DIGITAL IMAGE PROCESSING

Colour Image Processing

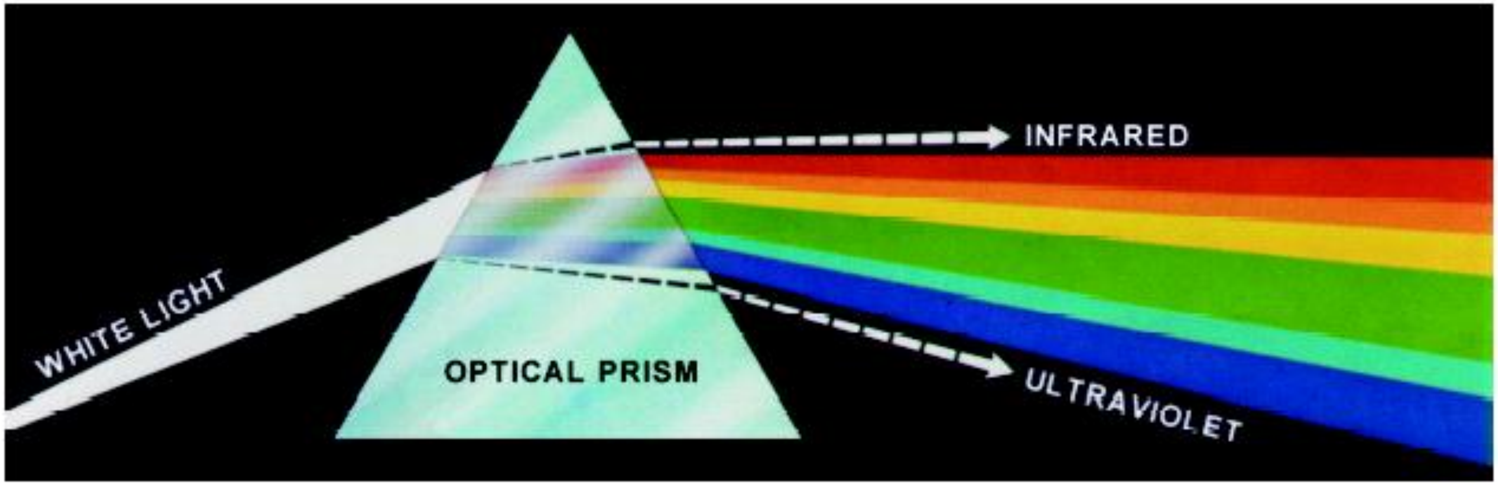
Introduction

Today we'll look at colour image processing, covering:

- Colour fundamentals
- Colour models

Colour Fundamentals

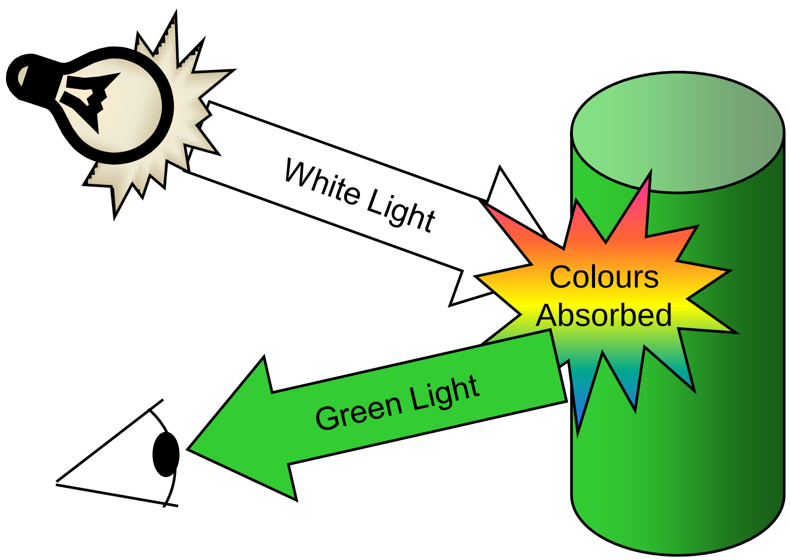
In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colours



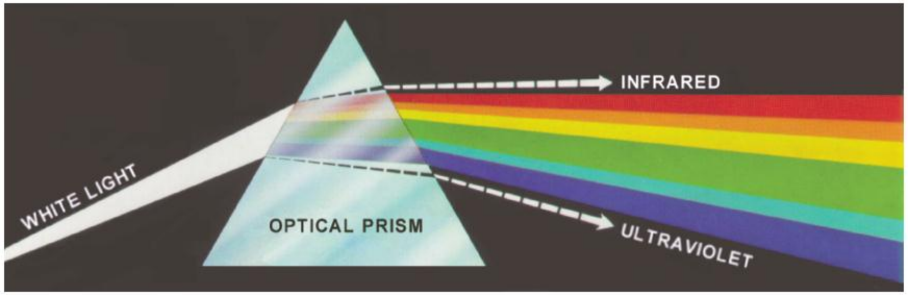
Colour Fundamentals (cont…)

The colours 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 wave lengths primarily in the range of 500 – 570 nm while absorbing most of the energy at other wavelengths



Colour Fundamentals

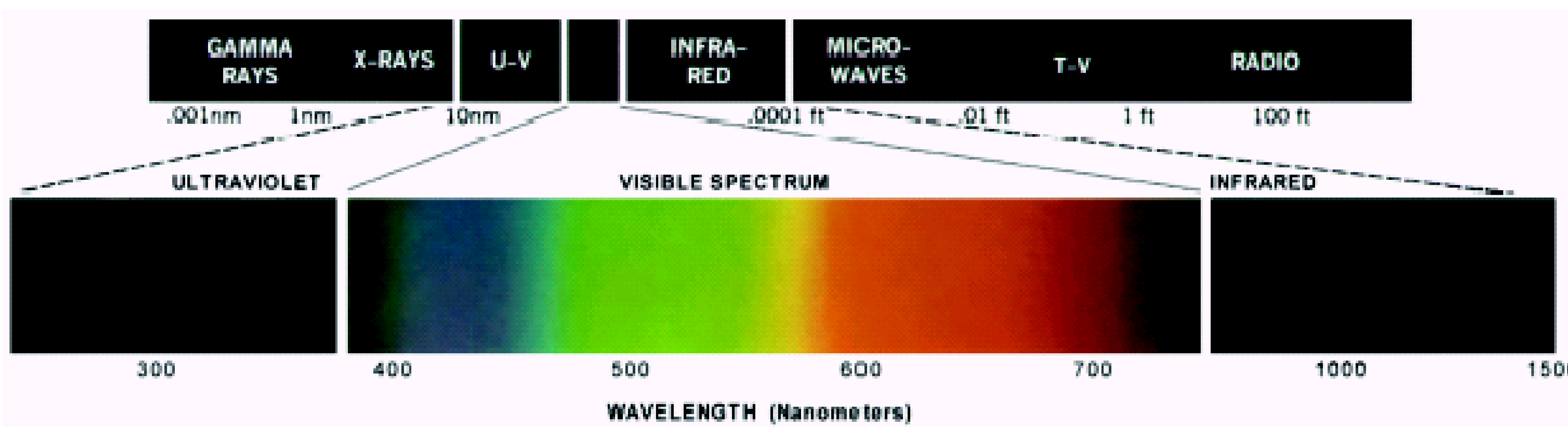


- Colours that a human eye can perceive are determined by the nature of light reflected from an object
- A body that reflects light that is balanced in all visible wavelengths appears white
- Similarly, reflection in a limited range of wavelengths exhibits some shade of the colour
- None of the colour abruptly ends but rather blends smoothly into the next colour

Colour Fundamentals (cont…)

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

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



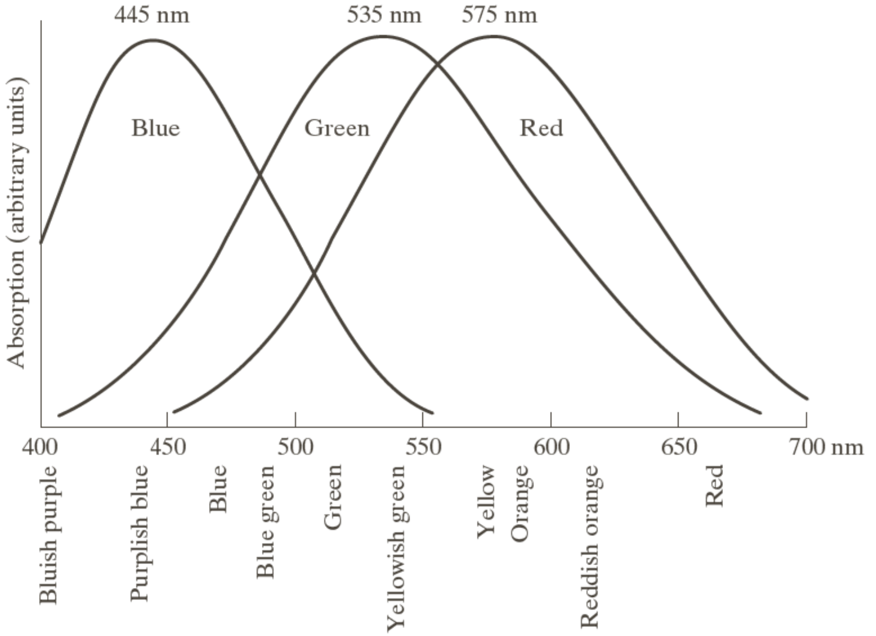
Colour Fundamentals

- The cones in the human eye, responsible for colour vision can be divided into three principal sensing categories, corresponding to Red, Green and Blue

Approximately 65% of all cones are sensitive to red light

33% to green and only 2% are sensitive to Blue light

The colours are seen as variable combinations of the so called ***primary colours, red, green and blue (RGB)***



Colour Fundamentals

- When the colour attribute of light is not considered, its only attribute of interest is its **intensity**
- The term gray level refers to the measure of intensity (ranging from black to white)
- Three basic quantities are used to describe the quality of a chromatic light source:
  - **Radiance**: is the total amount of energy that flows from a light source
  - **Luminance**: is the measure of the amount of energy an observer perceives from a light source
  - **Brightness**: is a subjective descriptor that is practically impossible to measure (kind of the achromatic notion of intensity)

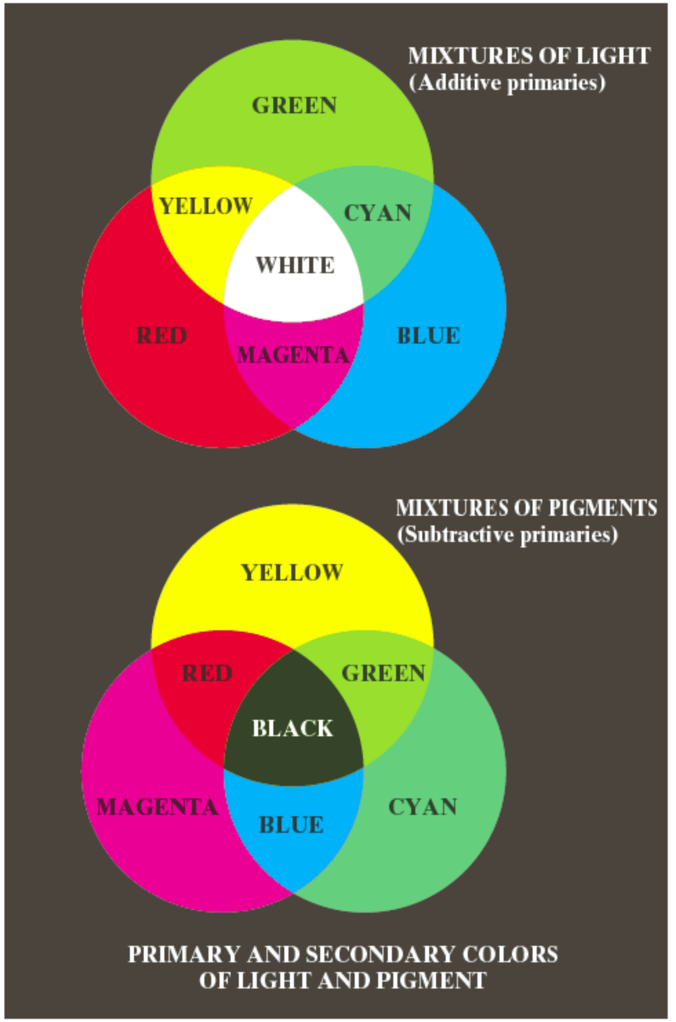
Colour Fundamentals

- **Additive Primaries: Primary** colours can be added to produce **secondary** colours of light
- Yellow (Red + Green)
- Magenta (Red + Blue)
- Cyan (Blue + Green)

Mixing the three primaries, or the secondary with its opposite primary produces white colour

Subtractive Primaries (Pigments):

Cyan (Blue + Green) + Yellow (Red + Green)= Green
Cyan (Blue + Green) + Magenta(Red + Blue)= Blue
Magenta (Red + Blue) + Yellow (Red + Green)= Red



Colour Fundamentals

- The characteristics generally used for colour differentiation are:
  - **Brightness** is similar to notion of intensity in monochrome domain
  - **Hue** represents the dominant wavelength in a mixture of light or it represents the perception of an observer about the dominant colour
  - **Saturation** refers to the purity of a colour or the amount of white light mixed with hue
  - For example, pink (red + white) and lavender (violet + white) are less saturated
- Hue and Saturation taken together are called **chromaticity**
- Therefore, **chromaticity** of a colour shows the **perception** of the **main colour** and the amount of **dilution** that it has because of addition of **white light**

