University of Kurdistan

Digital Image Processing (DIP)

Lecture 6: Color Image Processing

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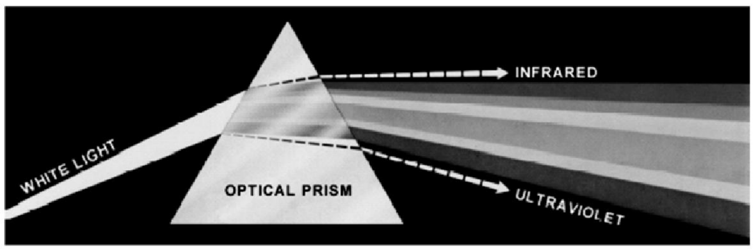
Contents

- This lecture will cover:
  - Color fundamentals
  - Color models
  - Pseudocolour image processing
  - Color image processing

Color fundamentals

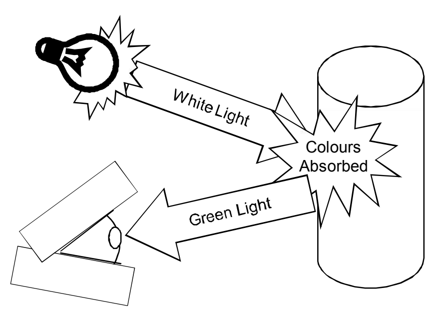
• In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colors.



Color fundamentals (cont …)

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

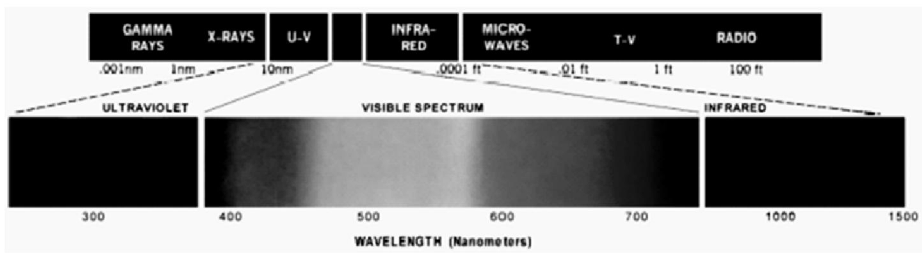
• For example, green objects reflect light with wavelengths primarily in the range of 500 – 570 nm while absorbing most of the energy at other wavelengths.



Color fundamentals (cont …)

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

• As we mentioned before human color vision is achieved through 6 to 7 million cones in each eye.



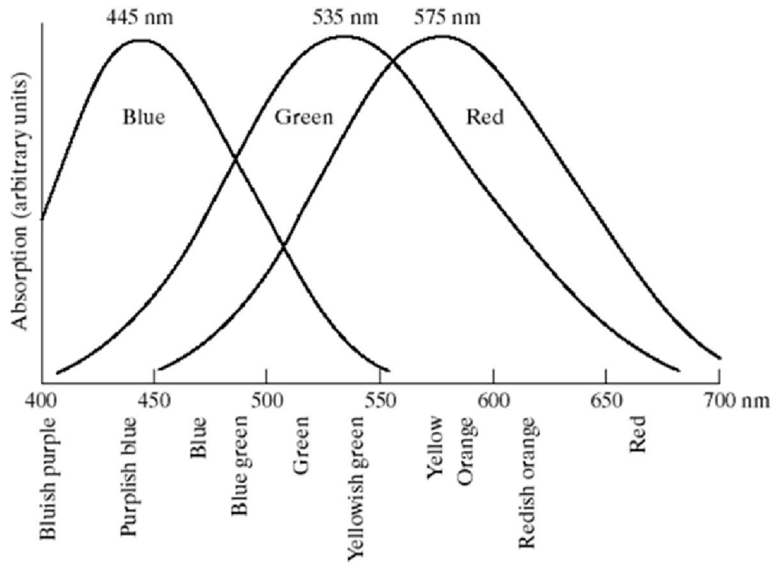
Color fundamentals (cont …)

• Approximately 66% of these cones are sensitive to red light, 33% to green light and 6% to blue light.

• Absorption curves for the different cones have been determined experimentally.

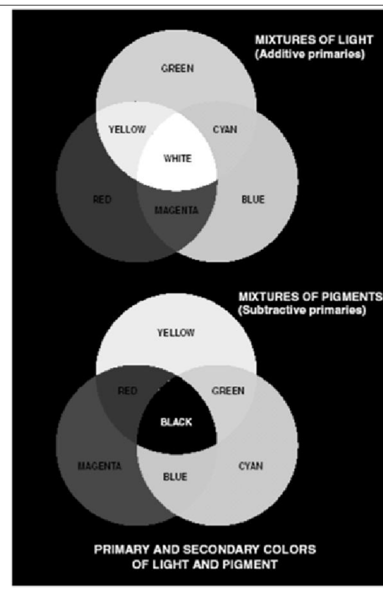
• Strangely these do not match the CIE standards for red (700nm), green (546.1nm), and blue (435.8nm) light as the standards were developed before the experiments!

