COLOR IMAGE PROCESSING

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Outline

- Introduction
- Color Fundamentals
- Color Models
- Pseudocolor Image Processing
- Full Color Processing
- Smoothing and Sharpening in Color Images

Color Fundamentals

- **Why color image processing?**
  - Color is powerful in identifying and extracting objects
  - Humans can distinguish thousands of color shades and intensities when compared to only two dozens of shades of gray

- **Two major processing techniques**
  - Full color processing
    - The image is acquired using full –color sensor (TV camera, color scanner)
  - Pseudo color processing
    - Assign colors to monochromatic intensity image

Color Fundamentals

- Color perception in humans is not fully understood
  - The physical nature of color is based on experimental and theoretical results
  - Sir Isaac Newton, 1666

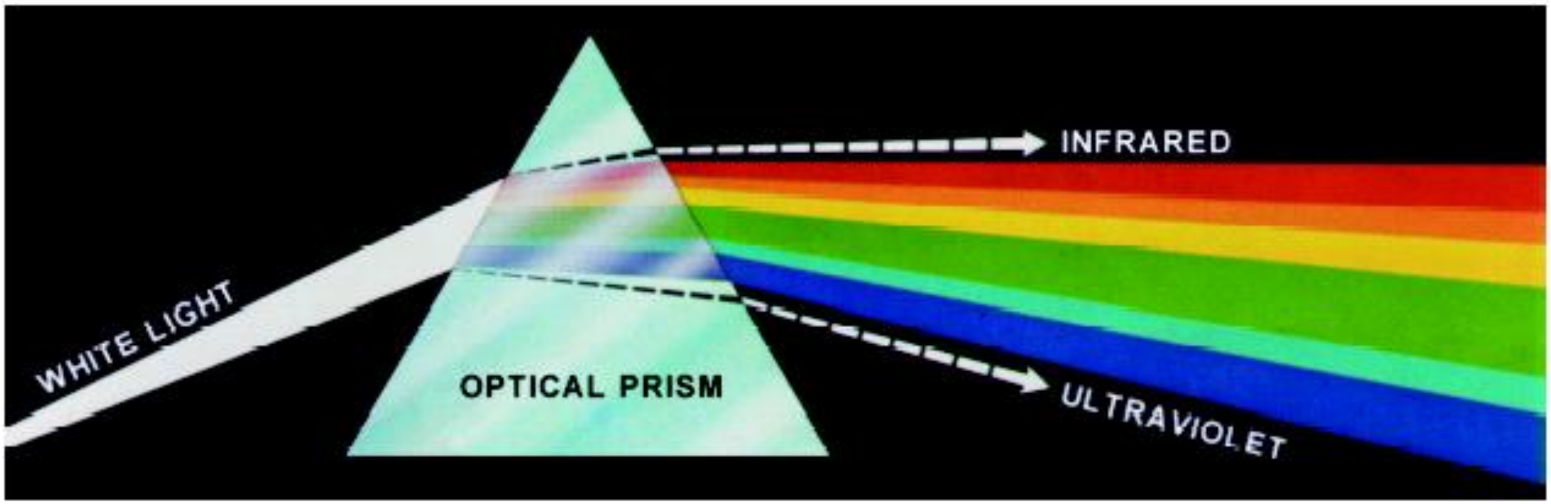
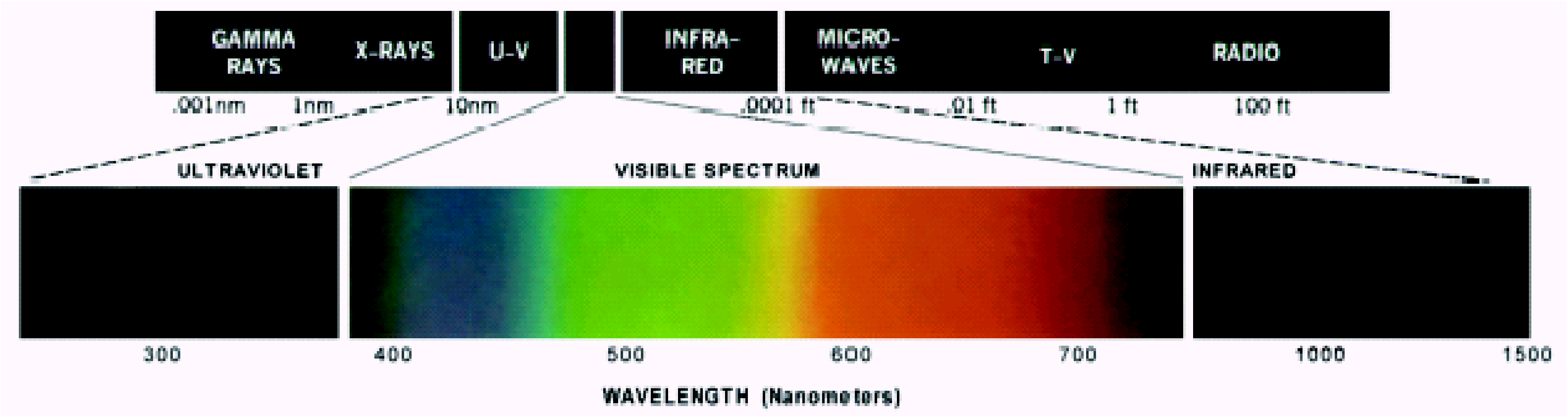


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- Colors that humans perceive are determined by the nature of the light that objects reflect



Visible light wavelength: from around 400 to 700 nm

Color Fundamentals

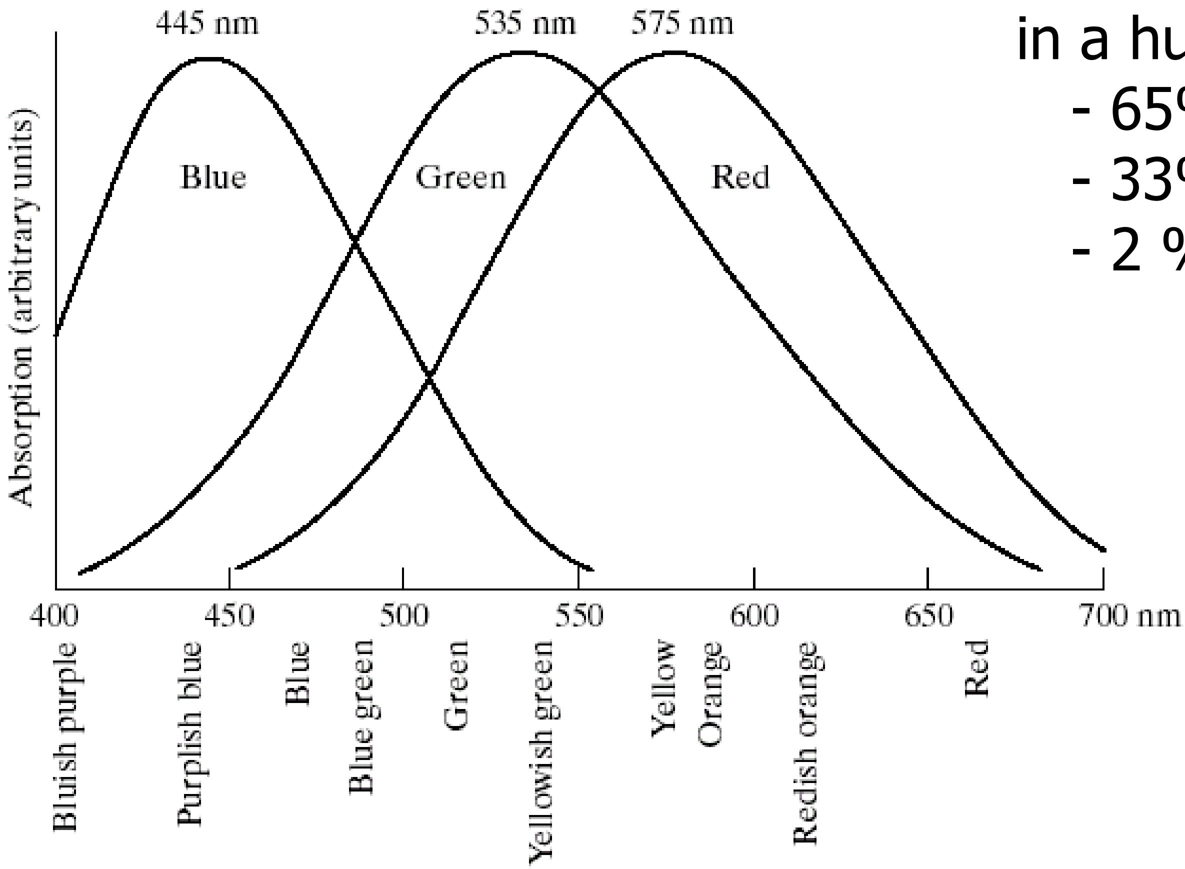
- **Achromatic light**
  - Intensity is the only attribute that describes it
  - Light that is void of color
  - Gray level (shades of gray)
- **Chromatic light**
  - Spans the electromagnetic spectrum from approximately 400 to 700 nm
  - Quantities that describe a chromatic light source:
    - Radiance = total amount of energy flow from a light source (Watts)
    - Luminance = amount of energy received by an observer (lumens)
    - Brightness = intensity
  - Cones in the eye are responsible for color vision
    - Can be divided based on their sensitivity/absorption of light into three types: Red, Green, and Blue cones
  - Based on this experimental classification of the cones, these 3 colors are called the **primary colors**

Color Fundamentals

- **Chromatic light**
  - There is no single frequency that describe these primary colors
  - Standard values set by the CIE in 1931
    - 700 nm for Red
    - 546.1 nm for Green
    - 435.8 nm for Blue
  - Primary does not mean we can generate all colors by mixing these frequencies. Instead, we have to vary the 6 frequencies of these primary colors

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

Color Fundamentals

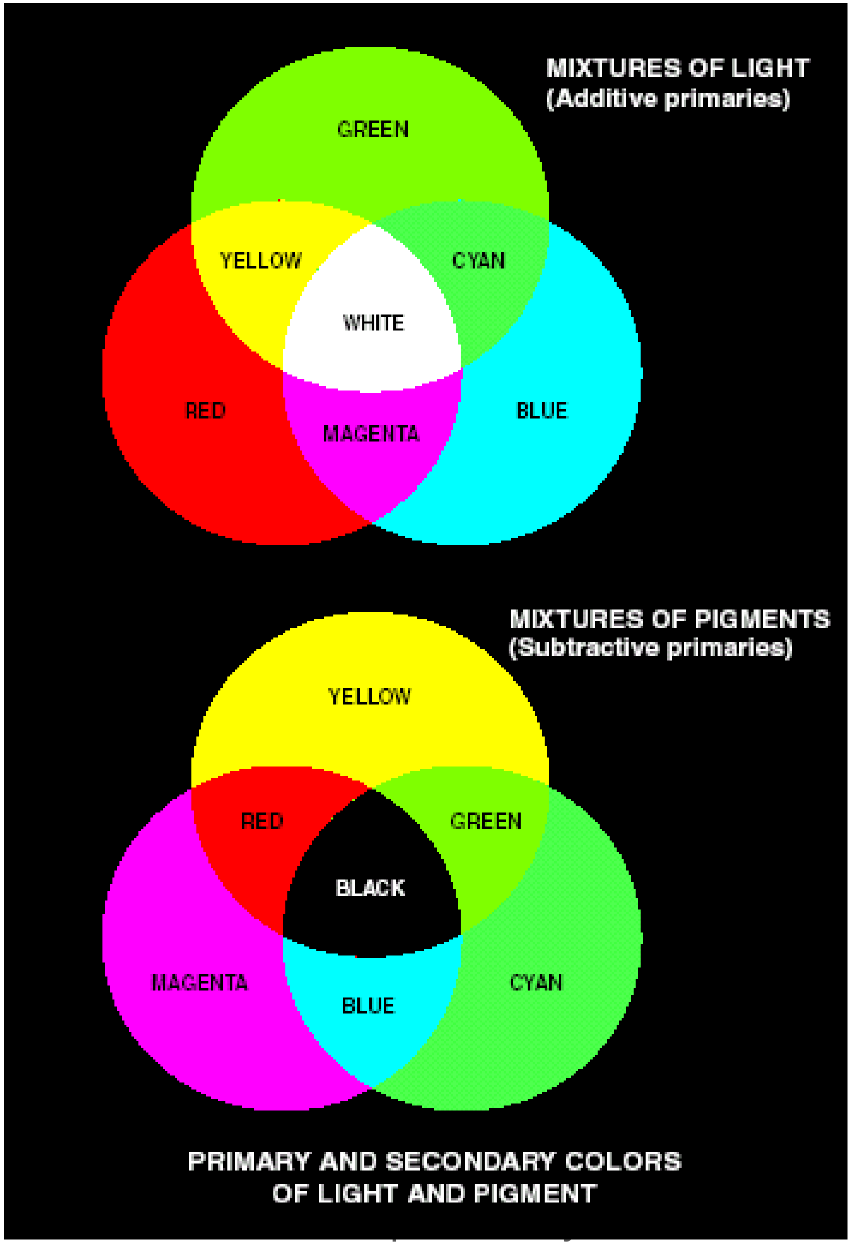


6-7 millions cones in a human eye
- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

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

Color Fundamentals

- **Chromatic light**
  - Additive Primaries (primary colors of light)
    - Primary colors (R,G,B) can be added to produce secondary colors; magenta (M), cyan (C) , and yellow (Y)
    - Mixing the three primaries, in the right intensities, produce white
  - Subtractive Primaries (primary colors of pigment)
    - Secondary colors (RGB) can be added to produce primary colors; red, green, and blue
    - Mixing the three secondary colors, in the right intensities, produce black



Color Fundamentals

- Three attributes are used to distinguish one color from another
  - **Hue:** a measure of the dominant wavelength in a mixture of light waves
  - **Saturation:** refers to the relative purity of or the amount of white light mixed with the hue. The pure spectrum colors (red) are fully saturated. Colors such as pink (red and white) and lavender (white and violet) are less saturated
  - **Brightness:** embodies the achromatic notion of intensity
- Hue and saturation taken together are called *chromaticity* . Thus, any color can be characterized by its brightness and chromaticity.