Colour Fundamentals- **Chromaticity diagram**

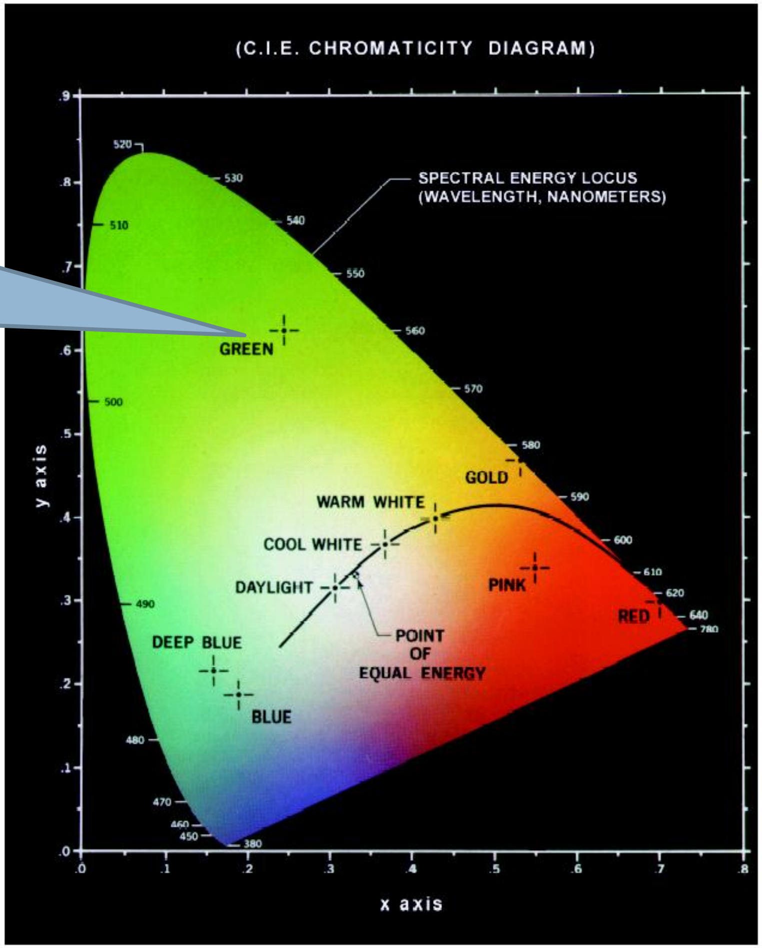
- The chromaticity diagram shows colour as a function of x(red) and y(green)

For any value of red and green, the corresponding blue can be obtained using:

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

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

Contains 62% green
25% red
And 13% blue



Any point located on the boundary is **fully-saturated**

A straight line connecting two points (two colours) on the chromaticity diagram shows that any combination of colours (along the line) can be obtained by adding those two colours (end points)

Colour Fundamentals- **Chromaticity diagram**

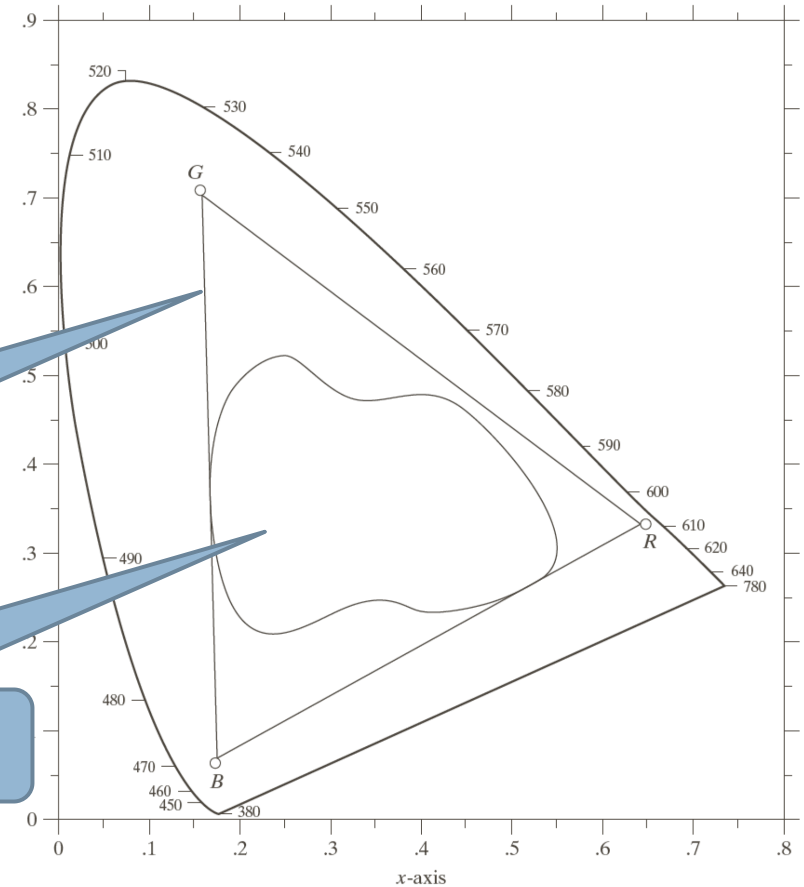
Determining range of colours from three different colours

•Any colour on the boundary or inside the triangle (connecting the three colours) can be produced by mixing the three colours

•Mixing the colours is a hard to control process

Colour gamut of RGB monitors

Colour gamut of printers



Gamut: subset of colors which can be accurately represented by a certain output device.

Colour Models

- Colour models are there to facilitate **specification** of colours in some standard
- Colour models provide specification of a coordinate system where each colour is represented by a single point
- Colour models are either hardware or application oriented
- Colour models used in practice are:
  - **RGB** for colour monitors, video cameras
  - **CMY** and **CMYK** models for colour printing
  - **HSI** closely corresponds to the way humans describe and interpret colour

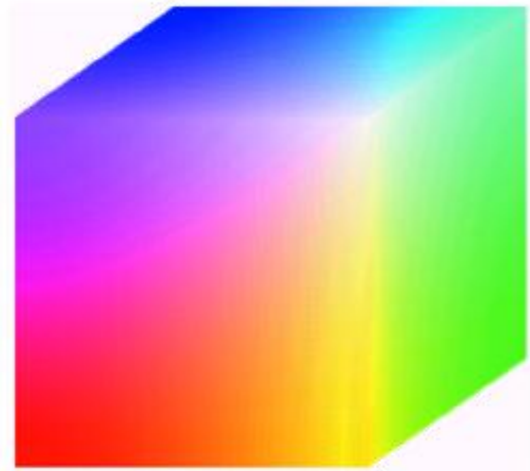
RGB

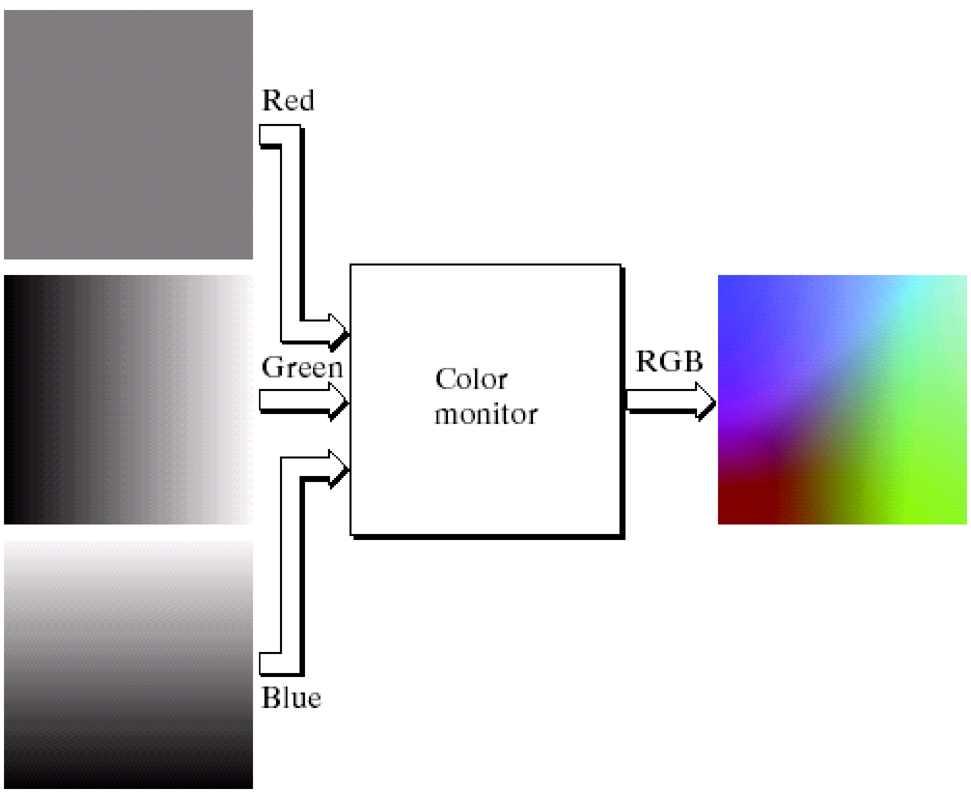
In the RGB model each colour appears in its primary spectral components of red, green and blue

The model is based on a Cartesian coordinate system

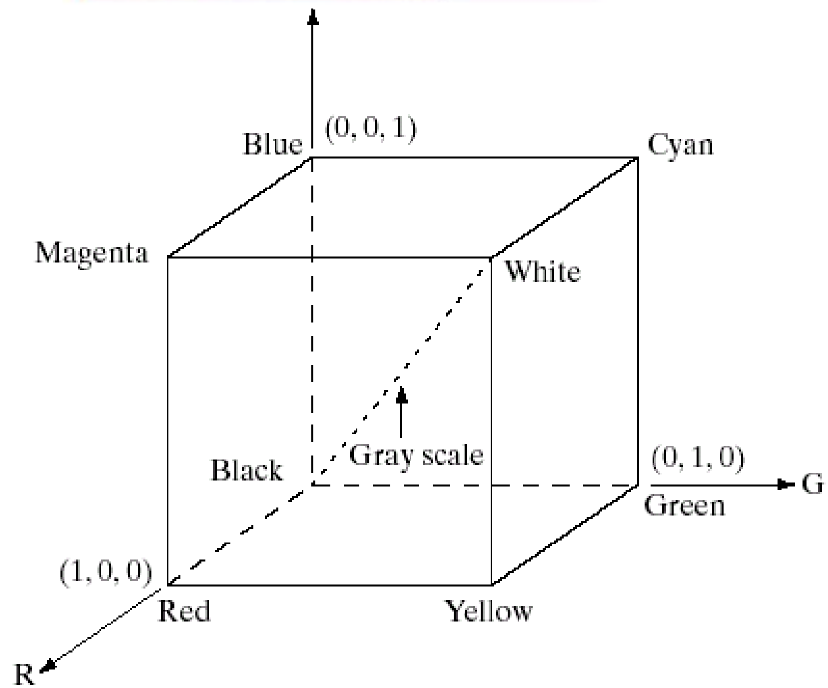
- RGB values are at 3 corners
- Cyan magenta and yellow are at three other corners
- Black is at the origin
- White is the corner furthest from the origin
- Different colours are points on or inside the cube represented by RGB vectors

RGB (cont…)





Red
Green
Blue
Color monitor
RGB



Blue
(0, 0, 1)
Cyan
Magenta
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

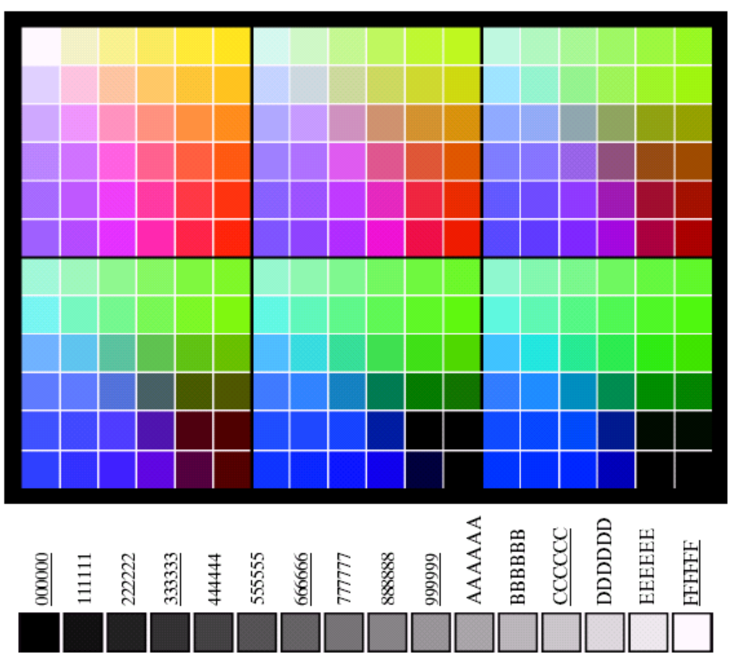
When fed into a monitor these images are combined to create a composite colour image

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

Colour Models – **RGB – The Web-safe/All systems safe colours**

- Given the variety of hardware systems the colour reproduction becomes an issue
- The web-safe colours is a subset (216 colours) that are tested to be produced in the same way by all hardware systems
- Web safe colours are used whenever it is desired that a certain colour viewed by most people appear the same



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 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

- For example, it is not common to say that a car's colour contains 30% red, 40% green and 10% blue in a normal conversation

RGB is great for colour generation, but HSI is great for colour description

The HSI Colour Model (cont…)

A more useful model is the HSI model

The HSI model uses three measures to describe colours:

- **Hue** represents the perception of an observer about the dominant colour
- **Saturation** refers to the purity of a colour or the amount of white light mixed with hue
- **Intensity** (gray level) gives a measure of the degree of blackness and whiteness

