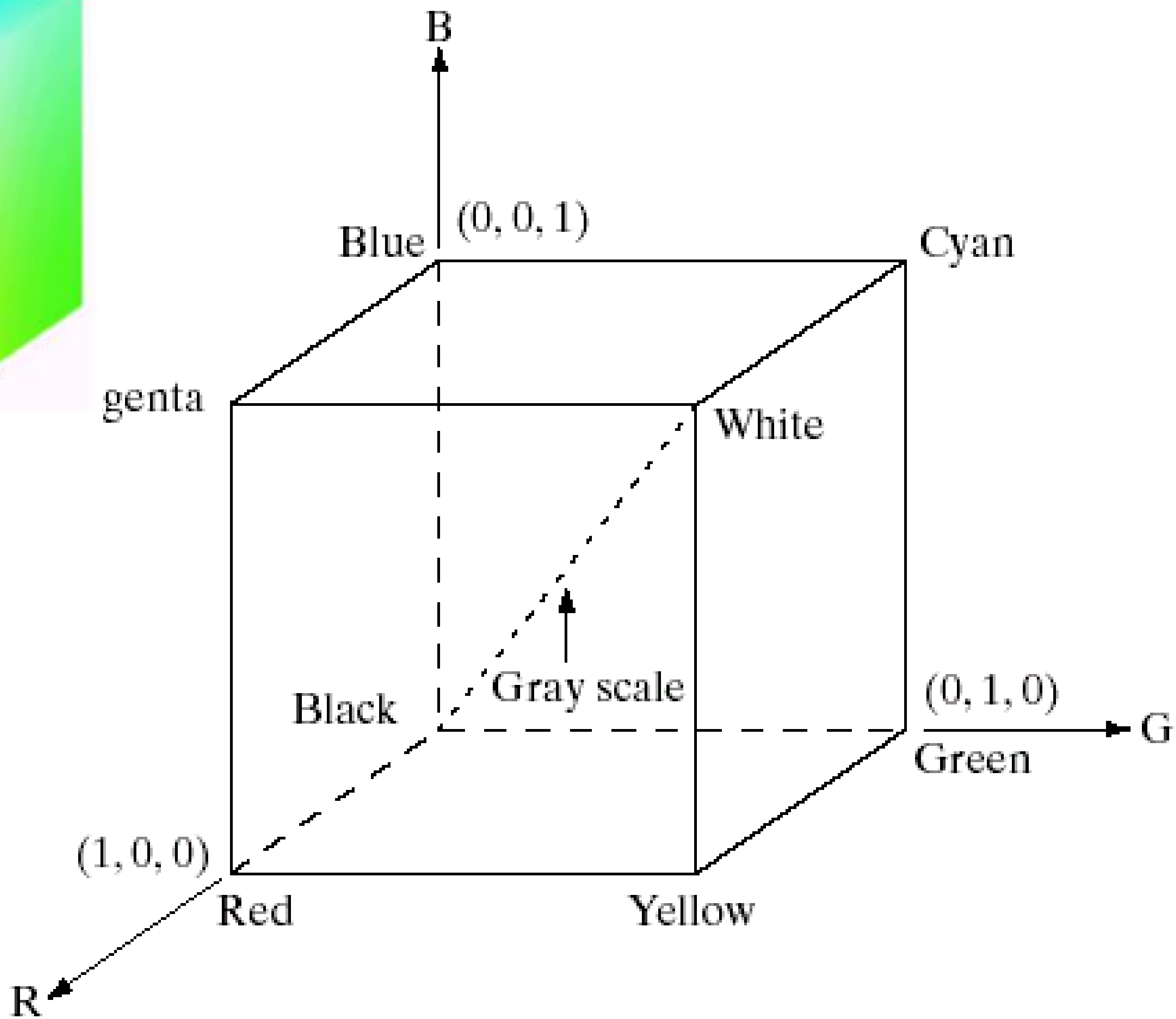
In the RGB model each colour appears in its primary spectral components of red, green and blue

The model is based on a Cartesian coordinate system

- RGB values are at 3 corners
- Cyan magenta and yellow are at three other corners
- Black is at the origin
- White is the corner furthest from the origin
- Different colours are points on or inside the cube represented by RGB vectors

RGB (cont…)




B
Blue
(0, 0, 1)
Cyan
genta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

RGB (cont…)

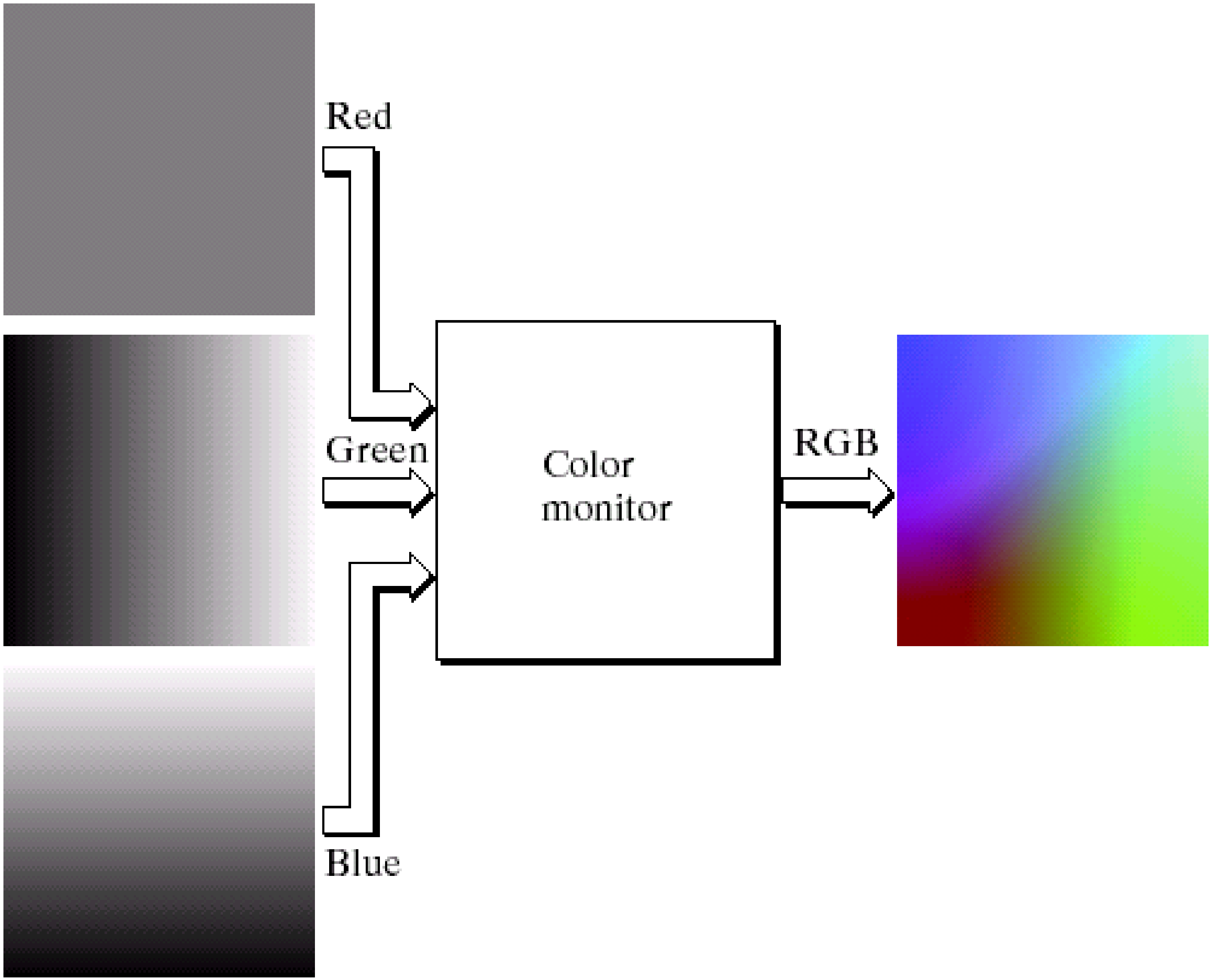
Images represented in the RGB colour model consist of three component images – one for each primary colour

When fed into a monitor these images are combined to create a composite colour image

The number of bits used to represent each pixel is referred to as the colour depth

A 24-bit image is often referred to as a full-colour image as it allows $\left(2^8\right)^3$ = 16,777,216 colours

RGB (cont…)



The HSI Colour Model

- RGB is useful for hardware implementations and is related to the way in which the human visual system works
- However, RGB is not a particularly intuitive way in which to describe colours
- Rather when people describe colours they tend to use **hue**, **saturation** and **brightness**
- HSI model is particularly good for colour description and manipulation

The HSI Colour Model (cont…)

The HSI model uses three measures to describe colours:

- **Hue:** dominant color perceived by an observer (say yellow, orange or red)
- **Saturation:** Gives a measure of relative purity or how much white is mixed with a pure colour (hue)
- **Intensity:** Intensity is the same achromatic notion that we have seen in grey level images.

HSI, Intensity & RGB

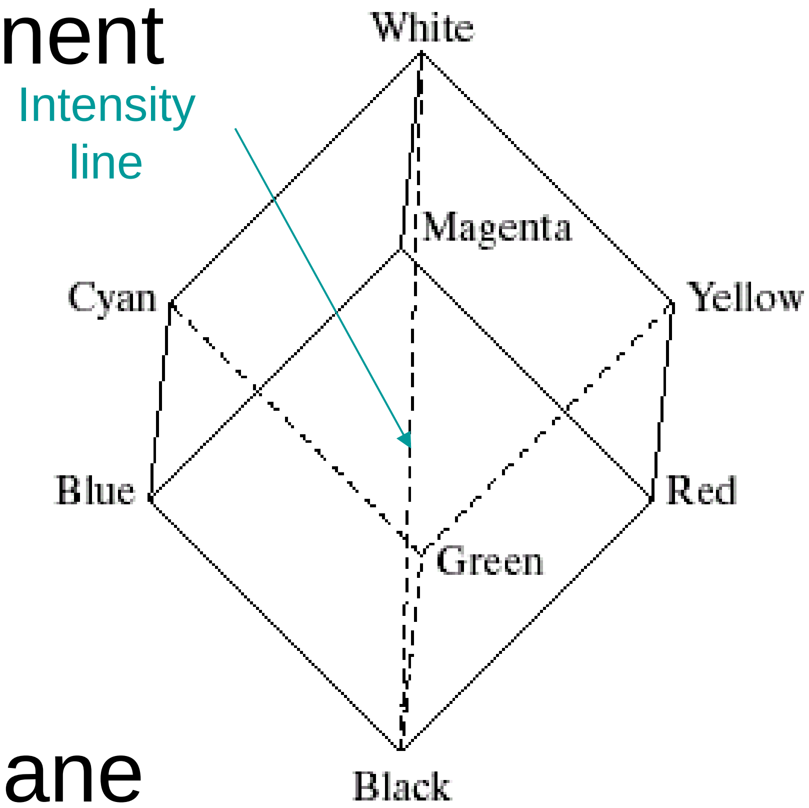
Intensity can be extracted from RGB images – which is not surprising if we stop to think about it

Remember the diagonal on the RGB colour cube that we saw previously ran from black to white

Now consider if we stand this cube on the black vertex and position the white vertex directly above it

HSI, Intensity & RGB (cont…)

Now the intensity component of any colour can be determined by passing a plane *perpendicular* to the intenisty axis and containing the colour point



The intersection of the plane with the intensity axis gives us the intensity component of the colour

HSI, Hue & RGB

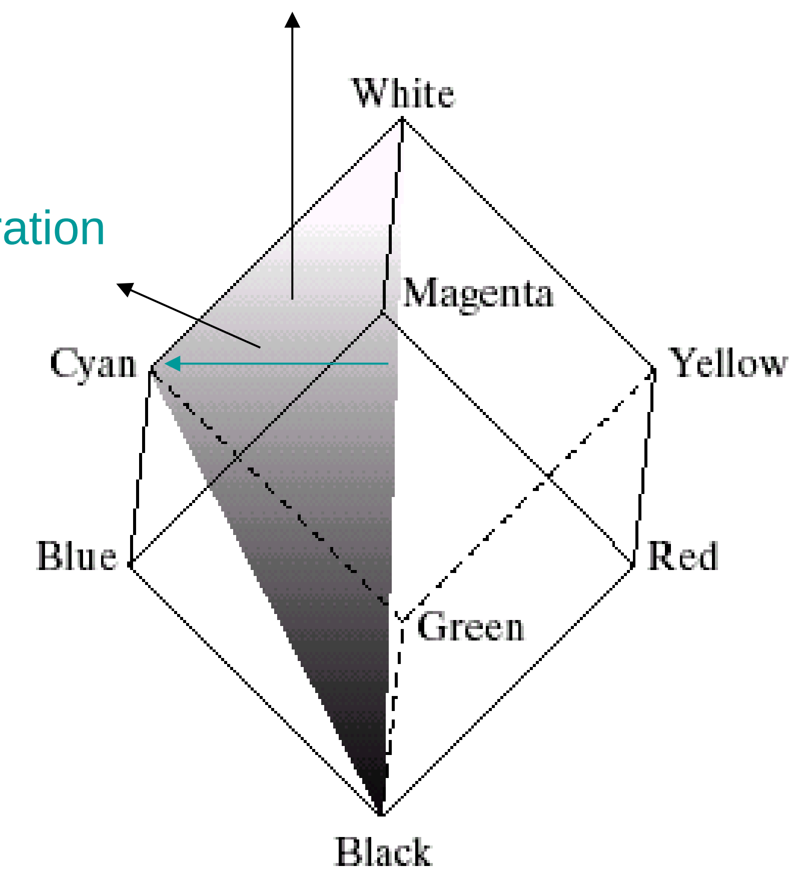
n a similar way we can extract the hue from
e RGB colour cube

onsider a plane defined by
e three points cyan, black
nd white

l points contained in
is plane must have the
ame hue (cyan) as black
nd white cannot contribute
ue information to a colour

