Digital Image Processing

Color Image Processing

DIP Chapter 6

Credit to slides: Brian Mac Namee

& artwork from DIP Textbook Gonzales & Woods

Introduction

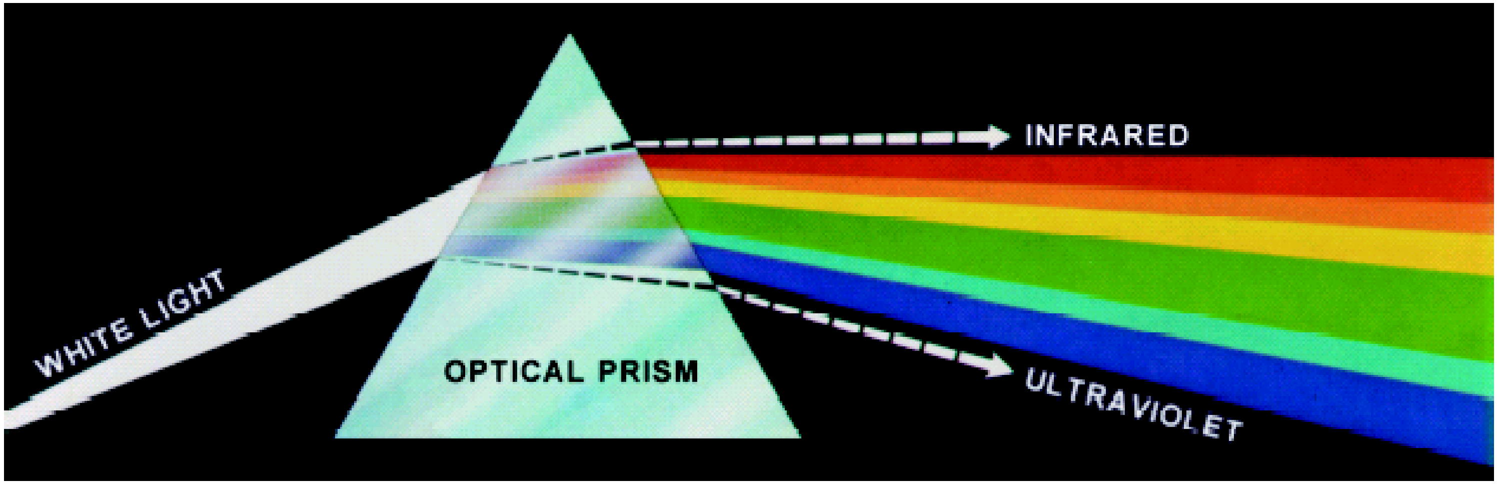
Today we'll look at color image processing, covering:

– Color fundamentals

– Color models

Color Fundamentals

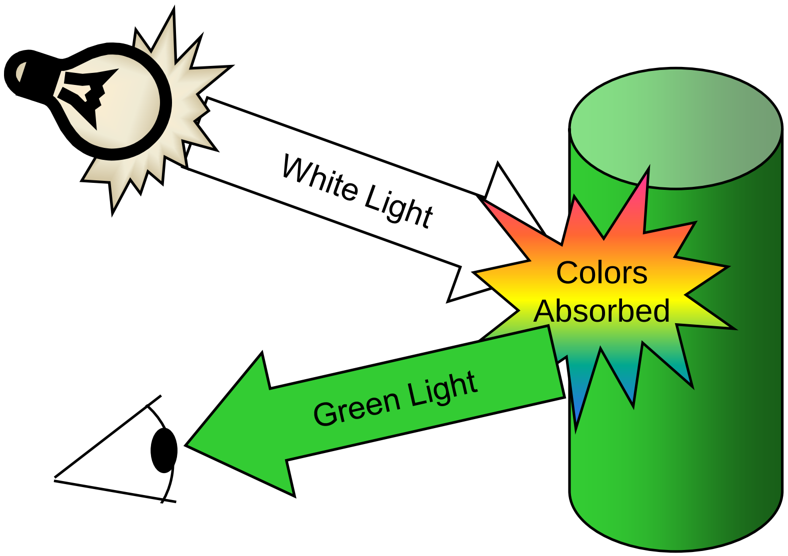
In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colors.



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



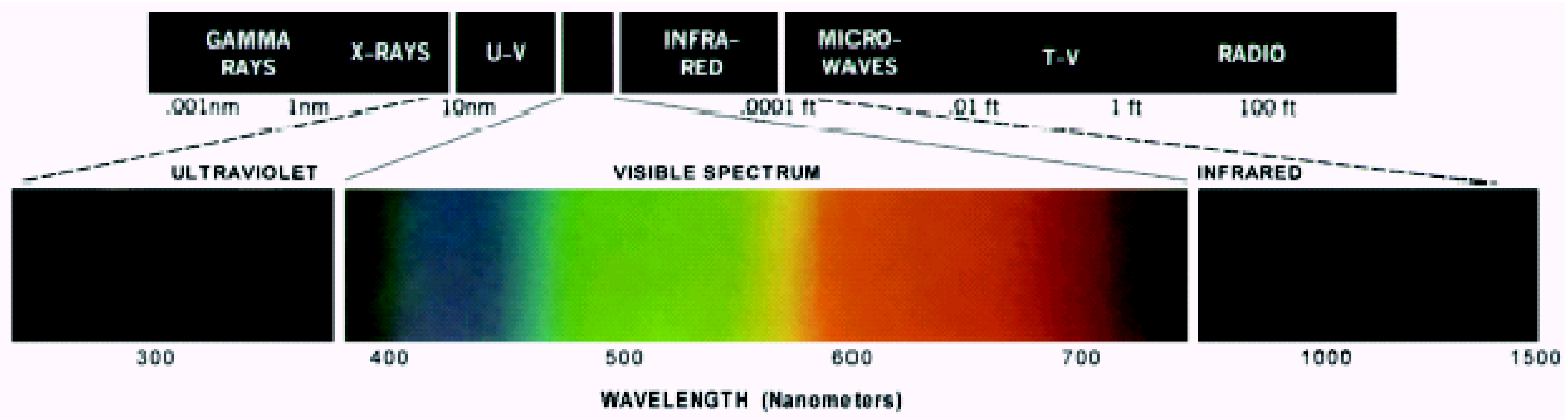
Color Fundamentals (cont…)

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 (e.g. light emitted as infrared which an observer can't perceive)
- **Brightness:** a subjective (practically unmeasurable) notion that embodies the intensity of light across parts of the spectrum.