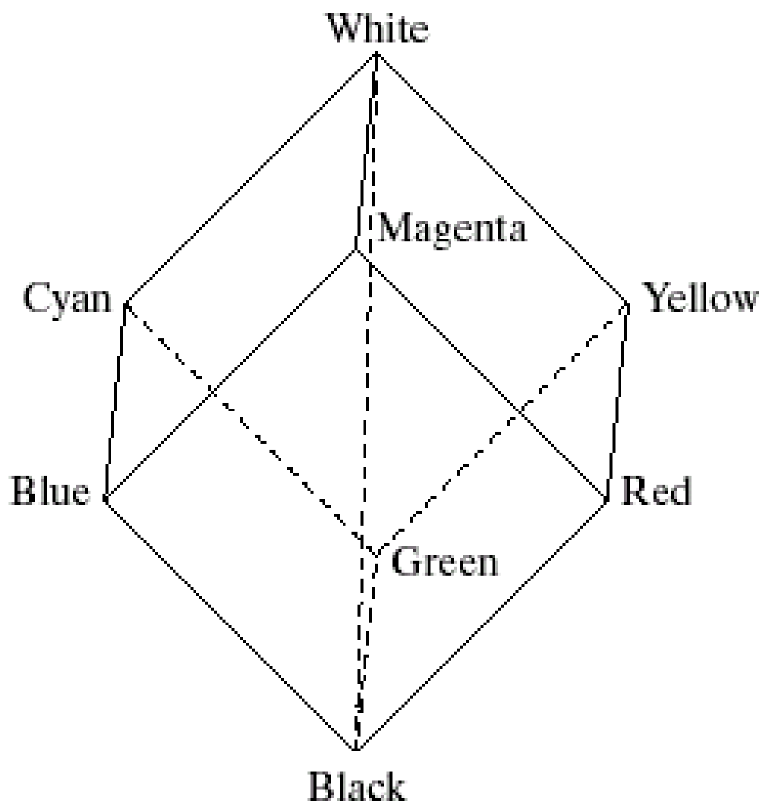
HSI, Intensity & RGB

- Intensity can be extracted from RGB images
- Remember the diagonal on the RGB colour cube that we saw previously ran from black to white – called intensity axis.
- 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



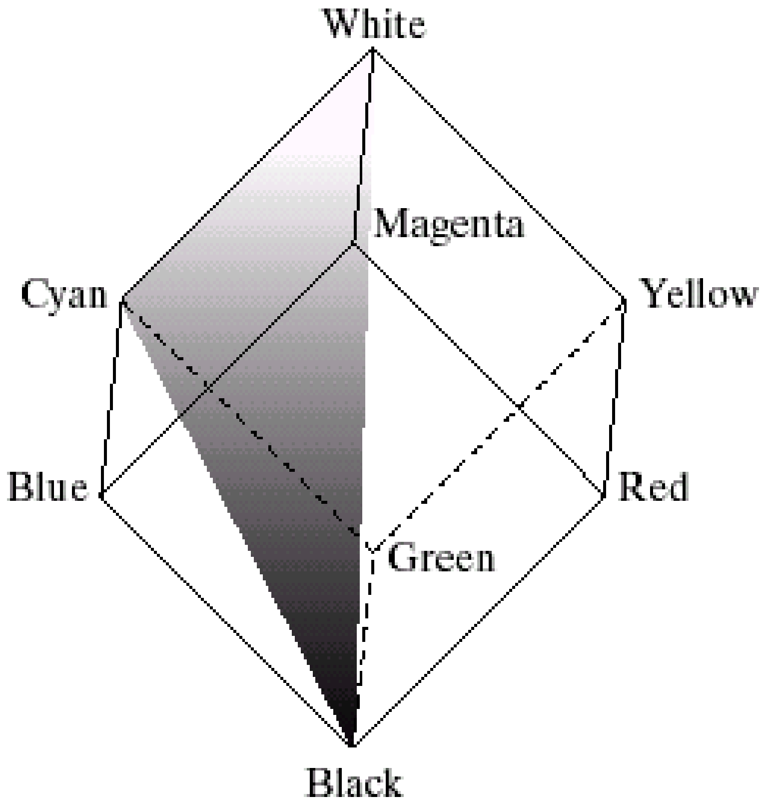
- Saturation of the colour increases as the distance from the intensity axis increases
- Saturation of point on the intensity axis is zero

HSI, Hue & RGB

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

Consider a plane defined by the three points cyan, black and white

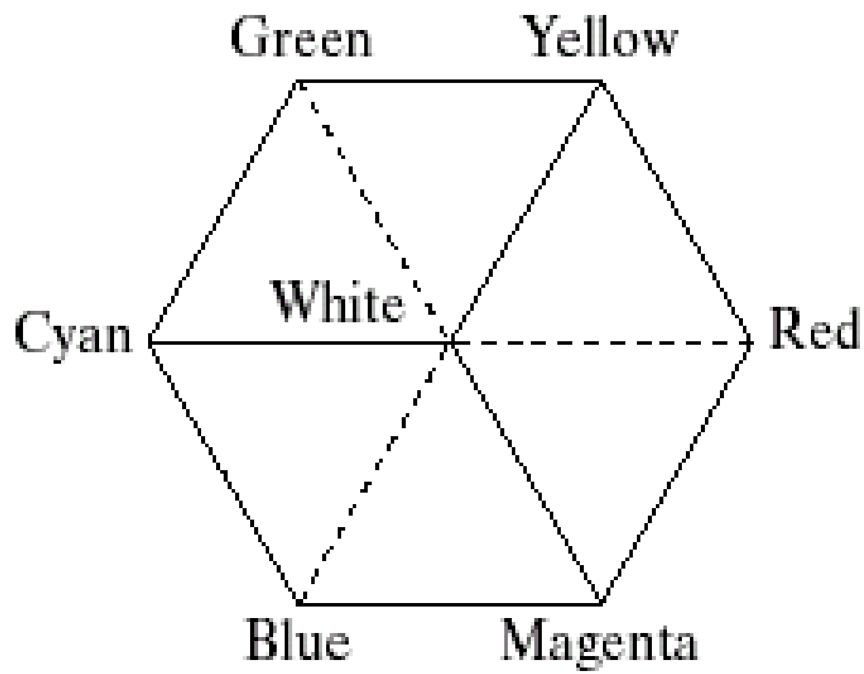
All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a colour



The HSI Colour Model

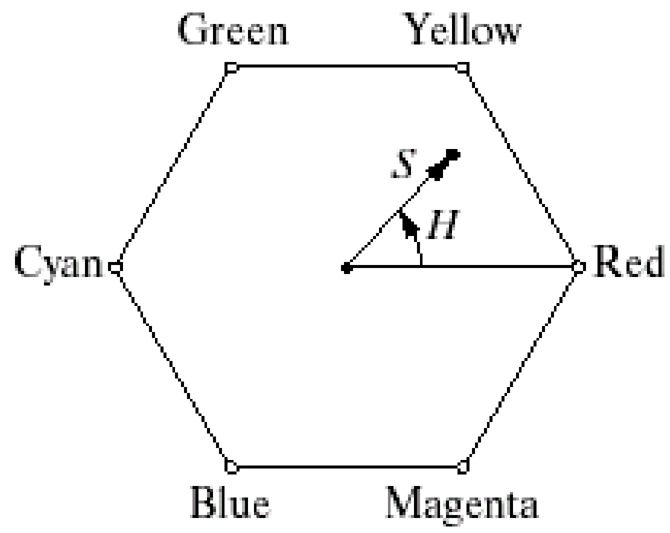
Consider if we look straight down at the RGB cube as it was arranged previously

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…)

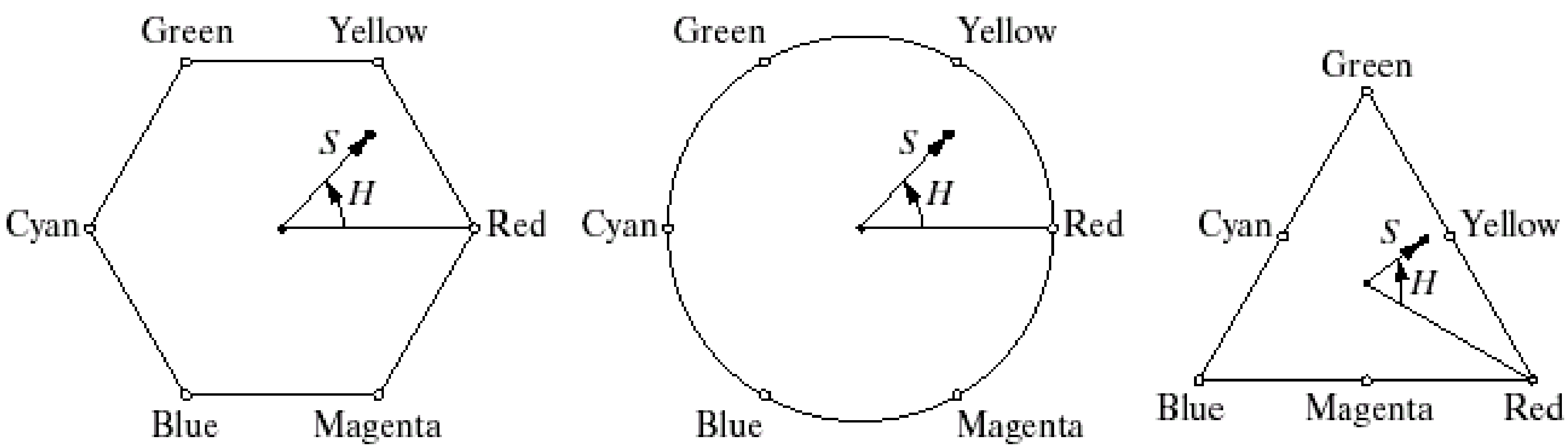


To the right we see a hexagonal shape and an arbitrary colour point

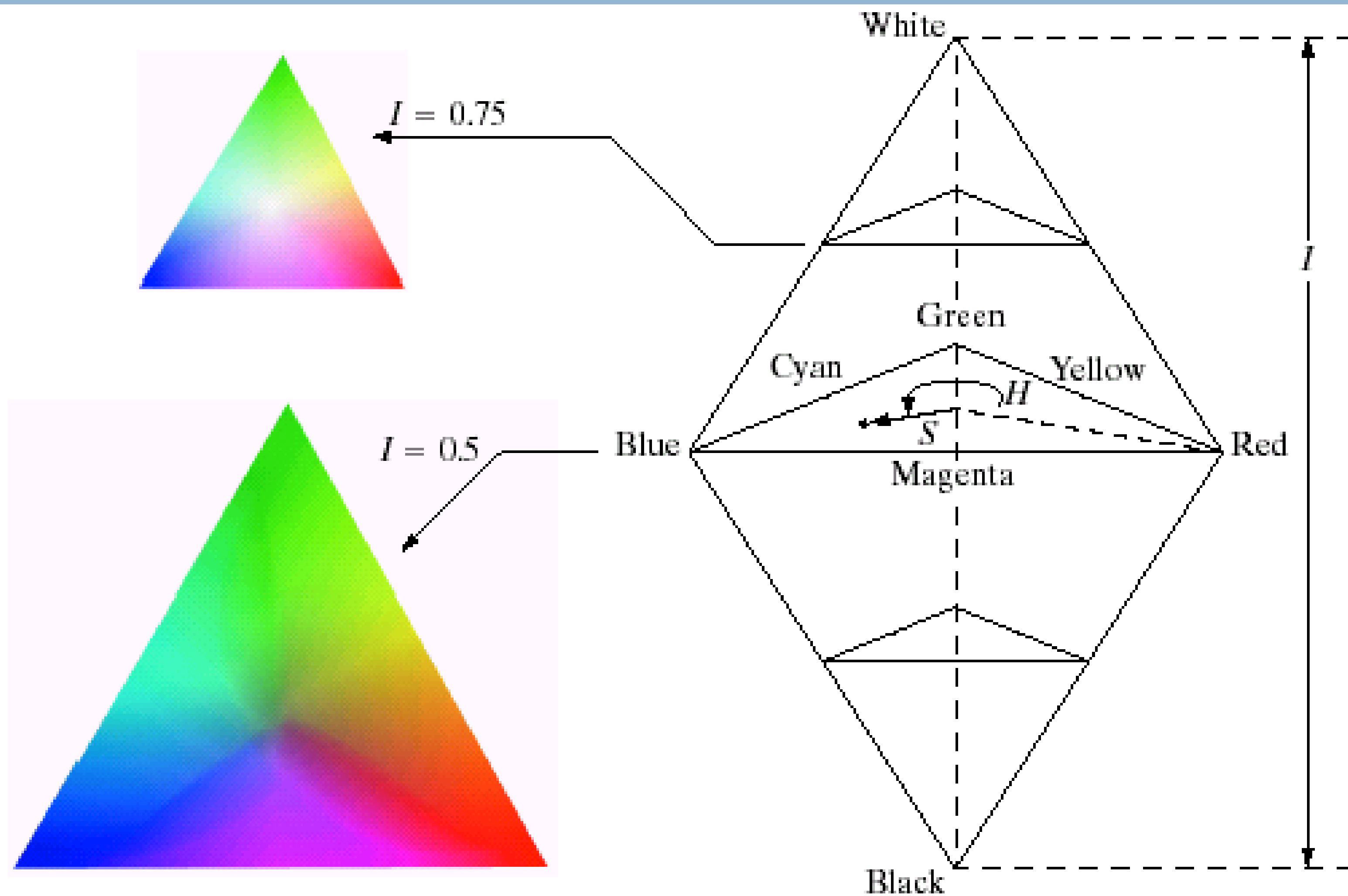
- The hue is determined by an angle from a reference point, usually red
- The saturation is the distance from the origin to the point
- The intensity is determined by how far up the vertical intenisty axis this hexagonal plane sits (not apparent from this diagram