Color fundamentals (cont …)



Primary & secondary colors of light

- 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.
- CMY add together to get Black.



Color fundamentals (cont …)

• 3 basic qualities are used to describe the quality of a chromatic light source:

❖ **Radiance**: the total amount of energy that flows from the light source (measured in watts).

❖ **Luminance**: the amount of energy an observer perceives from the light source (measured in lumens).

- Note we can have high radiance, but low luminance.

❖ **Brightness**: a subjective (practically unmeasurable) notion that embodies the intensity of light.

We'll return to these later on.

CIE chromacity diagram

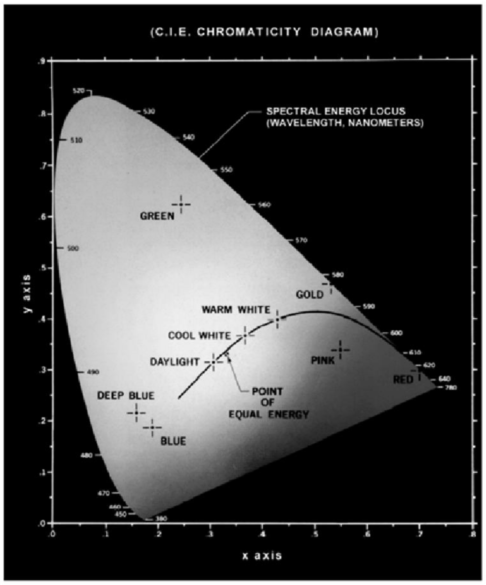
• Specifying colors systematically can be achieved using the CIE chromacity diagram.

• On this diagram, the x-axis represents the proportion of red and the y-axis represents the proportion of green used .

• The proportion of blue used in a colour 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 color located on the boundary of the chromacity chart is fully saturated.

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

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

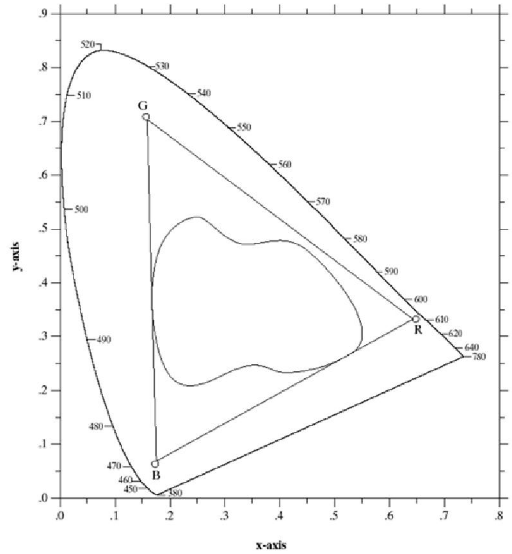
- This can be easily extended to three points.

CIE chromacity diagram (cont …)

• This means the entire color range cannot be displayed based on any three colors.

• The triangle shows the typical color gamut produced by RGB monitors.

• The strange shape is the gamut achieved by high quality color printers.



Color models

• From the previous discussion it should be obvious that there are different ways to model color.

• We will consider three very popular models used in color image processing:

  - RGB (Red Green Blue)
  - CMY (Cyan Magenta Yellow)/CMYK (Cyan Magenta Yellow Black)
  - HSI (Hue Saturation Intensity)

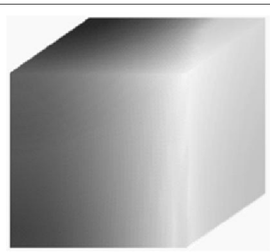
RGB color model

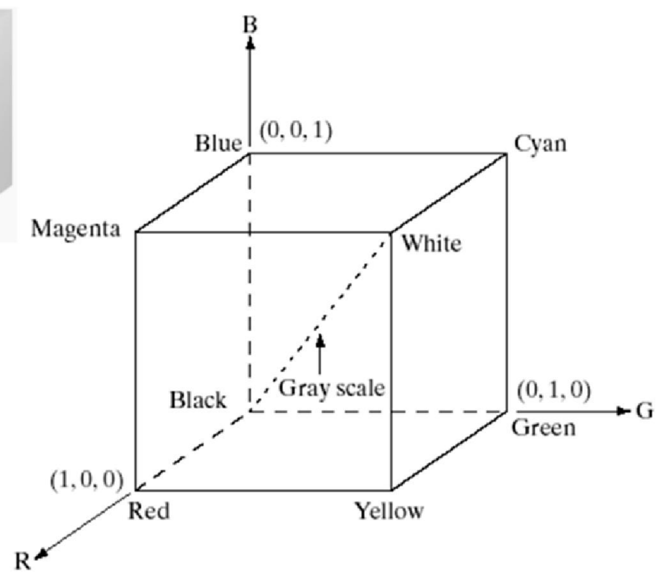
• In the RGB model, each color appears in its primary spectral components of red, green, and blue.