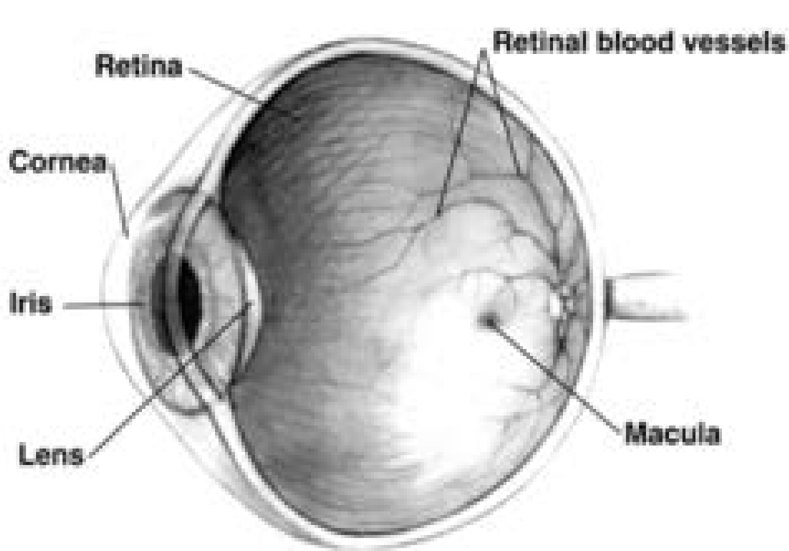
Color Fundamentals (cont…)

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



Human retina: Photoreceptor cells

Human color vision is achieved through 6 to 7 million cones in each eye.



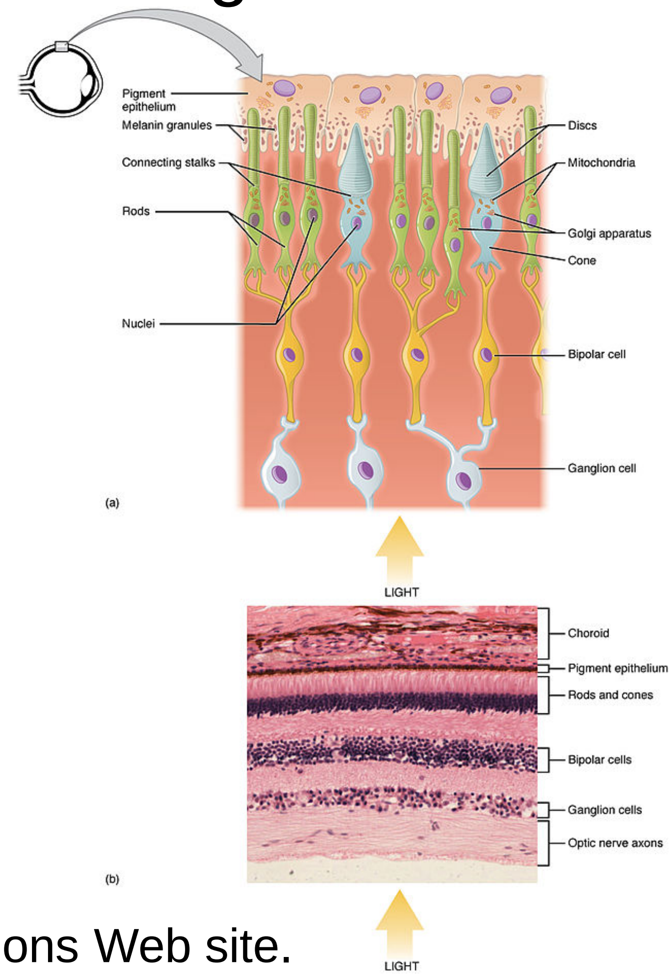
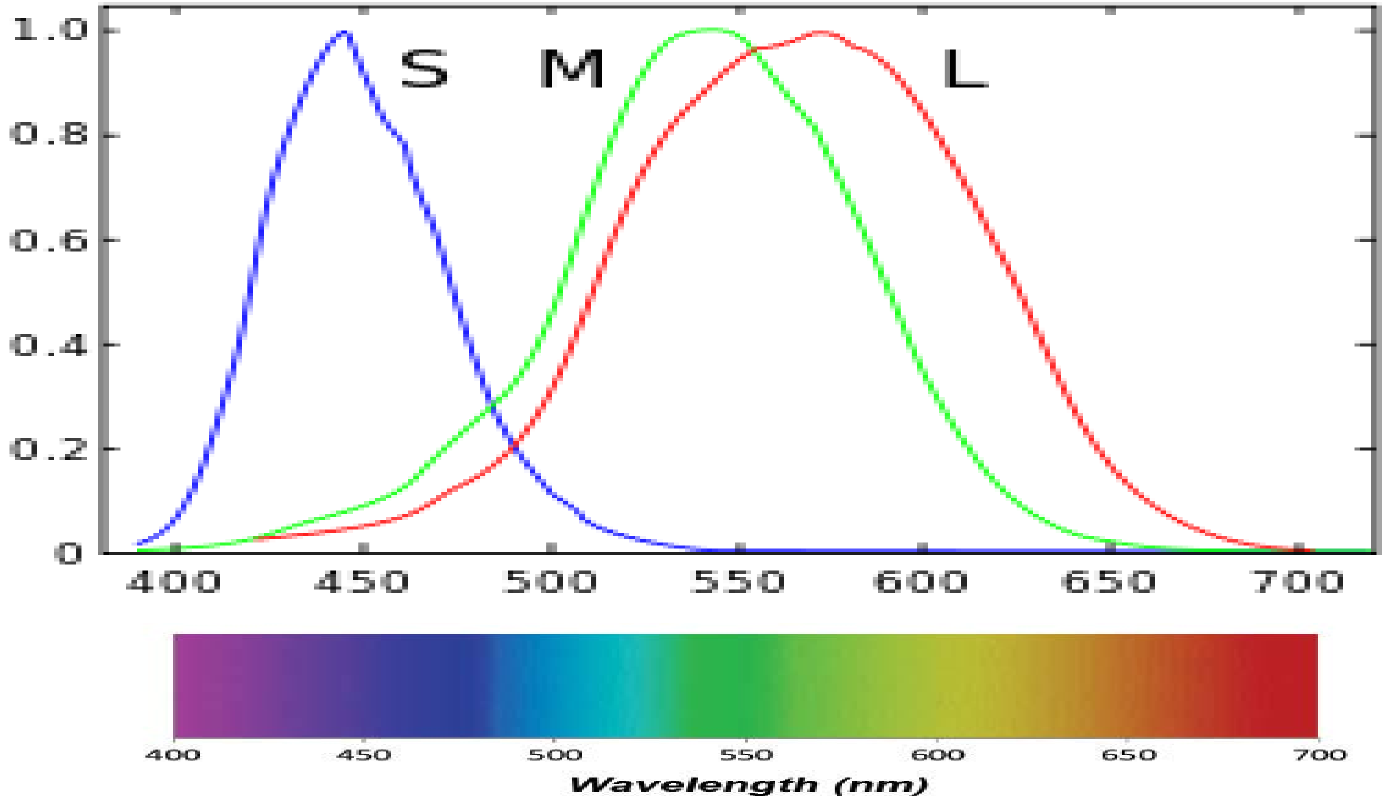


Illustration from Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/, Jun 19, 2013.