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

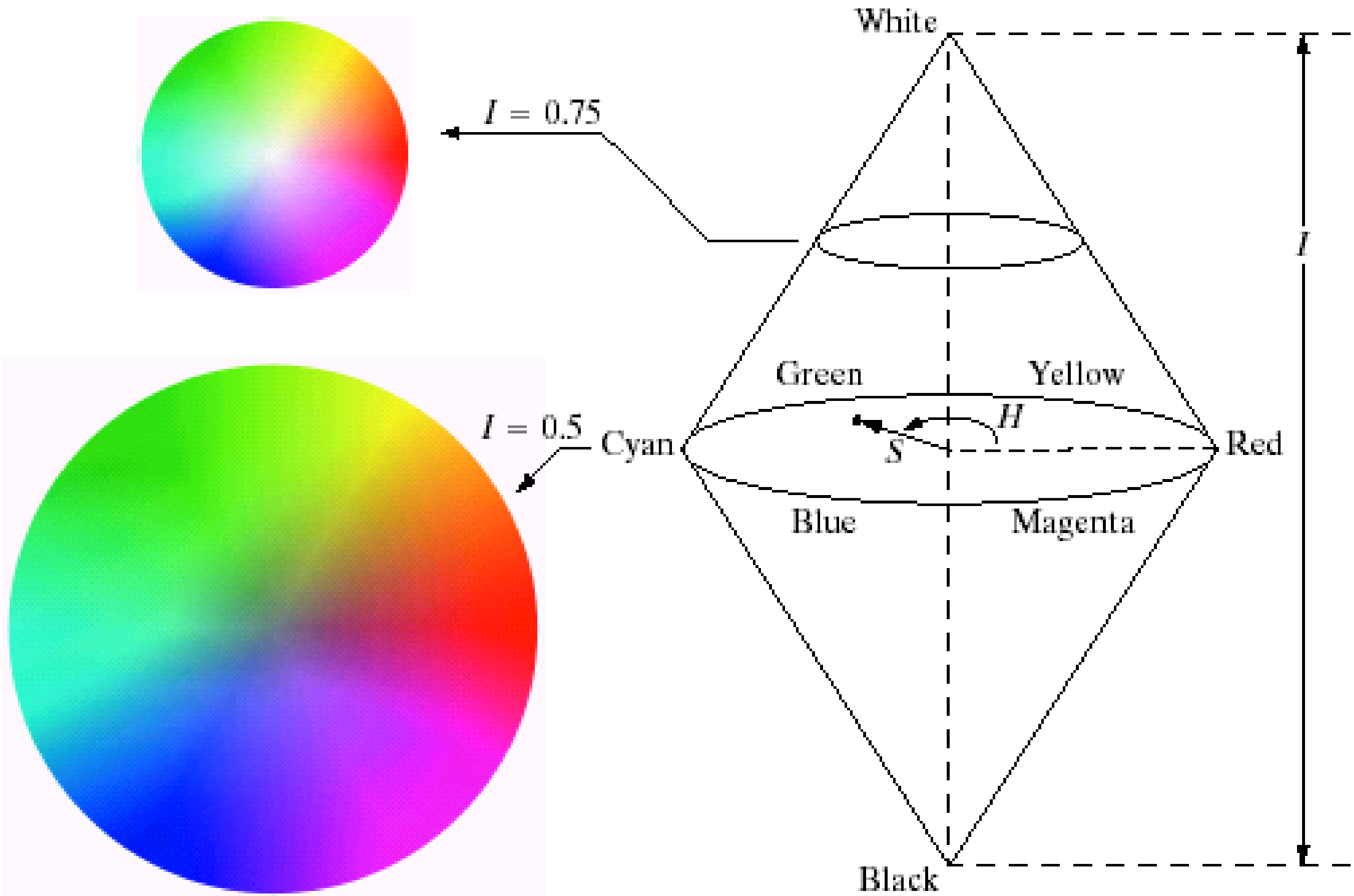


HSI Model Examples



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

HSI Model Examples



Converting From RGB To HSI

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

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

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

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°*)

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

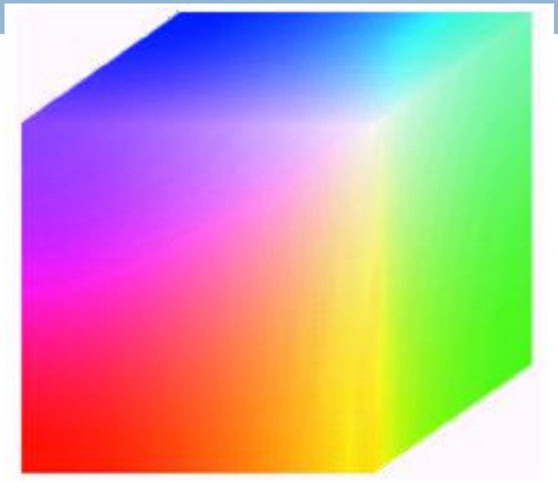
Converting From HSI To RGB (cont…)

- BR sector ($240° <= H <= 360°$)

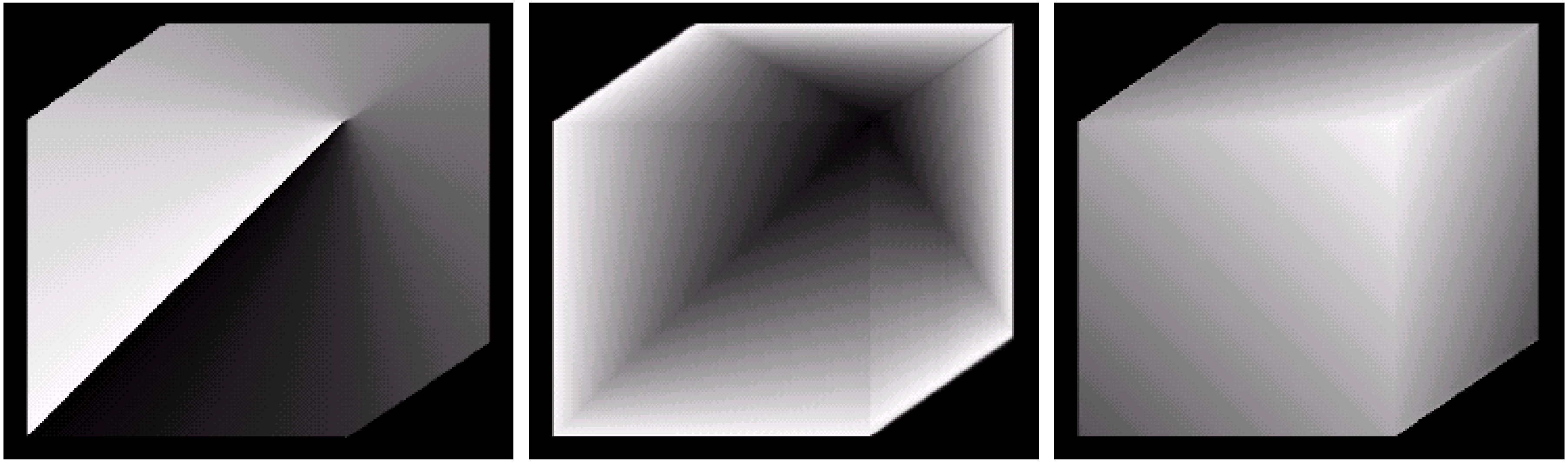
$$R = 3I - (G + B) \quad G = I(1 - S) \quad B = I\left[1 + \frac{S\cos(H - 240)}{\cos(H - 180)}\right]$$

HSI & RGB

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



RGB Colour Cube

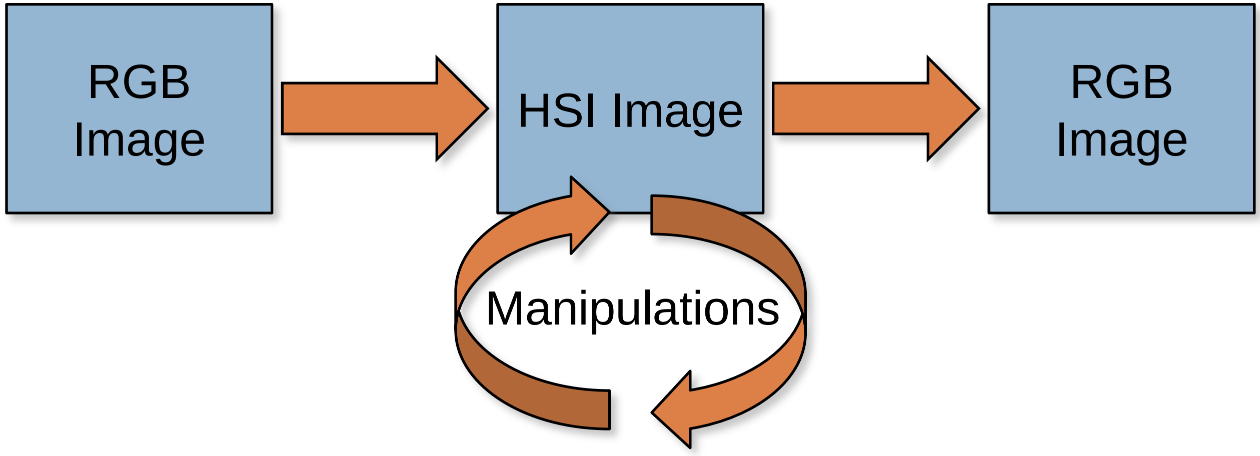


H, S, and I Components of RGB Colour Cube

Manipulating Images In The HSI Model

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

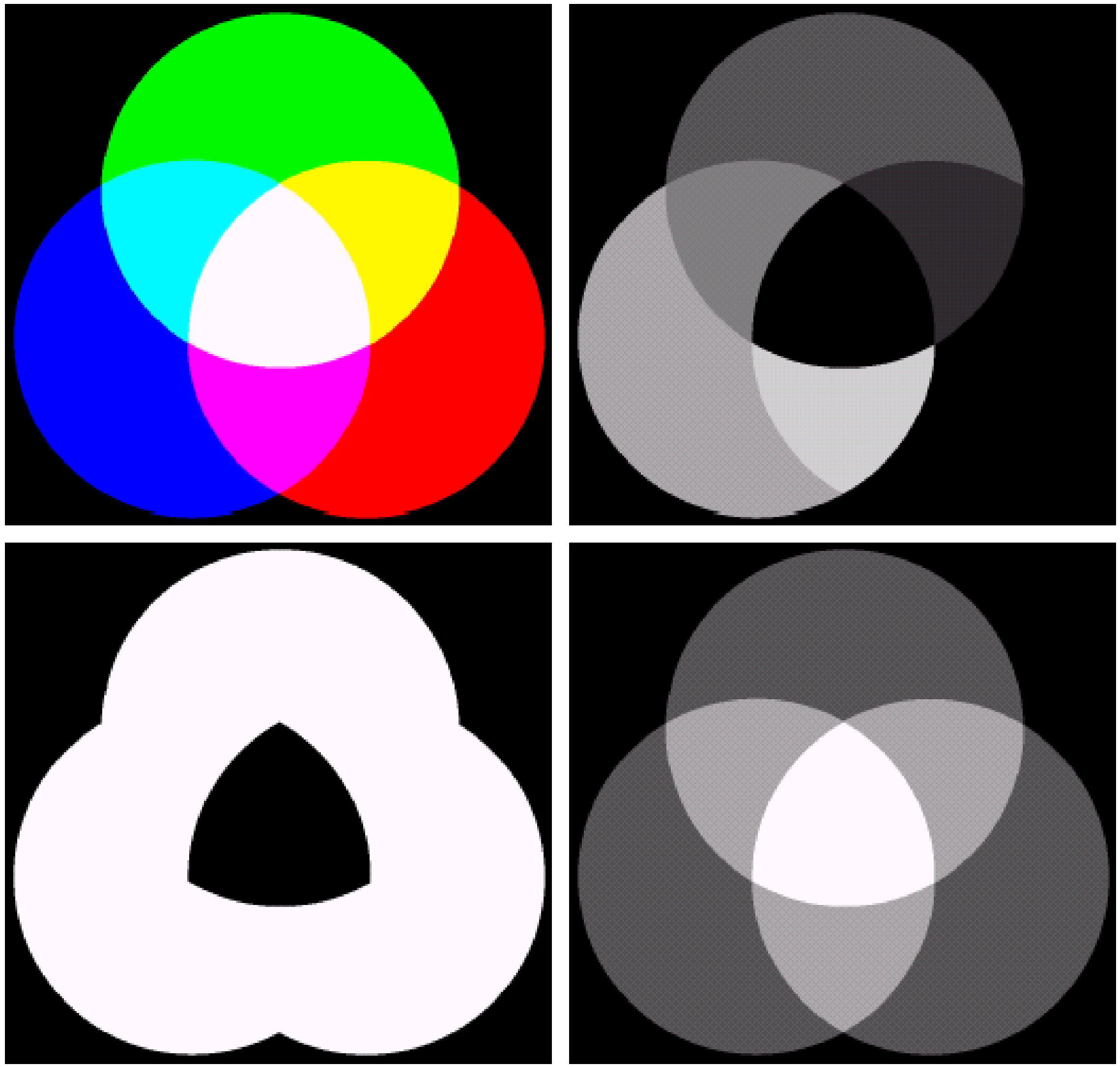
- First convert it from RGB to HSI
- Perform our manipulations under HSI
- Finally convert the image back from HSI to RGB