• 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 colors are points on or inside the cube represented by RGB vectors.

RGB color model (cont …)





RGB color model (cont …)

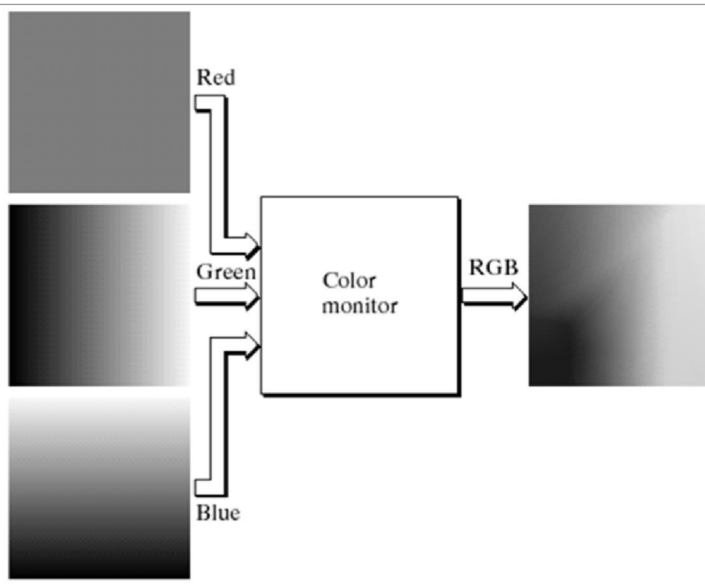
• Images represented in the RGB color model consist of three component images – one for each primary color.

• When fed into a monitor these images are combined to create a composite color image.

• The number of bits used to represent each pixel is referred to as the *color depth*.

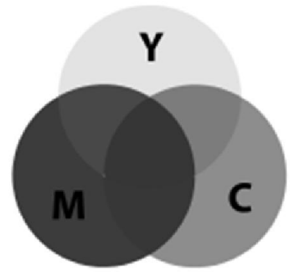
• A 24-bit image is often referred to as a full-color image as it allows $(2^8)^3$ = 16,777,216 colors.

RGB color model (cont …)



CMY/CMYK color model

- Color printer and copier
- Deposit colored pigment on paper
- Relationship with RGB 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

Example :surface coated with pure cyan does not contain red (C = 1 — R)

HSI color model

- RGB is useful for hardware implementations and is serendipitously related to the way in which the human visual system works.
- However, RGB is not a particularly intuitive way in which to describe colors.
- Rather when people describe colors they tend to use **hue**, **saturation**, and **brightness**.
- RGB is great for color generation, but HSI is great for color description.

The HSI color model (cont …)

• The HSI model uses three measures to describe colors:

- **Hue**: A color attribute that describes a pure color (pure yellow, orange, or red).
- **Saturation**: Gives a measure of how much a pure color is diluted with white light.
- **Intensity**: Brightness is nearly impossible to measure because it is so subjective. Instead we use 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.

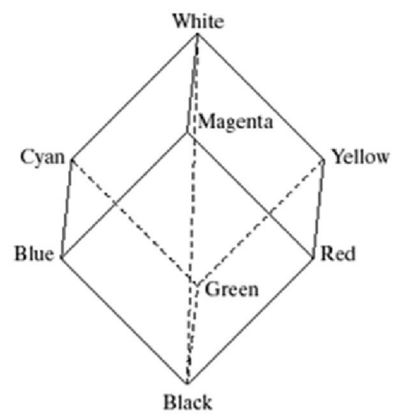
• Remember the diagonal on the RGB color cube that we saw previously ran from black to white.

• 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 color can be determined by passing a plane perpendicular to the intensity axis and containing the color point.

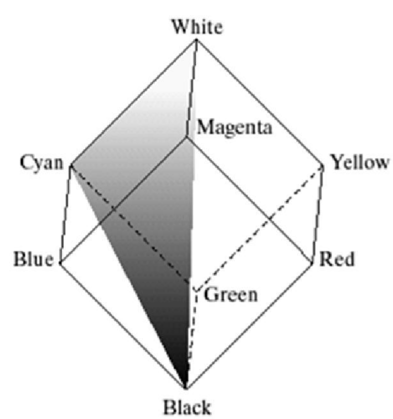
- The intersection of the plane with the intensity axis gives us the intensity component of the color.



HSI, Hue & RGB

- In a similar way we can extract the hue from the RGB color cube.