Color Fundamentals (cont…)

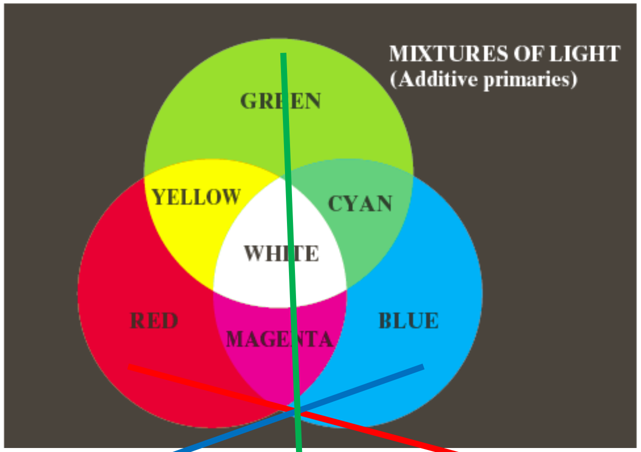


SML:
short
medium
long

Cone SML absorption characteristics (experiments 1965):
Colors seen as combinations across spectrum.

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

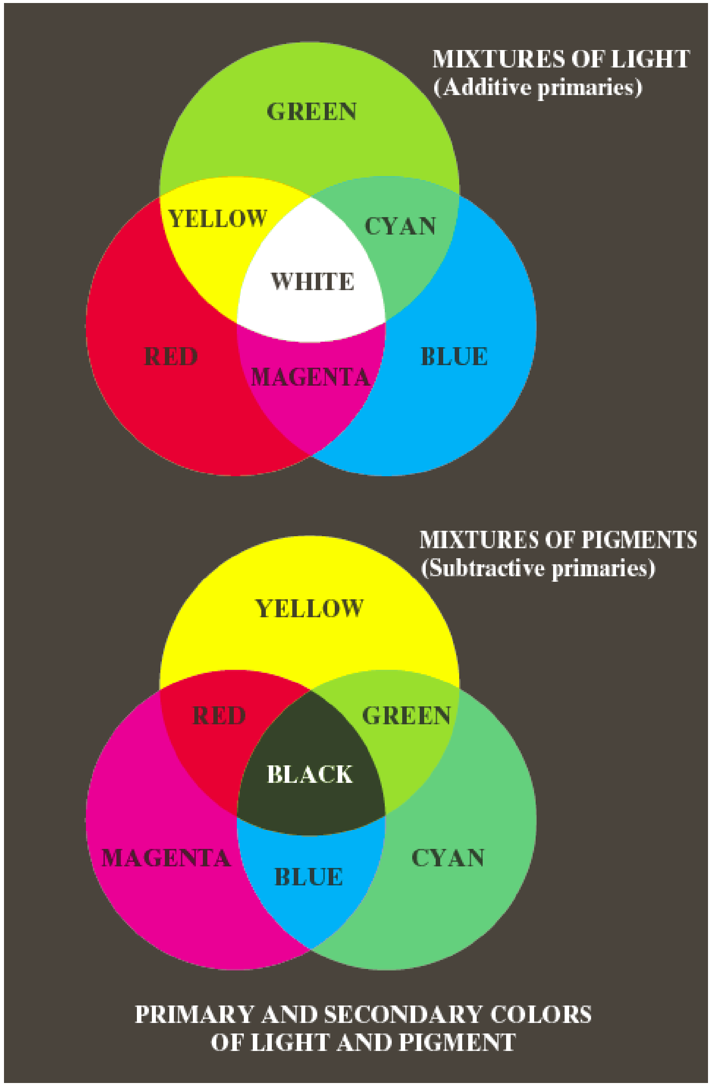
CIE Standard 1931
International Commission on Illumination

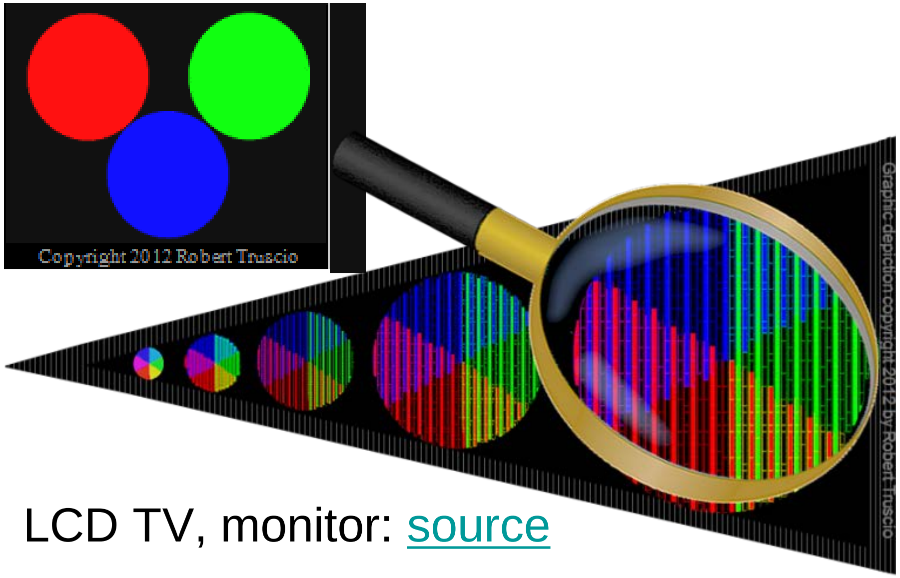


CIE 1931:Primary Colors:
Red (700nm)
Green (546.1nm)
Blue (435.8nm)

- "Primary colors": Does <u>not</u> mean that mix can produce all visible colors!
- Mismatch between "primary RGB" and human perception.

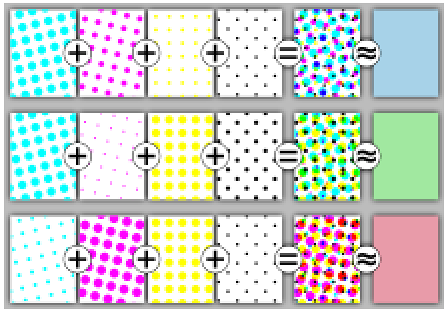
Primary & Secondary Colors





LCD TV, monitor: source

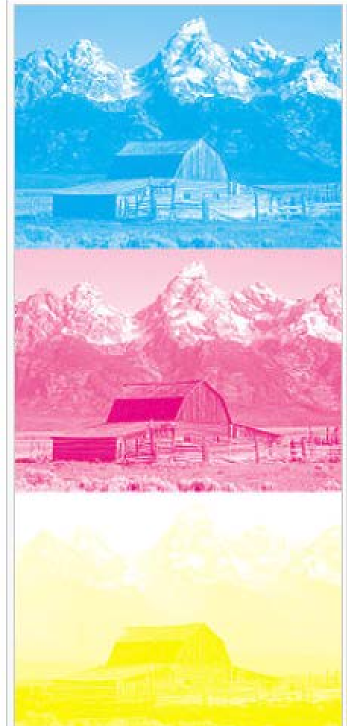
Color printing:



Color Printing: CMYK

CMYK: cyan, magenta, yellow, and key (black).