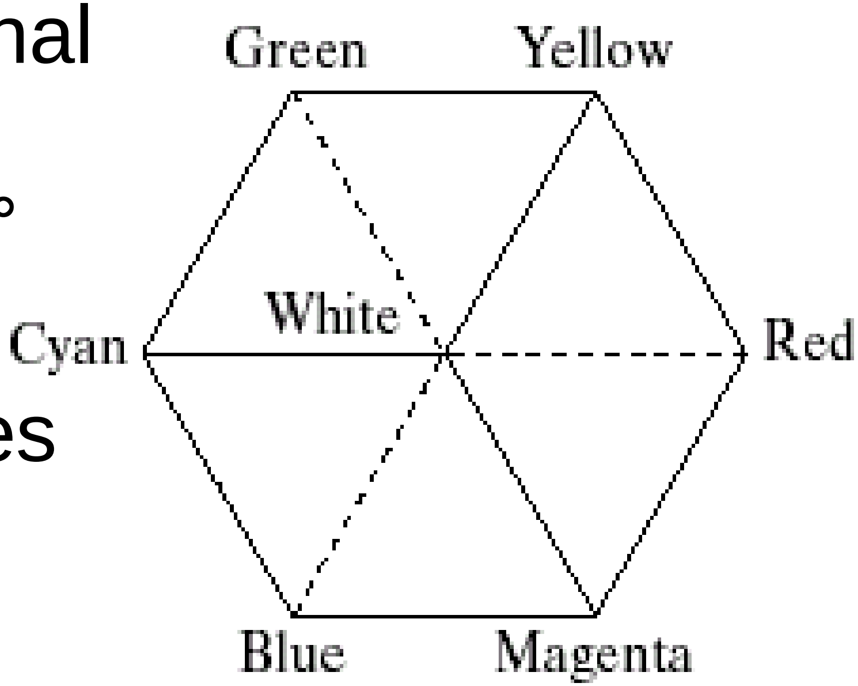
Colors on this triangle
Have the same hue

saturation



The HSI Colour Model

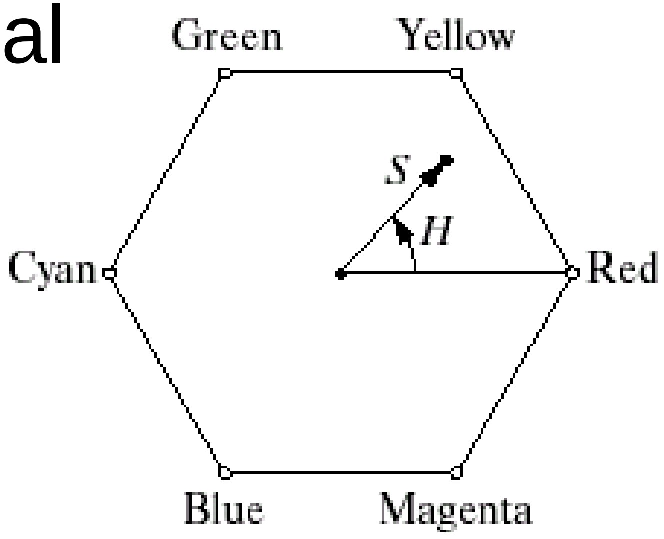
- Consider if we look straight down at the RGB cube as it was arranged previously
- We would see a hexagonal shape with each primary colour separated by 120° and secondary colours at 60° from the primaries



- So the HSI model is composed of a vertical intensity axis and the locus of colour points that lie on planes perpendicular to that axis

The HSI Colour Model (cont…)

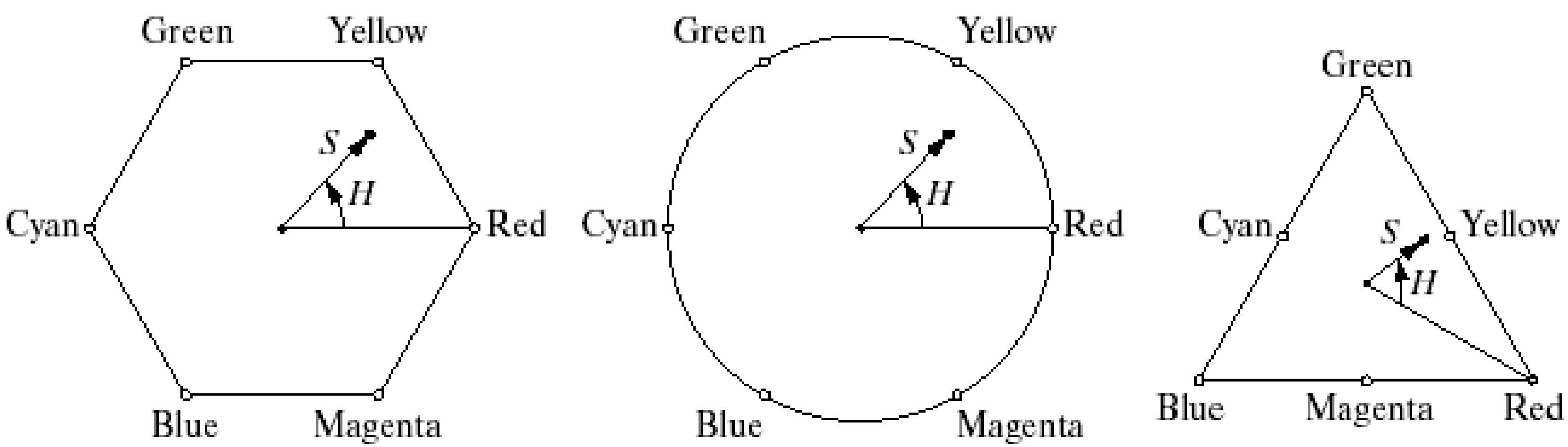
To the right we see a hexagonal shape and an arbitrary colour point



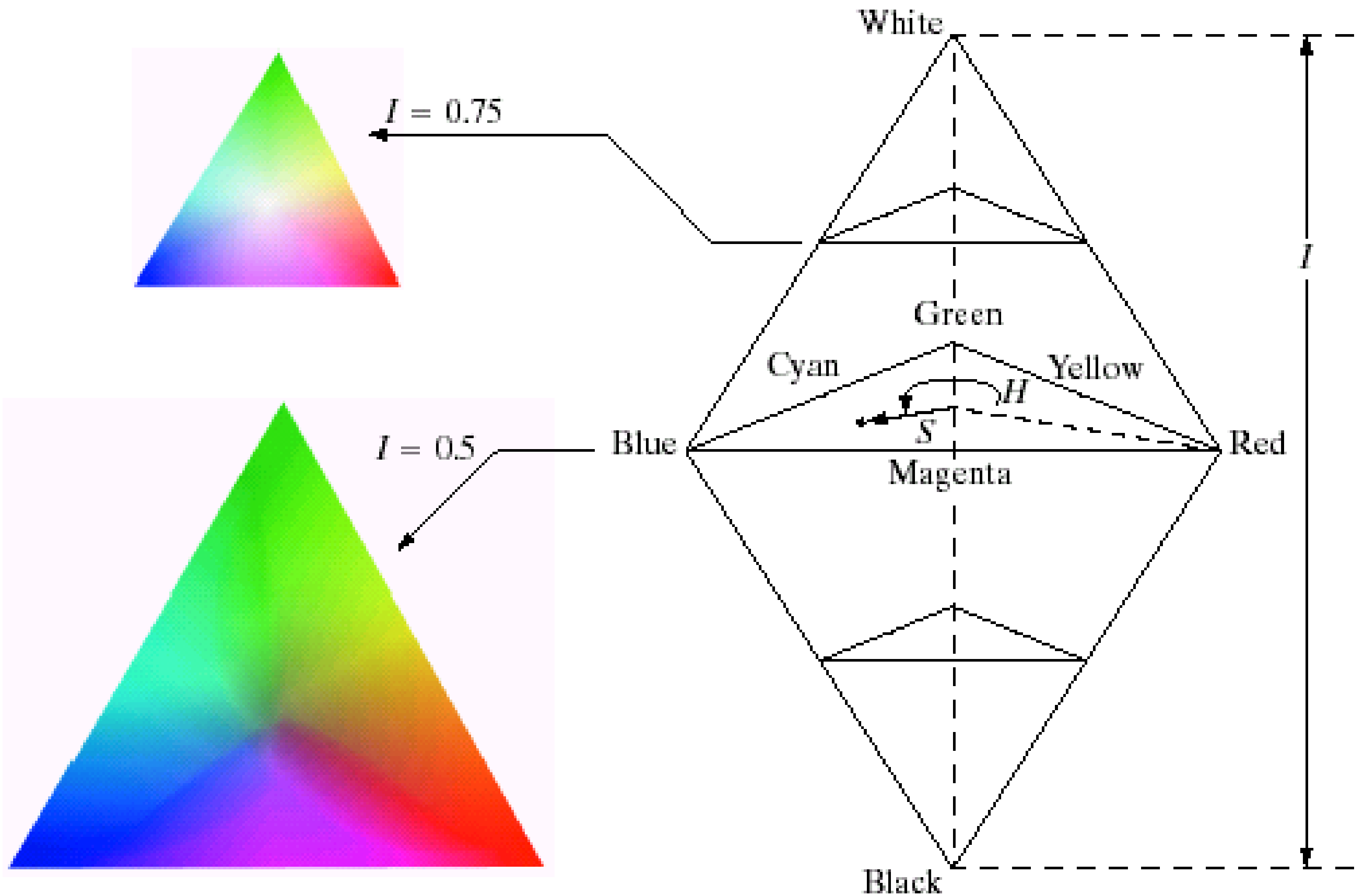
- The hue is determined by an angle from a reference point, usually red
- The saturation is the distance from the origin to the point
- The intensity is determined by how far up the vertical intenisty axis this hexagonal plane sits (not apparent from this diagram

The HSI Colour Model (cont…)

Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle

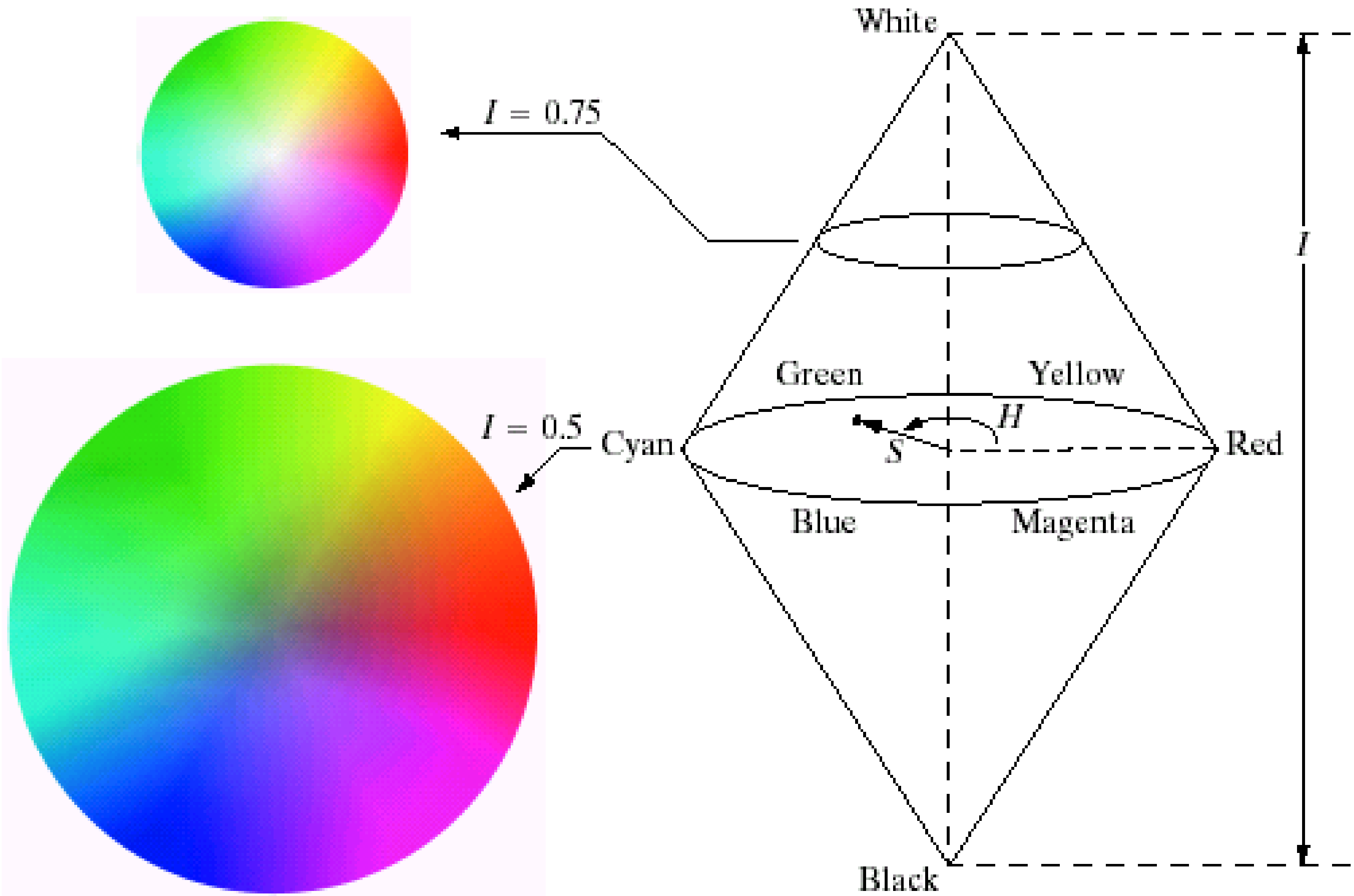


HSI Model Examples



HSI Model Examples

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Converting From RGB To HSI

Given a colour as R, G, and B its H, S, and I values are calculated as follows:

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

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

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

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

Converting From HSI To RGB

Given a colour as H, S, and I it's R, G, and B values are calculated as follows:

– RG sector ($0 <= H < 120°$)

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

– GB sector ($120° <= H < 240°$)