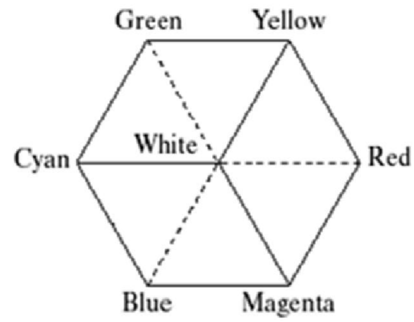
- Consider a plane defined by the three points cyan, black, and white. All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a color.



The HSI color 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 color separated by 120° and secondary colors at 60° from the primaries. So the HSI model is composed of a vertical intensity axis and the locus of color points that lie on planes perpendicular to that axis.



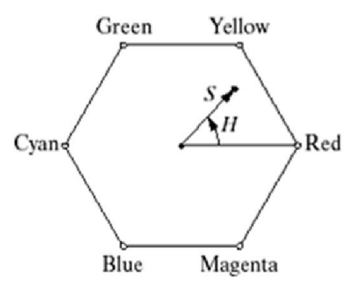
The HSI color model (cont …)

• To the right we see a hexagonal shape and an arbitrary color point.

❑ The hue is determined by an angle from a reference point, usually red.

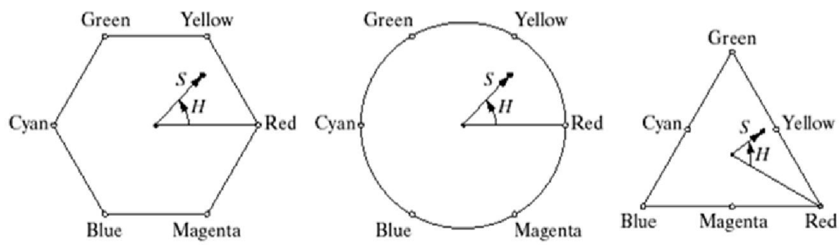
❑ The saturation is the distance from the origin to the point.

❑ The intensity is determined by how far up the vertical intensity axis this hexagonal plane sits (not apparent from this diagram).

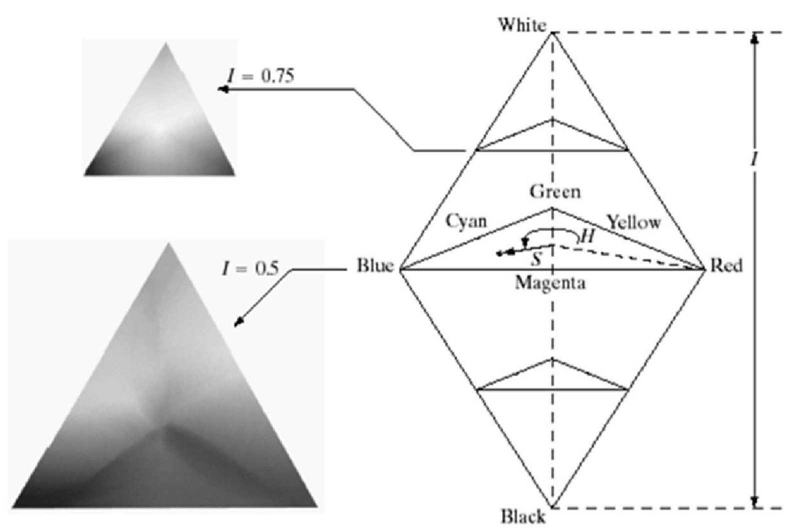


The HSI color model (cont …)

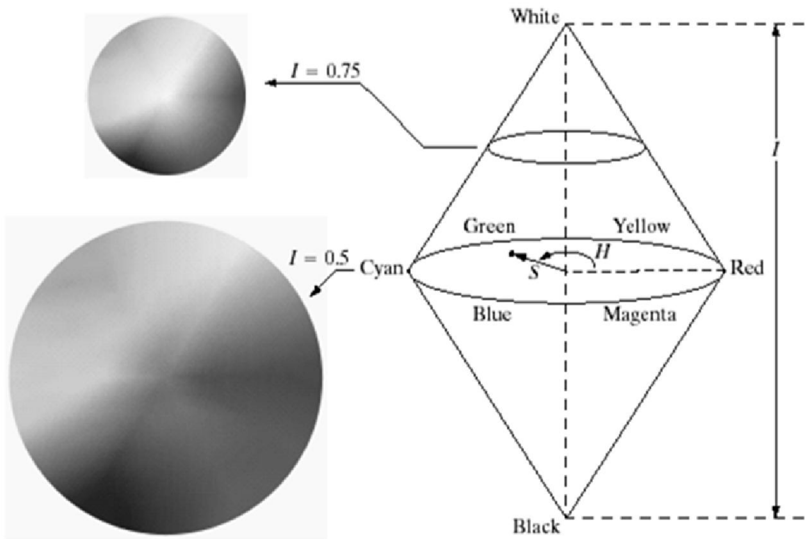
• Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle.