A color photograph of the Teton Range.

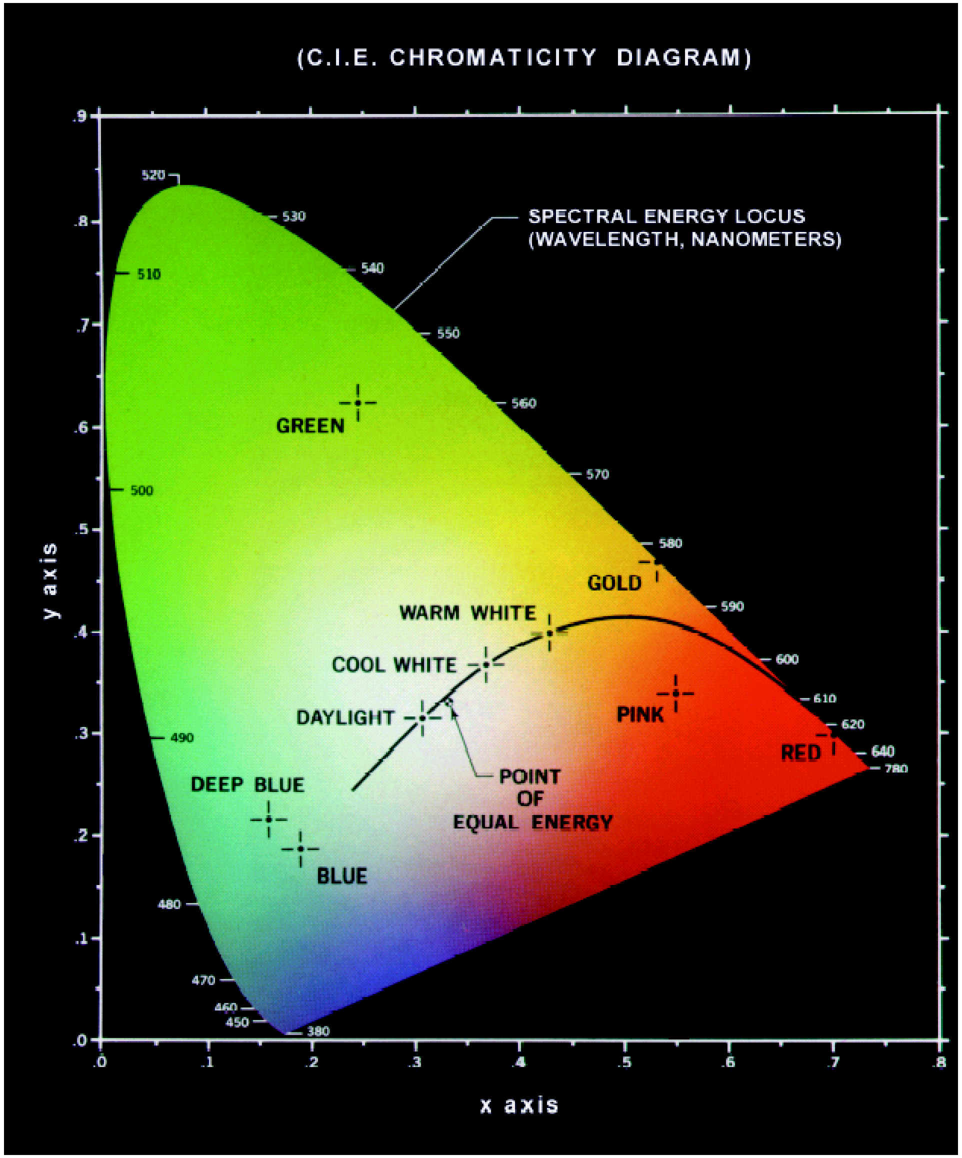


The image above, separated for printing with process cyan, magenta, and yellow inks.

The same image, this time separated with maximum black, to minimize ink use.

CIE Chromaticity Diagram

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



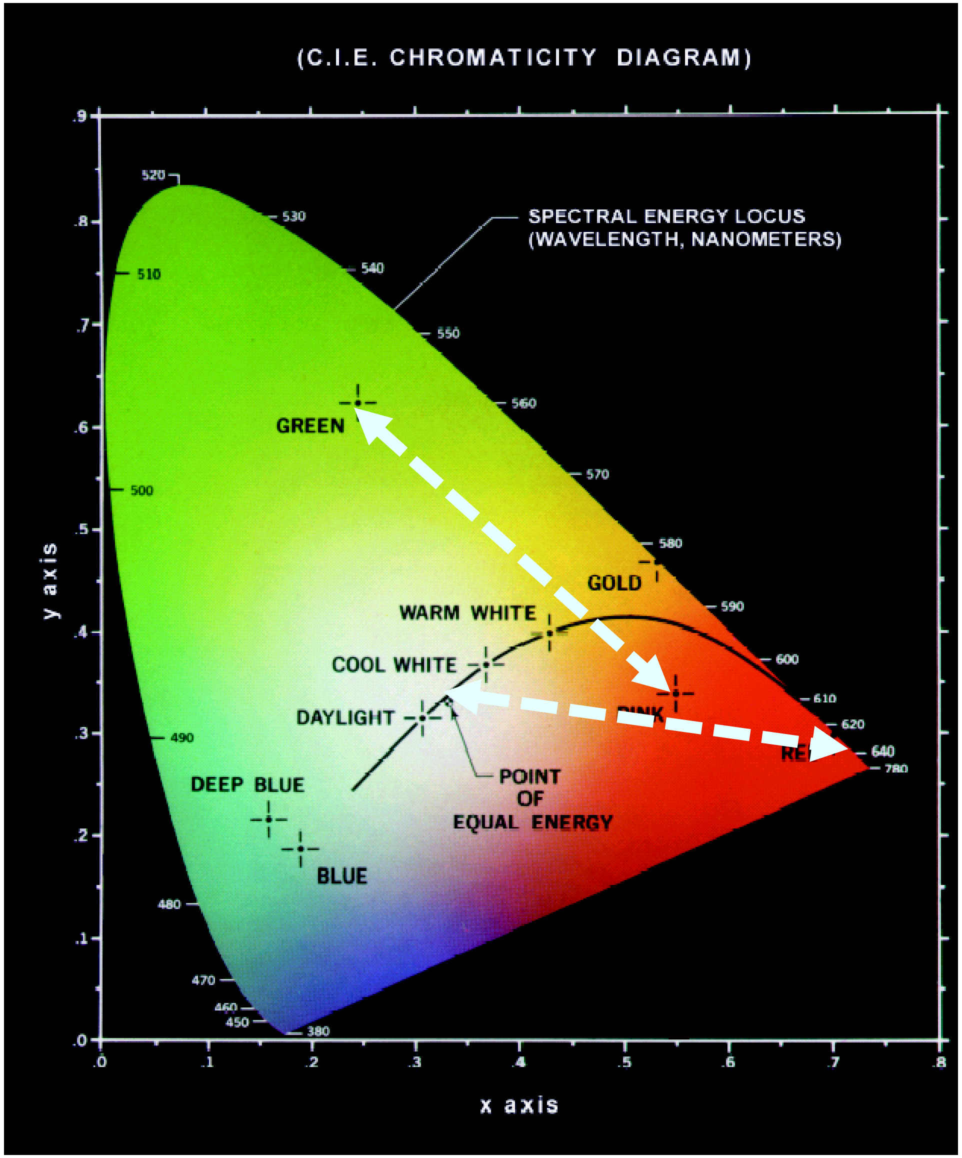
Trichromatic coefficients x,y,z, with x+y+z=1:

CIE diagram: (x,y axis = red, green):

- Green: 62% green, 25% red and 13% blue
- Red: 32% green, 67% red and 1% blue
- Blue: 20% green, 20% red and 60% blue.
- White: 33% RGB

[*Demo*]

CIE Diagram

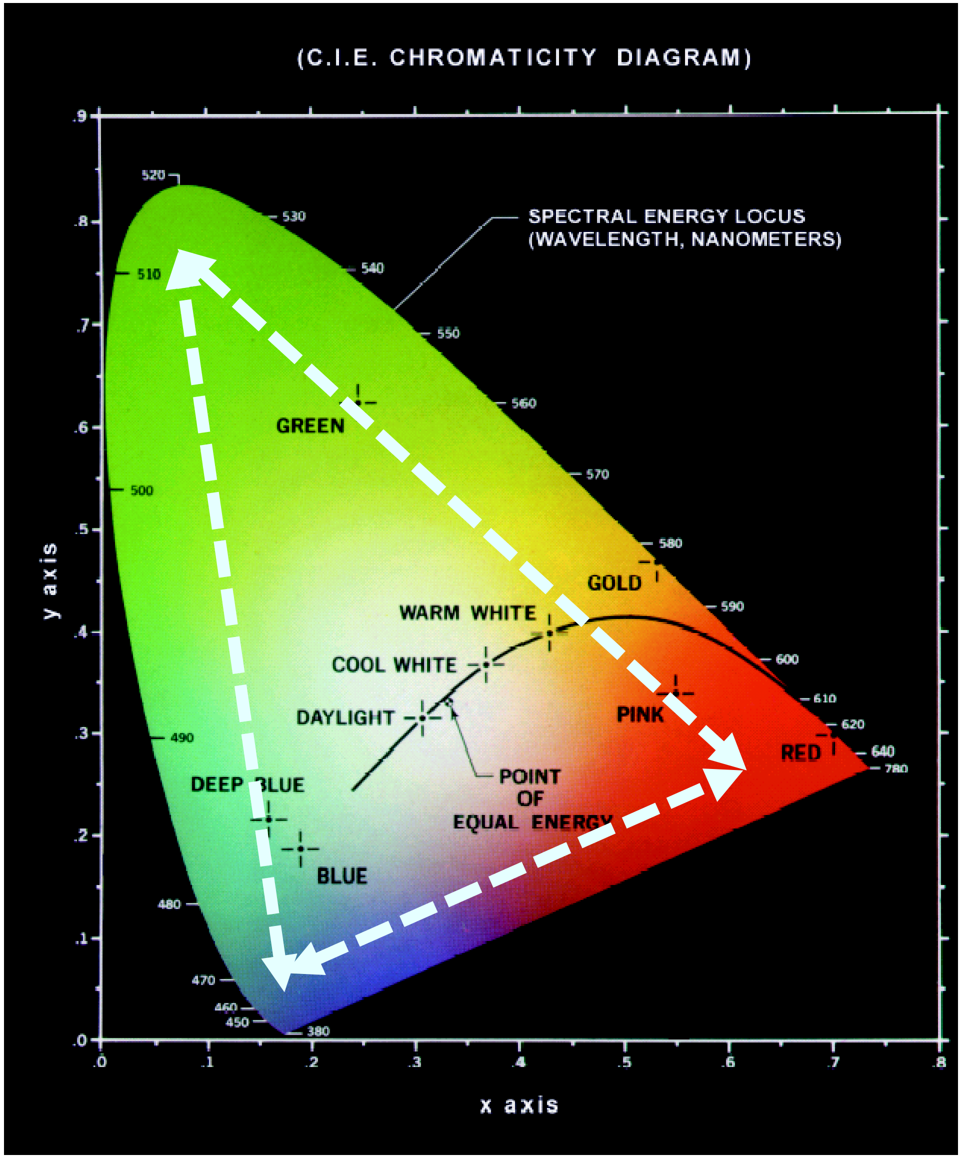


Use for additive color mixing:

Mixing of red and green: all colors along line can be produced.

Mixing red to white: Saturation max to zero.