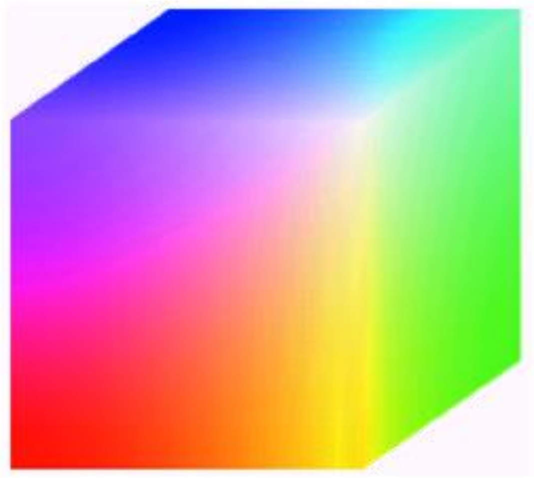
$$R = I(1 - S) \quad G = I\left[1 + \frac{S\cos(H - 120)}{\cos(H - 60)}\right] \quad B = 3I - (R + G)$$

Converting From HSI To RGB (cont…)

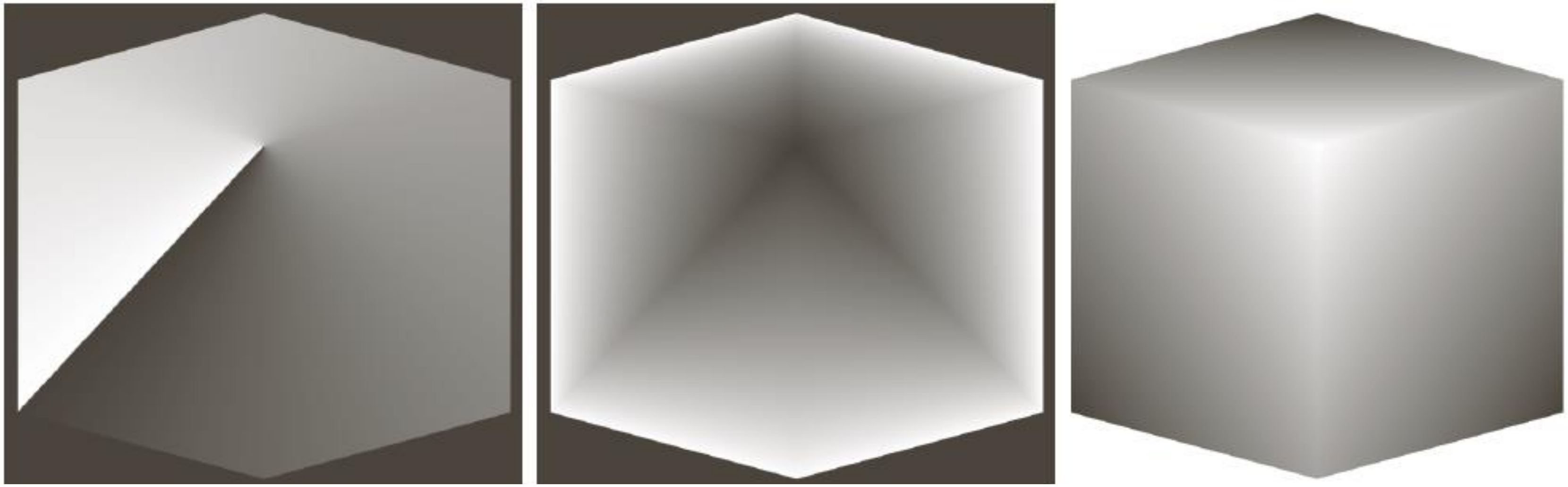
– BR sector ($240^\circ <= H <= 360^\circ$)

$$R = 3I - (G + B) \quad G = I(1 - S) \quad B = I\left[1 + \frac{S\cos(H - 240)}{\cos(H - 180)}\right]$$

HSI & RGB



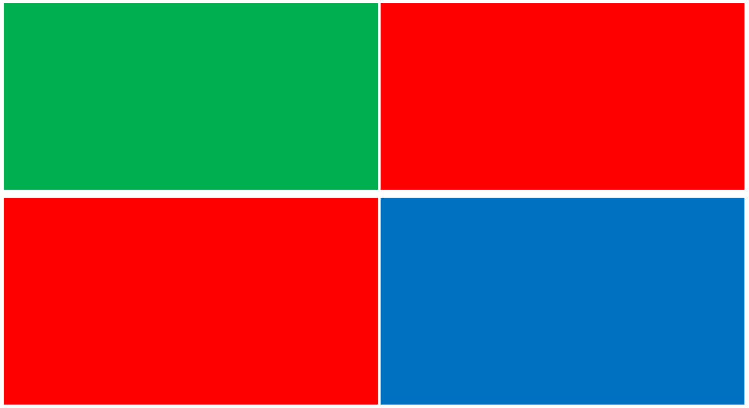
RGB Colour Cube



H, S, and I Components of RGB Colour Cube

Question

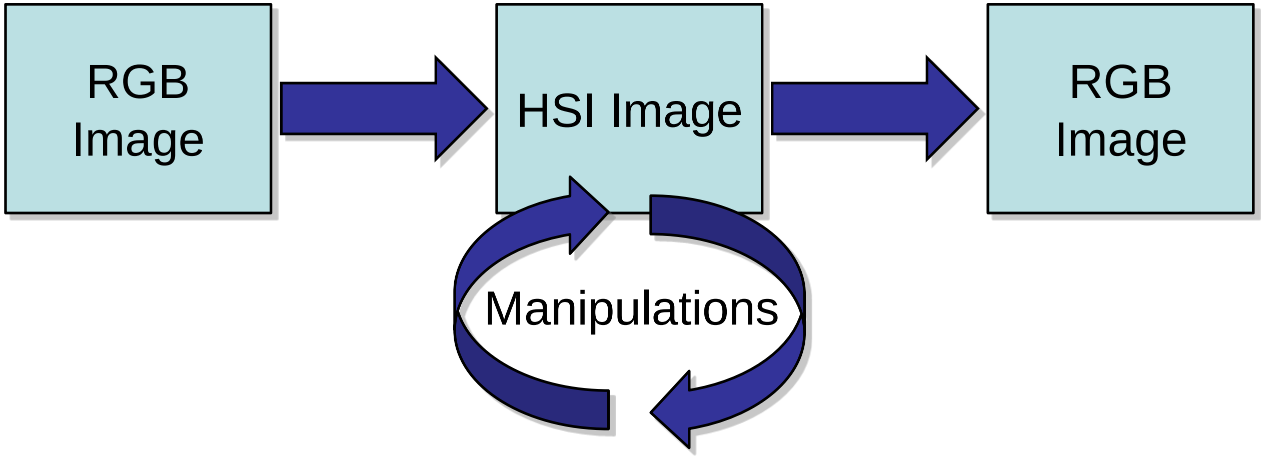
- Consider the following RGB image, in which the squares are fully saturated and each of the colors is at maximum intensity. An HSI image is generated from this image. Describe the appearance of each HSI component image.



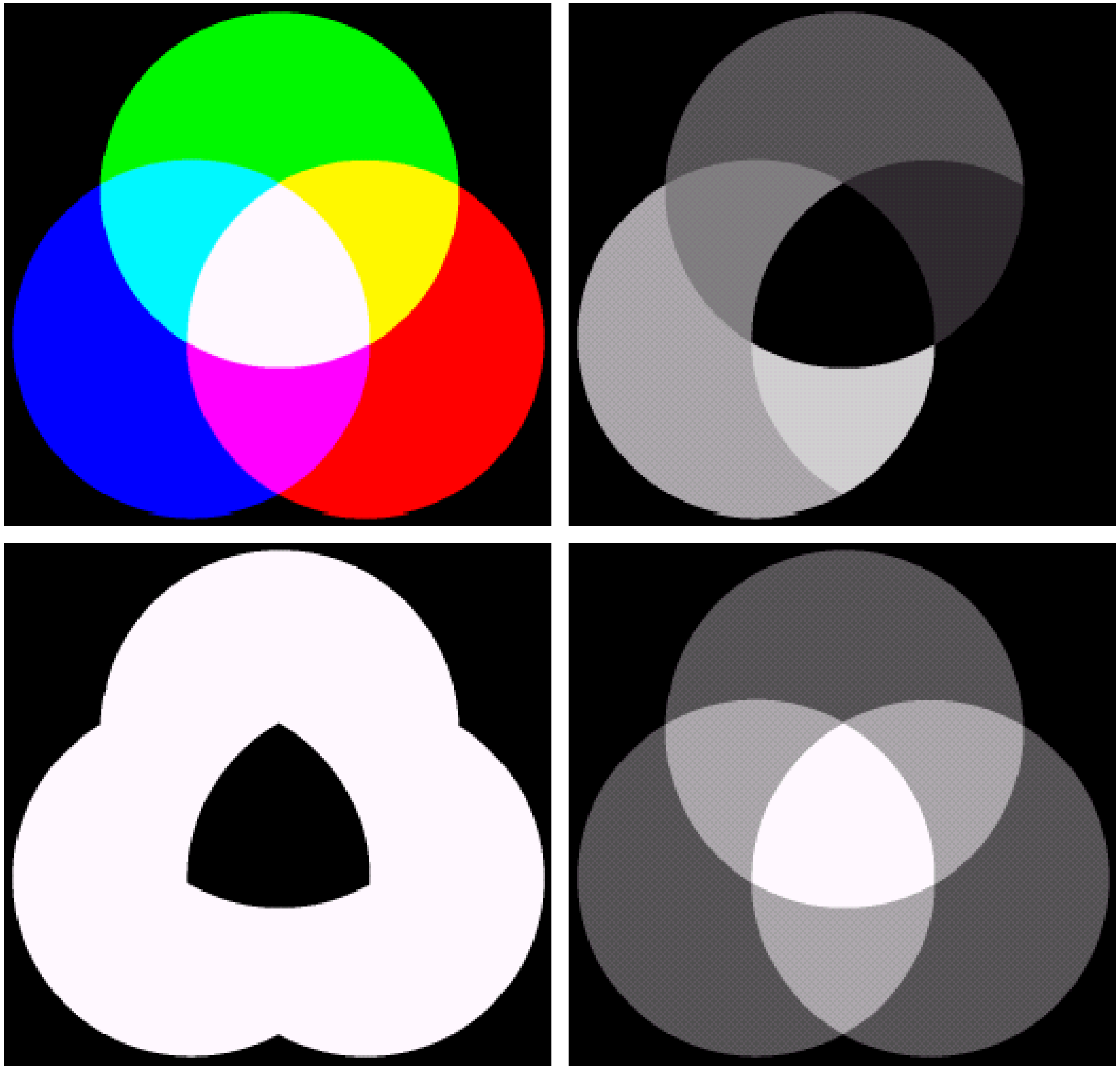
Manipulating Images In The HSI Model

In order to manipulate an image under the HSI model we:

– First convert it from RGB to HSI
– Perform our manipulations under HSI
– Finally convert the image back from HSI to RGB



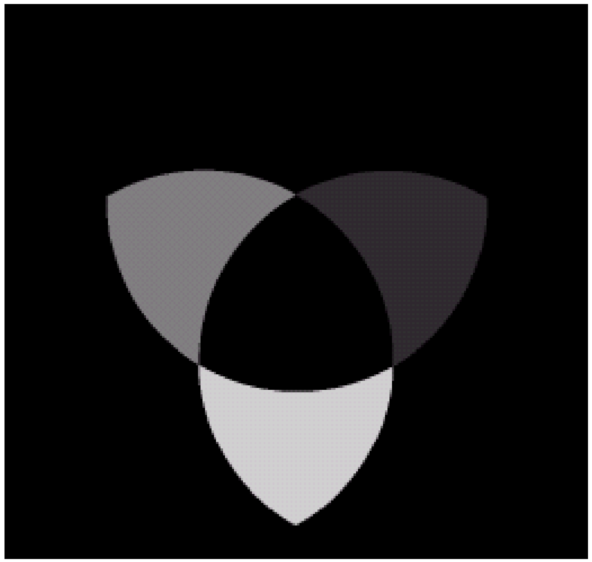
RGB -> HSI -> RGB

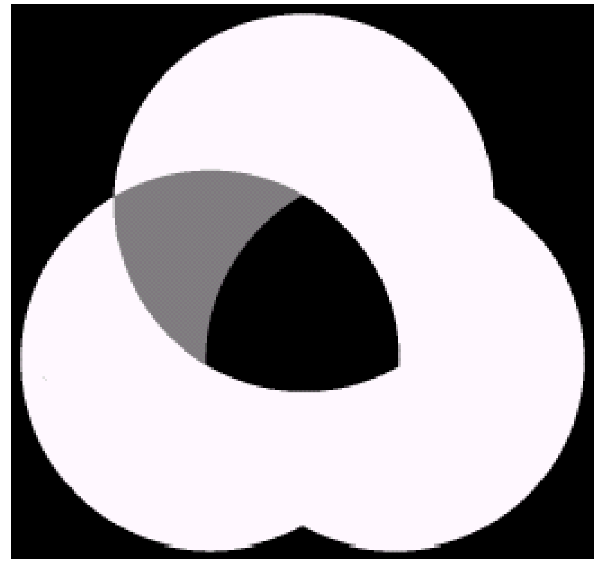


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

RGB -> HSI -> RGB (cont…)