Color Fundamentals

- The amount of red, green, and blue required to form any particular light are called the *tristimulus* values, X, Y, and Z, respectively.
- We can specify any color by its trichromatic coefficients

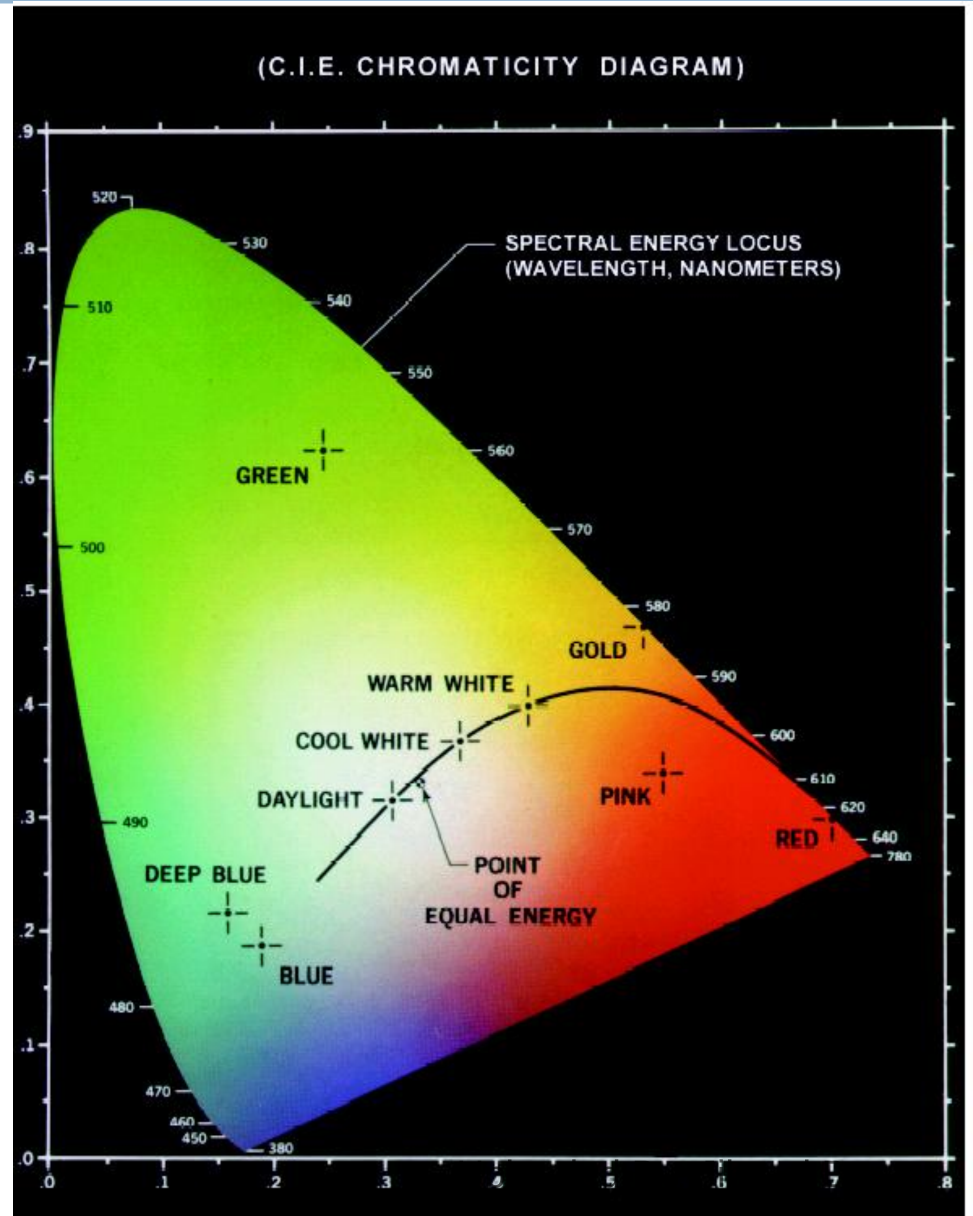
$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

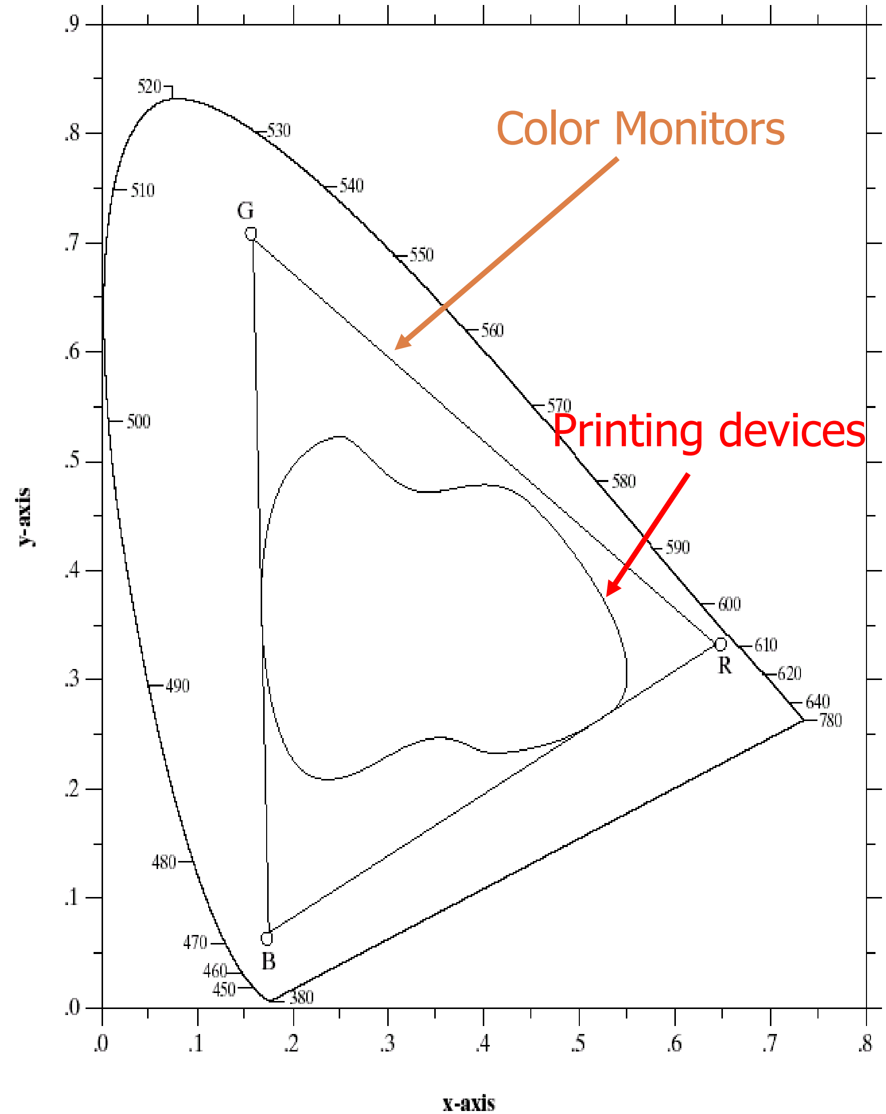
- In order to determine the appropriate tristimulus values for any color, we use experimental tables or curves, e.g. *the chromaticity diagram*

Color Fundamentals

- **The CIE Chromaticity Diagram**
  - Very useful in color mixing
  - It shows the color composition as a function of x (red) and y(green)
  - To determine z (blue) value for any color, use z = 1 – (x+y)
  - Colors on the boundary are fully saturated
  - Any point not on the boundary is a mix of colors
  - The point of equal energy defines color white



- **The CIE Chromaticity Diagram**
  - Very useful in color mixing
  - A line connecting two points in the diagram defines all color variations that can be produced by combining these color additively
  - Three points in the diagram define a triangle. The point inside the triangle represent all possible colors that can be obtained by mixing different intensities of the three colors



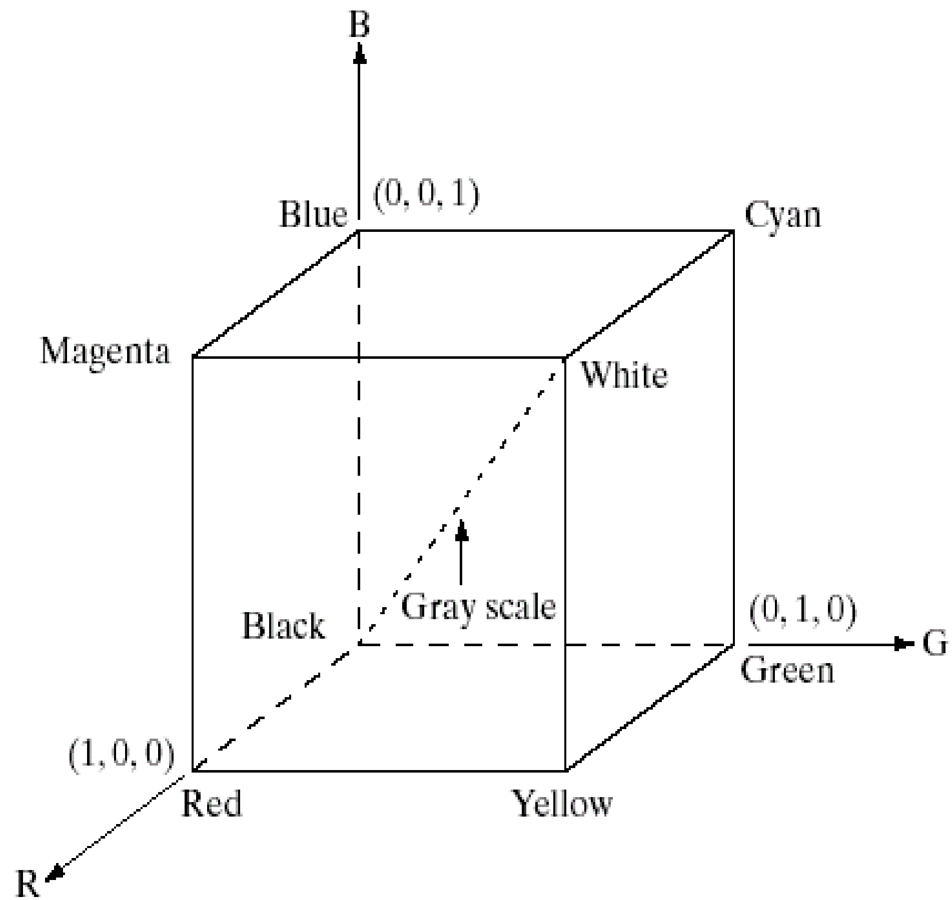
Color Models

- Color models/spaces/systems facilitate the specification of colors following some standard way
- A color model specifies a subspace within some coordinate system in which each color is represented as a point
- Classification of color models
  - Hardware-oriented
    - Generate colors in hardware
    - RGB, CMY, and CMYK
  - Software-oriented
    - The ultimate use is manipulation and processing of color images
    - HSI

The RGB Color Model

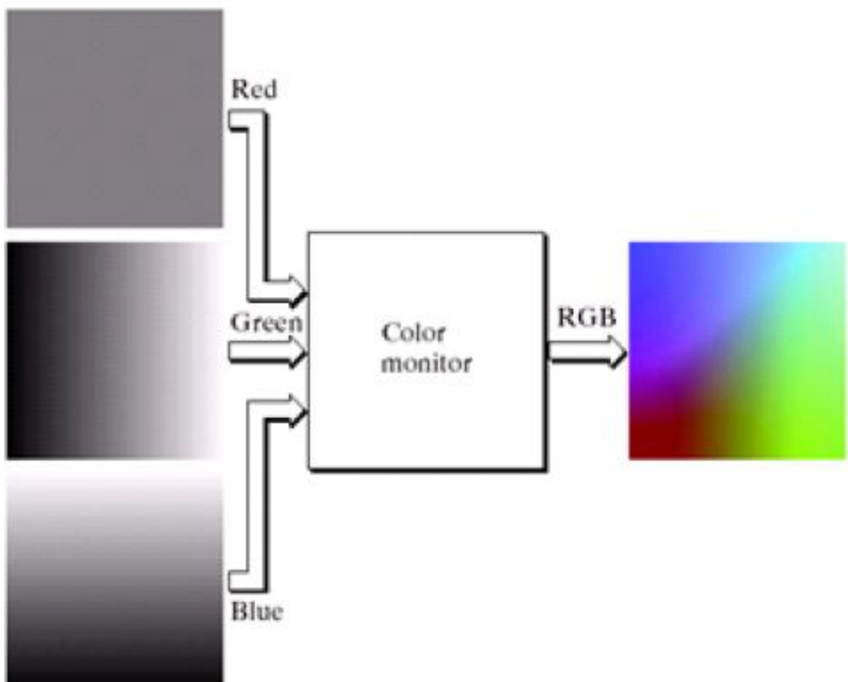
- The RGB color model is based on the Cartesian coordinate system. Each color is represented by its primary spectral components (R,G,B)

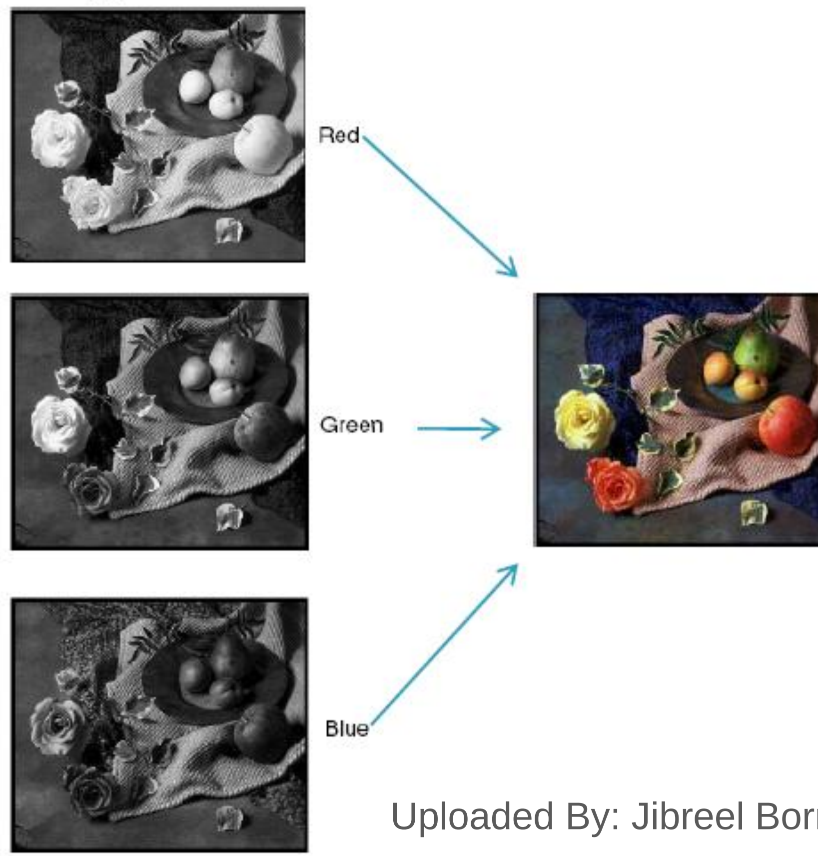
- The subspace of interest is the unit cube. Colors are represented by points on or inside the cube



The RGB Color Model

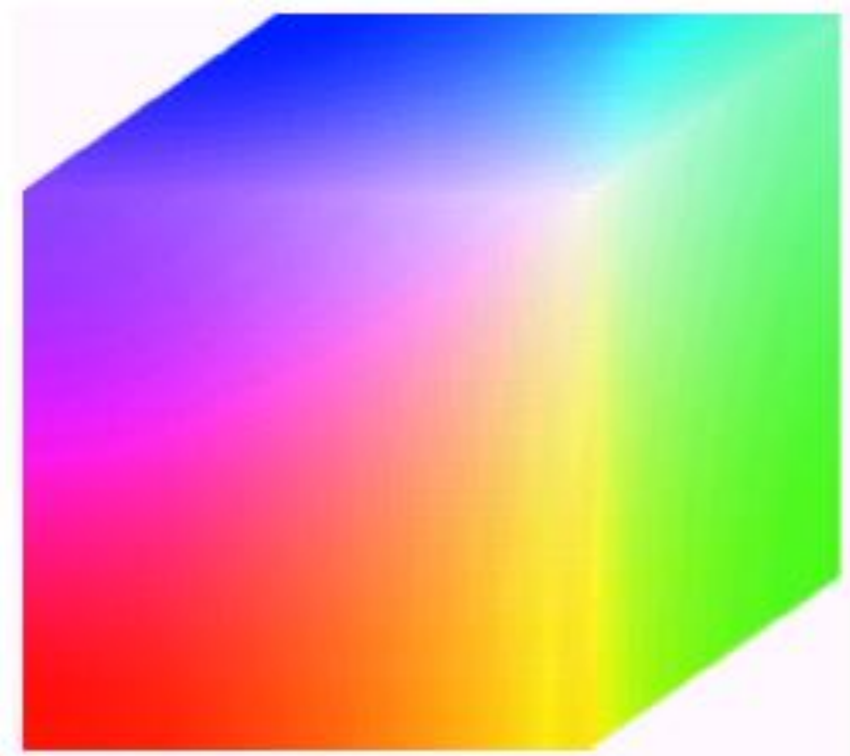
- Images represented in the RGB color model consist of three component images.
- When fed into the RGB monitor, they combine to produce the composite color image





The RGB Color Model

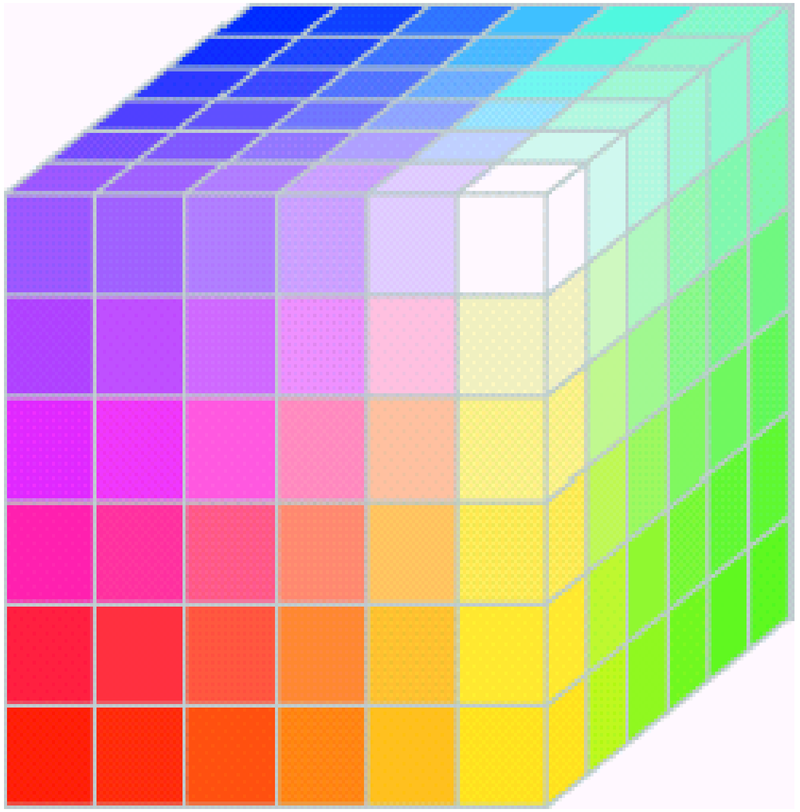
- **Full RGB Colors**
  - Each of the R,G, and B images are 8-bit,
  - The number of bits per pixel in the color image (pixel depth) is 24-bit
  - Total number of colors is 2^{24} = 16 M



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

The RGB Color Model

- **Safe RGB Colors**
  - Uses 256 colors
  - Colors are chosen such that they can be reproduced faithfully independent of hardware
  - Actually, 40 colors are processed differently by different operating systems
  - A safe color is formed by three RGB values. However, the values can be any of the following six values:: 0, 51,102,153,204, or 255.