HSI model examples



HSI model examples



Converting from RGB to HSI

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

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

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

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

Converting from HSI to RGB

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

❑ RG sector ($0 <= H < 120°$)

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

$$G = 3I - (R + B)$$

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

❑ GB sector ($120° <= H < 240°$)

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

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

$$B = 3I - (R + G)$$

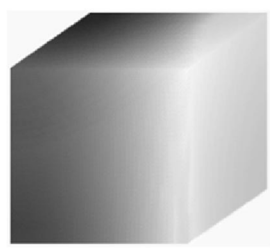
❑ BR sector ($240° <= H <= 360°$)

$$R = 3I - (G + B)$$

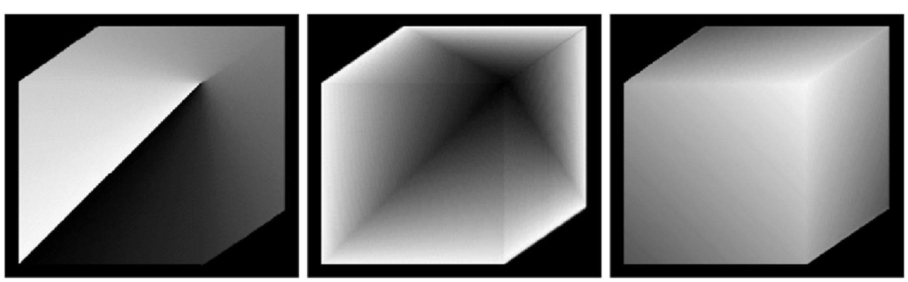
$$G = I(1 - S)$$

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

HSI & RGB



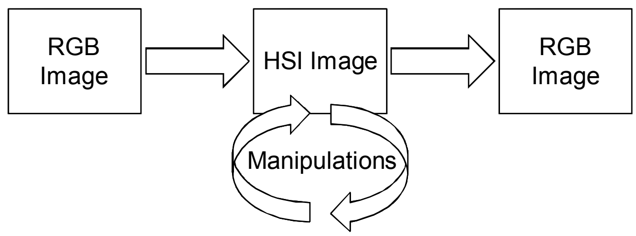
RGB Colour Cube



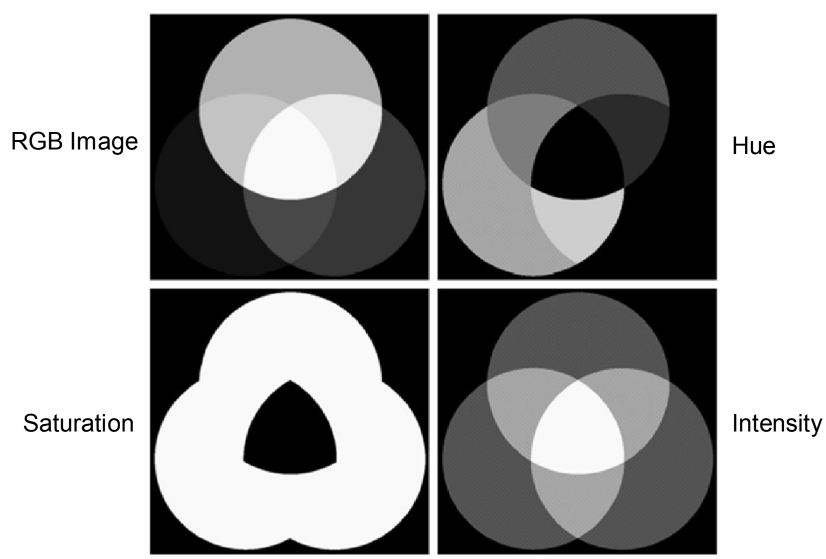
H, S, and I Components of RGB Color Cube

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 manipulations under HSI.
  - Finally convert the image back from HSI to RGB.



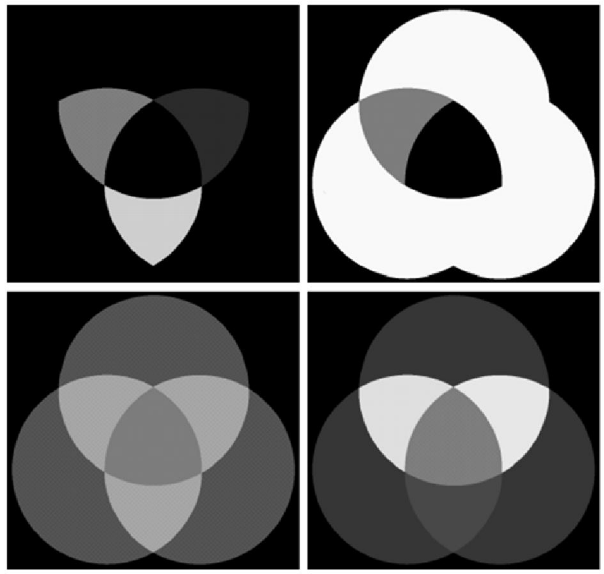
RGB -> HSI -> RGB



RGB -> HSI -> RGB (cont …)

Hue

Saturation



Intensity

RGB Image

Pseudocolor image processing

• Pseudocolor (also called false color) image processing consists of assigning colors to grey values based on a specific criterion.