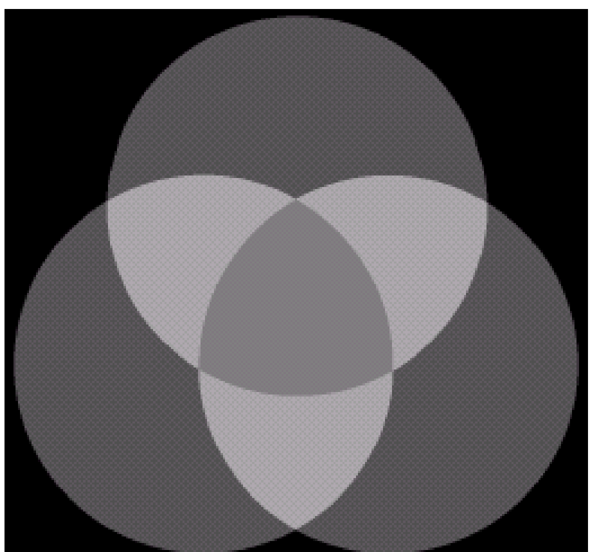
Hue

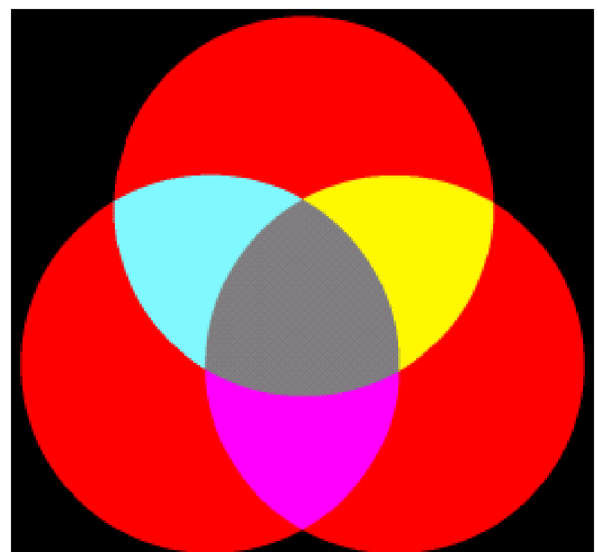




Saturation

Intensity





RGB Image

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Color image processing

- **Color image processing is divide into two major area:**
  - *Pseudo-Color* Processing
  - *Full-Color* Processing

Pseudo-color image processing: Motivation

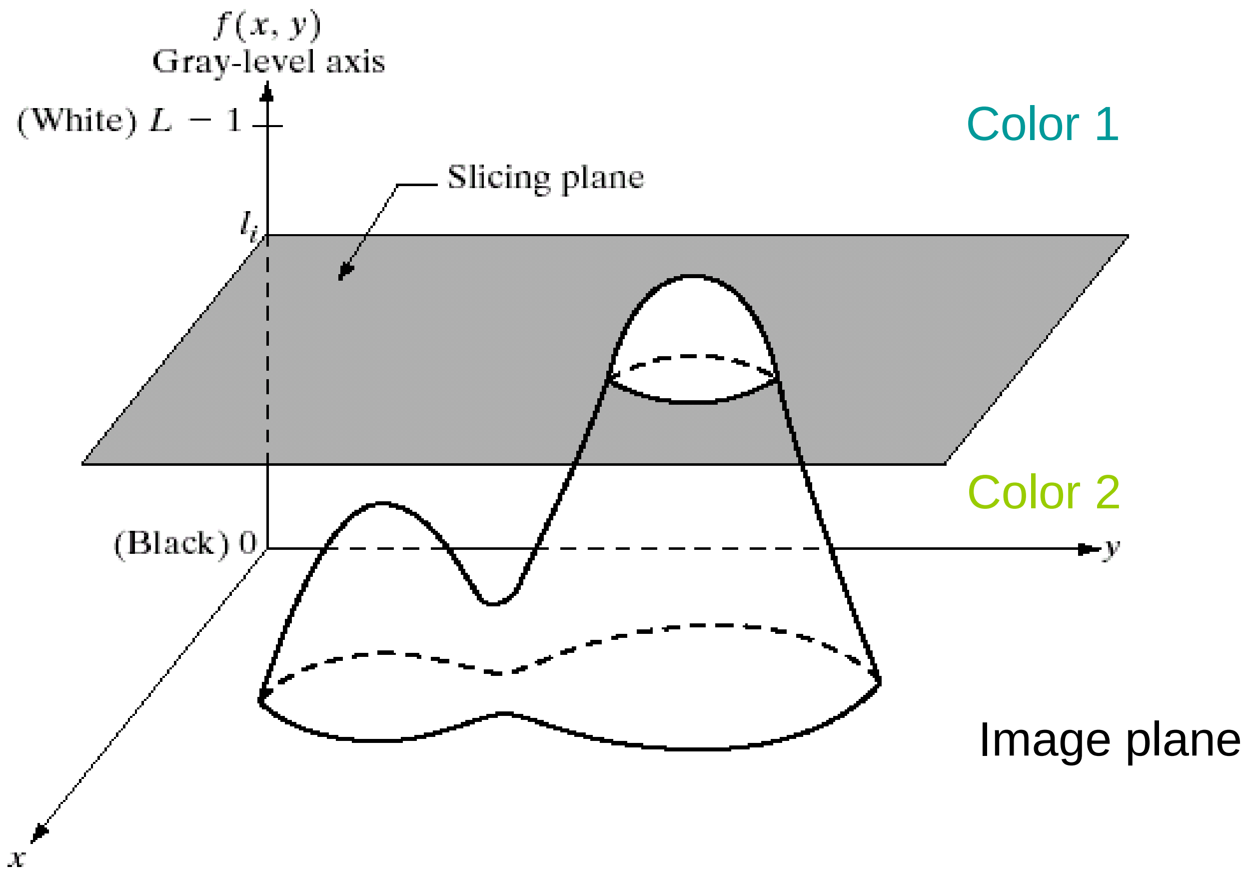
Pseudo-color image processing: Motivation

Pseudo-color image processing

- Assign colors to gray values based on a specified criterion
- For human visualization and interpretation of gray-scale events
- Intensity slicing
- Gray level to color transformations

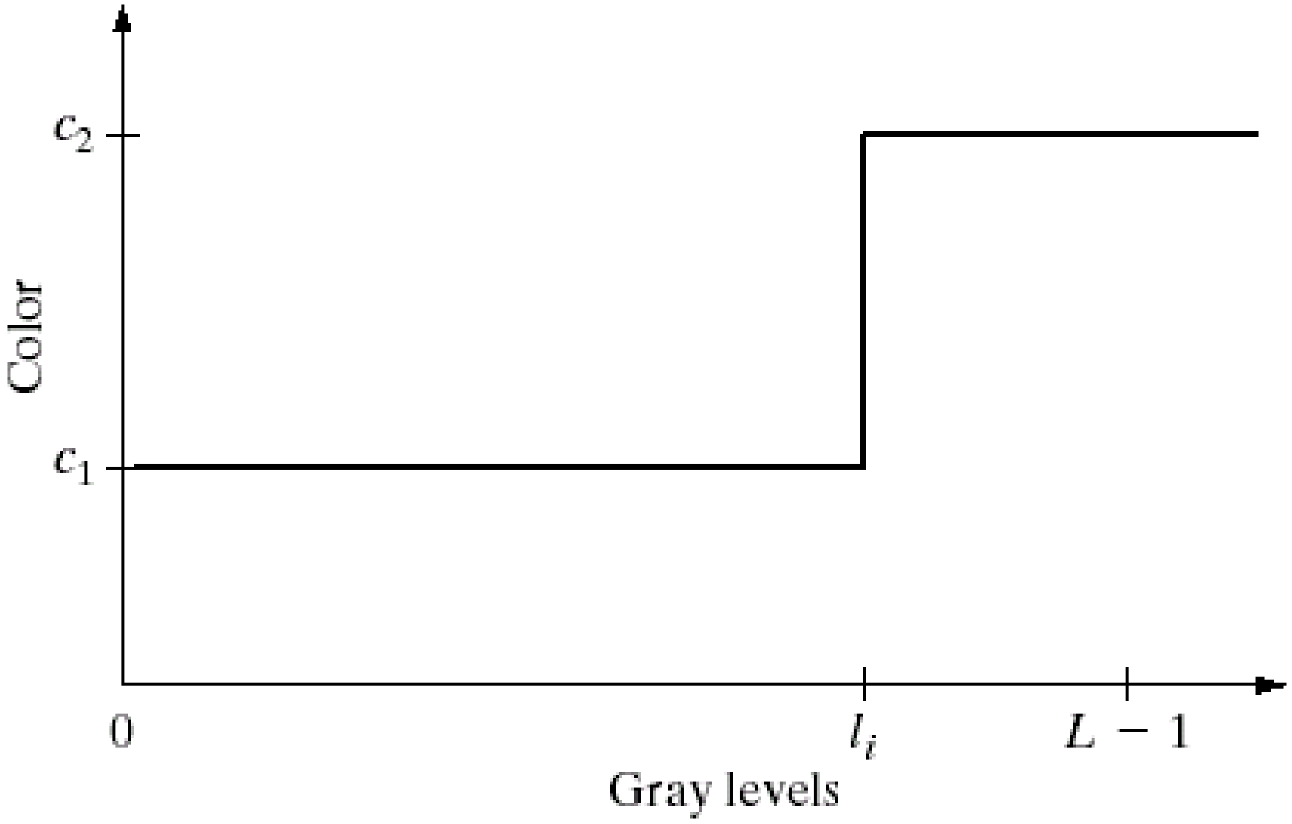
Intensity slicing

- 3-D view of intensity image



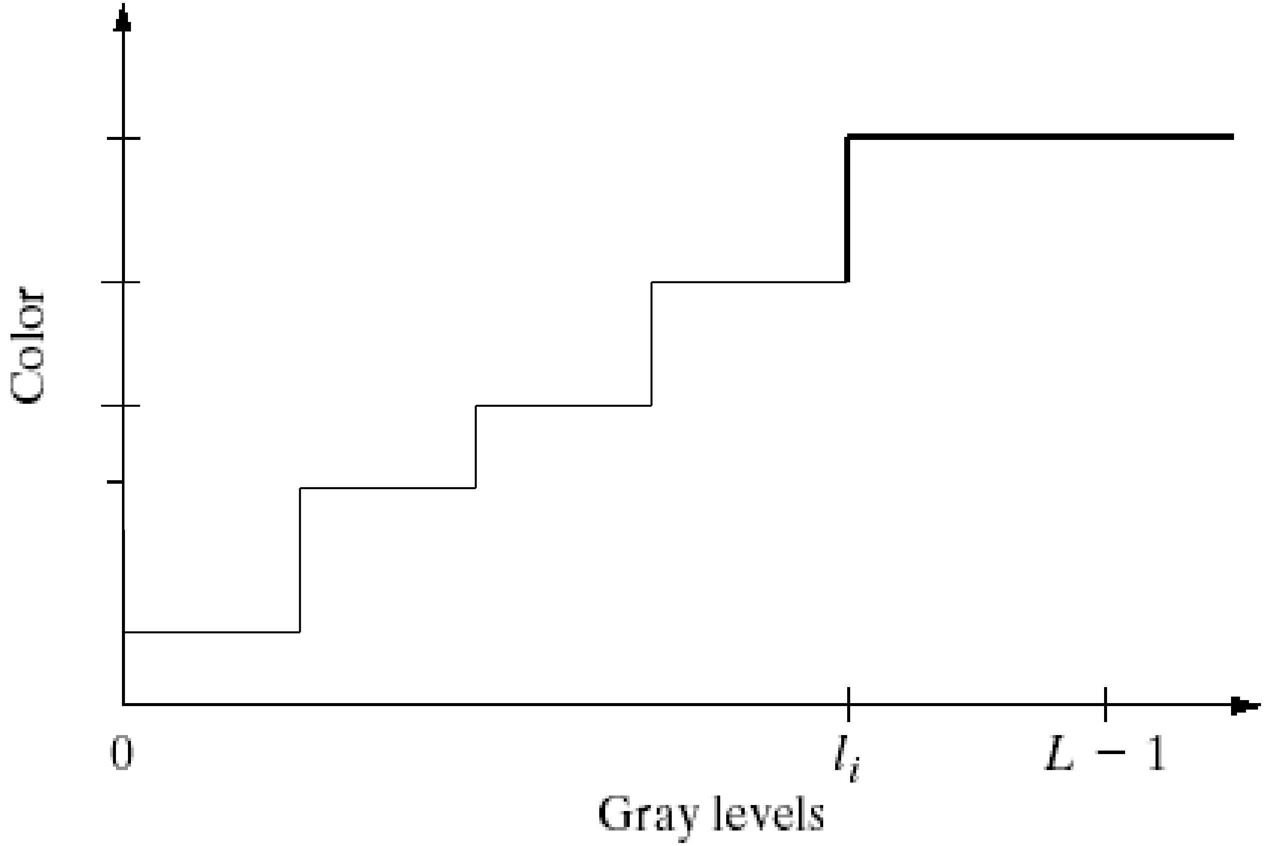
Intensity slicing (cont.)