CIE Diagram

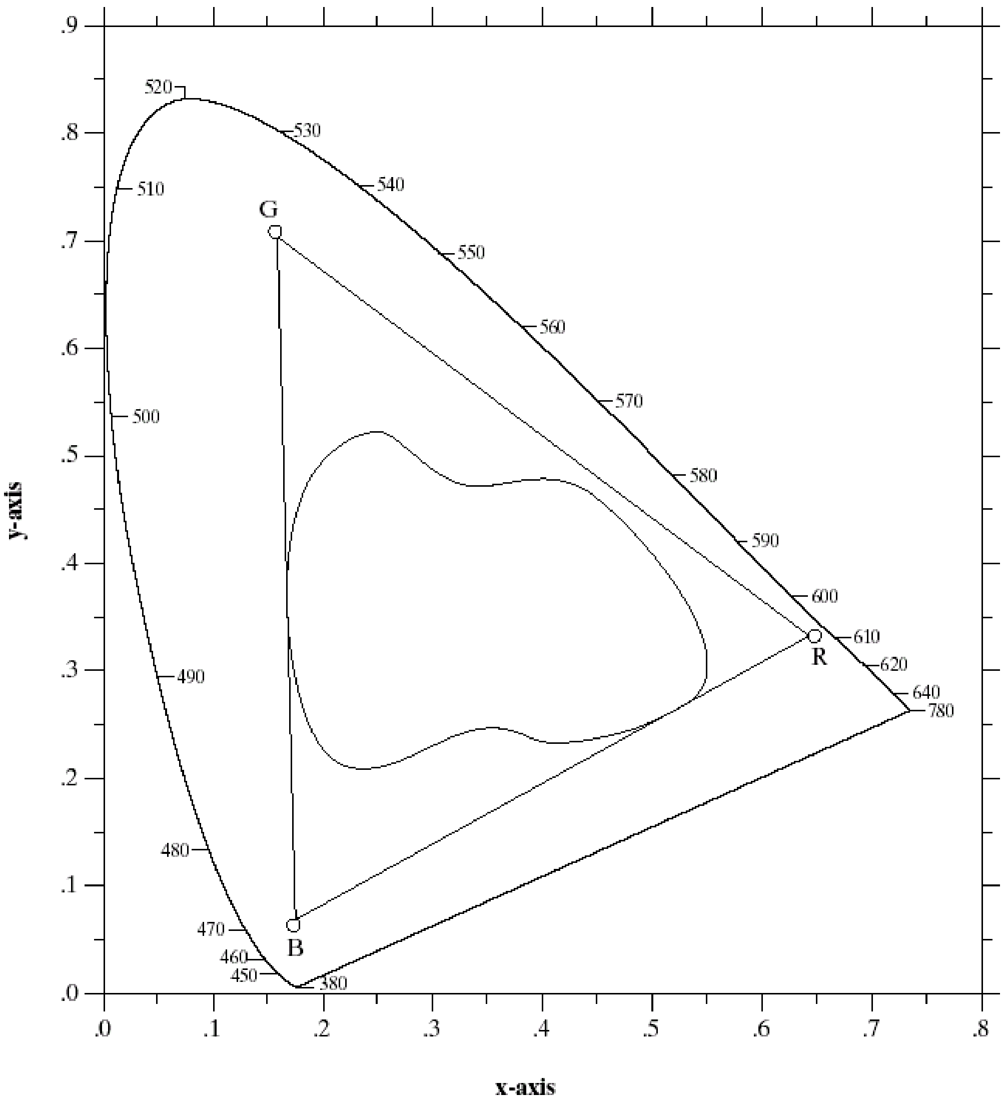


Use for additive color mixing:

Mixing of 3 colors: All colors along boundaries but also inside triangle can be produced.

*: 40% red, 15% green → 55% blue: Appears Magenta

CIE Chromaticity Diagram (cont…)



Limitation: Entire color range cannot be displayed based on three primary colors.

Triangle: Typical color gamut produced by RGB monitors.

Irregular region: 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 two very popular models used in color image processing:

– RGB (**R**ed **G**reen **B**lue)

– HSI (**H**ue **S**aturation **I**ntensity), or HSV (Hue, Saturation, Value)

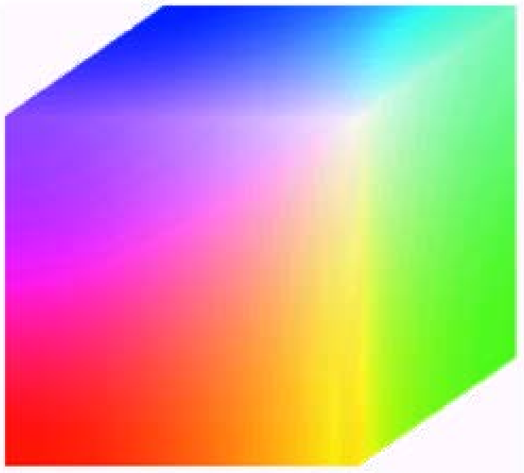
RGB

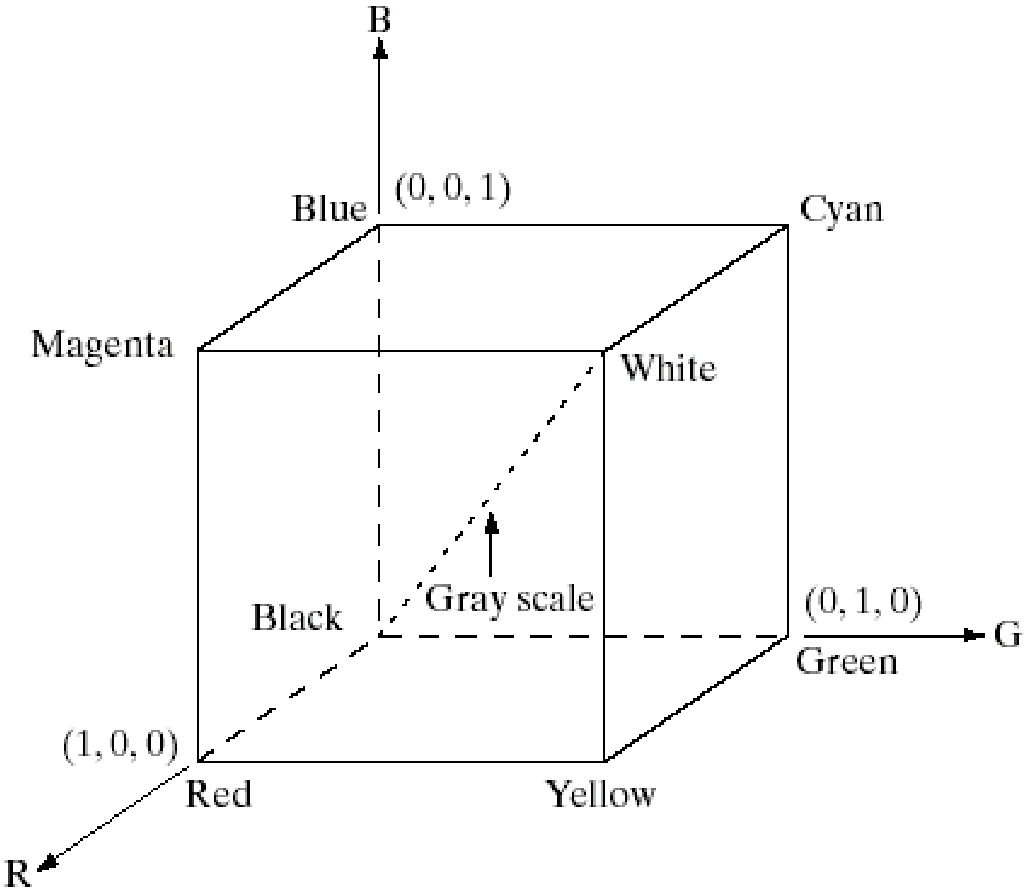
In the RGB model each color appears in its primary spectral components of red, green and blue

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 (cont…)





demo

RGB (cont…)