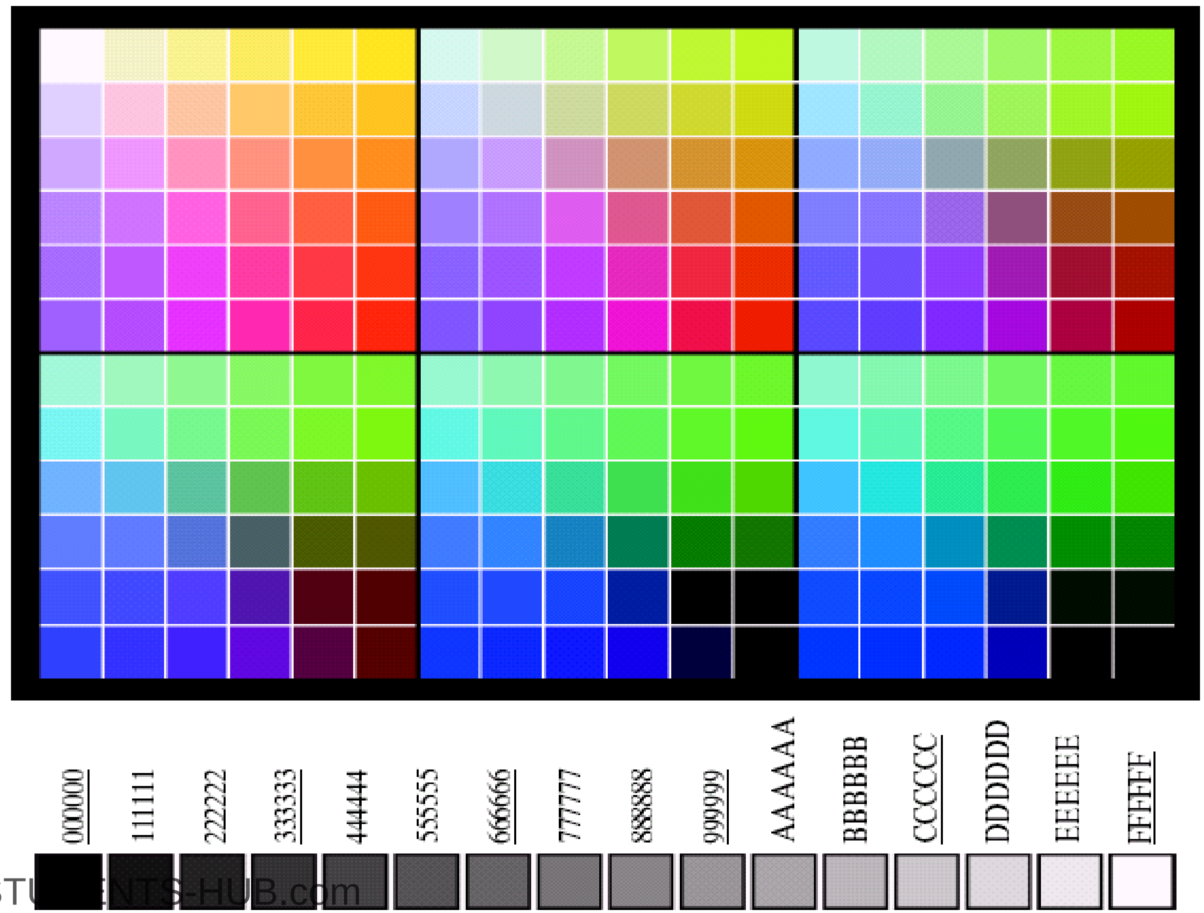
The RGB Cube is divided into 6 intervals on each axis to achieve the total 6^3 = 216 common colors.

Valid colors are on the surface only

The RGB Color Model

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.



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).

The CMY Color Model

- Uses secondary colors, or the primary colors of pigments, cyan, magenta, and yellow to represent colors
- Used commonly in color printers
- Conversion between RGB and CMY

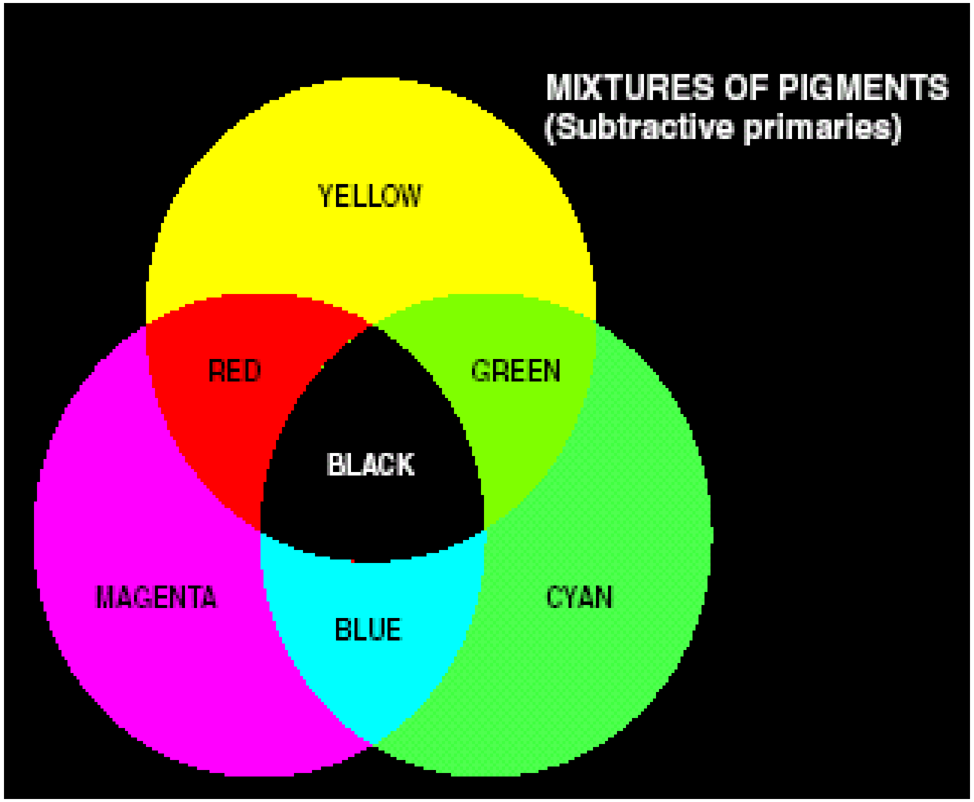
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Combining the three secondary colors should produce black. In practice, they produce muddy black. To produce black, a fourth color, black, is added.
- This is known as the CMYK, or four-color printing system

The CMY Color Model

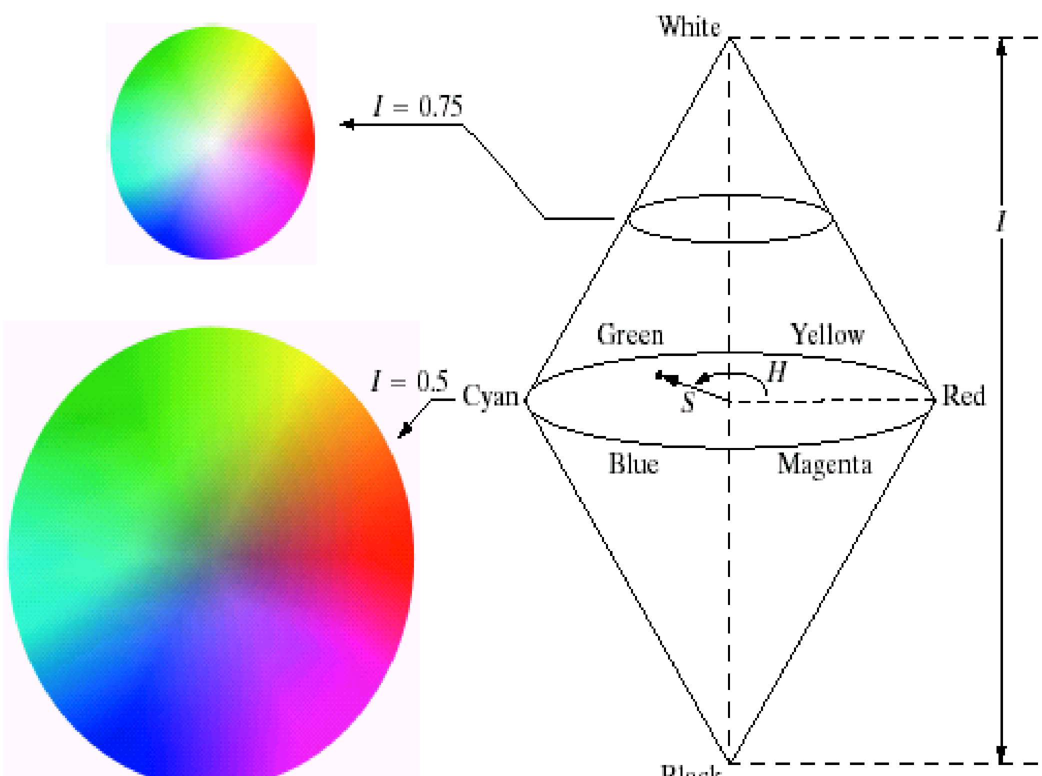
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

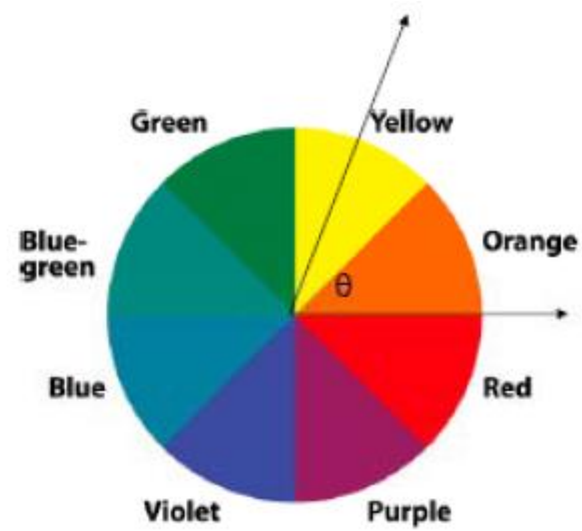
C = Cyan
M = Magenta
Y = Yellow
K = Black



The HSI Color Model

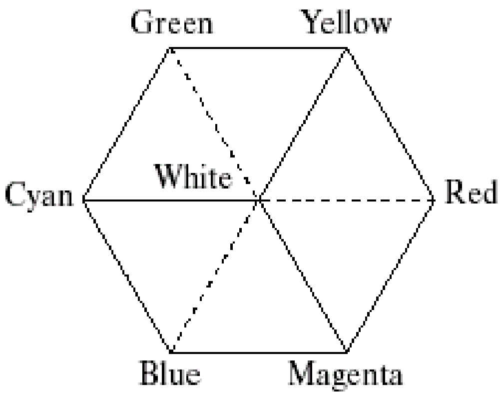
- The RGB and CMY models are well suited for hardware implementation
- It is often hard to use them in describing colors the way humans do
- Humans describe color by its hue (H), saturation (S), and intensity (I)
- These descriptors are the basis of the HSI color model

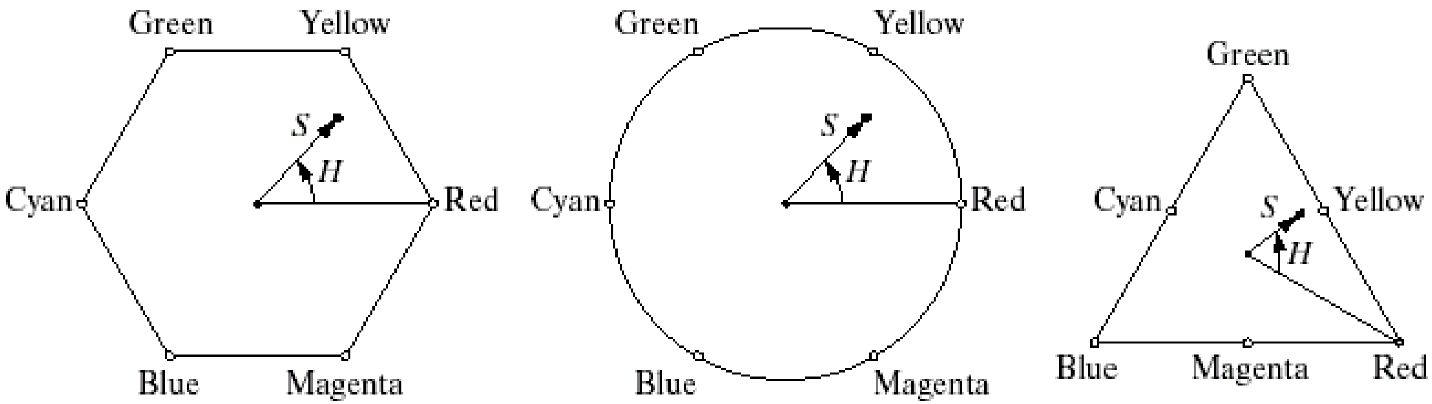




The HSI Color Model

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.