- Alternative representation of intensity slicing

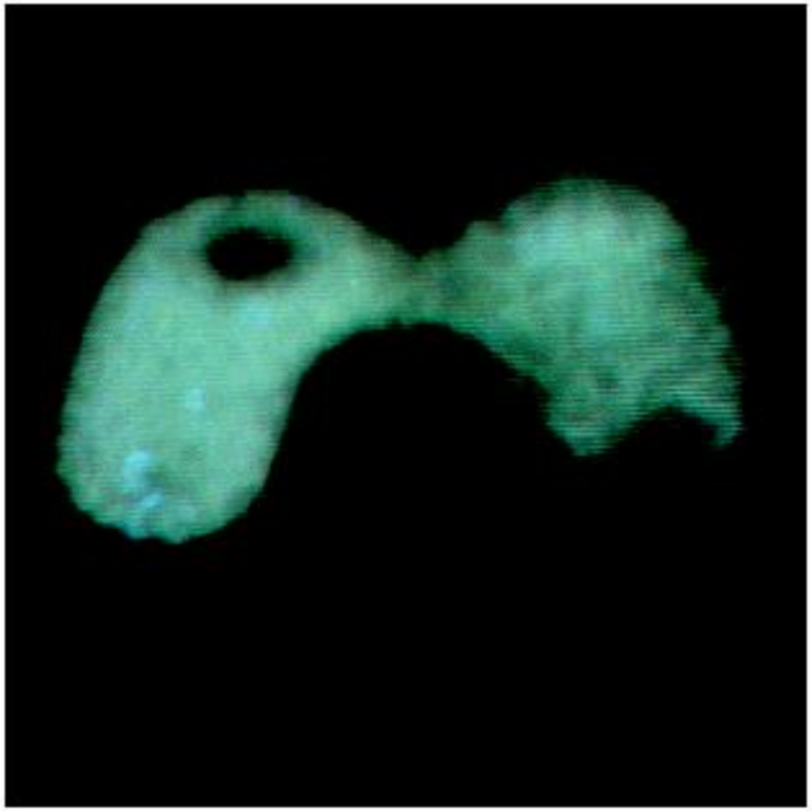


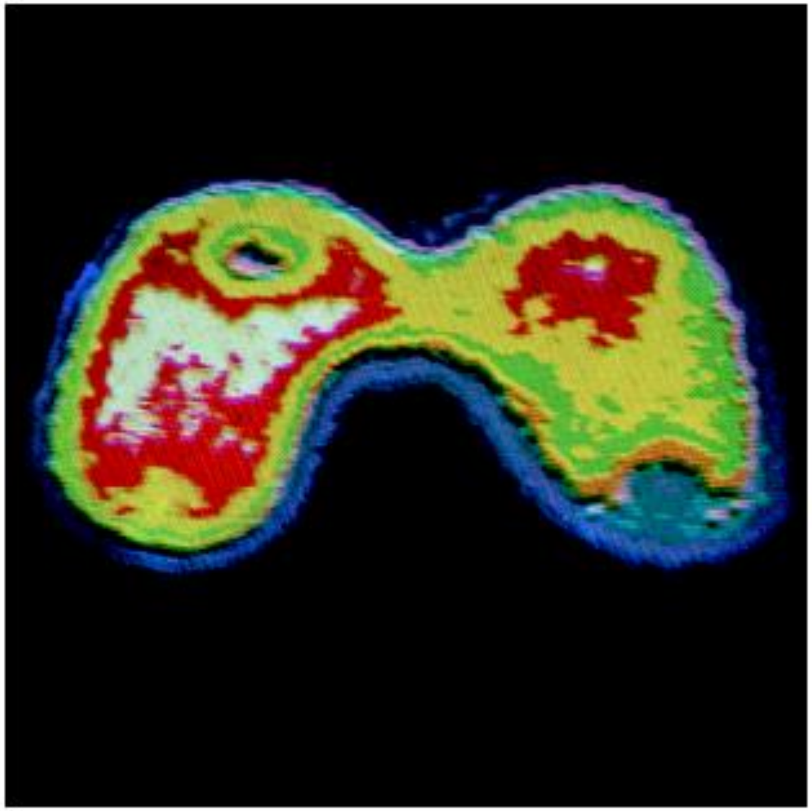
Intensity slicing (cont.)

- More slicing plane, more colors



Example Applications

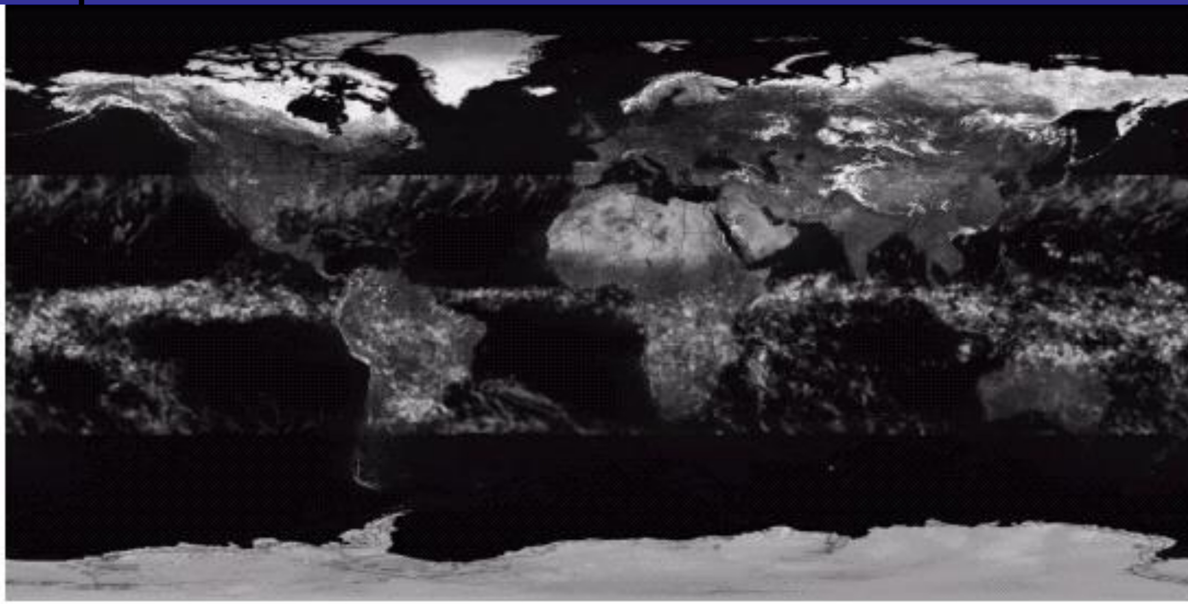




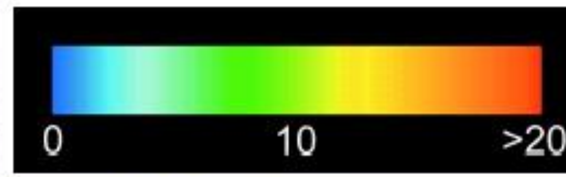
Radiation test pattern → 8 color regions

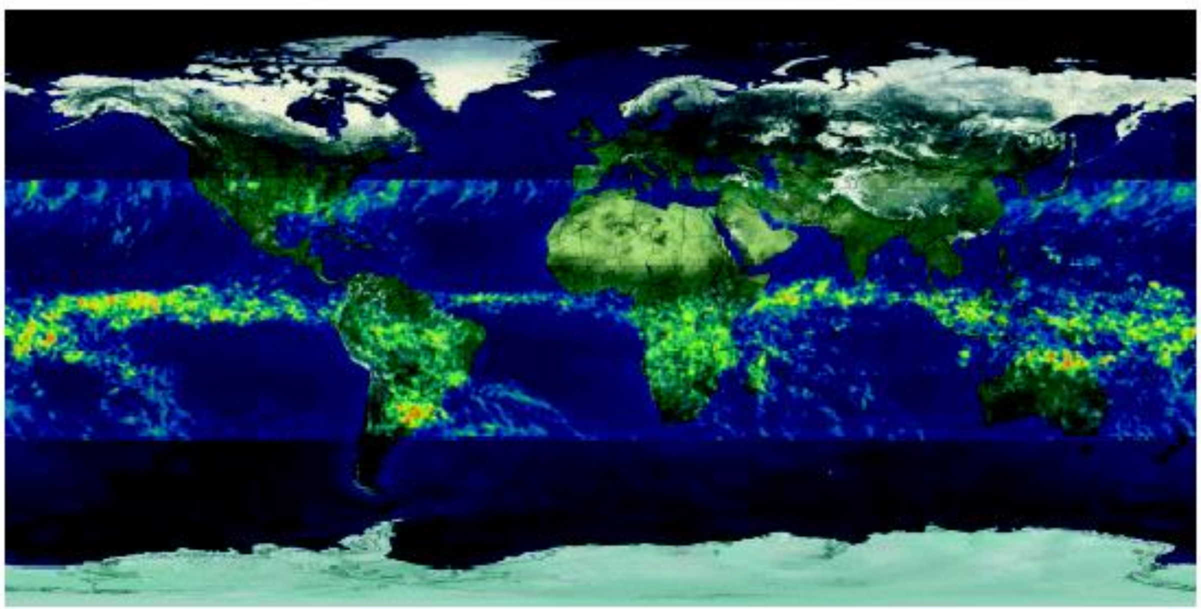
* See the gradual gray-level changes

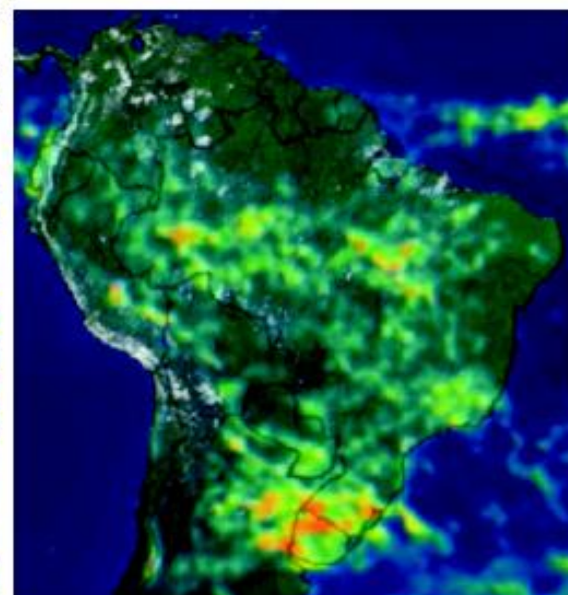
Example Applications



Rainfall statistics







Gray level to color transformation

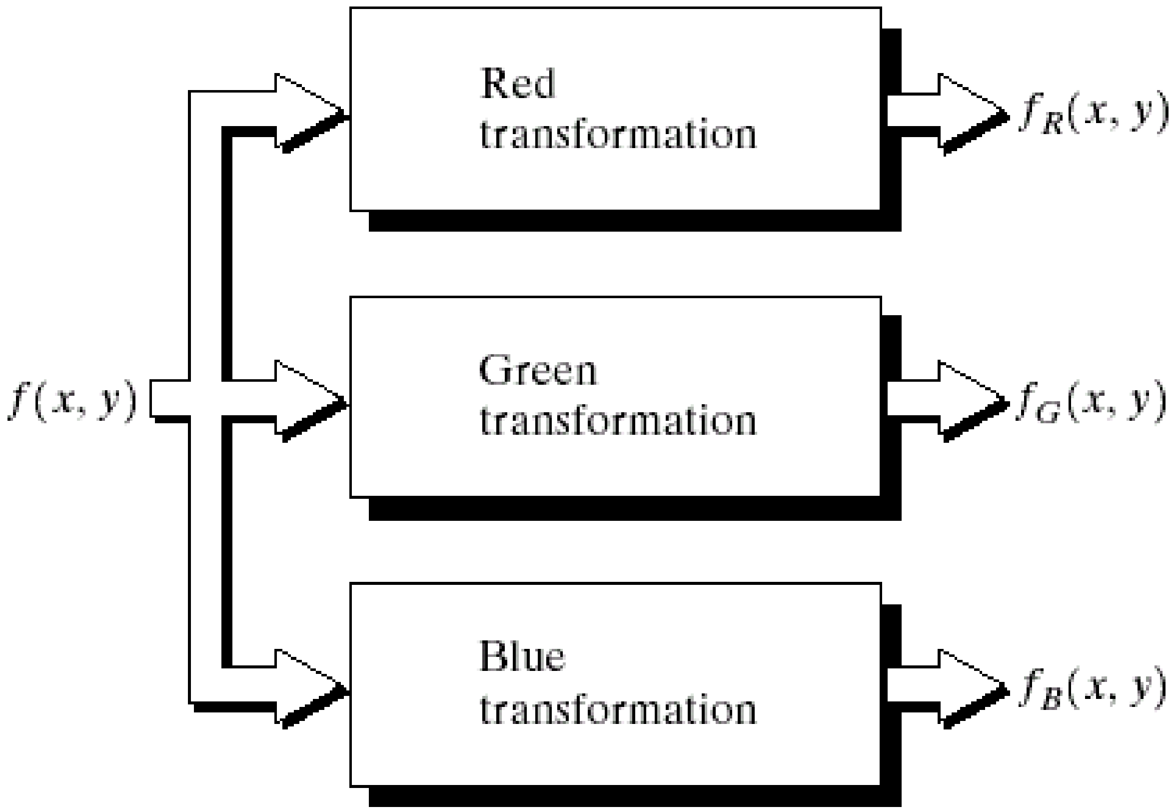
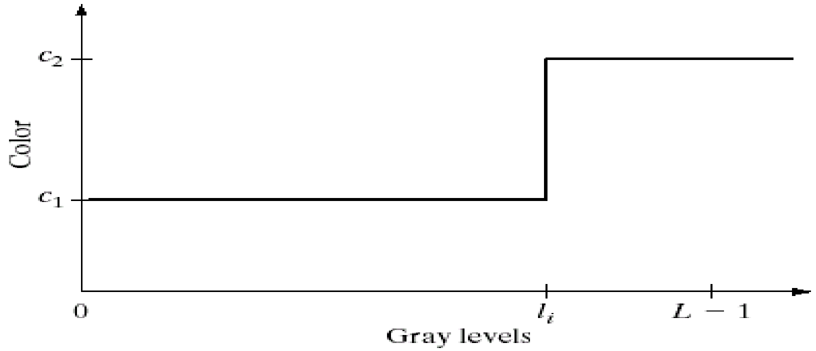


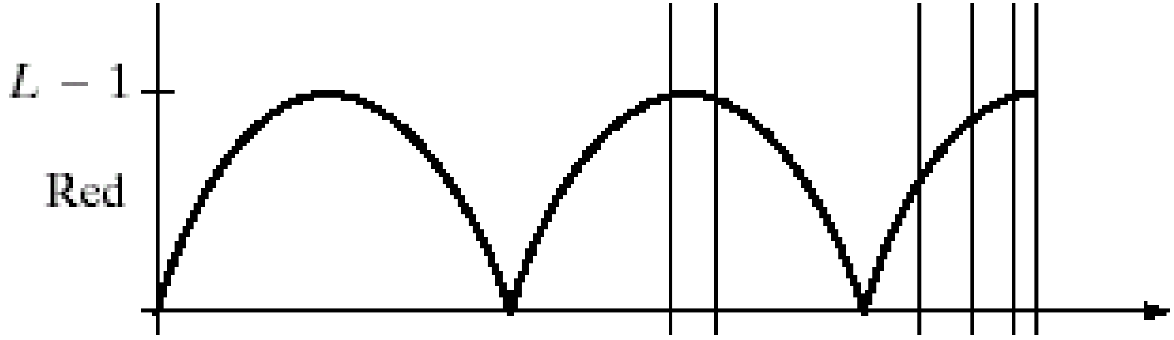
FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Gray level to color transformation