RGB -> HSI -> RGB

RGB Image

Hue



Saturation

Intensity

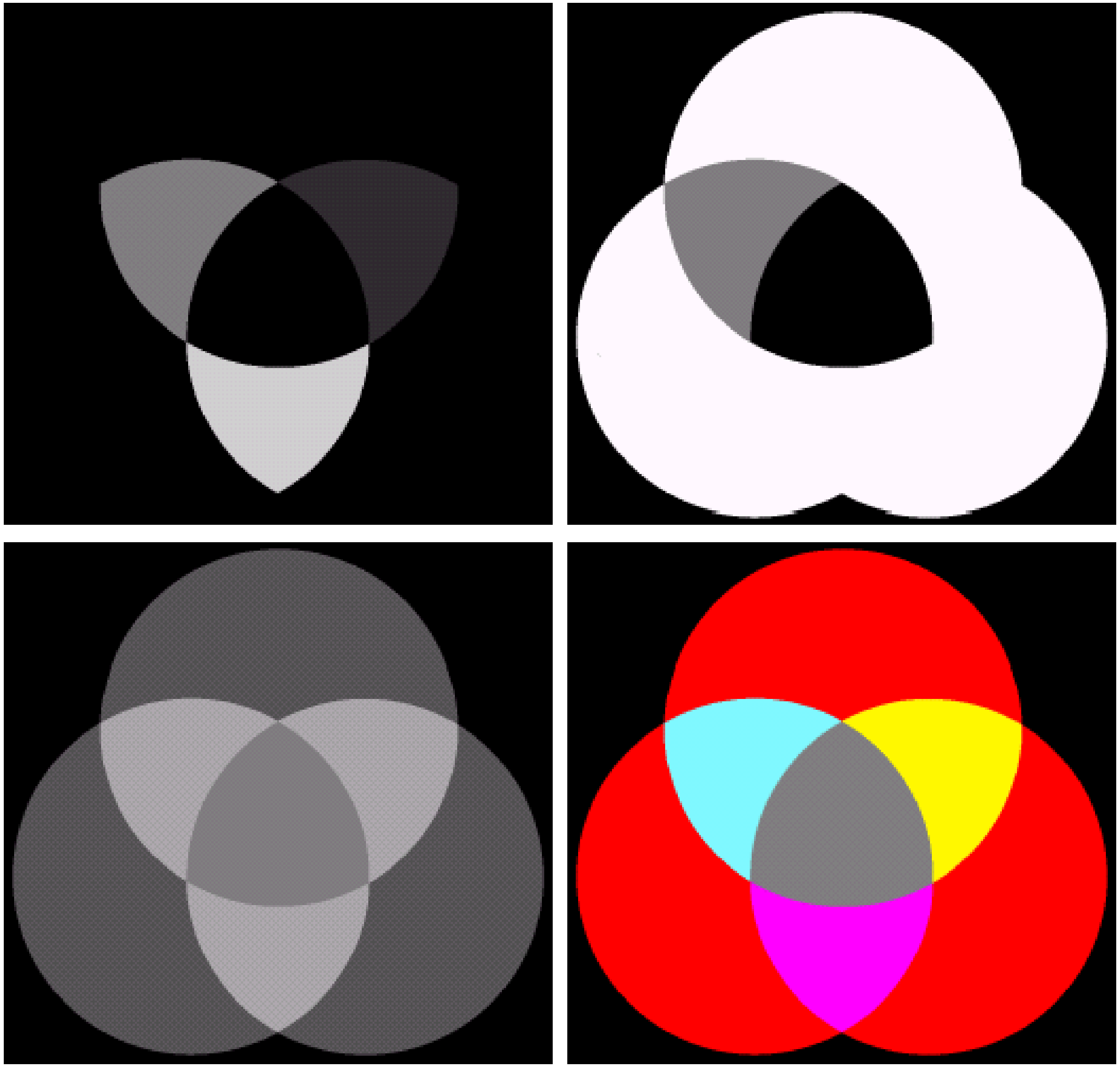
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

RGB -> HSI -> RGB (cont…)

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

Hue

Saturation



Intensity

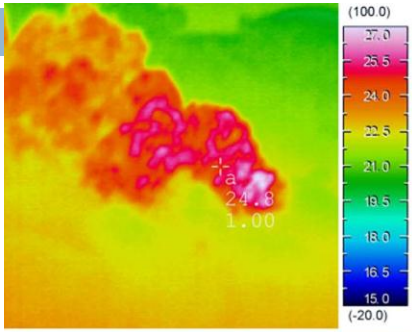
RGB Image

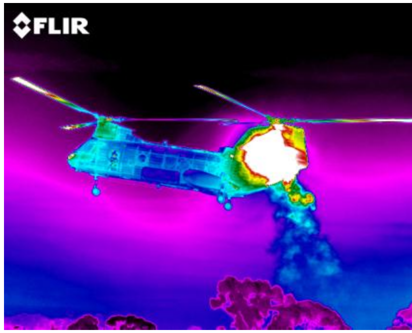
Pseudocolour Image Processing

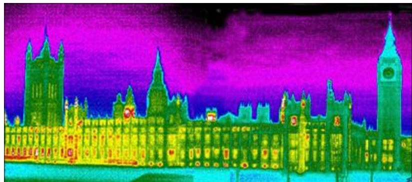
Pseudocolour (also called false colour) image processing consists of assigning colours to grey values based on a specific criterion

The principle use of pseudocolour image processing is for human visualisation

- Humans can discern between thousands of colour shades and intensities, compared to only about two dozen or so shades of grey







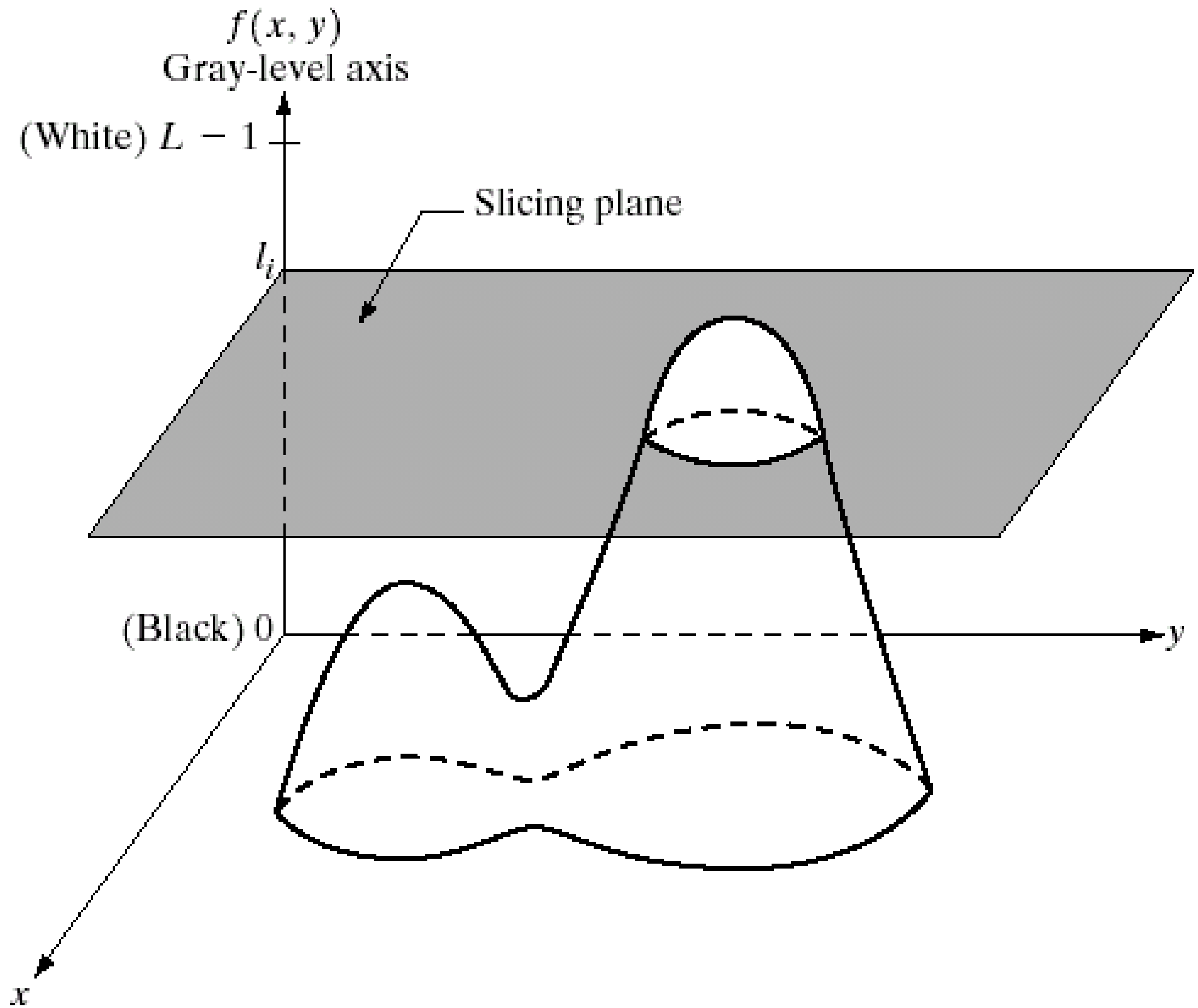
Pseudo Colour Image Processing – Intensity Slicing

Intensity slicing and colour coding is one of the simplest kinds of pseudocolour 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 colour, and a different colour if on the other side



f (x, y)
Gray-level axis
(White) L − 1
Slicing plane
l_i
(Black) 0
y
x

In general intensity slicing can be summarised as:

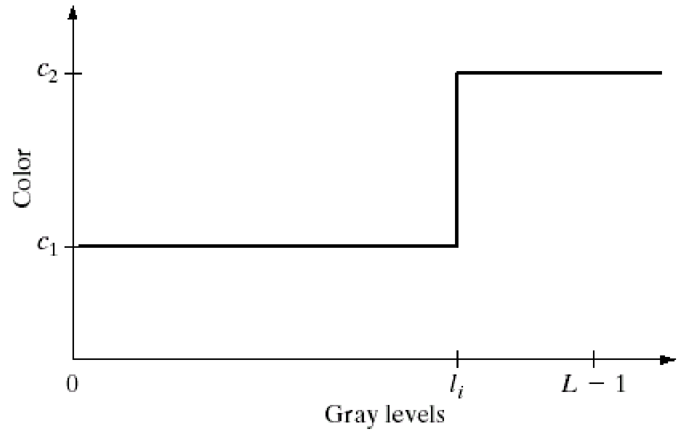
- Let $[0, L-1]$ represent the grey scale
- Let l_0 represent black $[f(x, y) = 0]$ and let l_{L-1} represent white $[f(x, y) = L-1]$
- Suppose P planes perpendicular to the intensity axis are defined at levels $l_1, l_2, \ldots, l_p$
- Assuming that $0 < P < L-1$ then the P planes partition the grey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

- Grey level colour assignments can then be made according to the relation:

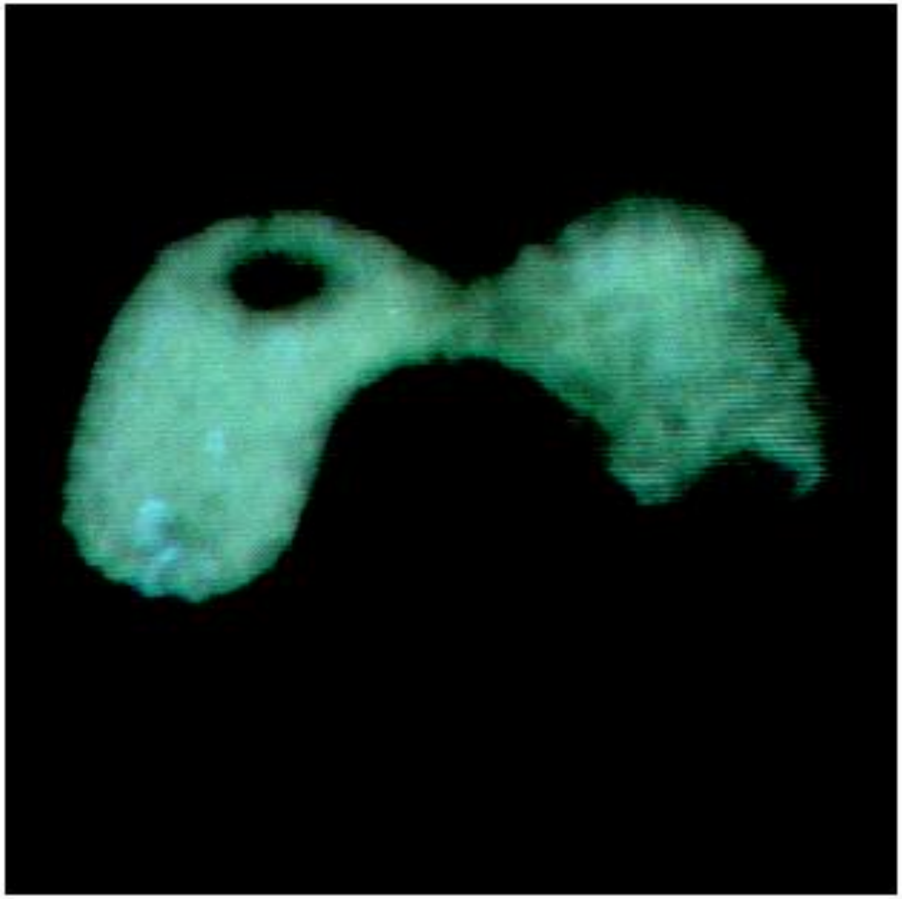
$$f(x,y) = c_k \qquad \text{if } f(x,y) \in V_k$$