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

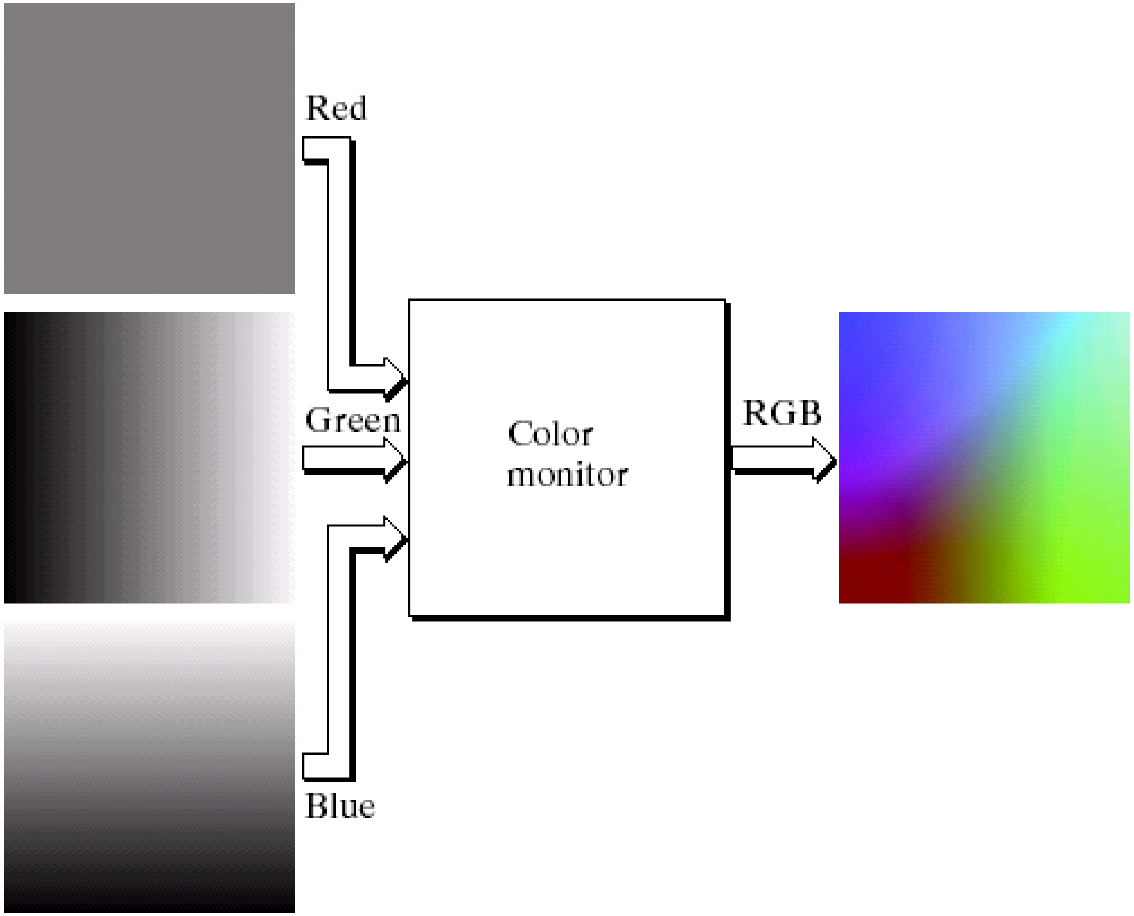
When fed into a monitor these images are combined to create a composite color image.

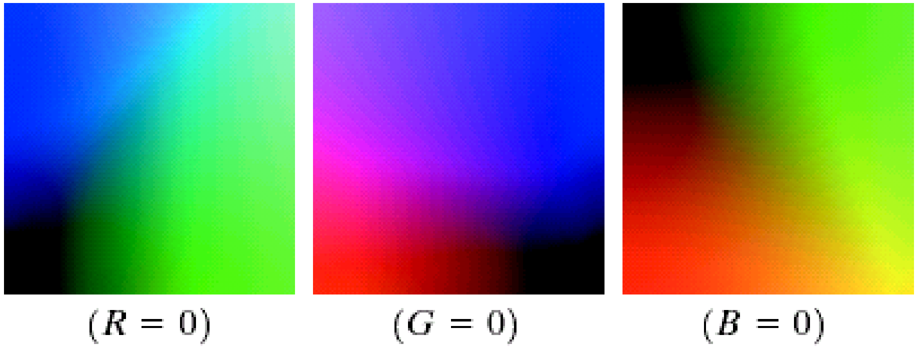
The number of bits used to represent each pixel is referred to as the color depth.

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

a
b

FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane (127, G, B).
(b) The three hidden surface planes in the color cube of Fig. 6.8.





The 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

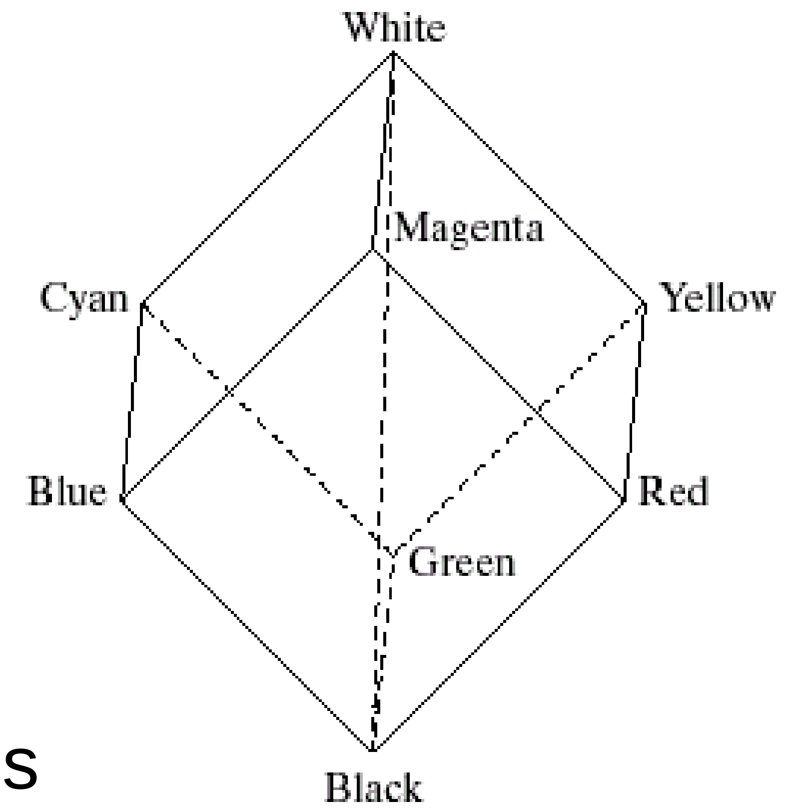
HSI, Intensity & RGB

Intensity can be extracted from RGB images. 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.