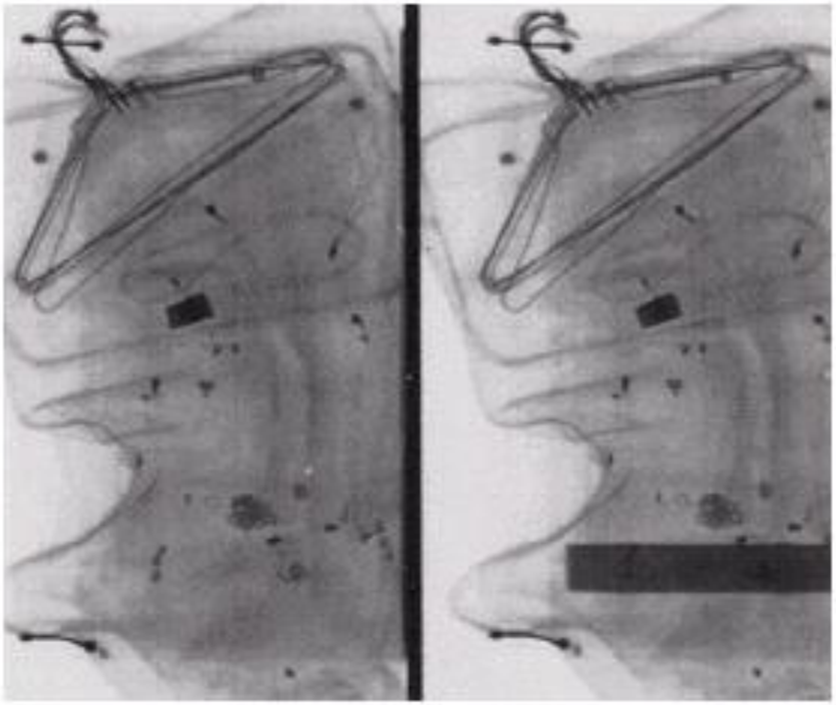
- Intensity slicing: piecewise linear transformation

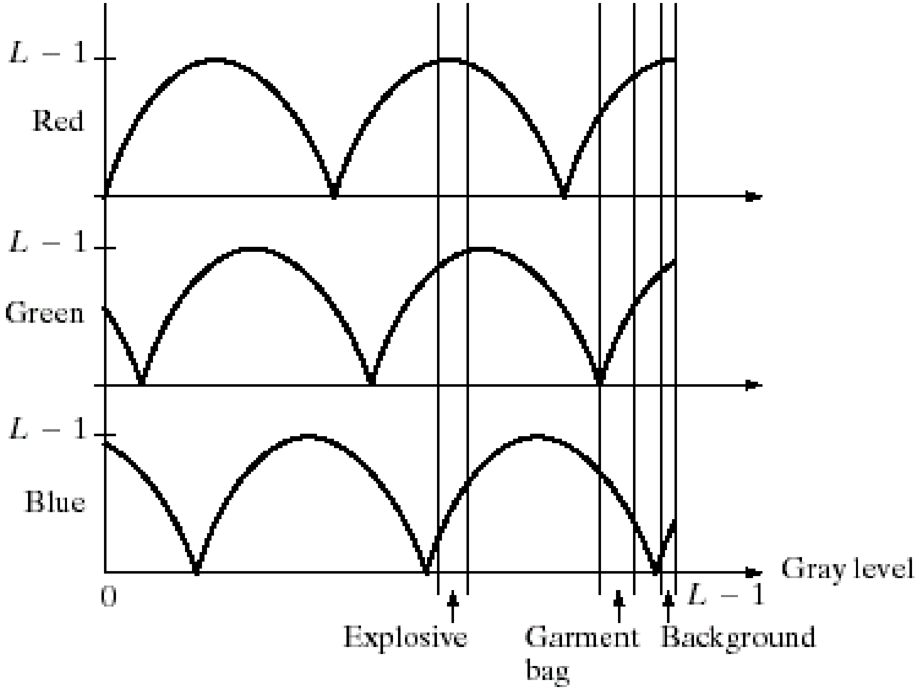


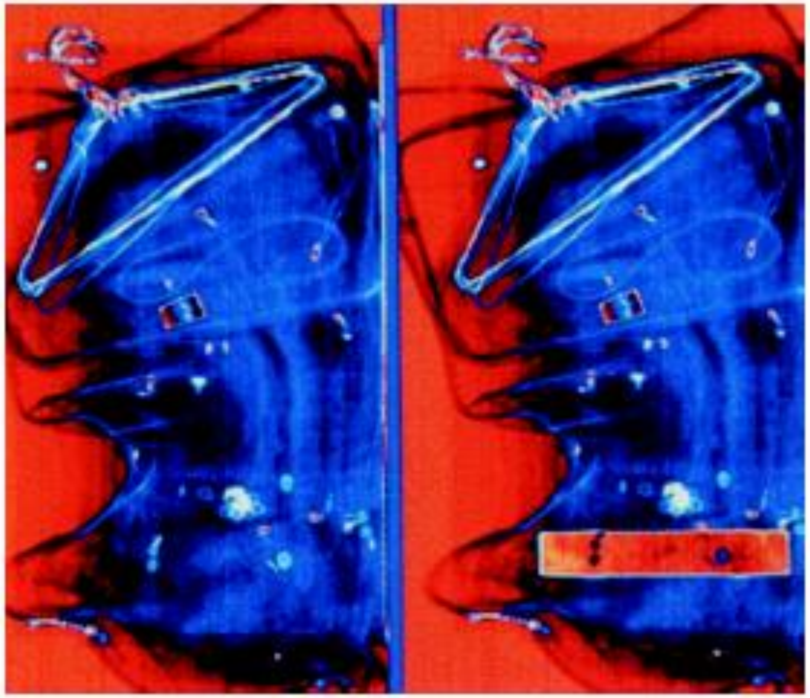
- General Gray level to color transformation



Application

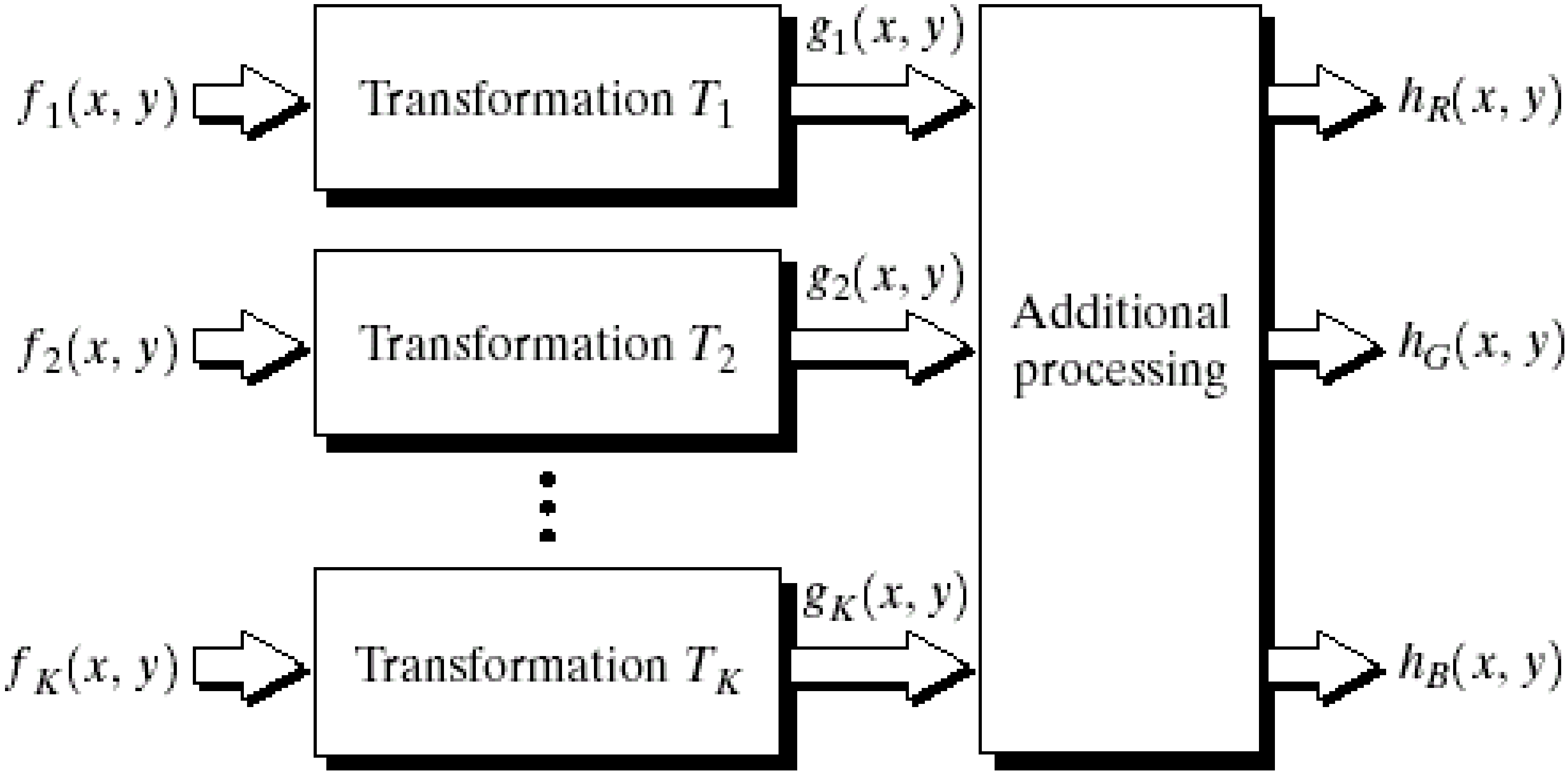






Combine several monochrome images

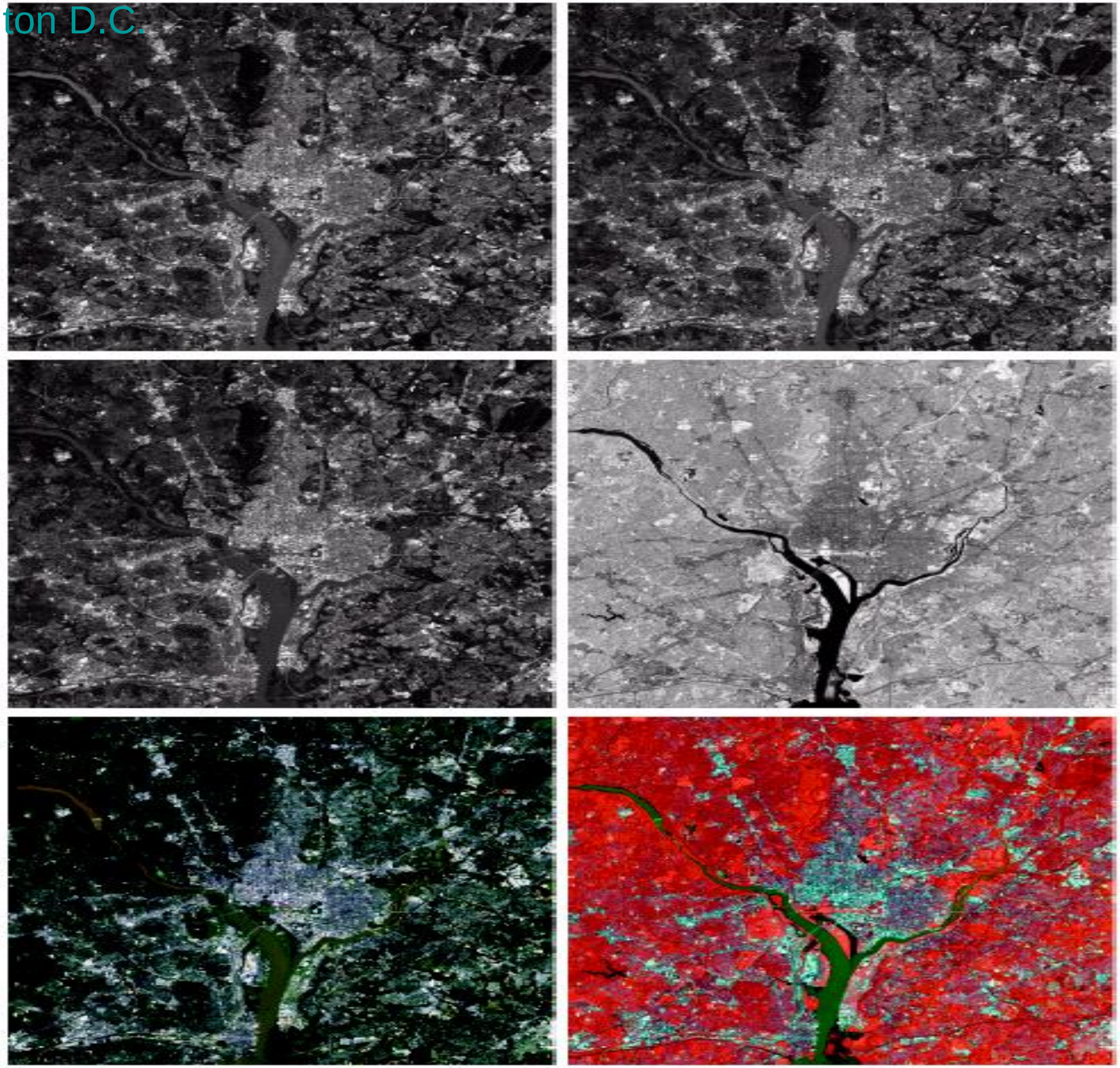
Example: multi-spectral images



Washington D.C.