The HSI Color Model

- **Converting RGB colors into HSI**

  Given an image in RGB format, with normalized R, G, and B values, we can compute the HSI components by

  - The Hue Component

$$H = \begin{cases} \theta & , \text{ if } B \le G \\ 360 - \theta & , \text{ if } B > G \end{cases} \Rightarrow \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{\left[(R-G)^2 + (R-B)(R-G)\right]^{1/2}} \right\}$$

θ is measured with respect to the red axis

  - The Saturation Component

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

  - The Intensity Component

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

The HSI Color Model

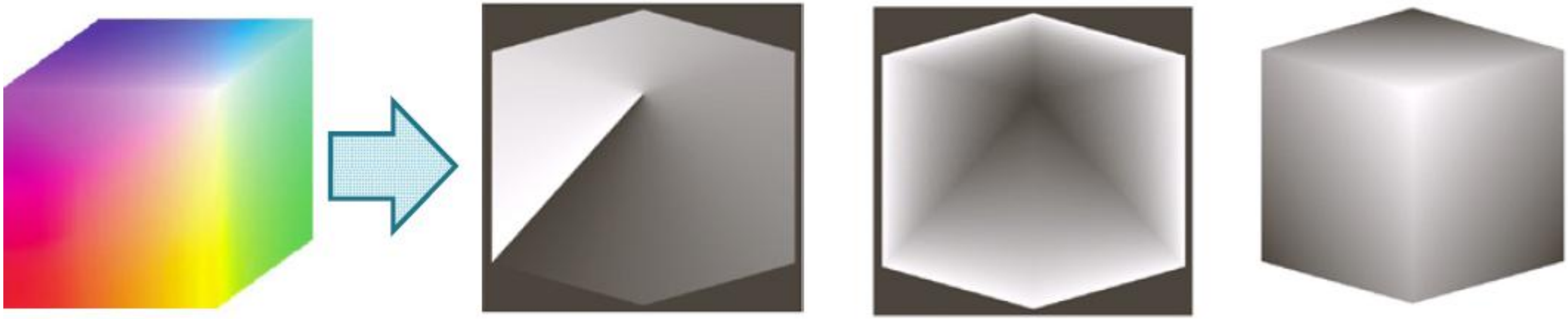
- **Converting HSI colors into RGB**

  Given an image in HSI format , we have three different cases based on the value of H

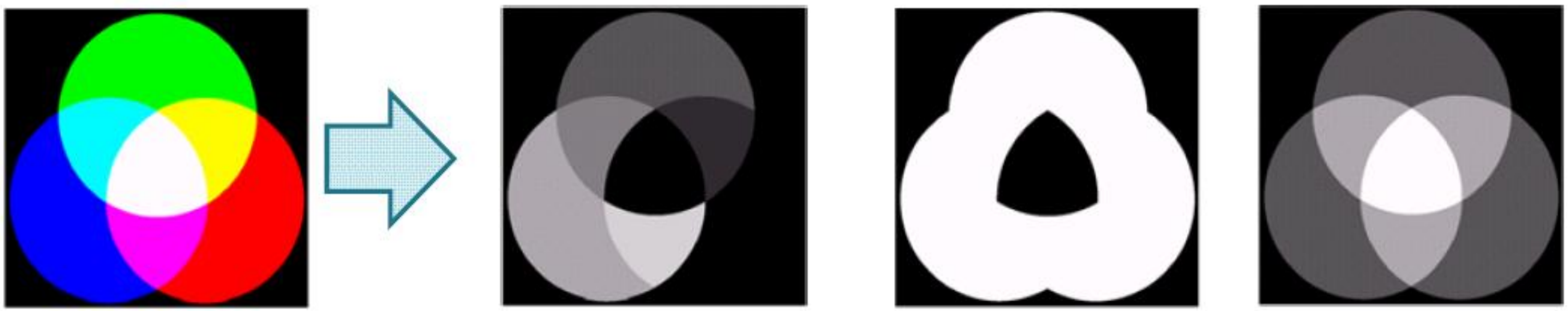
RG sector ($0° \le H < 120°$)	$R = \left[1 + \frac{S \cos H}{\cos(60^o - H)}\right] I$ $B = (1 - S)\, I$ $G = 3I - (R + B)$
GB sector ($120° \le H < 240°$)	$H = H - 120^o \;,\; R = (1 - S)\, I$ $G = \left[1 + \frac{S \cos H}{\cos(60^o - H)}\right] I$ $B = 3I - (R + G)$
BR Sector ($240° \le H \le 360°$)	$H = H - 240^o \;,\; G = (1 - S)\, I$ $B = \left[1 + \frac{S \cos H}{\cos(60^o - H)}\right] I$ $R = 3I - (B + G)$

The HSI Color Model

- **Manipulating HSI Component Images**



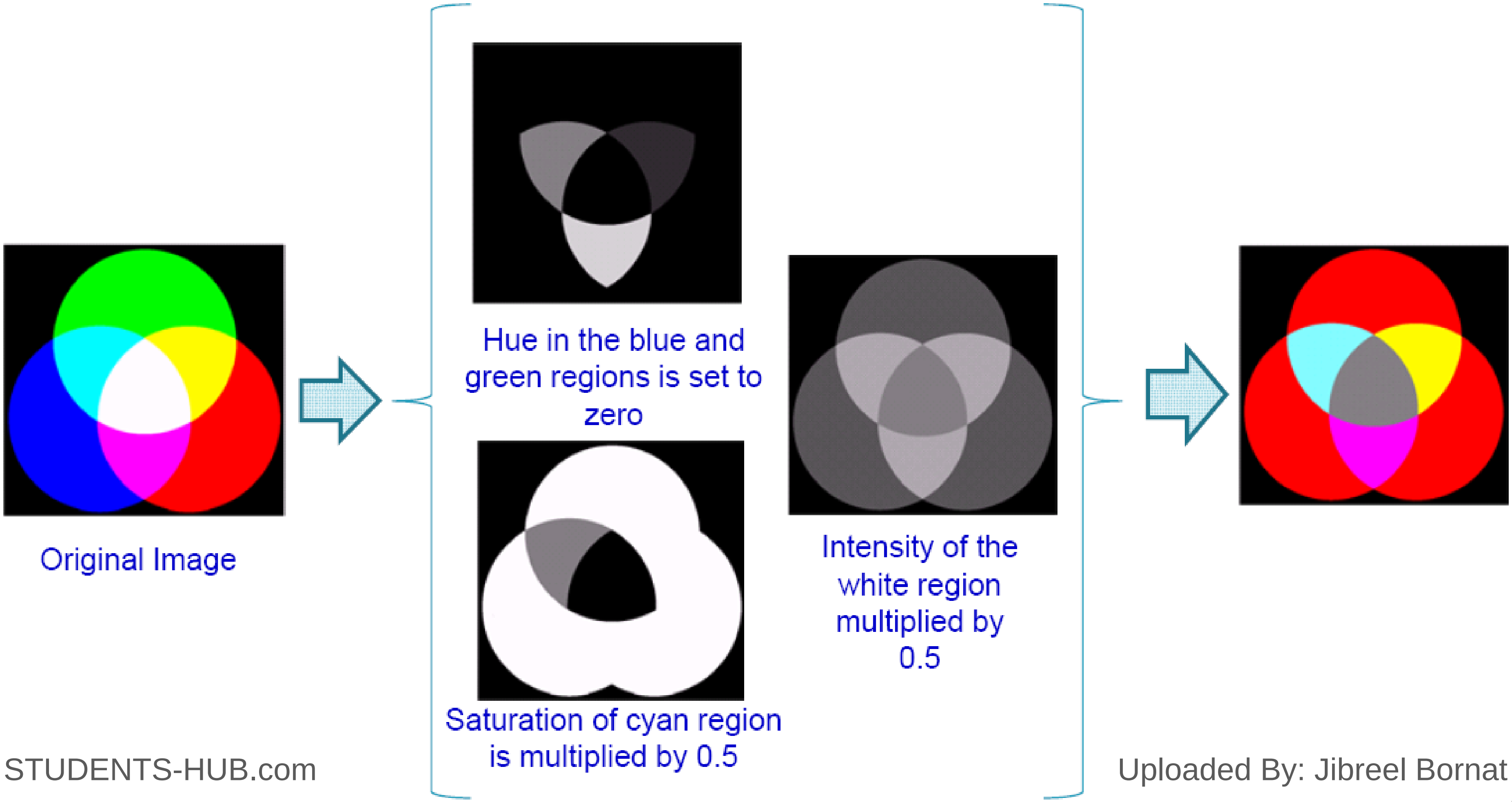
Hue Saturation Intensity



Pure colors Hue Saturation Intensity

The HSI Color Model

- **Manipulating HSI Component Images**
  - Once the components are decoupled, we can operate on one or more of these components to change the image appearance



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

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

Pseudo Color Processing

- Pseudo or false color processing refers to the process of assigning color to gray values based on some criterion

- The idea is to take advantage of the capability of the human eye to distinguish thousands of colors when compared to about two dozens of shades of gray

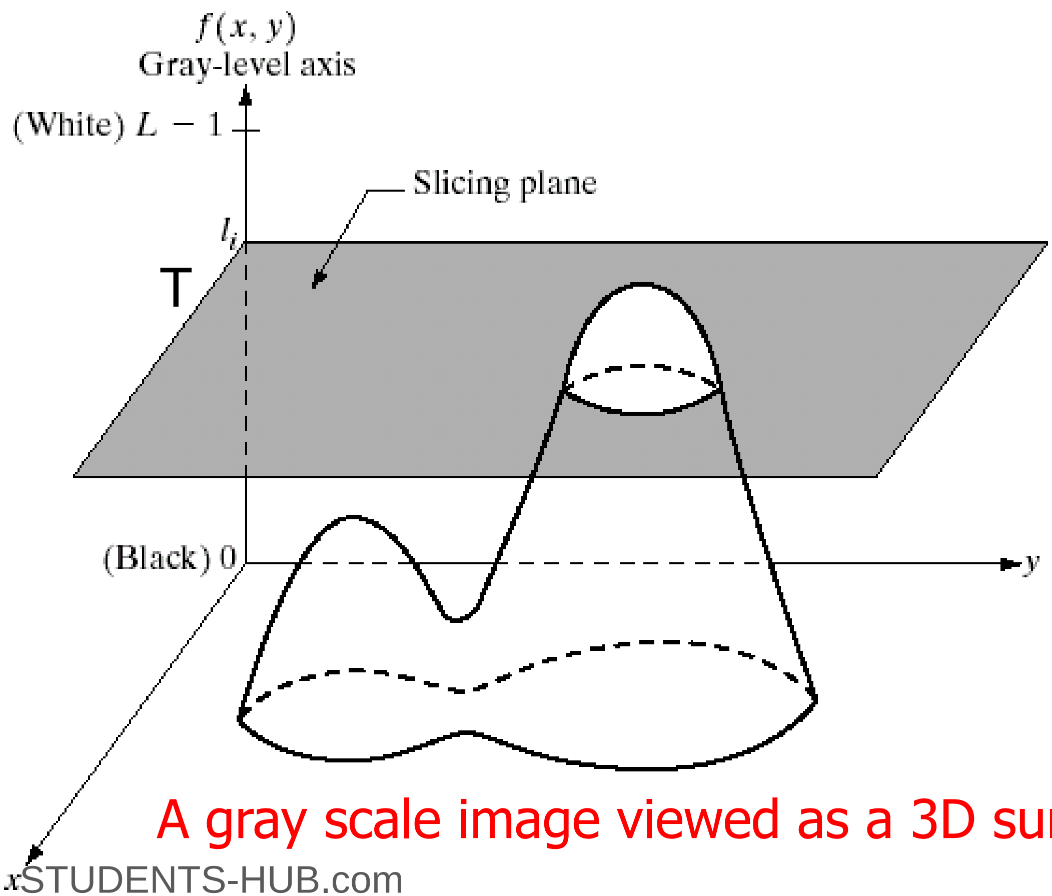
- Two principle approaches
  - Intensity Slicing
  - Intensity to Color Transformation

Pseudo Color Processing

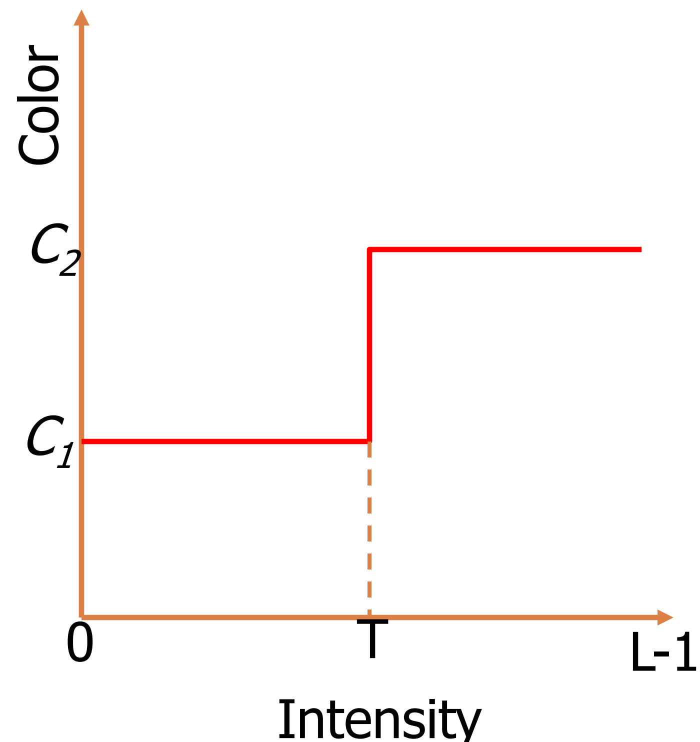
Formula:

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

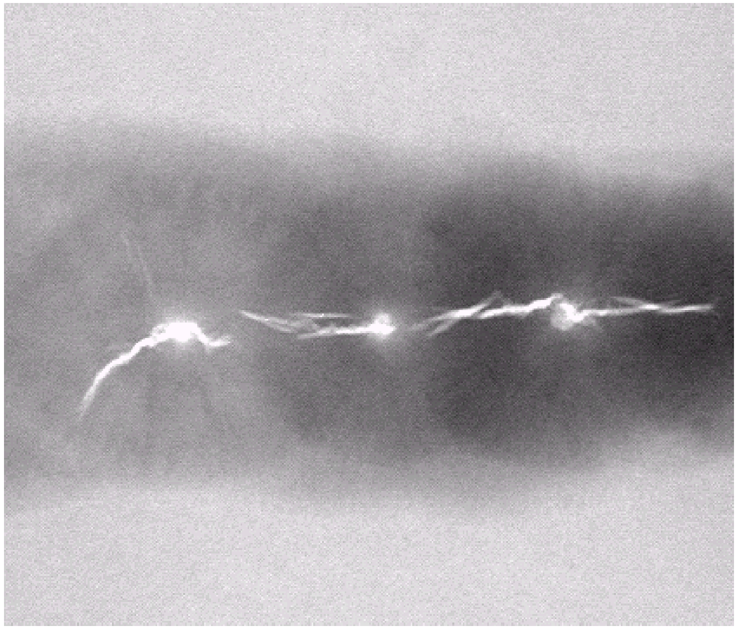
C_1 = Color No. 1
C_2 = Color No. 2



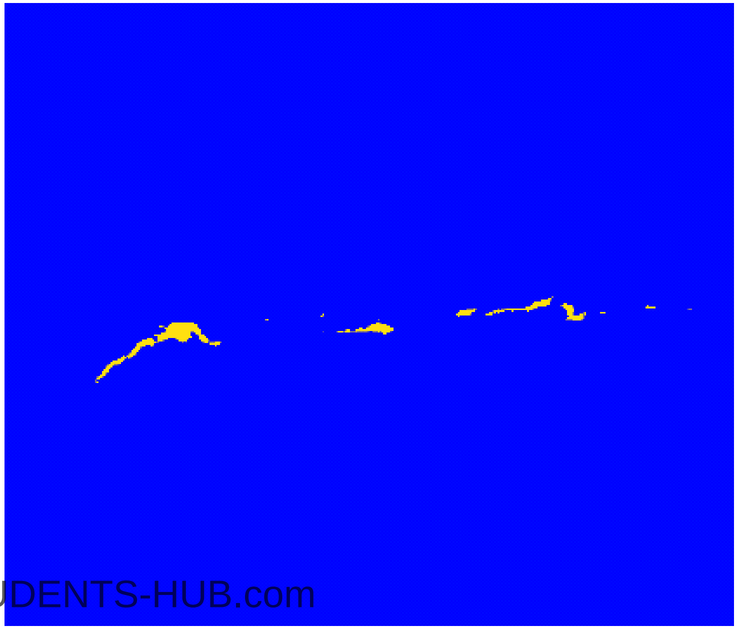
A gray scale image viewed as a 3D surface.