• The principle use of pseudocolor image processing is for human visualization.

– Humans can discern between thousands of color shades and intensities, compared to only about two dozen or so shades of grey.

Pseudocolor image processing – Intensity slicing

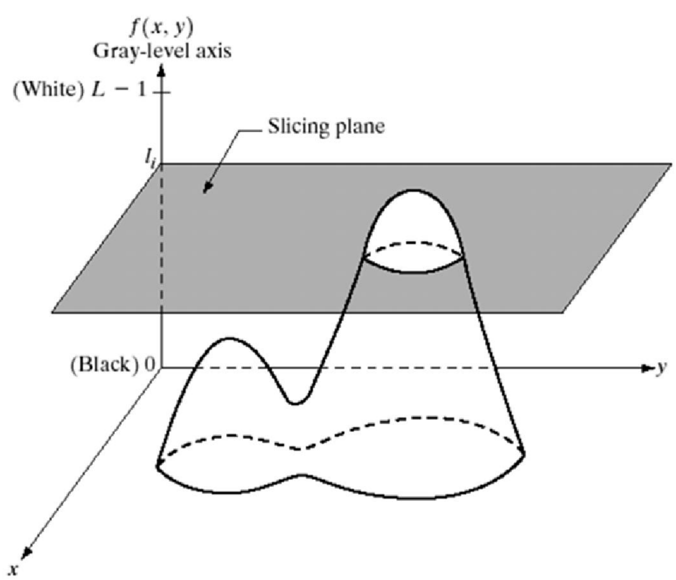
• Intensity slicing and color coding are the simplest kinds of pseudocolor image processing.

• First we consider an image as a 3D function mapping spatial coordinates to intensities (that we can consider heights).

• Now consider placing planes at certain levels parallel to the coordinate plane.

• If a value is one side of such a plane it is rendered in one color, and a different color if on the other side.

Pseudocolor image processing – Intensity slicing (cont …)



Pseudocolor image processing – Intensity slicing (cont …)

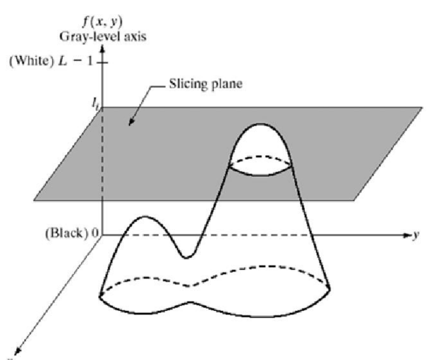
In general intensity slicing can be summarized as:

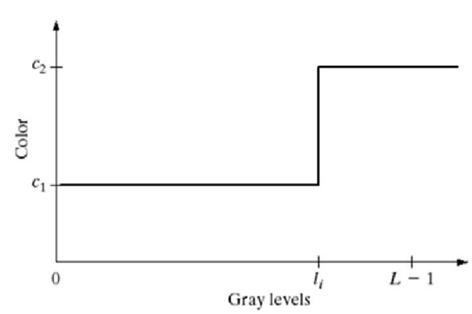
- Let $[0, L\text{-}1]$ represent the grey scale.
- Let l_0 represent black $[f(x, y) = 0]$ and let l_{L-1} represent white $[f(x, y) = L\text{-}1]$.
- Suppose P planes perpendicular to the intensity axis are defined at levels $l_1, l_2, \ldots, l_p$.
- Assuming that $0 < P < L\text{-}1$ then the P planes partition the grey scale into $P + 1$ intervals $V_1, V_2, \ldots, V_{P+1}$.
- Grey level color assignments can then be made according to the relation:

$$f(x, y) = c_k \quad \text{if} \quad f(x, y) \in V_k$$

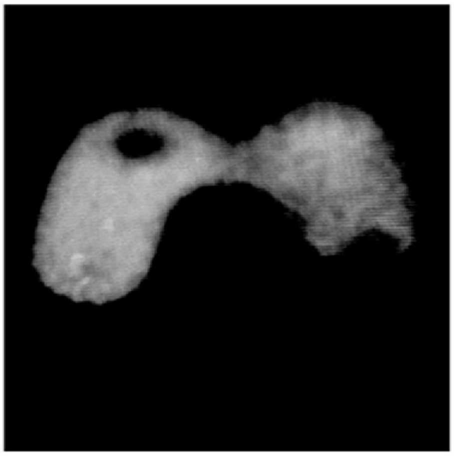
where ck is the color associated with the k^{th} intensity level V_k defined by the partitioning planes at $l = k - 1$ and $l = k$.