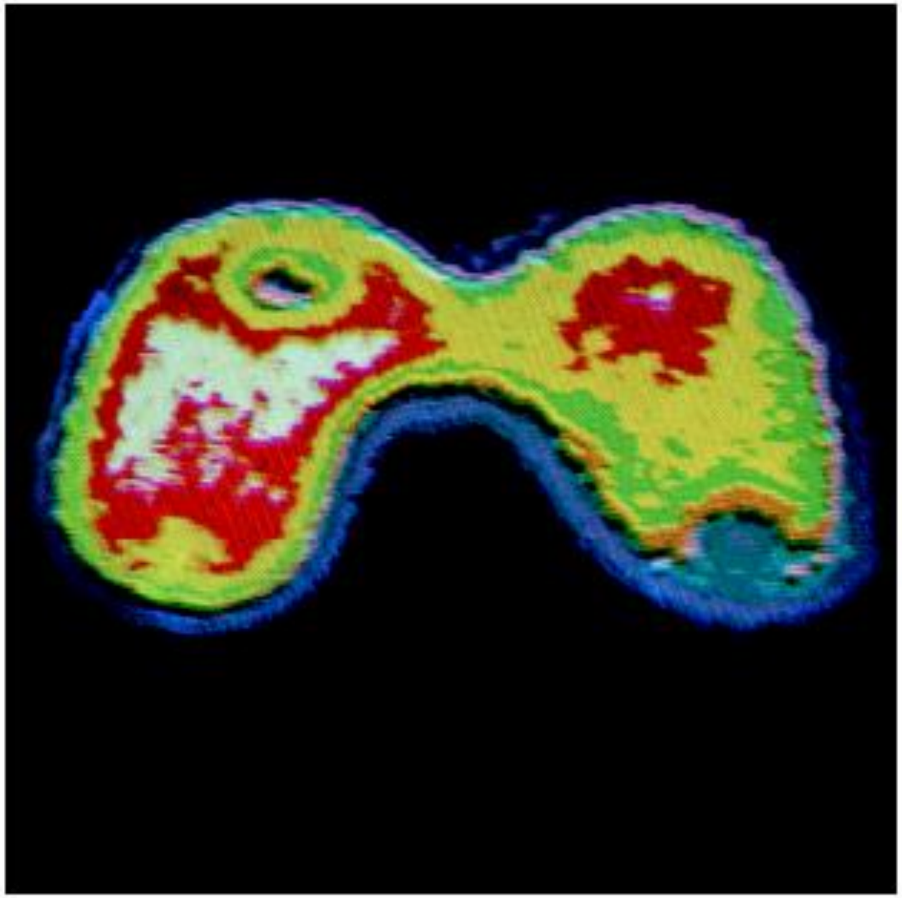
- where c_k is the colour associated with the k^{th} intensity level V_k defined by the partitioning planes at $l = k - 1$ and $l = k$

RGB -> HSI -> RGB (cont…)



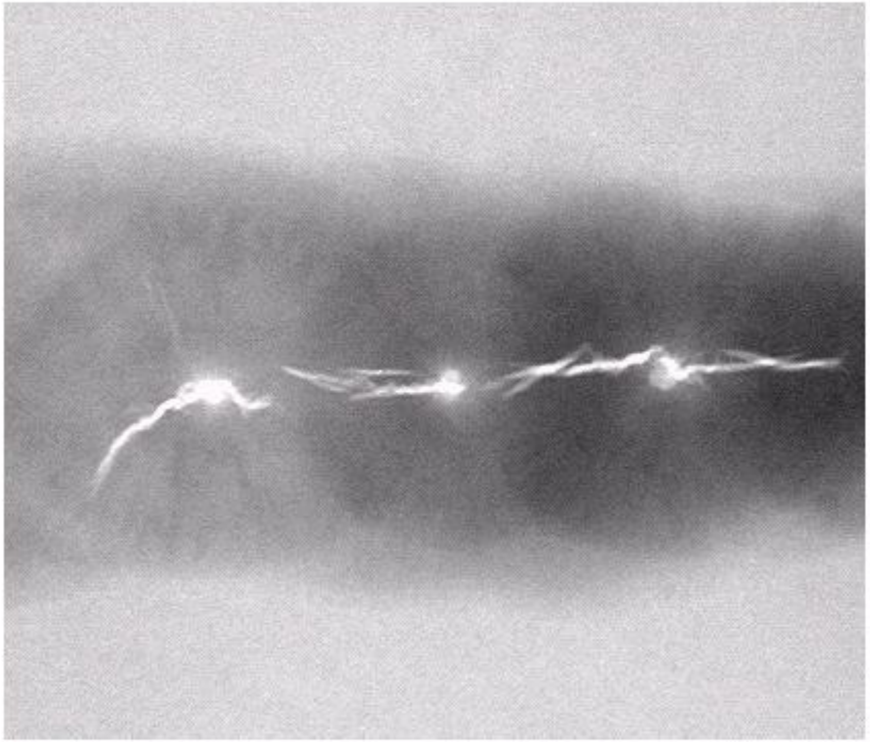
RGB -> HSI -> RGB (cont…)

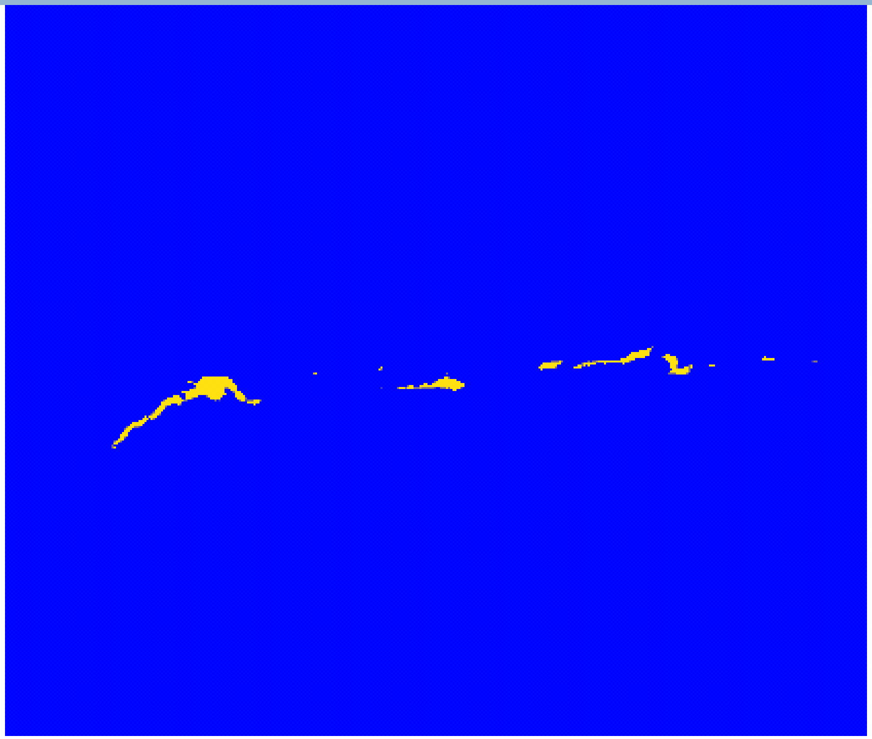




Images taken from Gonzalez & Woods, Digital Image Processing (2002)

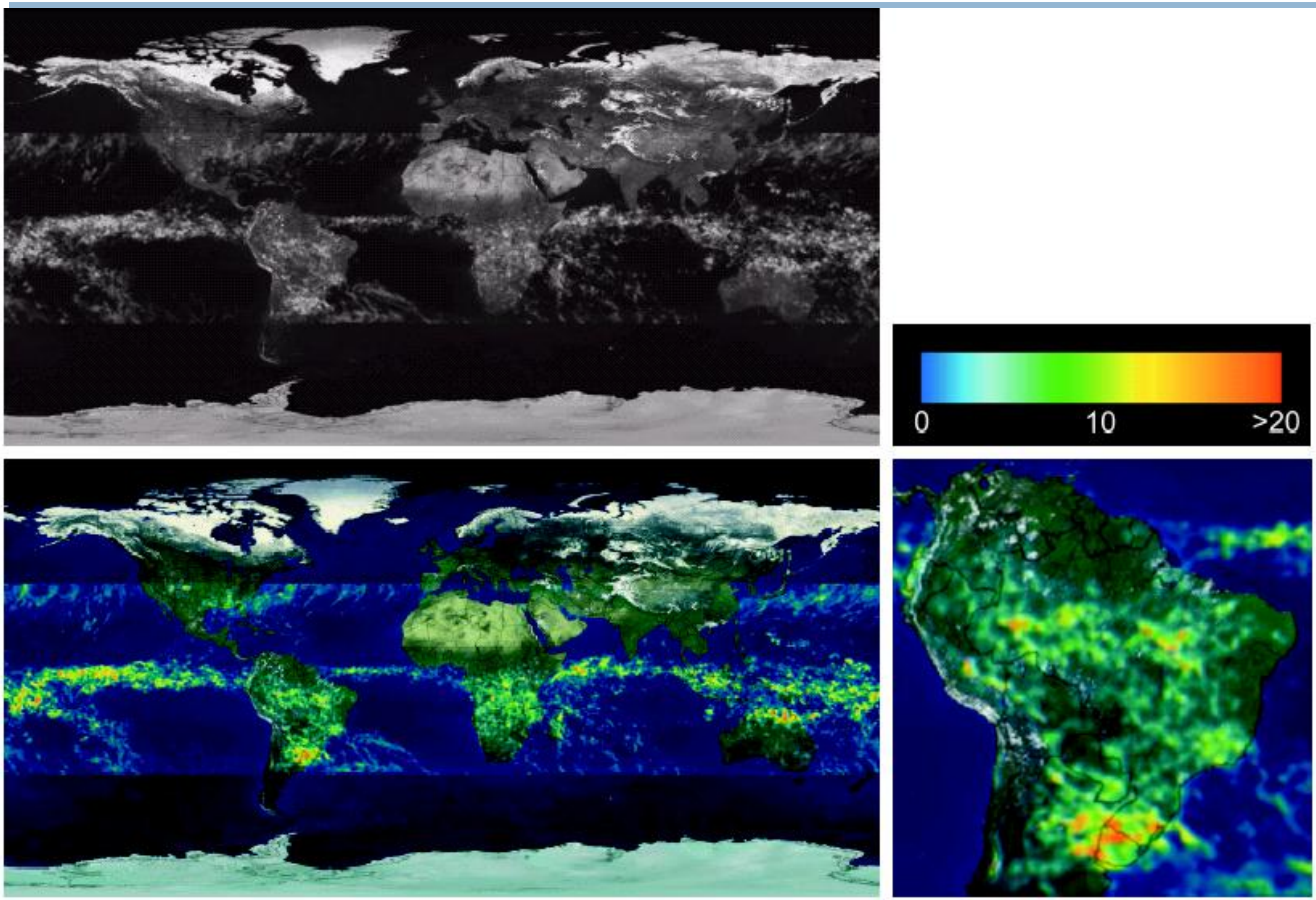
RGB -> HSI -> RGB (cont…)





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

RGB -> HSI -> RGB (cont…)



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

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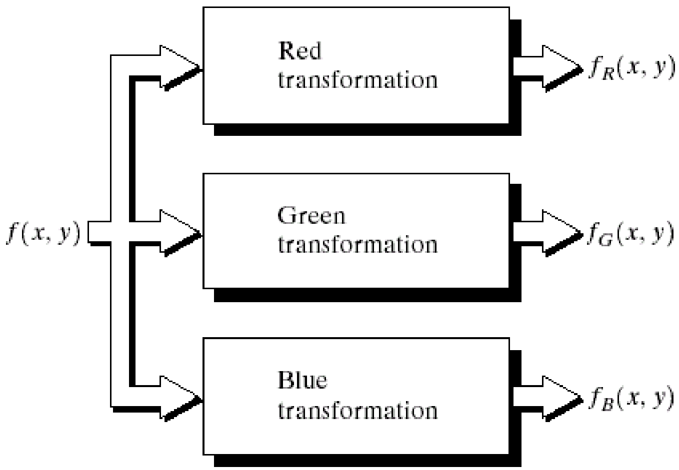
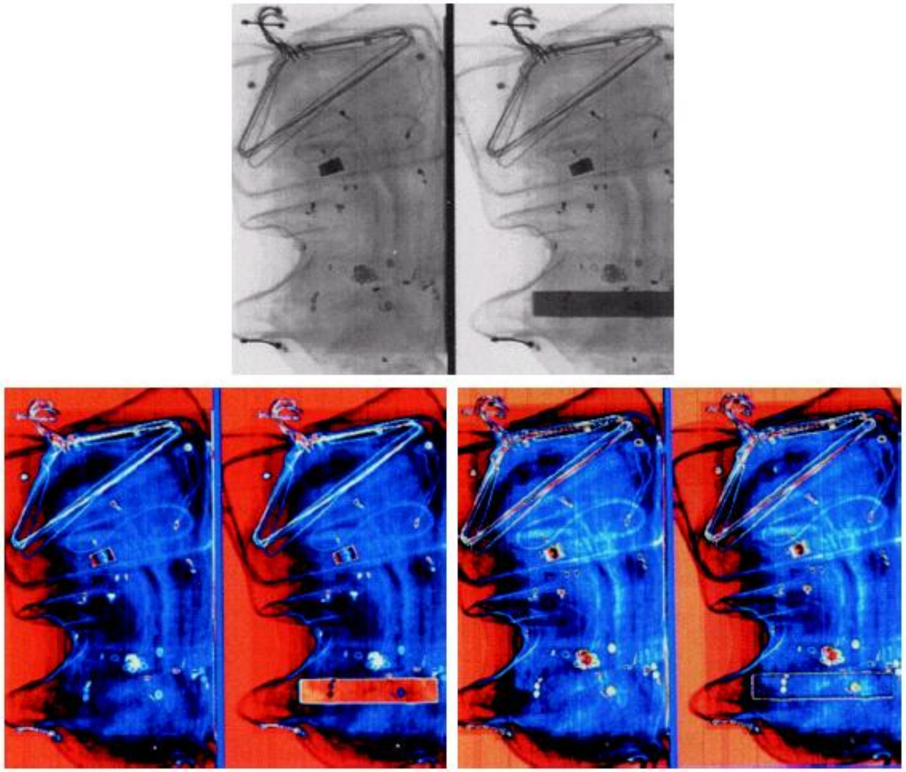