Pseudo Color Processing



An X-ray image of a weld with cracks



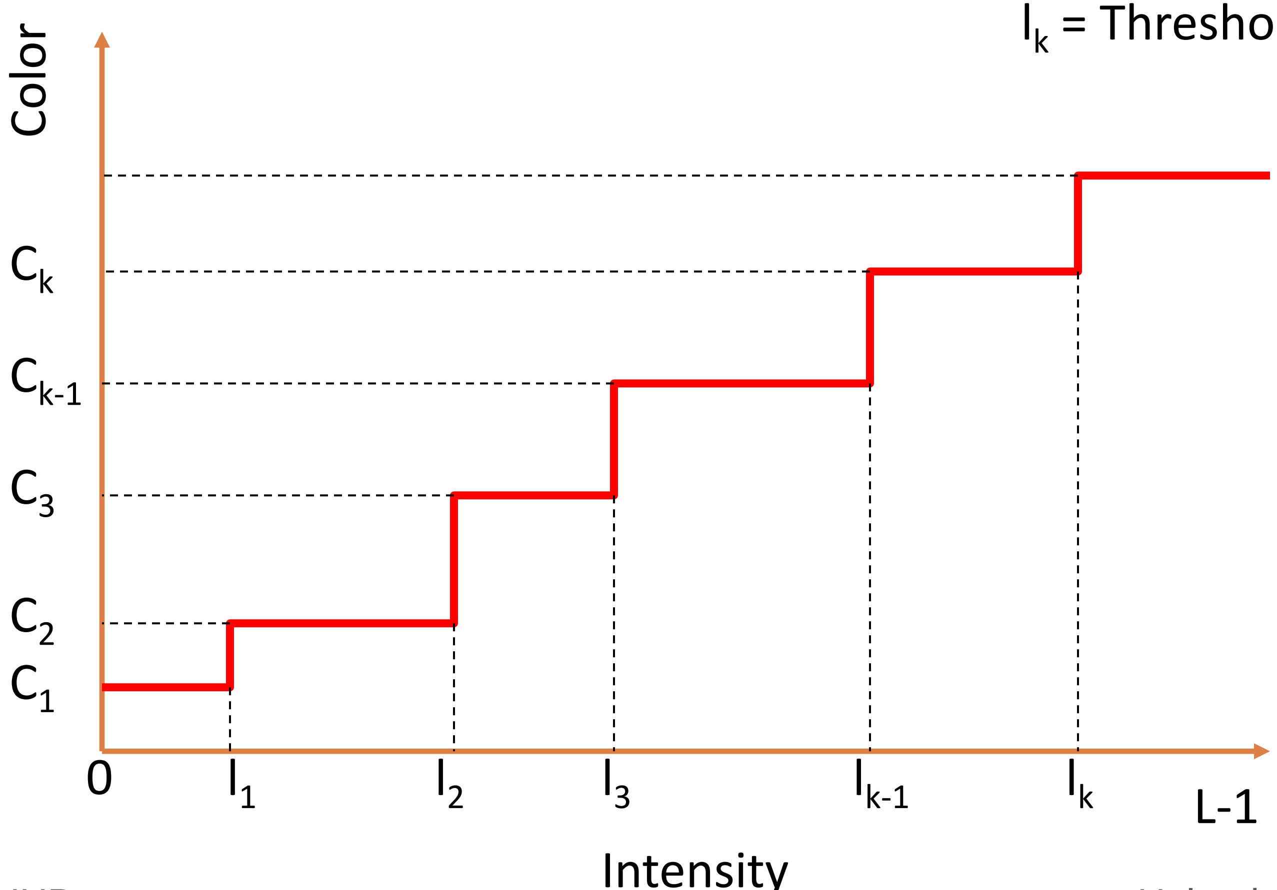
After assigning a yellow color to pixels with value 255 and a blue color to all other pixels

Multi Level Intensity Slicing

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

C_k = Color No. k

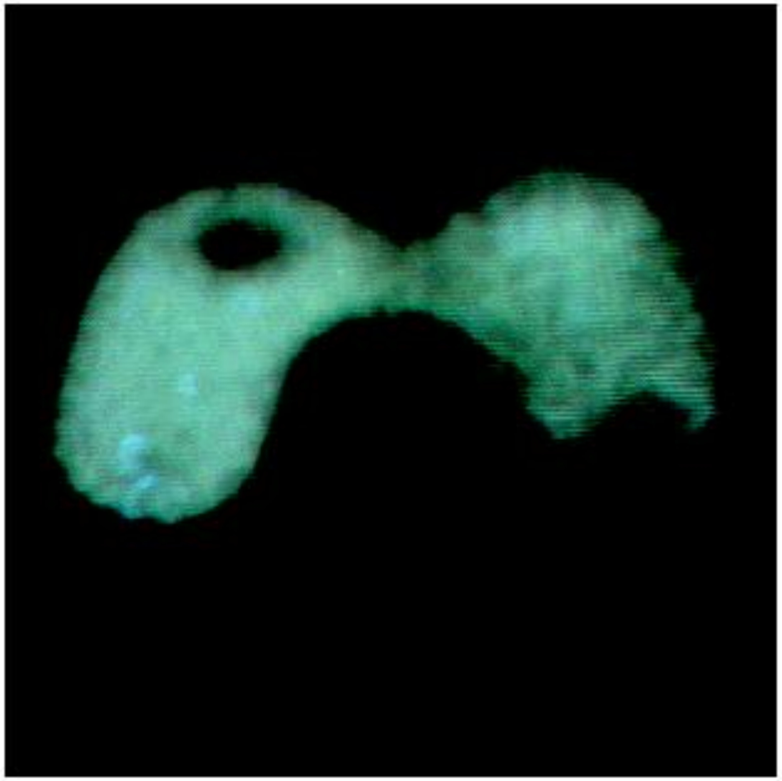
l_k = Threshold level k



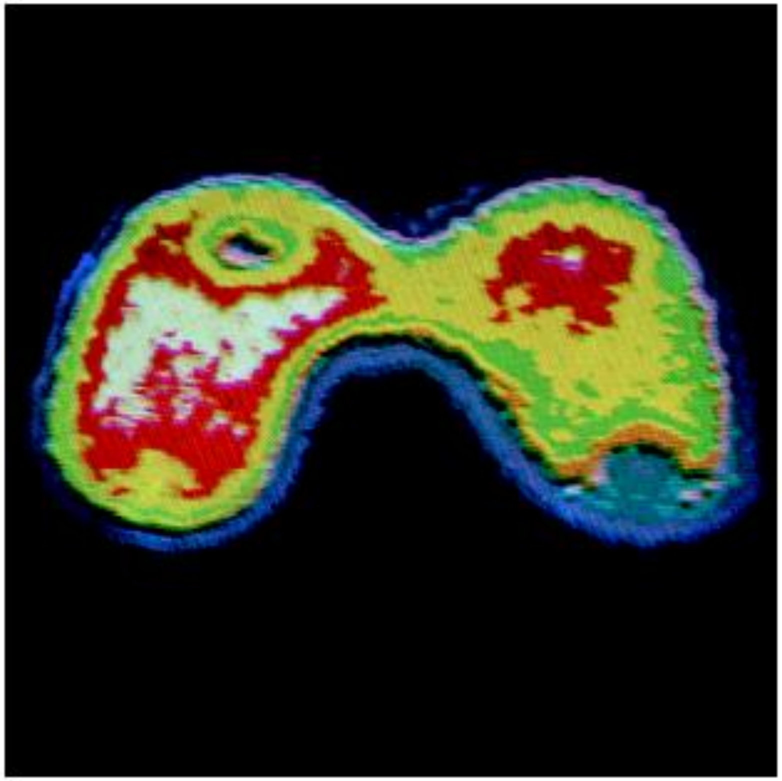
Pseudo Color Processing

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

C_k = Color No. k
l_k = Threshold level k

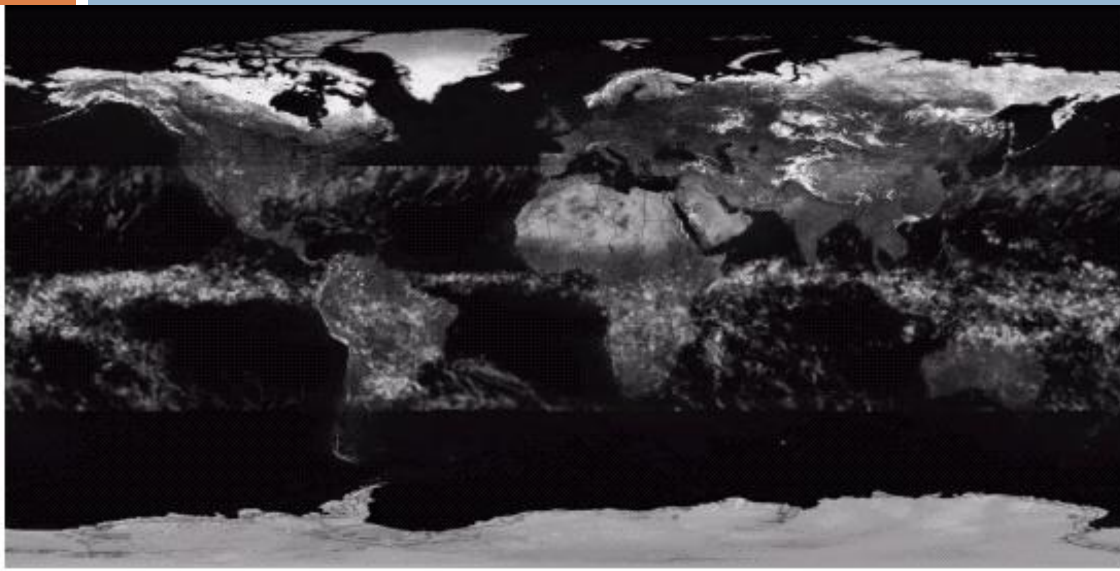


An X-ray image of the Picker Thyroid Phantom.



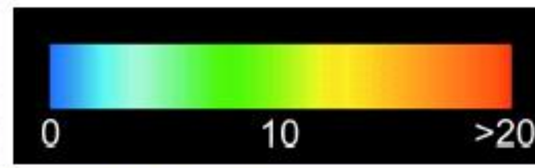
After density slicing into 8 colors

Pseudo Color Processing

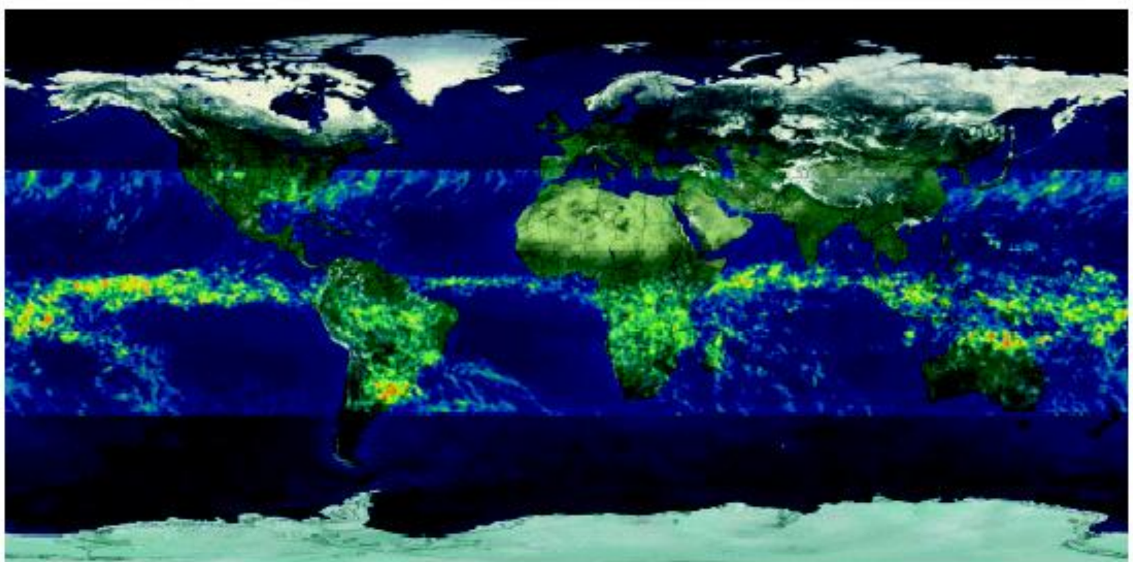


A unique color is assigned to each intensity value.

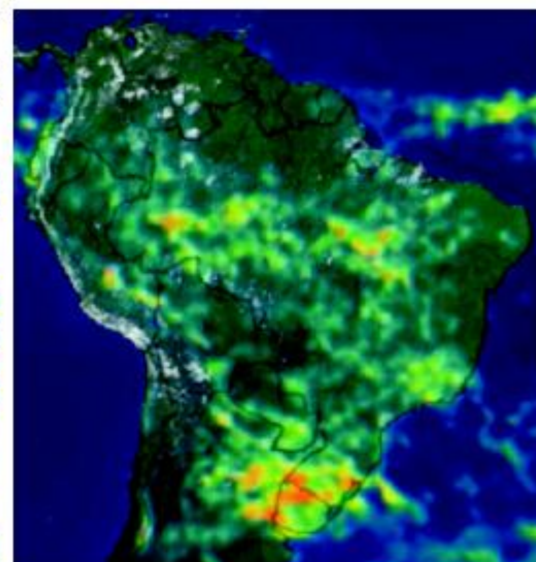
Gray-scale image of average monthly rainfall.



Color map



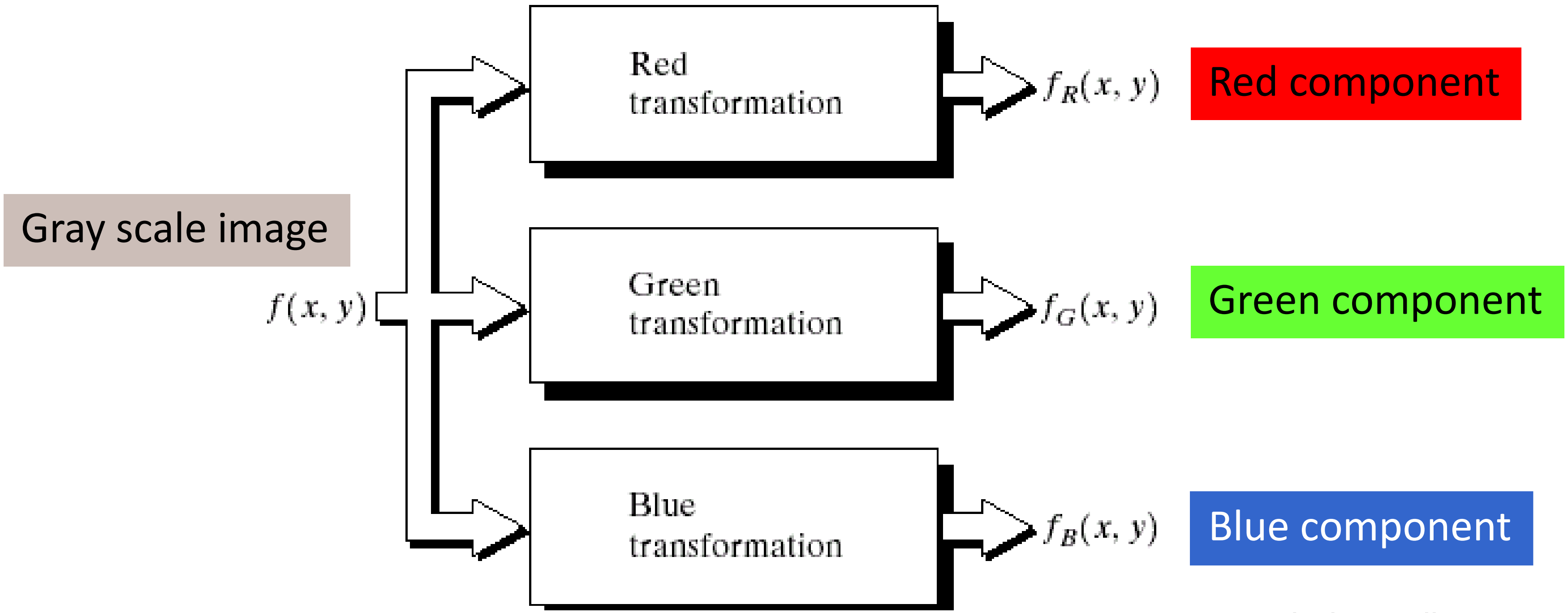
Color coded image



South America region

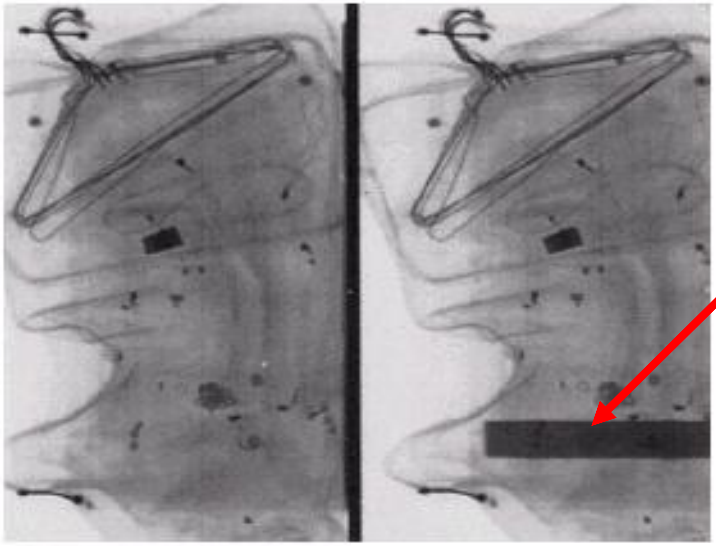
Pseudo Color Processing

- **Intensity to Color Transformation**
  - The basic idea is to transform the monochrome image into three composite images (RGB) using different transformation functions
  - It is a generalization of intensity slicing where we can achieve a wider range of pseudo color enhancement