R

G



Near Infrared (sensitive to biomass)

B

R+G+B

near-infrared+G+B

Full Color Image Processing

- A pixel at (x,y) is a vector in the color space
  - RGB color space

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

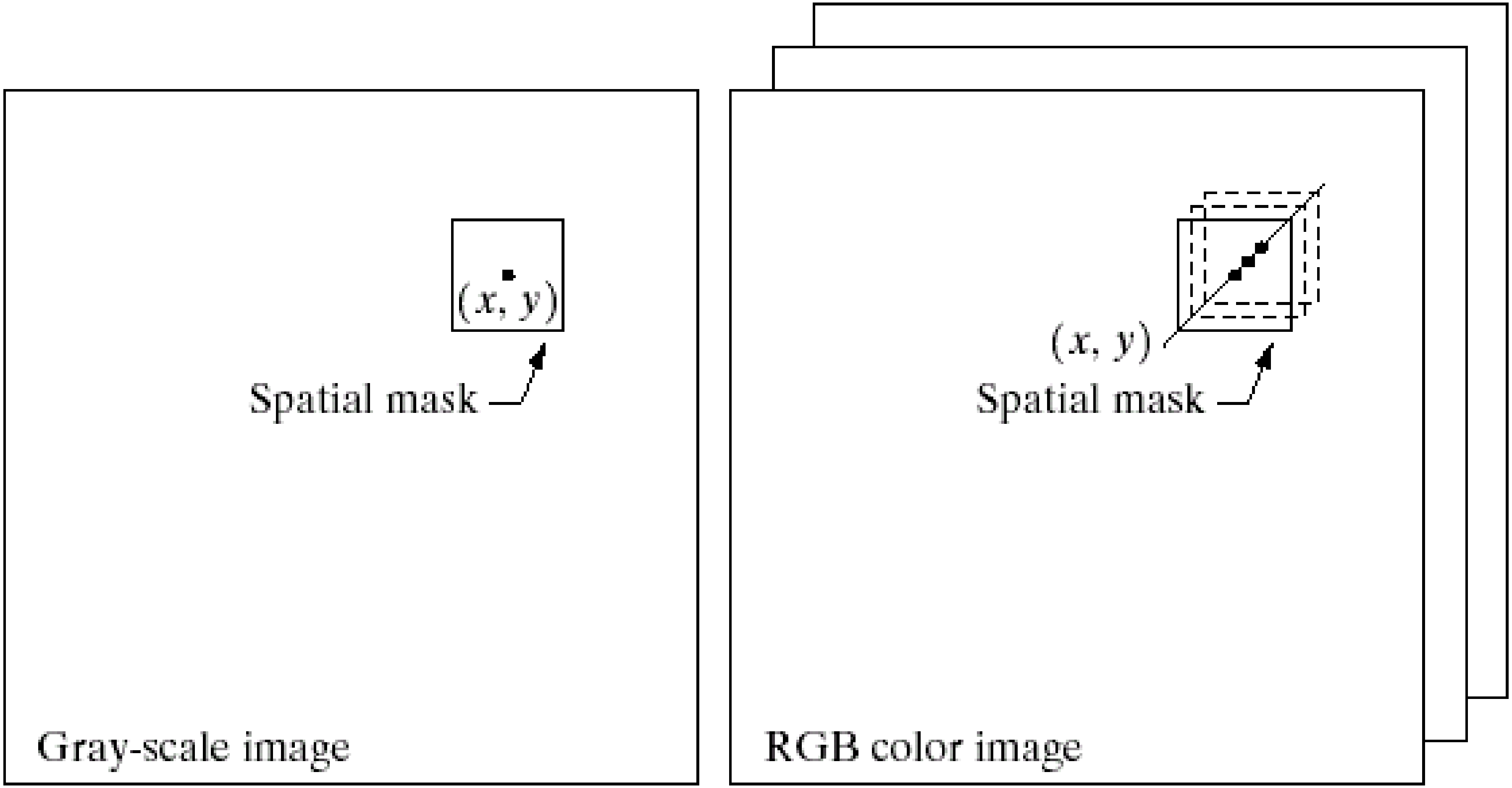
c.f. gray-scale image

f(x,y) = I(x,y)

How to deal with color vector?

- Per-color-component processing
  – Process each color component
- Vector-based processing
  – Process the color vector of each pixel
- When can the above methods be equivalent?
  – Process can be applied to both scalars and vectors
  – Operation on each component of a vector must be independent of the other component

Example: spatial mask



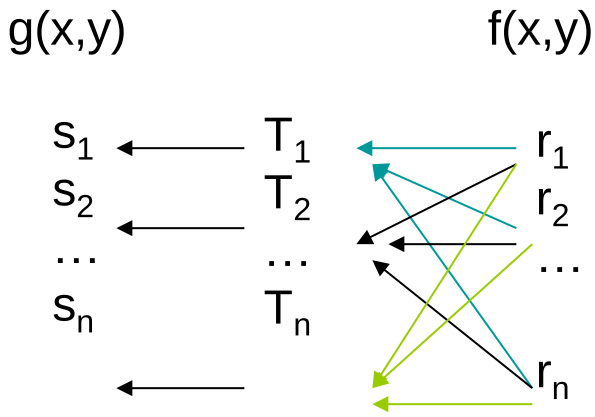
Two spatial processing categories

- Similar to gray scale processing studied before, we have to major categories
- Pixel-wise processing
- Neighborhood processing

Color transformation

- Similar to gray scale transformation
  – g(x,y)=T[f(x,y)]
- Color transformation

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

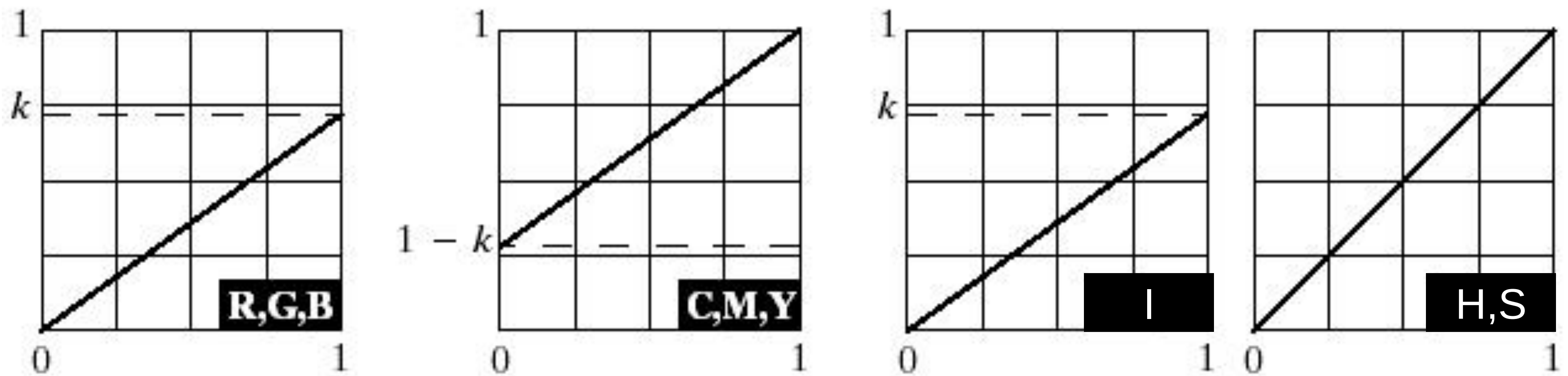


Use which color model in color transformation?

- RGB ⇔ HSI
- Theoretically, any transformation can be performed in any color model
- Practically, some operations are better suited to specific color model

Example: modify intensity of a color image

- **Example:** $g(x,y)=k\,f(x,y)$, $0<k<1$
- HSI color space
  - Intensity: $s_3 = k\ r_3$
  - Note: transform to HSI requires complex operations
- RGB color space
  - For each R,G,B component: $s_i = k\ r_i$

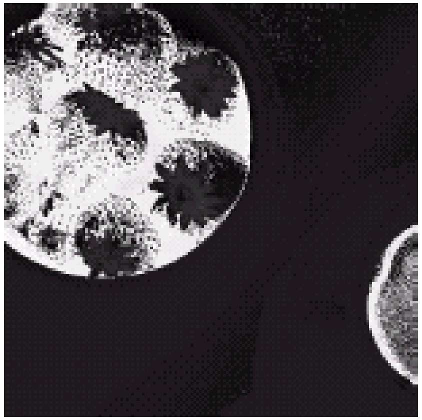


1
k
0
1
R,G,B
1
1 − k
0
1
C,M,Y
1
k
0
1
I
0
1
H,S


Red


Green


Blue

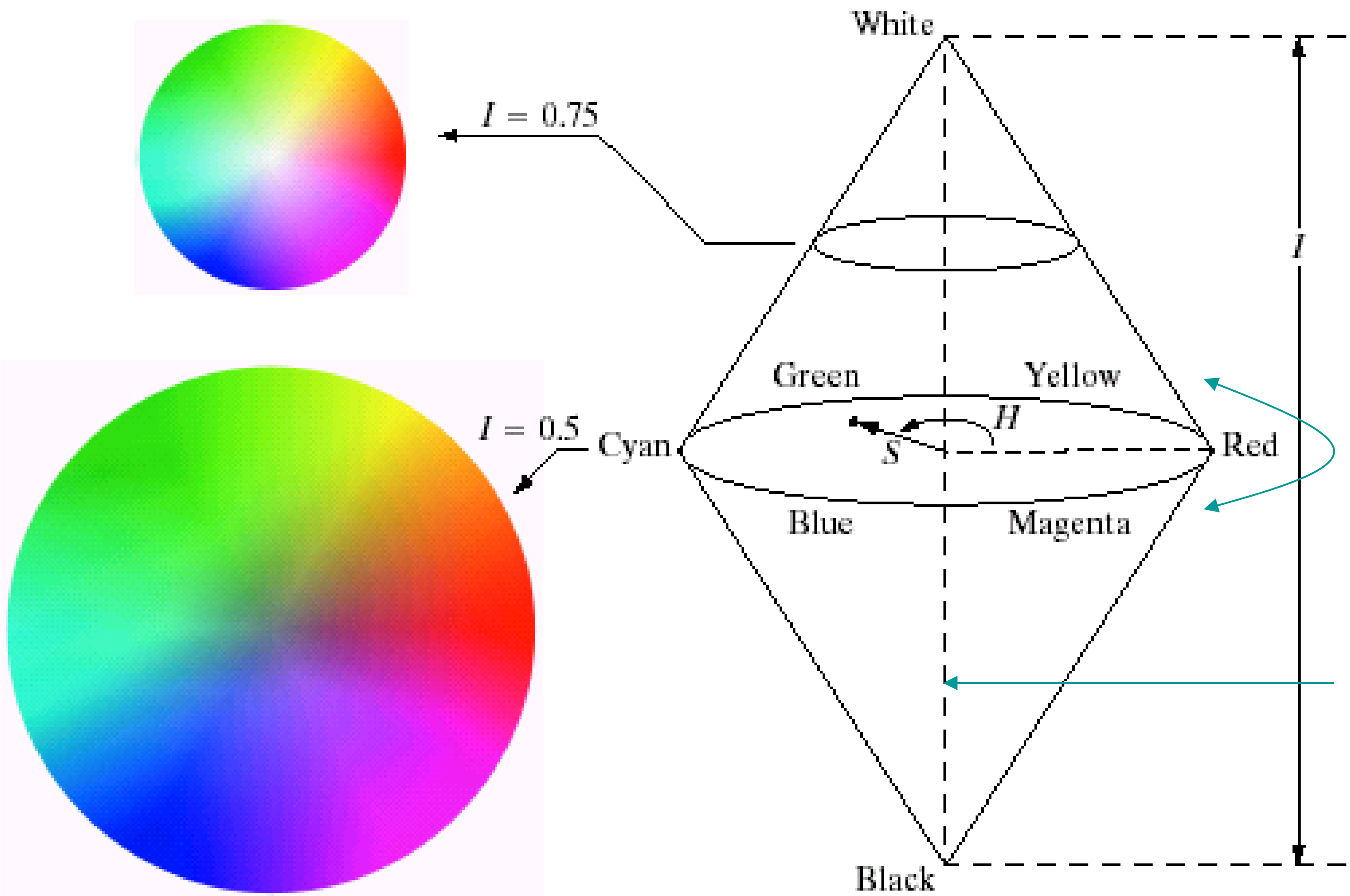

Hue


Saturation


Intensity


Full color

Problem of using Hue component

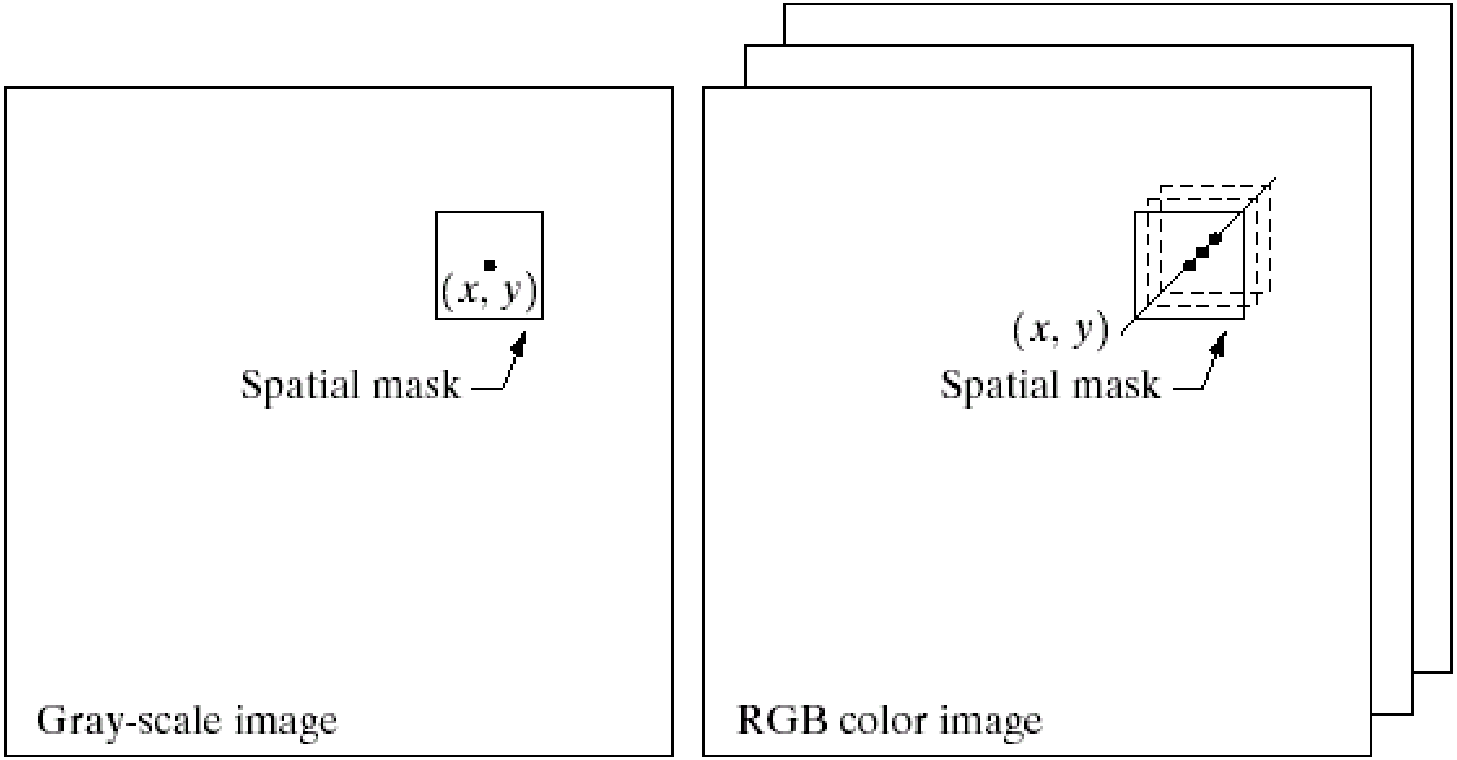


dis-continuous

Un-defined over gray axis

Color image smoothing

- Neighborhood processing



Color image smoothing: averaging mask

$$\bar{\mathbf{c}}(x, y) = \frac{1}{K} \sum_{(x,y)\in S_{xy}} \mathbf{c}(x, y)$$

vector processing

Neighborhood
Centered at (x,y)