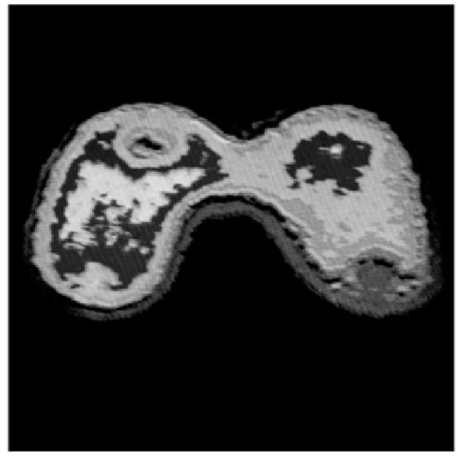
Pseudocolor image processing – Intensity thresholding



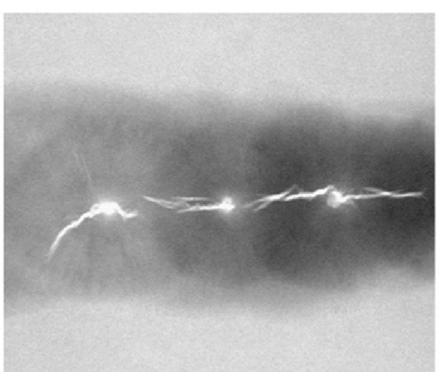


Intensity slicing example

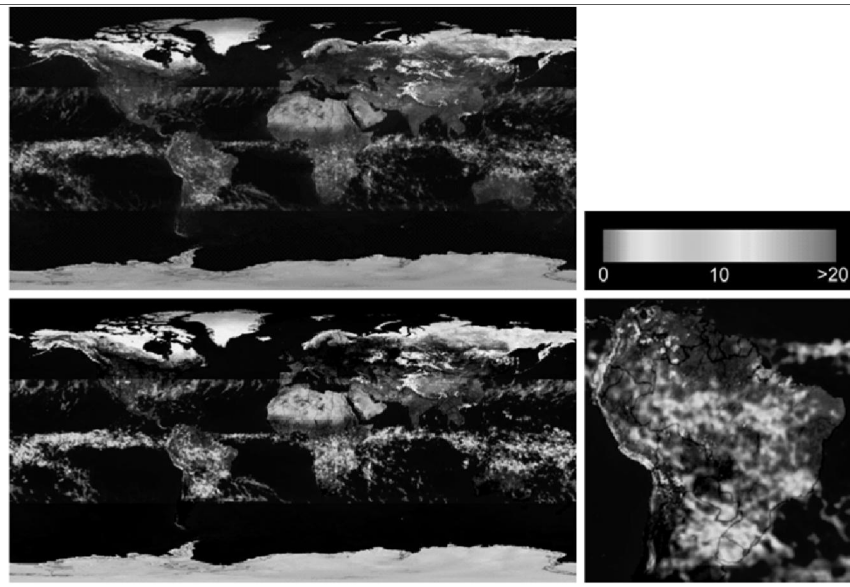




Intensity thresholding example 1



Intensity thresholding example 2



Pseudocolor image processing – Color transformation intensity

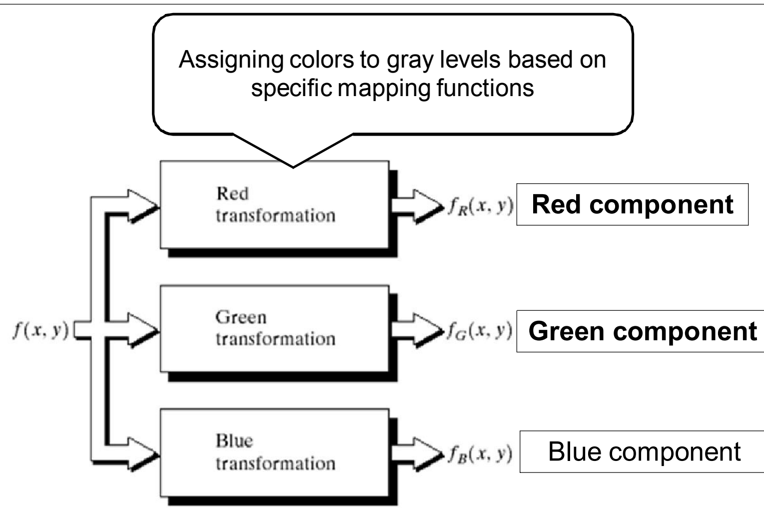
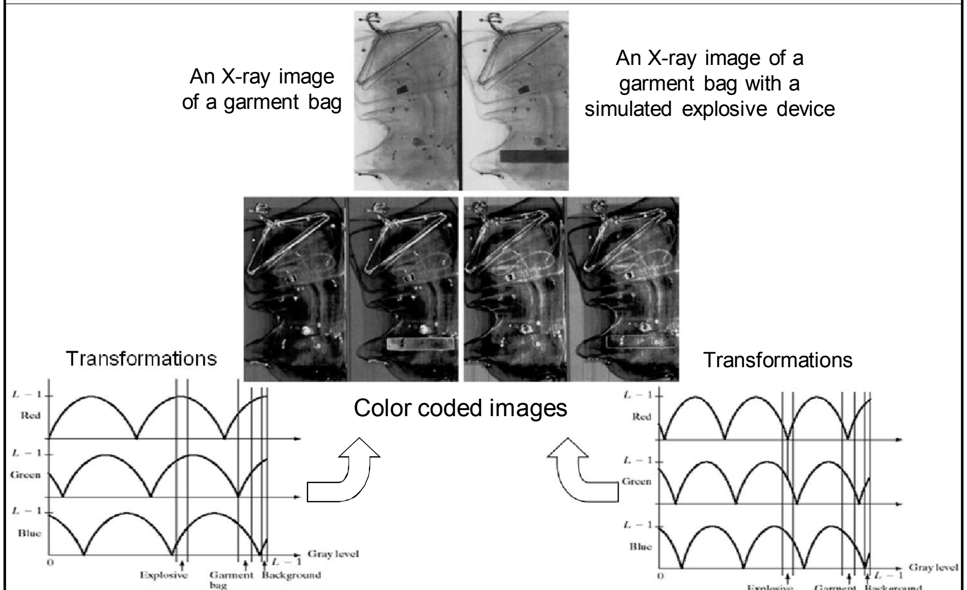