Pseudo Color Processing

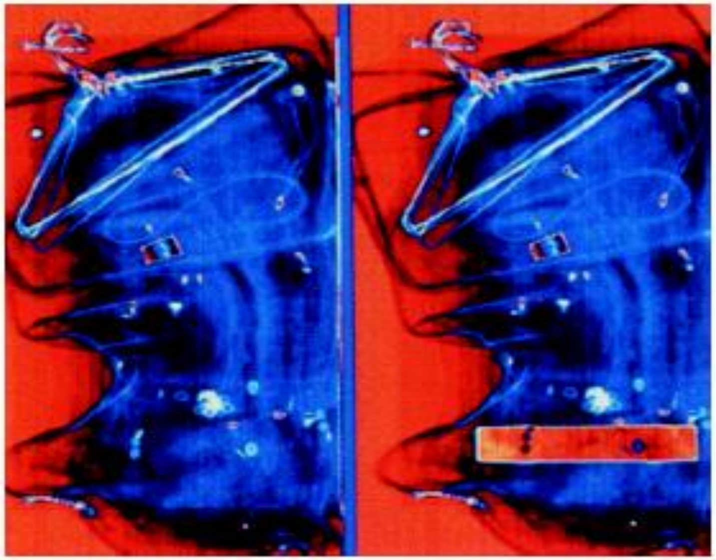
An X-ray image of a garment bag

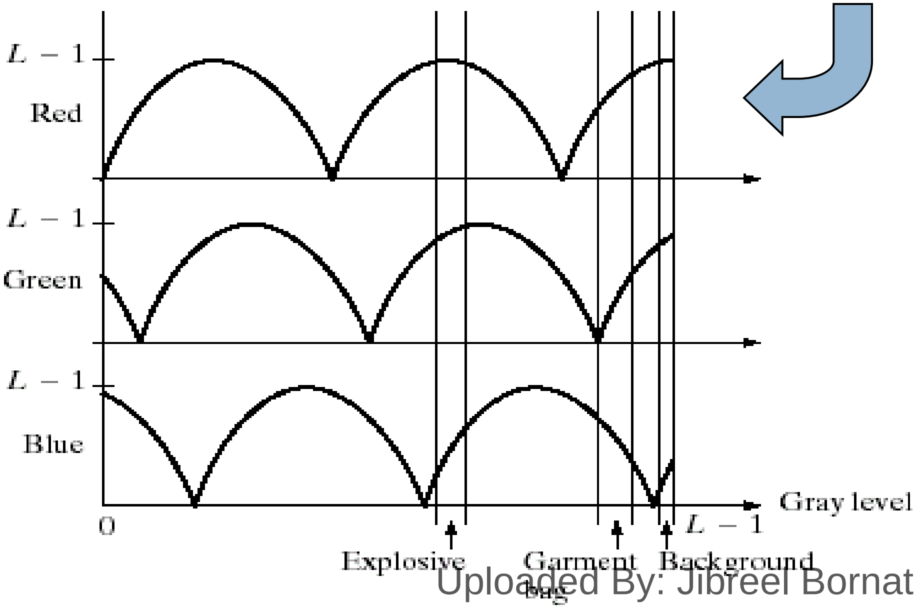


An X-ray image of a garment bag with a simulated explosive device

Transformations

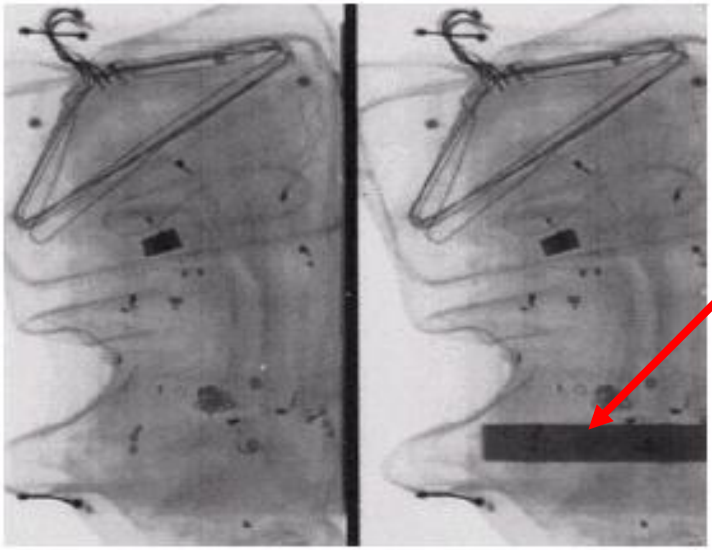
Color coded images





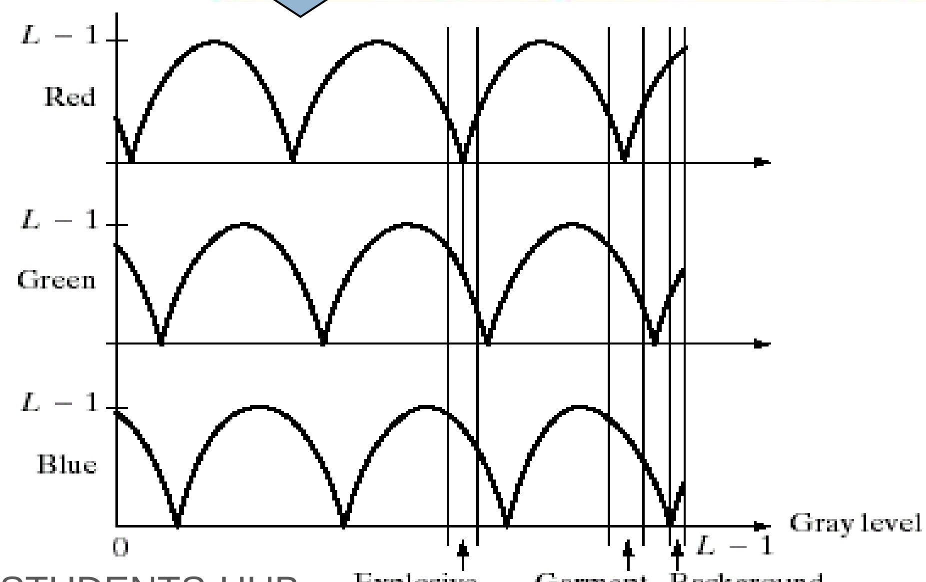
Pseudo Color Processing

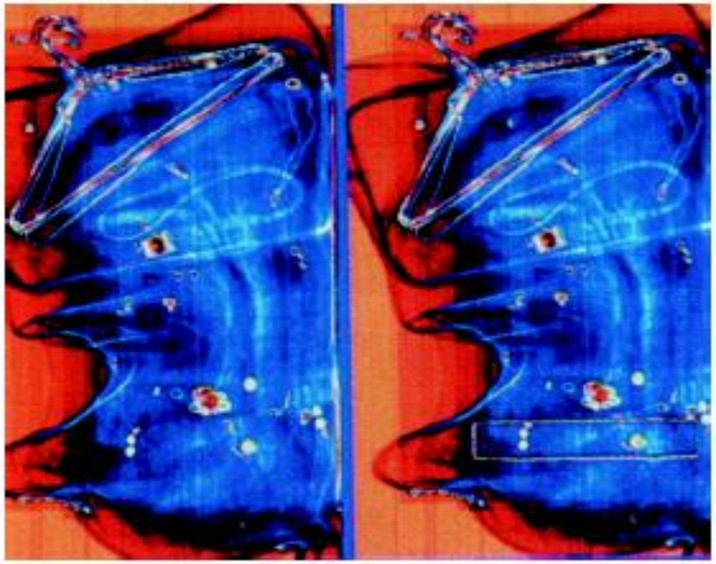
An X-ray image of a garment bag



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

Transformations

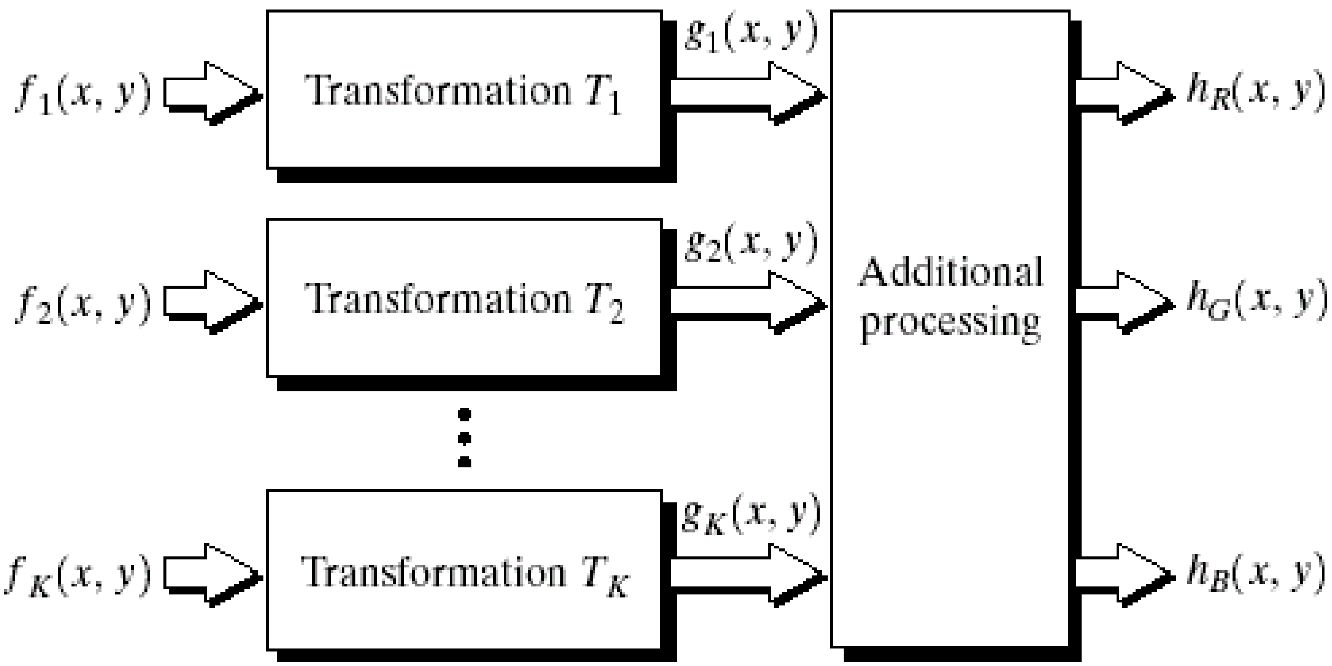




Color coded images

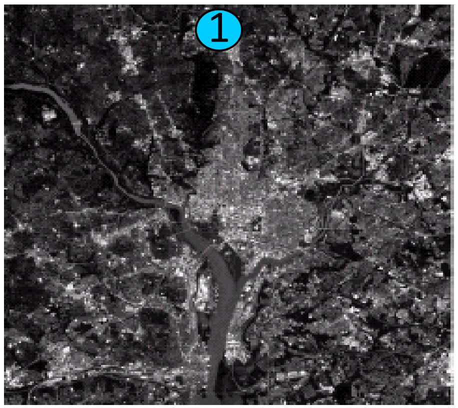
Pseudocolor Coding

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

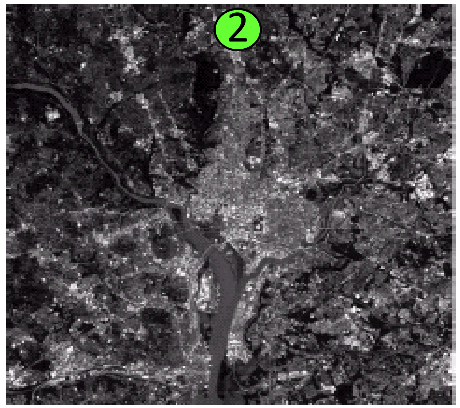


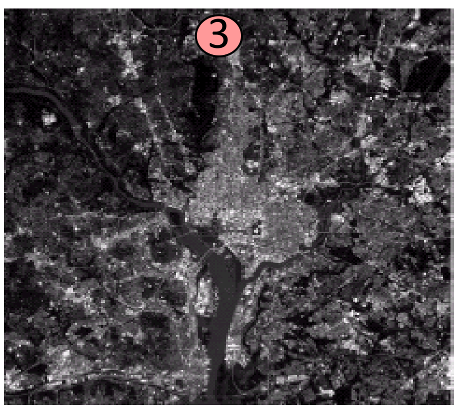
Pseudo Color Processing

Visible blue
λ= 0.45-0.52 mm
Max water penetration

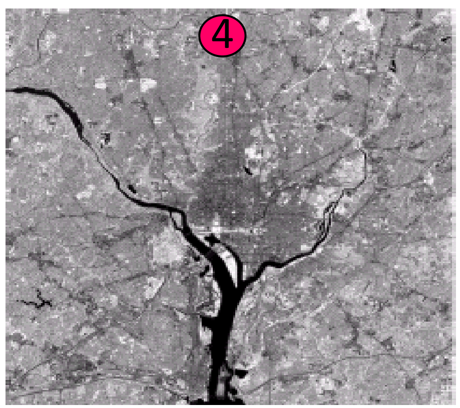


Visible green
λ= 0.52-0.60 mm
Measuring plant





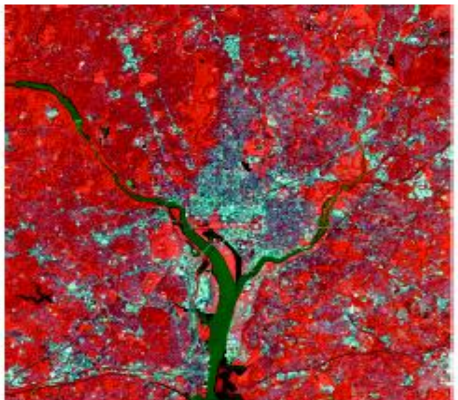
Visible red
λ= 0.63-0.69 mm
Plant discrimination



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

Color composite images

Red = 1
Green = 2
Blue = 3



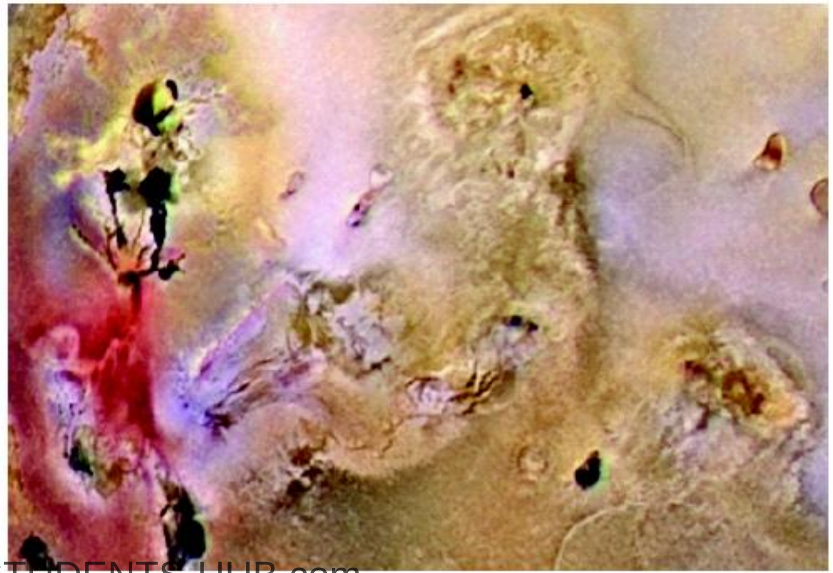
Red = 1
Green = 2
Blue = 4

Washington D.C. area

Pseudo Color Processing

Psuedocolor rendition of Jupiter moon Io

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



A close-up

Full-Color Processing

- Color processing can be performed by
  - Operating on each color channel separately then compose the color image
  - Operating on color pixels directly
- Color Transformations
  - We can model color transformation as