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.



a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

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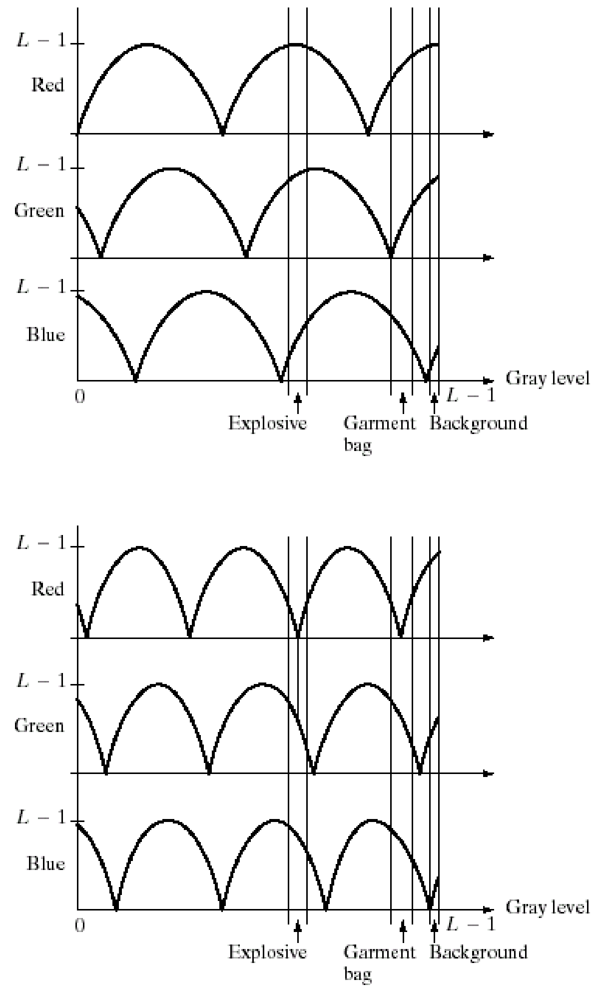

a
b

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

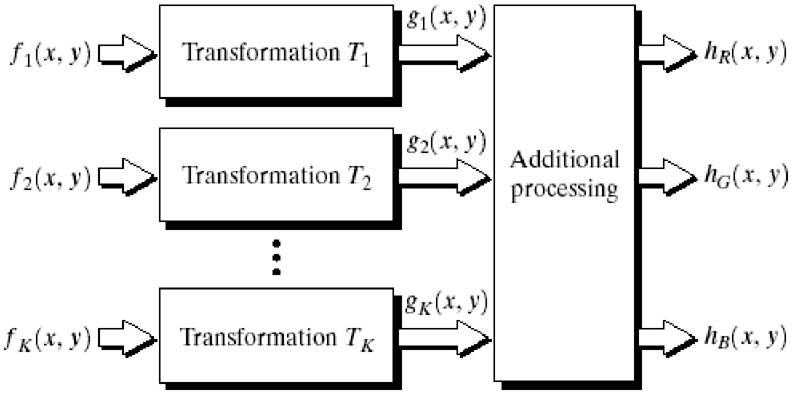

FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

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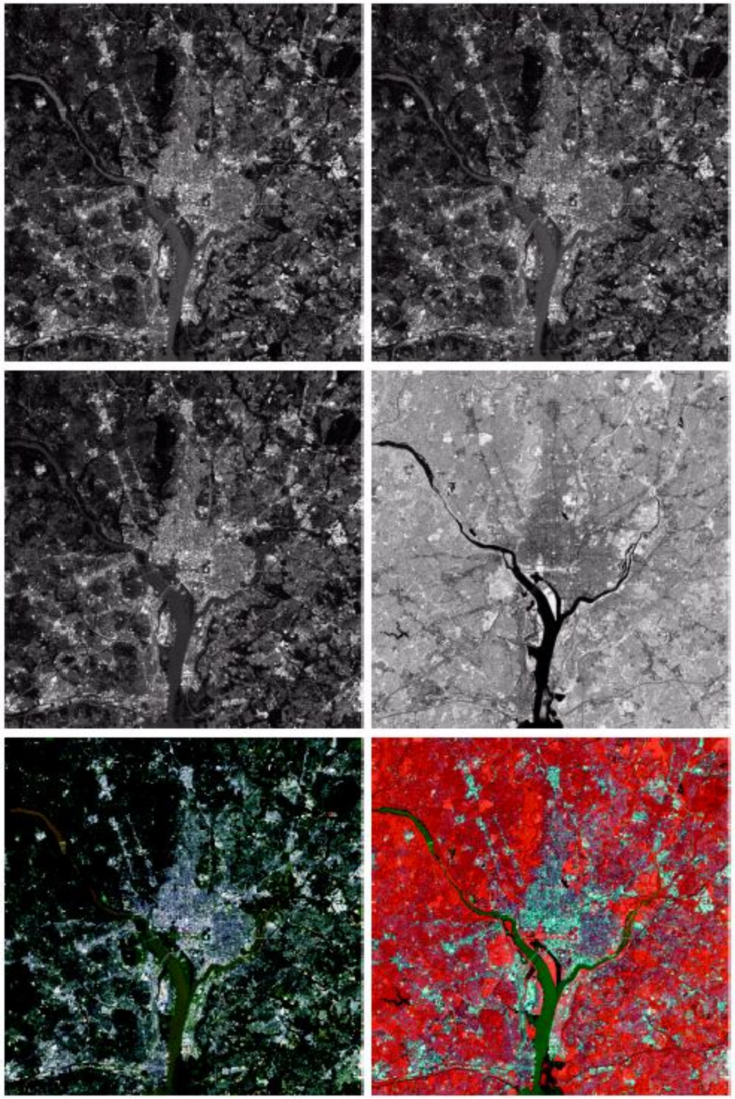
a b
c d
e f

FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)



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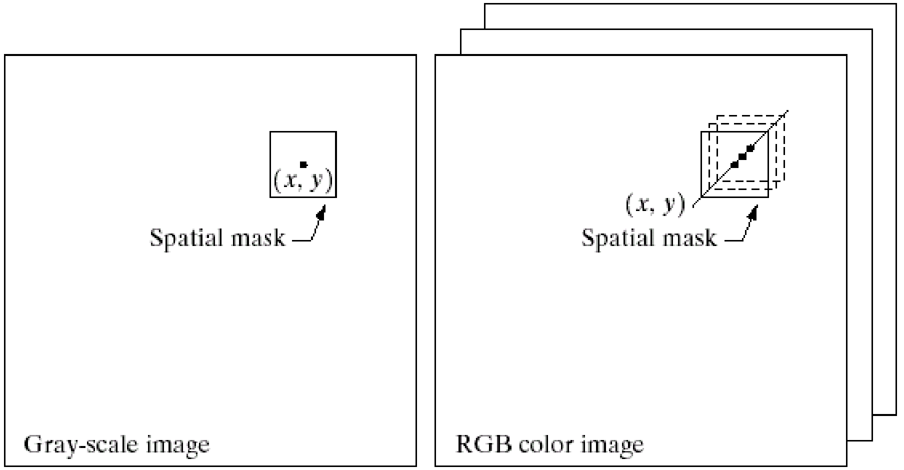

a b

FIGURE 6.29 Spatial masks for gray-scale and RGB color images.

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FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)

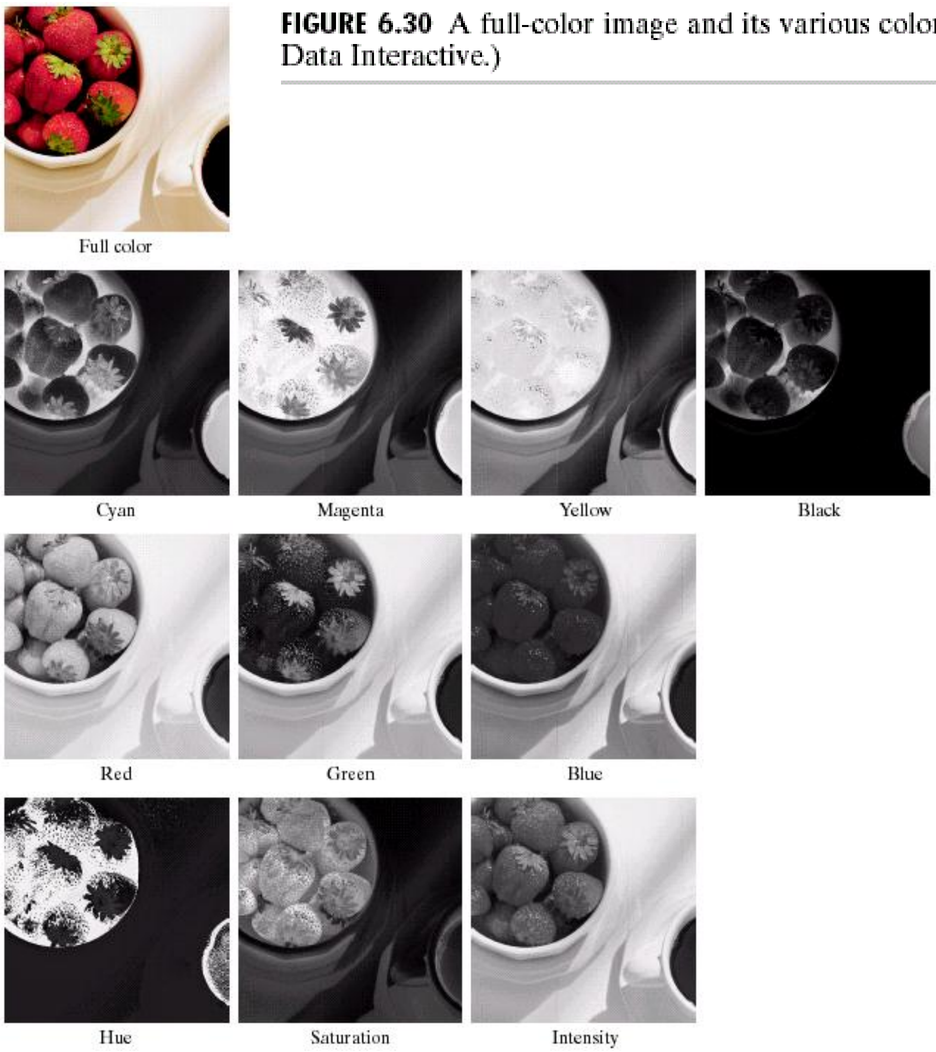

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FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

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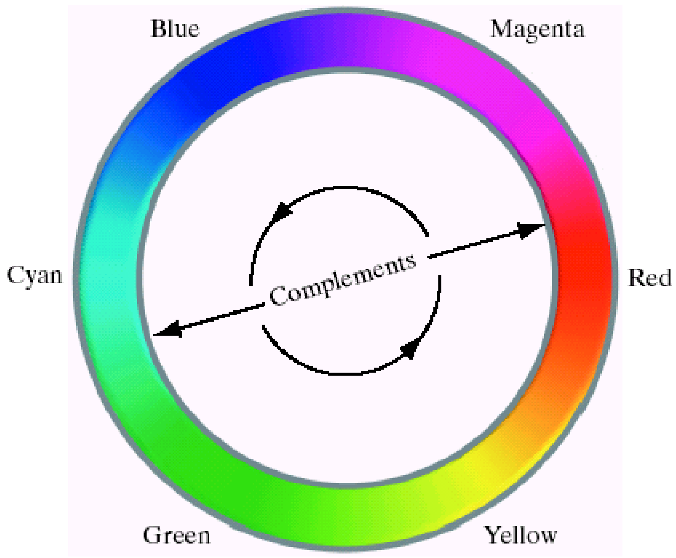

FIGURE 6.32 Complements on the color circle.