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Pseudocolor image processing – Color transformation intensity example



Pseudocolor coding

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

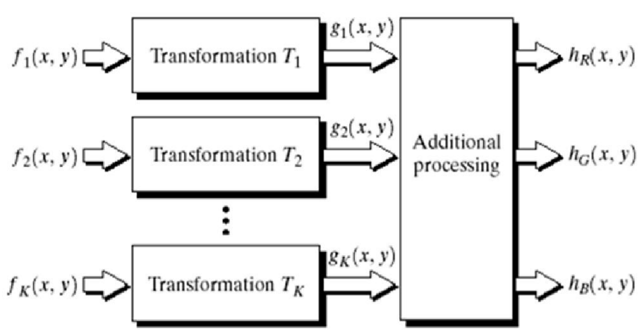
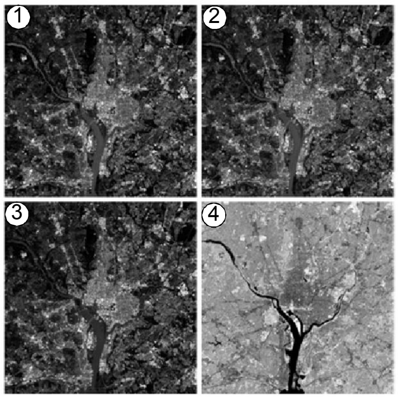


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

Pseudocolor coding example 1

Visible blue
λ= 450-520 nm
Max water penetration

Visible green
λ= 520-600 nm
Measuring plant

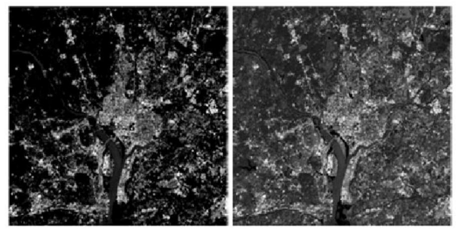


Visible red
λ= 630-690 nm
Plant discrimination

Near infrared
λ= 760-900 nm
Biomass and shoreline mapping

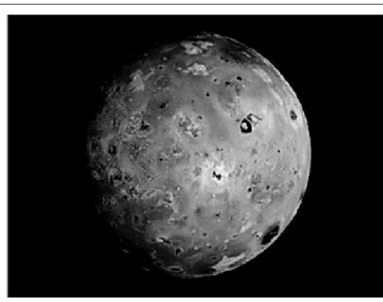
③ Red
② Green
① Blue

④ Red
② Green
① Blue



Color composite images

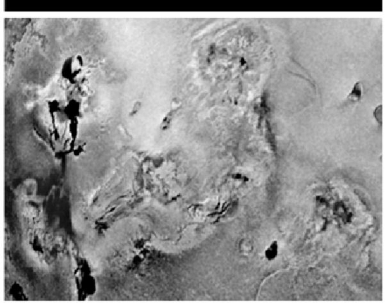
Pseudocolor coding example 2



Psuedocolor rendition of Jupiter moon

Yellow areas = older sulfur deposits.

Red areas = material ejected from active volcanoes.



A close-up

Summary

- We have looked at:
  - Color fundamentals
  - RGB, CMY/CMYK, and HSI color models
  - Pseudocolour image processing
  - Color image processing