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

per-component processing

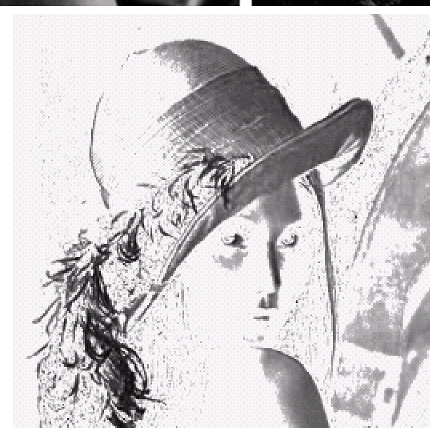
original

R

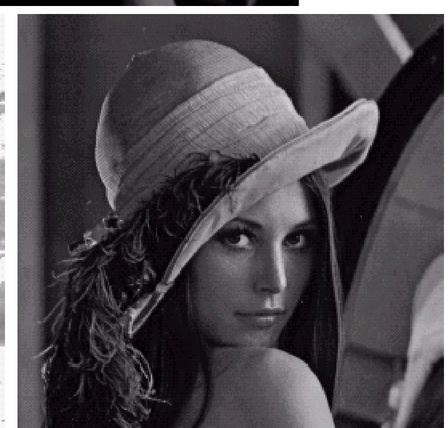
G

G

H



S



I

Example: 5x5 smoothing mask

RGB model

Smooth I
in HSI model

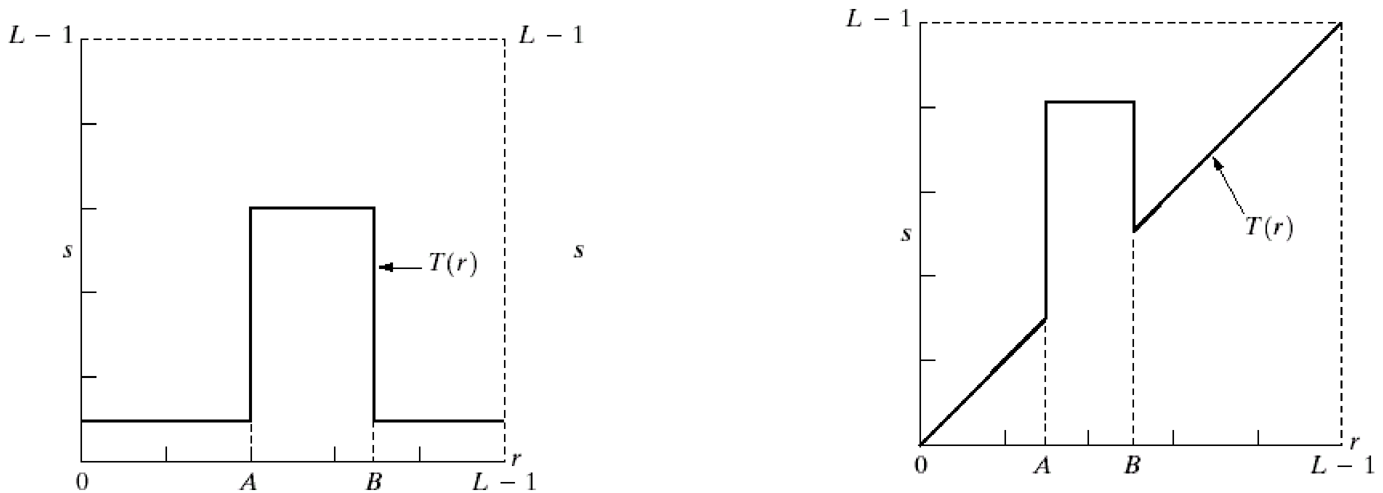
difference

a b c

FIGURE 6.40 Image smoothing with a 5 × 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.

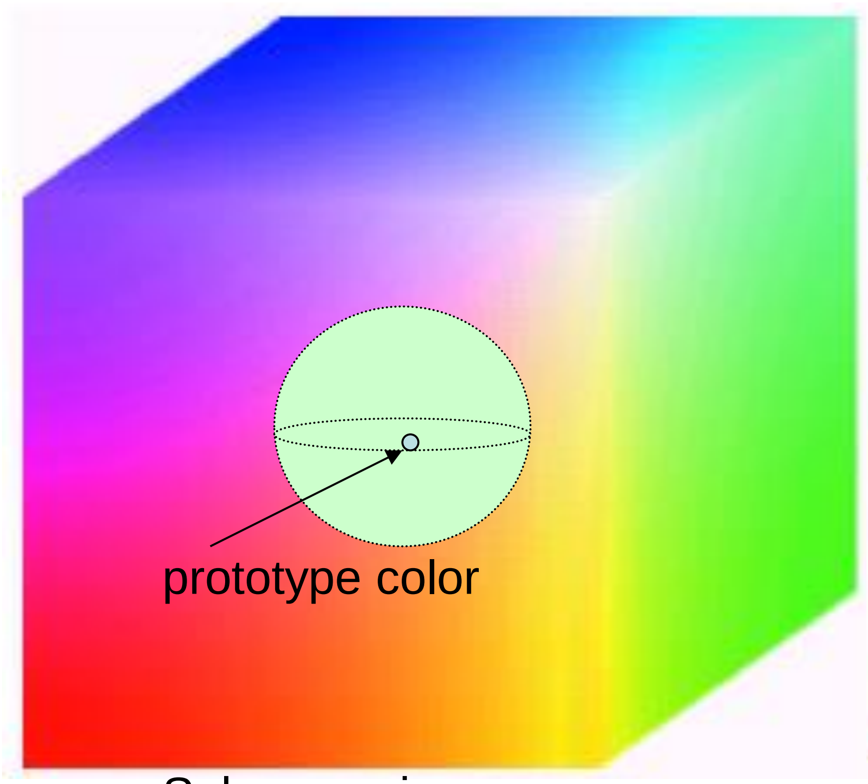
Color slicing

- **Highlighting/Extracting a specific range of colors in an image**
- **Use the region defined by the colors as a mask for further processing**
- Recall the gray level slicing

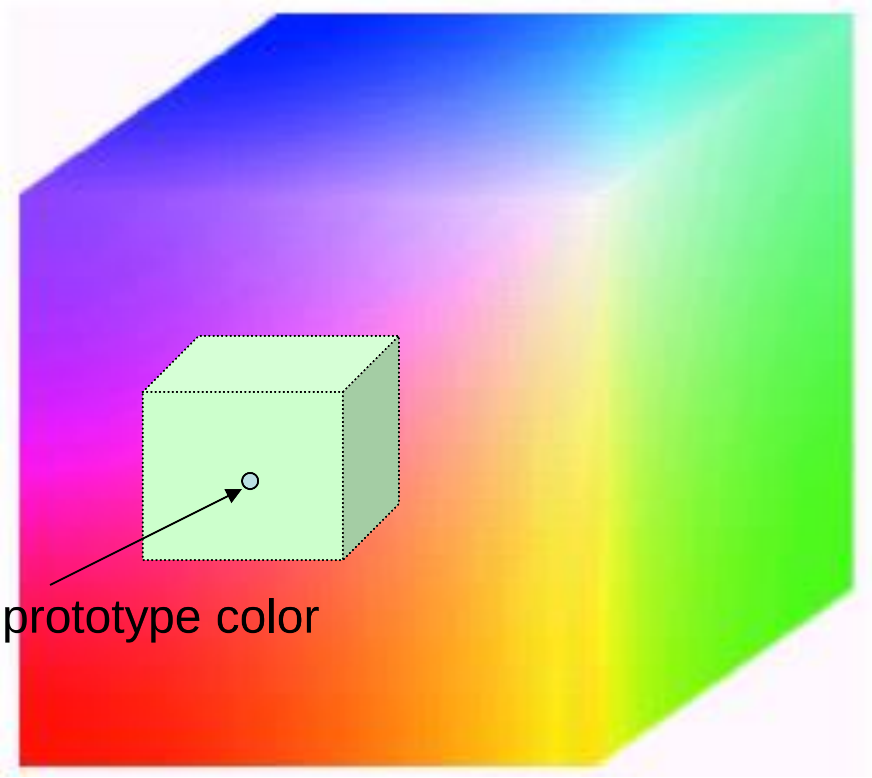


Implementation of color slicing

- How to take a region of colors of interest?



Sphere region



Cube region

Implementation of color slicing

1. Colors of interest are enclosed by ***cube*** (or ***hypercube*** for n>3)

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

2. Colors of interest are enclosed by ***Sphere***

$$s_i = \begin{cases} 0.5 & if \sum_{j=1}^{n} (r_j - a_j)^2 > R_0^2 \\ r_i & otherwise \end{cases} , \quad i = 1,2,...,n$$

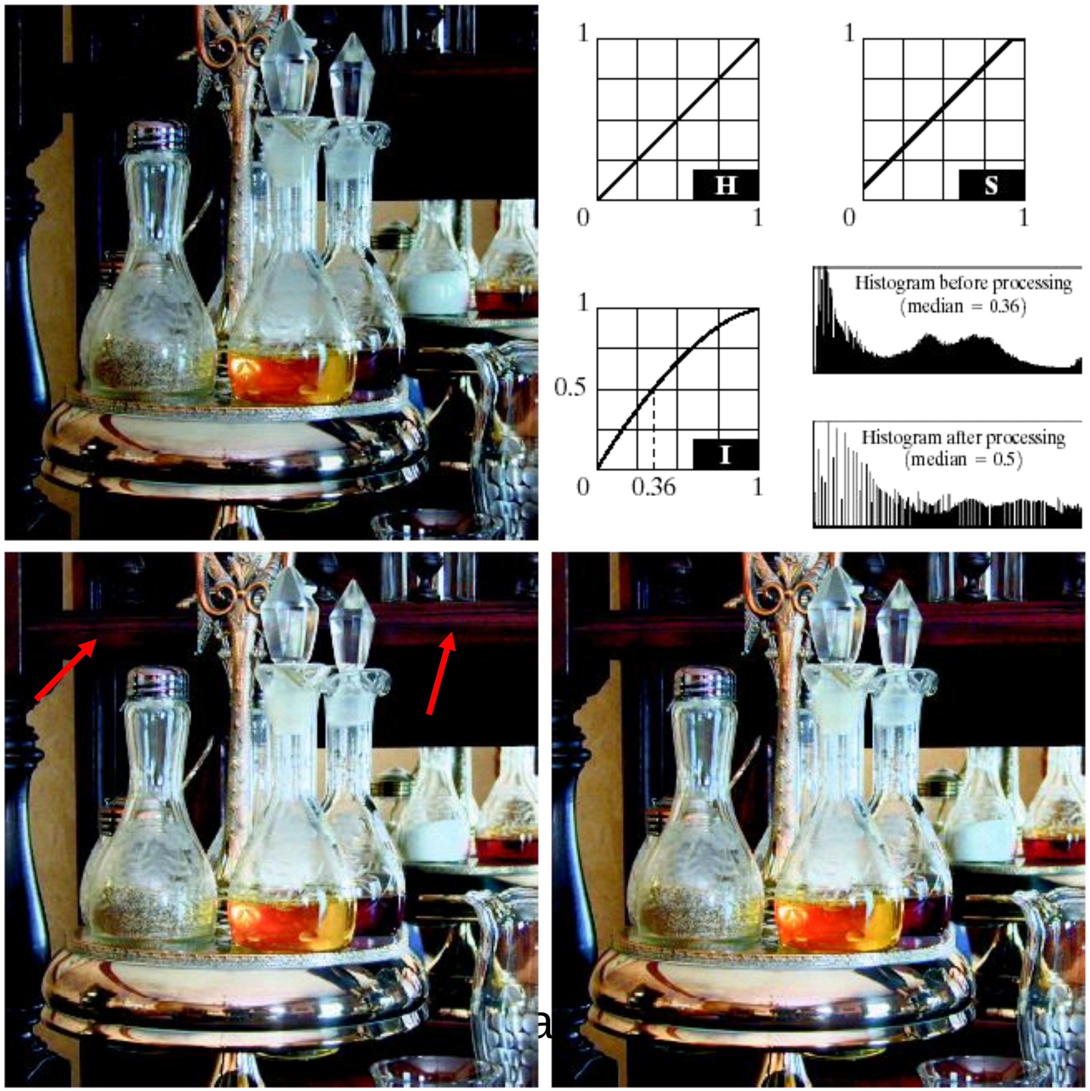
Example

Full color

cube

sphere

Histogram Processing



a b
c d

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

Histogram Equalizing the Intensity

Saturation Adjustment