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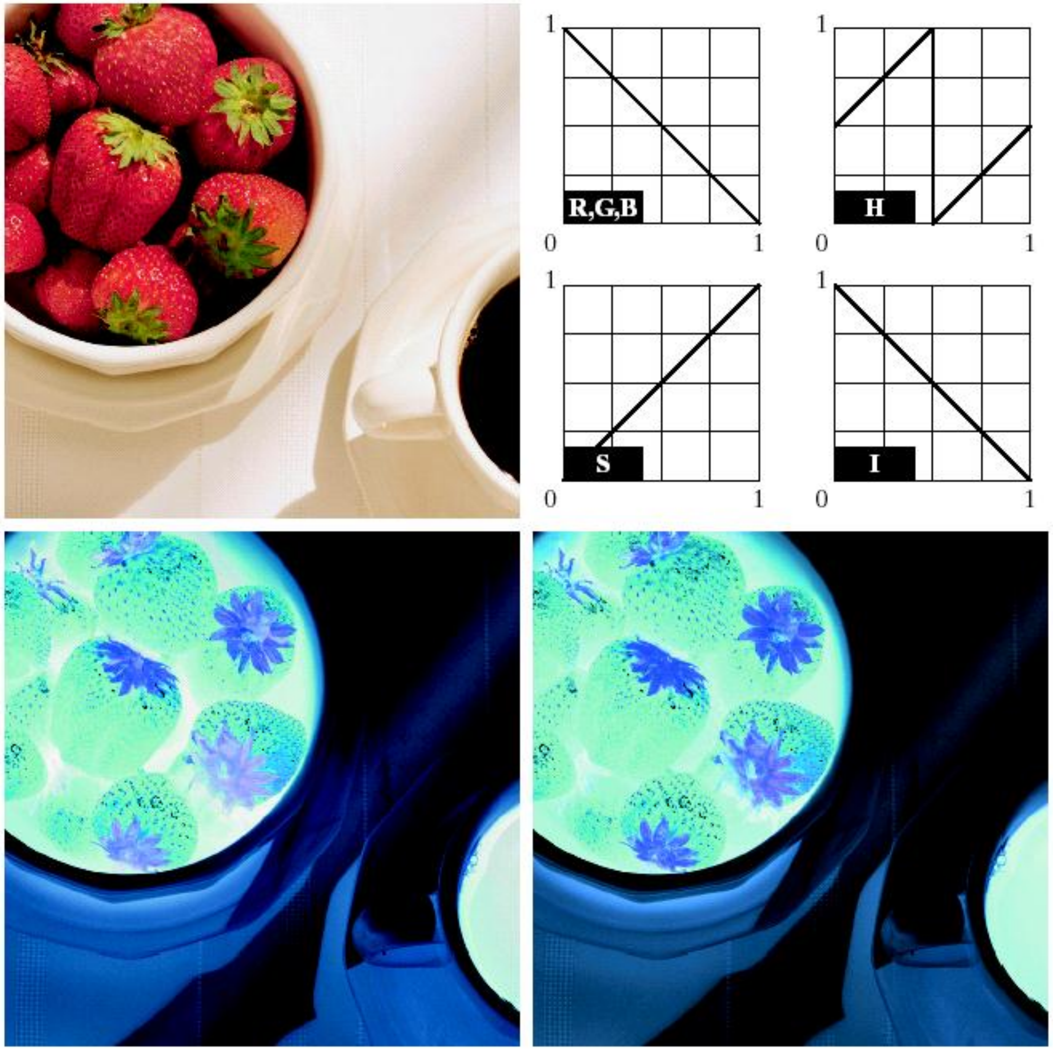
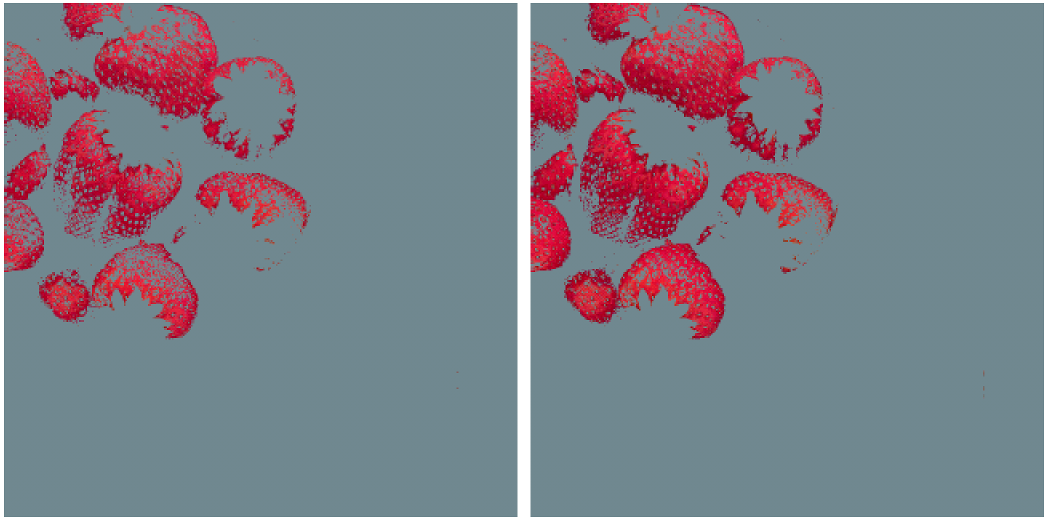


FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.



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 $(0.5, 0.5, 0.5)$.

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

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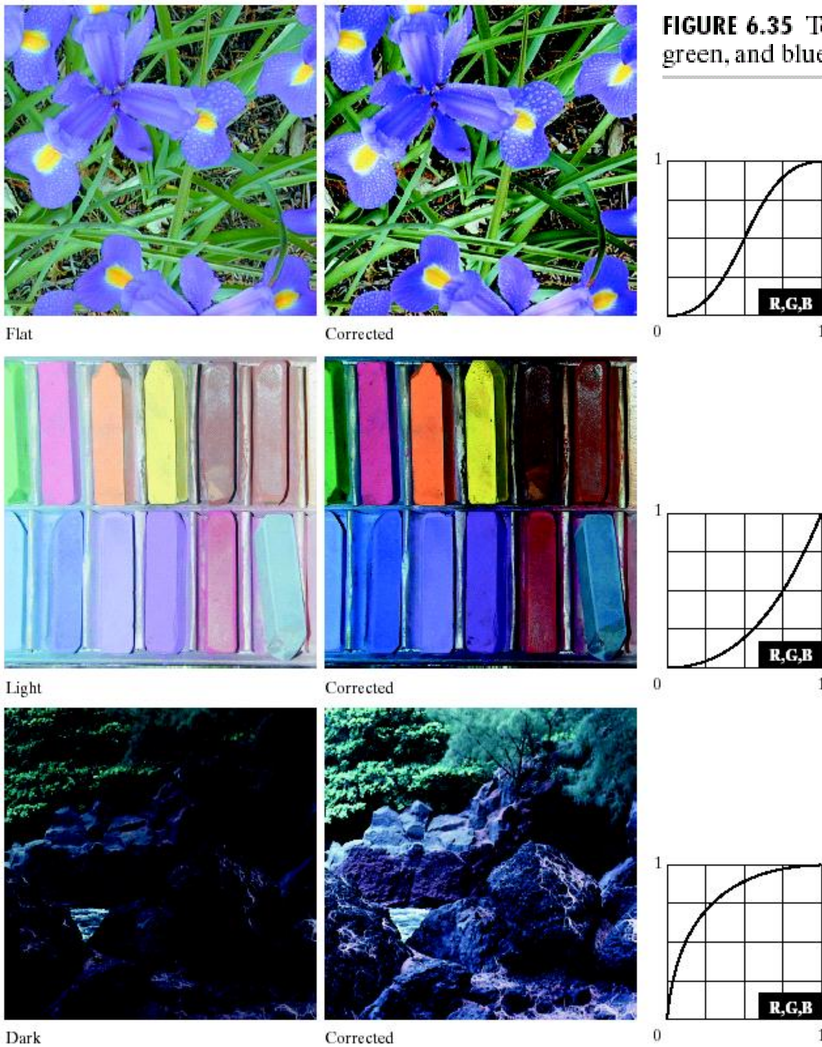

FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.

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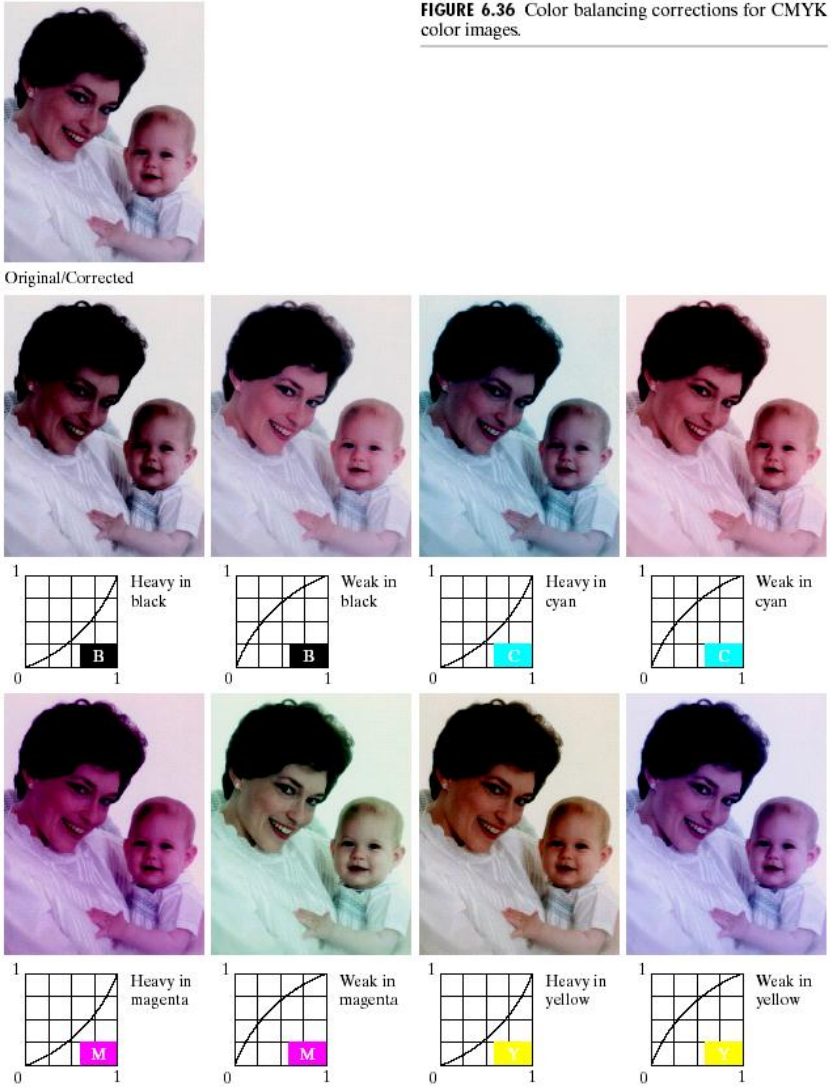

FIGURE 6.36 Color balancing corrections for CMYK color images.

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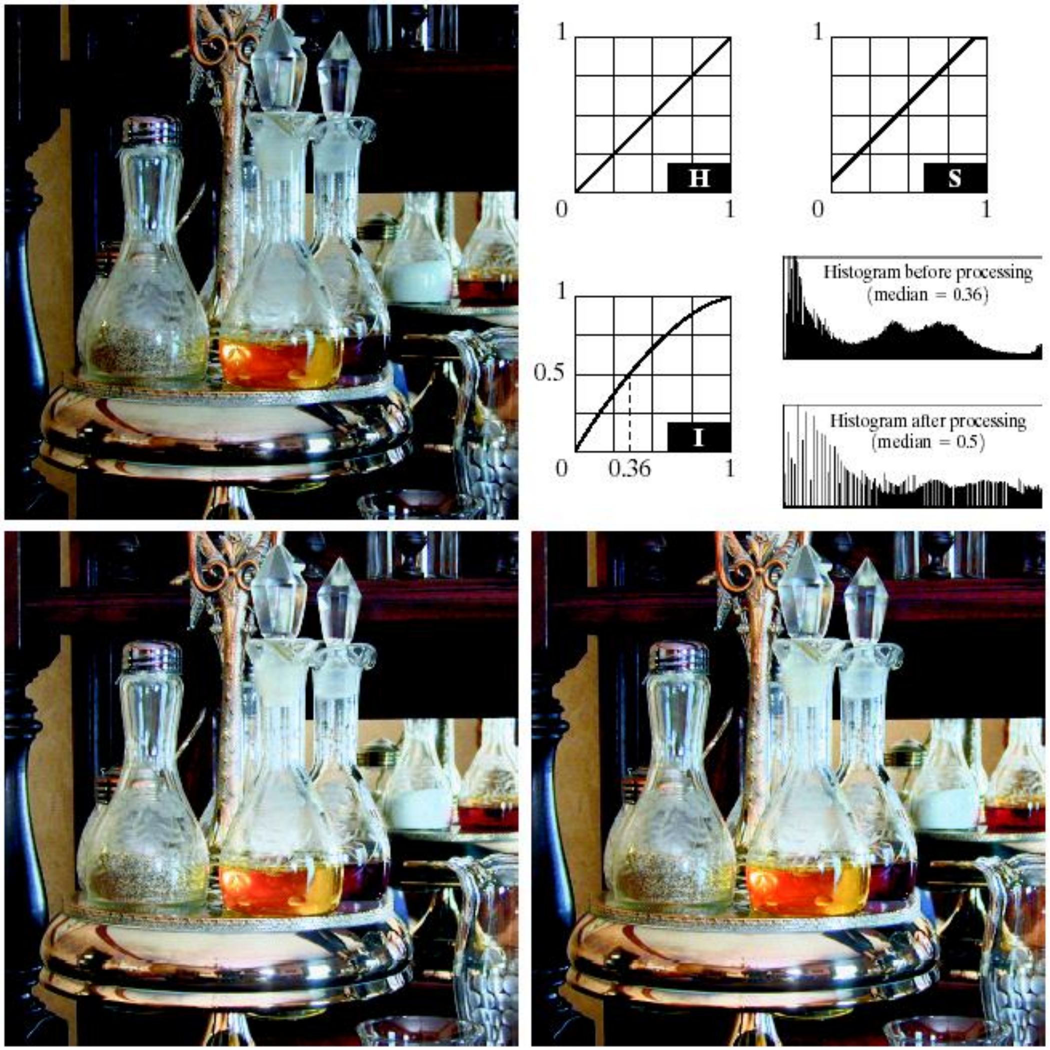

a b
c d

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

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a b
c d

FIGURE 6.38
(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

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a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

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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.

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a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.