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

  - Note that f(x,y) here represent a triplet or quartets (three or four values)
  - In general, color transformations are of the form

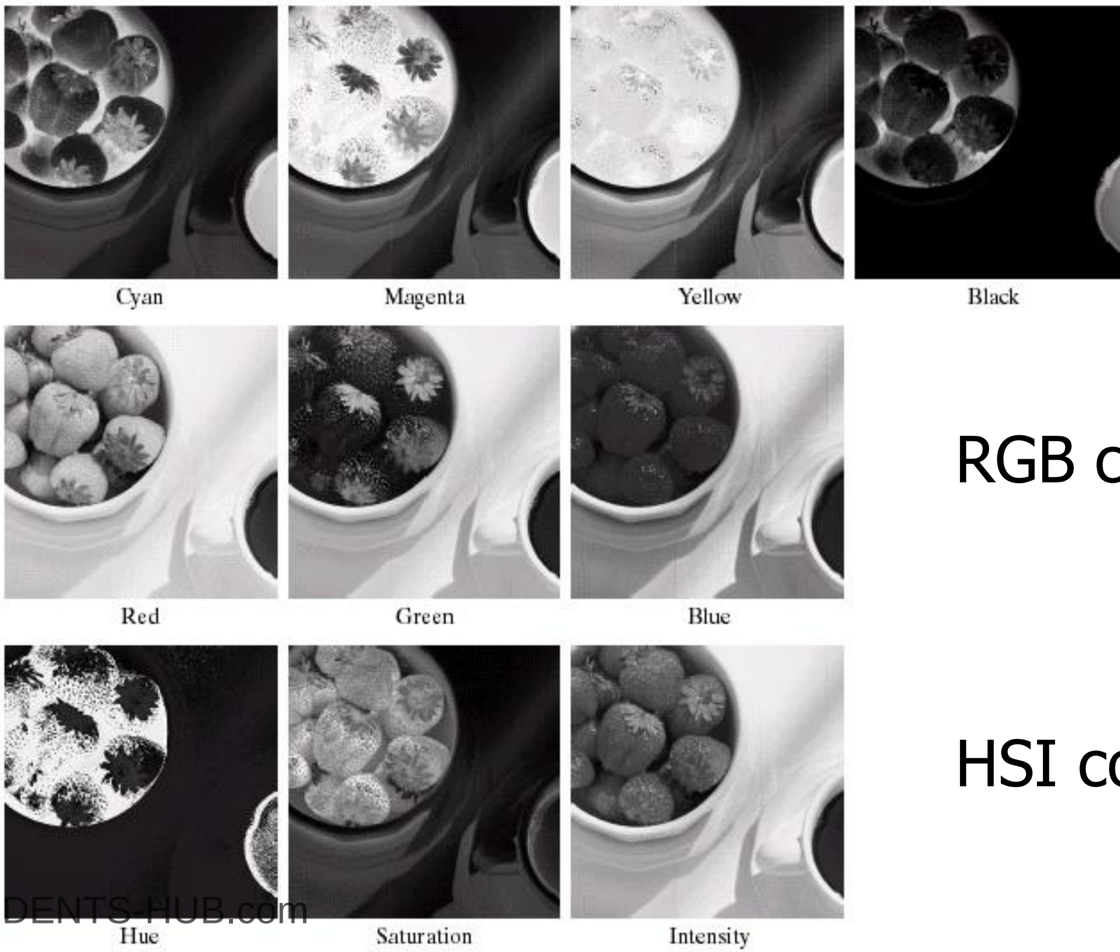
$$s_i = T_i(r_1, r_2, r_3, \ldots, r_n) \quad , \quad n = 1,2,3,\ldots, n$$

    - n is the number of color components
    - Each transformation function T_i operate on different channel r_i to produce s_i
    - The result is combined into a single image

Full-Color Processing

Full color

Color image



CMYK components

RGB components

HSI components

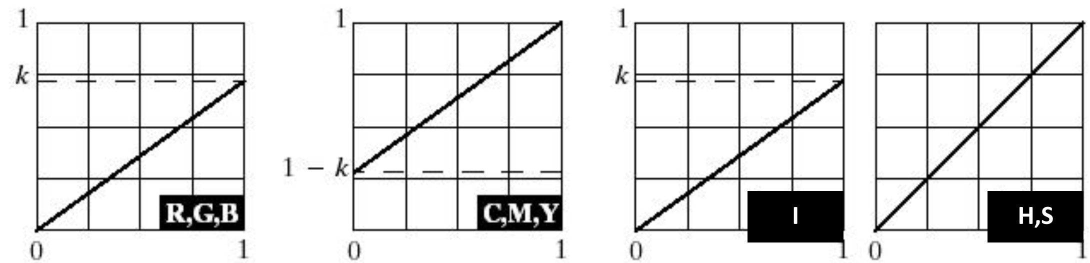
Full-Color Processing

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:

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



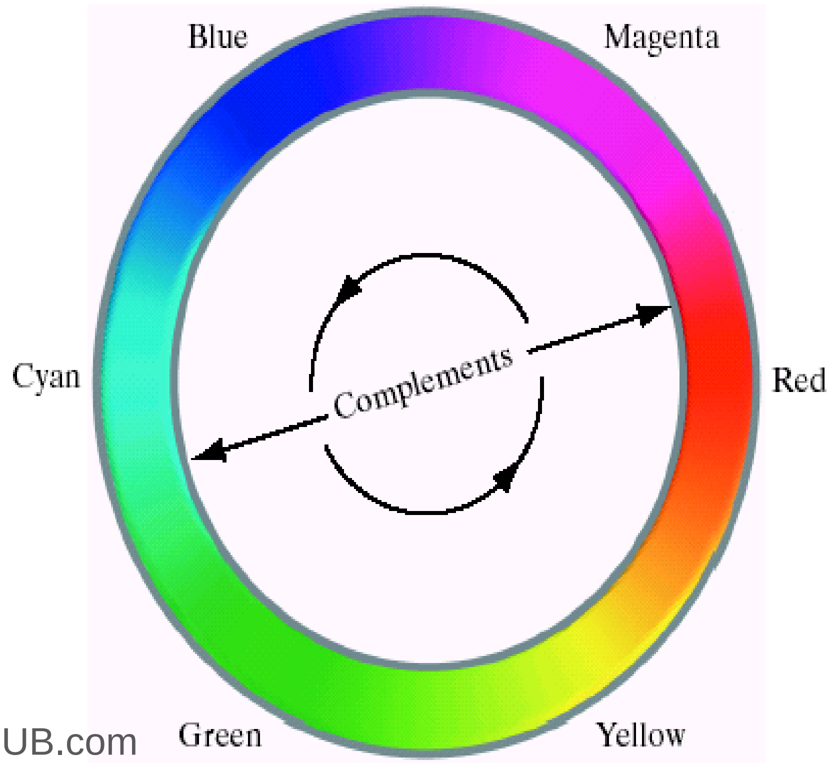
Formula for CMY:

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

These 3 transformations give the same results.

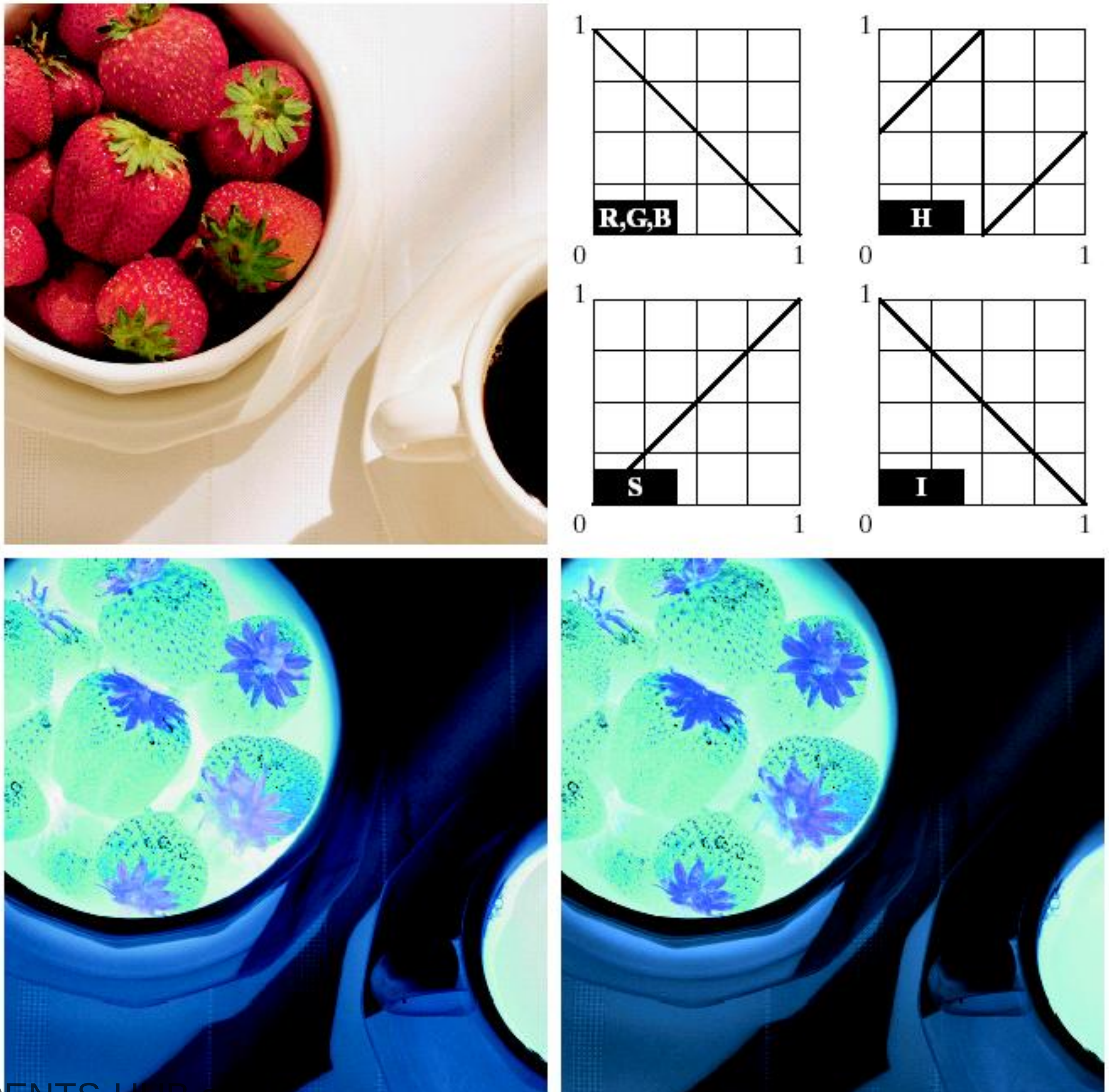
Full-Color Processing

- 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.
  - Useful in enhancing small dark details embedded in bright regions or the opposite
  - Use the Hue color circle



Color circle

Full-Color Processing



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.

Full-Color Processing

- **Color Slicing**
  - Analogous to gray-scale slicing
  - Approach: map the colors outside the range of interest to some neutral nonprominnet color
  - To define the colors that fall in the range of interest we may use a hypersphere with radius R_o

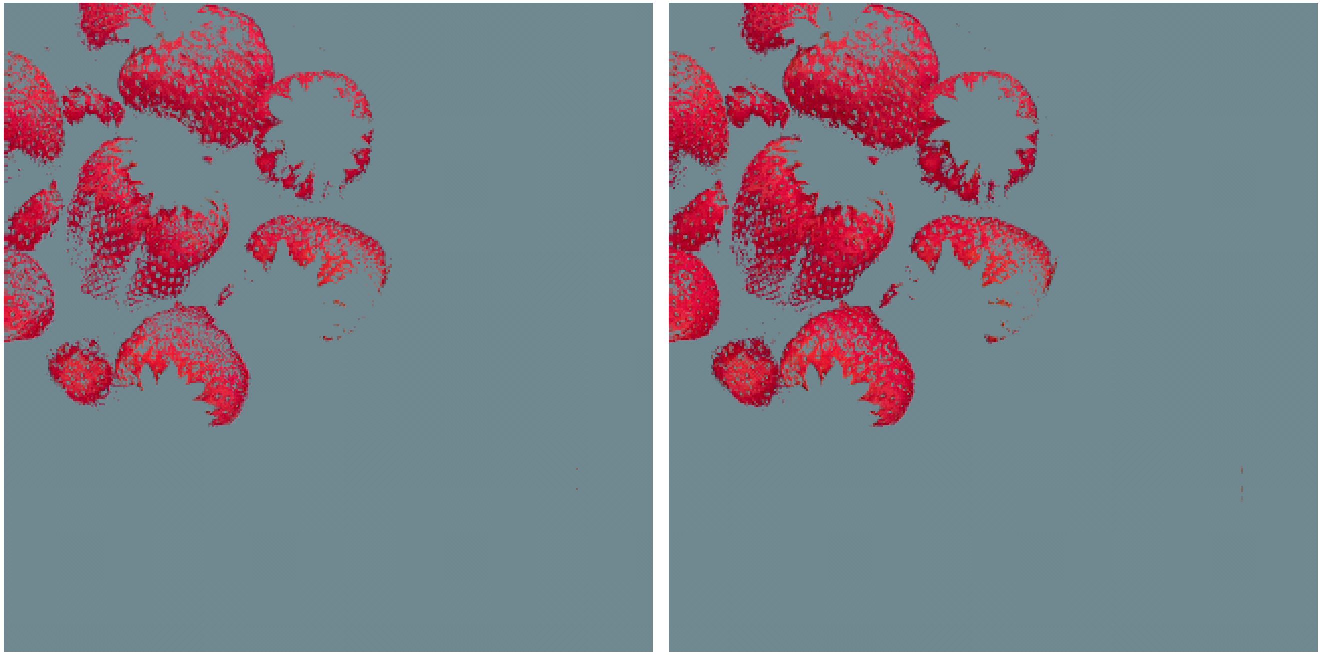
$$s_i = \begin{cases} 0.5 \;, & \sum_{j=1}^{n} (r_i - a_i)^2 > R_o^2 \\ r_i \;, & otherwise \end{cases} \qquad i=1,2,3\ldots,n$$

  - a_i represents the color components at the center of sphere (prototypical color)

Full-Color Processing

After color slicing

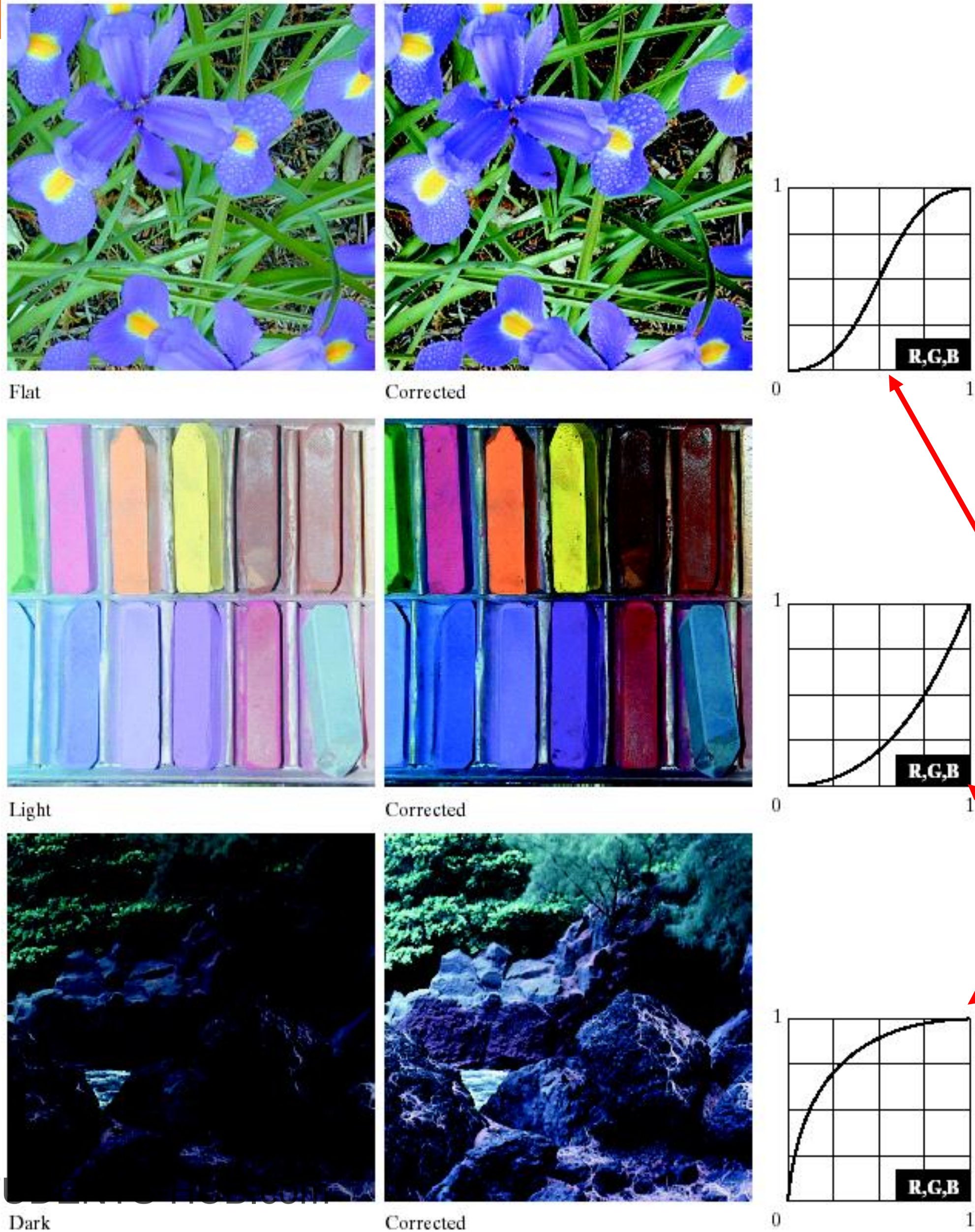
Original image



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).

Full-Color Processing



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

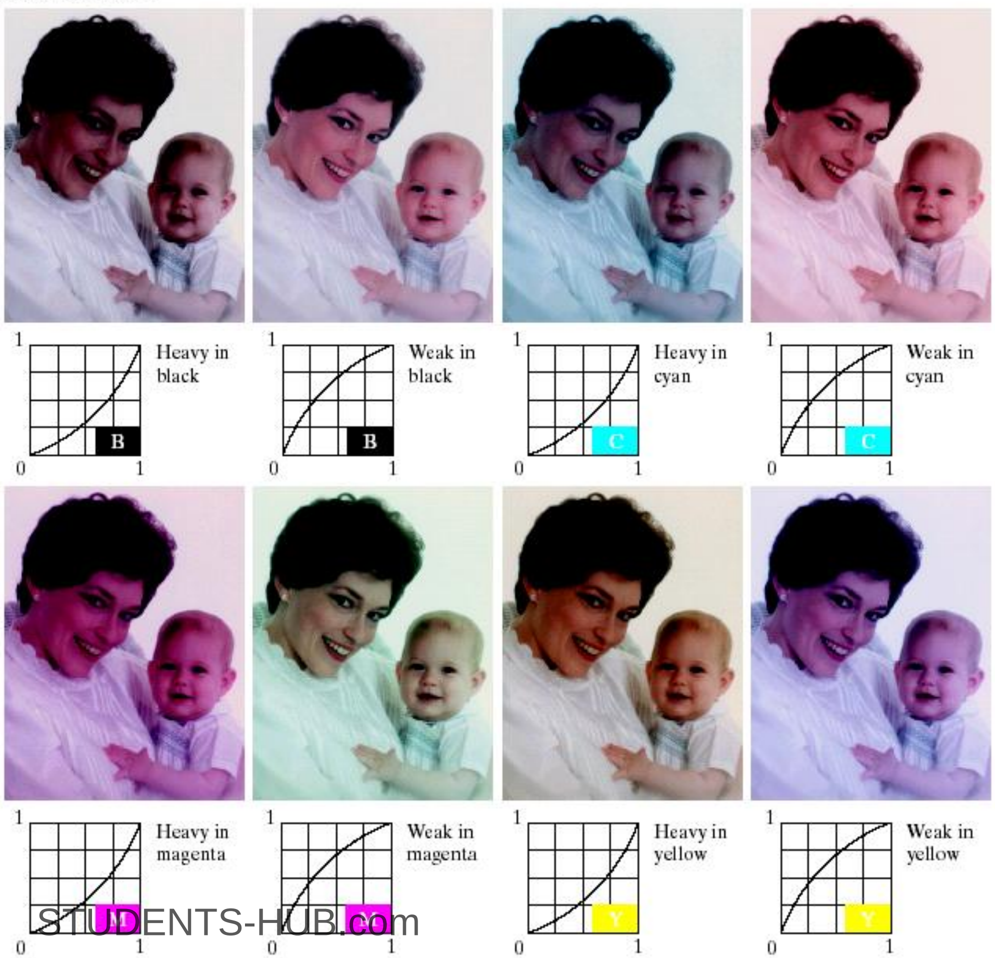
This can be done by using the same transformation for all RGB components.

Contrast enhancement

Power law transformations

Full-Color Processing

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.

Full-Color Processing

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

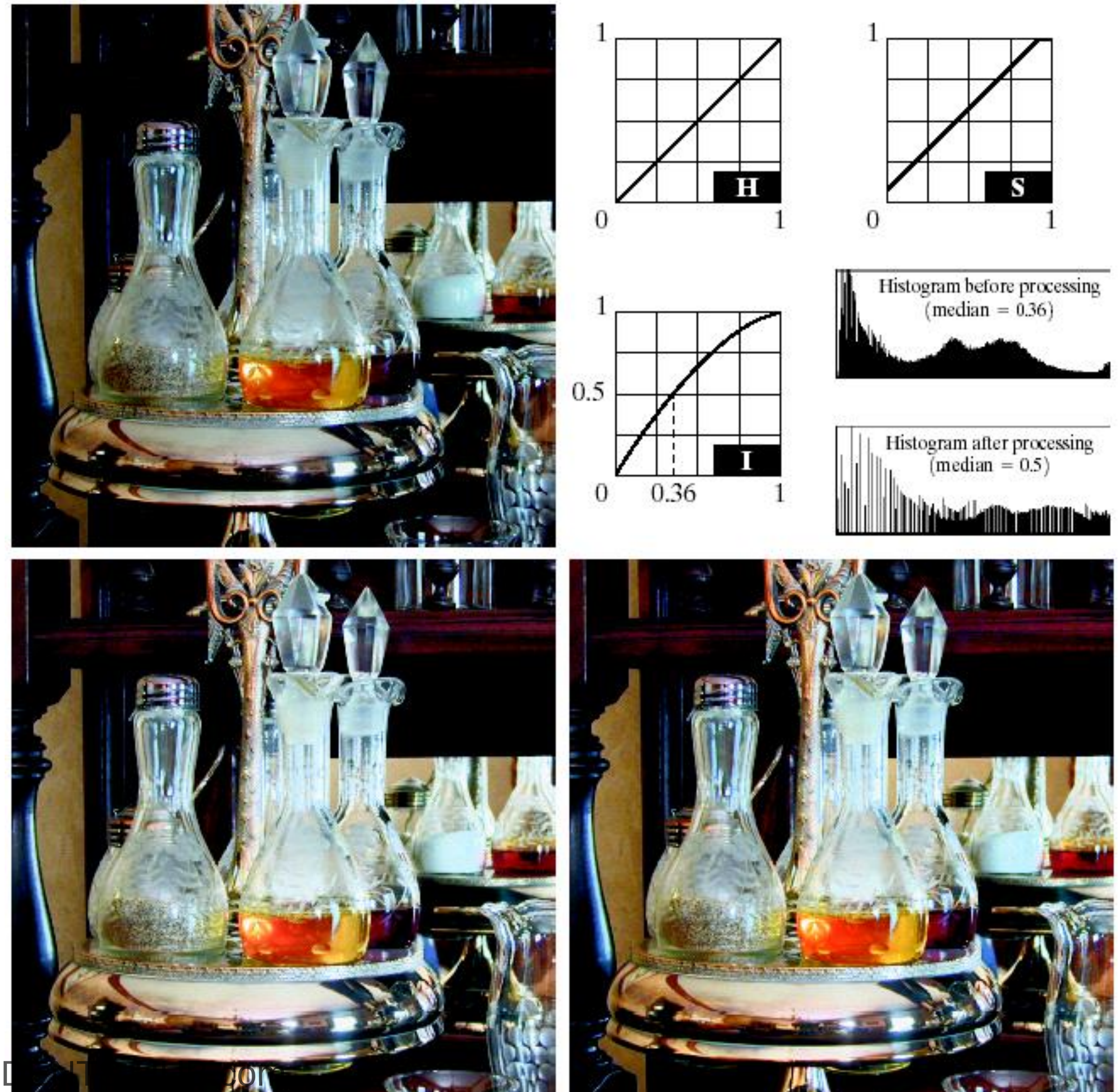
❖ The HSI model is suitable for histogram equalization where only Intensity (I) component is equalized.

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

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

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

Full-Color Processing



a b
c d

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

Full-Color Processing

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.

Color Image Smoothing Example (cont.)

Color image

Red

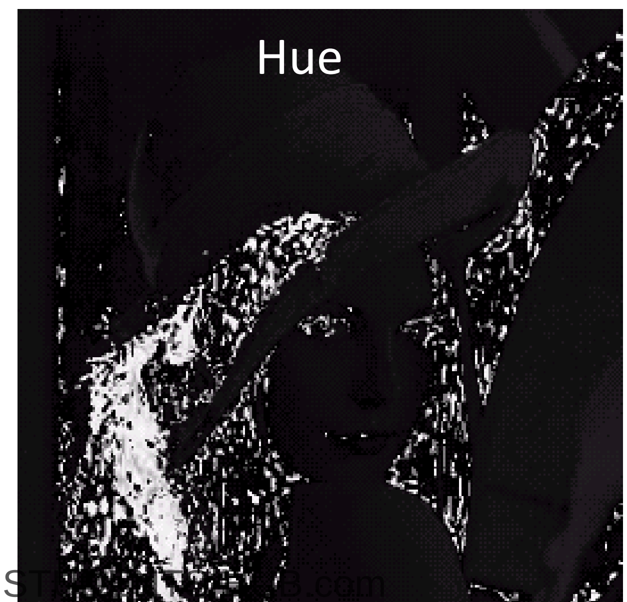
Green

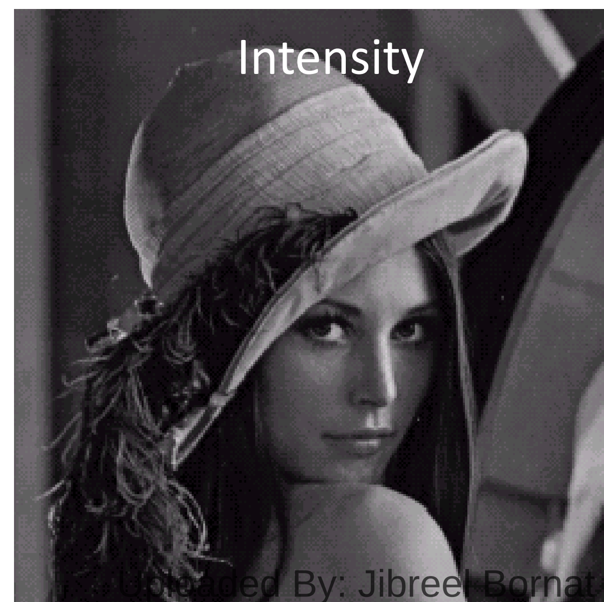
Blue

Color Image Smoothing Example (cont.)

Color image

HSI Components





Color Image Smoothing Example (cont.)

Smooth all RGB components

Smooth only I component of HSI

(faster)

Color Image Smoothing Example (cont.)

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

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.)

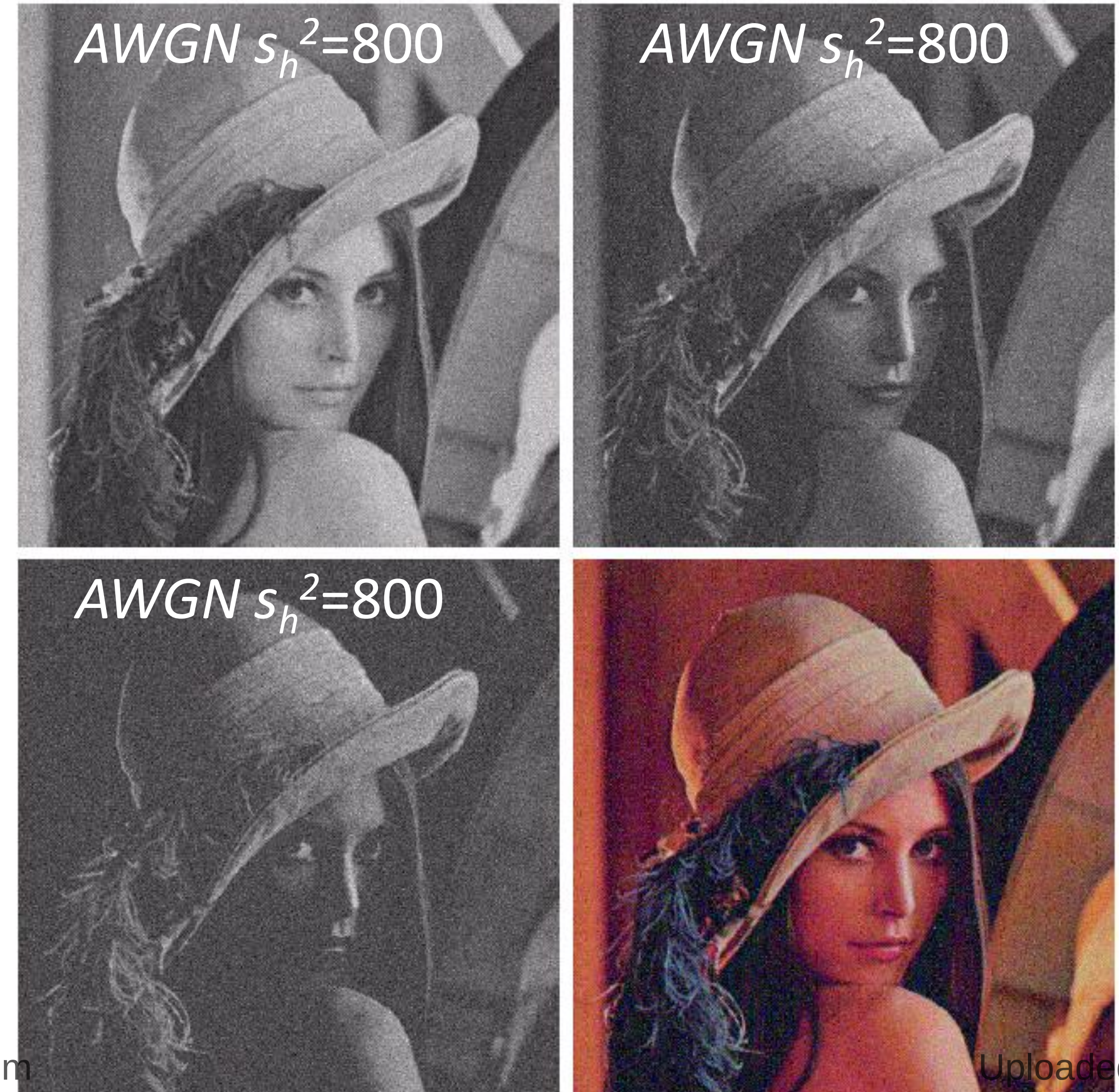
Difference between sharpened results from 2 methods in the previous slide.

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

Noise in Color Images

a b c

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

Noise in Color Images

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.