demo

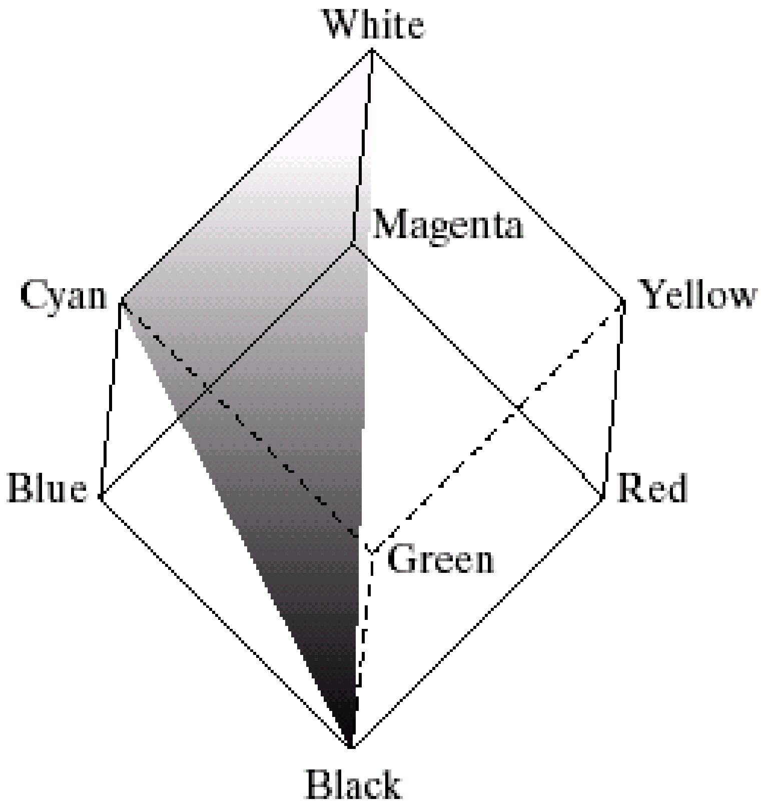
HSI, Hue & RGB

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.

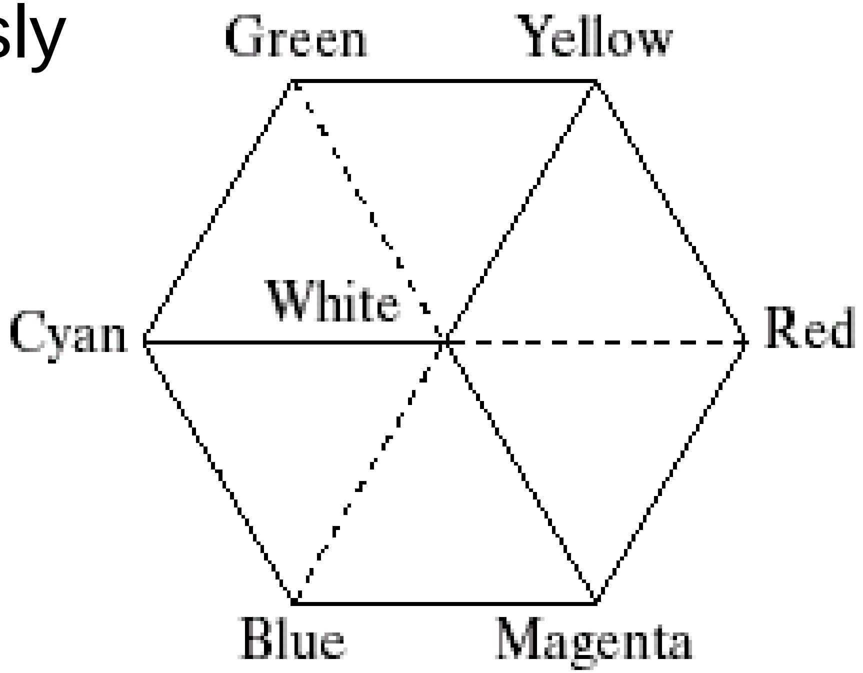
All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a color.

demo



The HSI Color Model

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



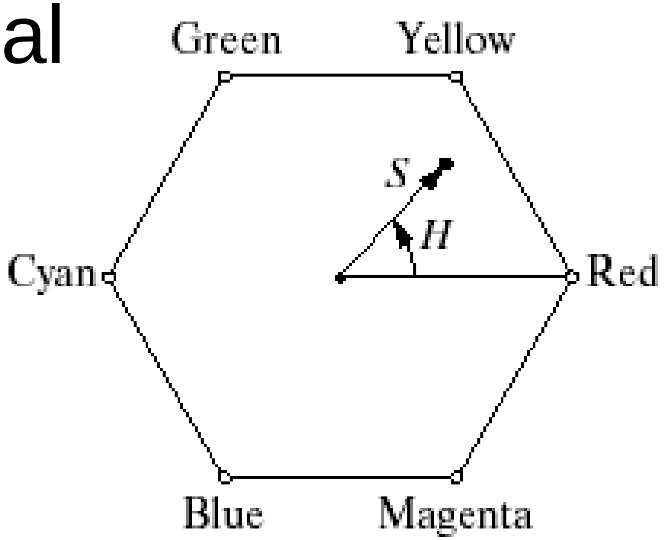
We would see a hexagonal shape with each primary color separated by 120° and secondary colors at 60° from the primaries

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.

demo

The HSI Color Model (cont…)

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



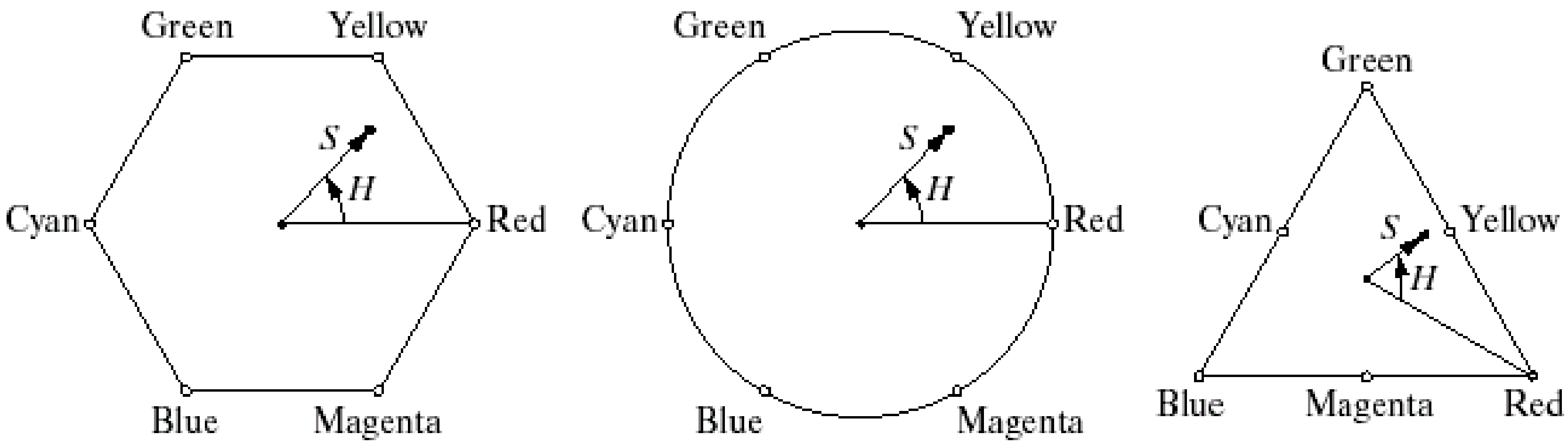
– The hue is determined by an angle from a reference point, usually red

– The saturation is the distance from the origin to the point

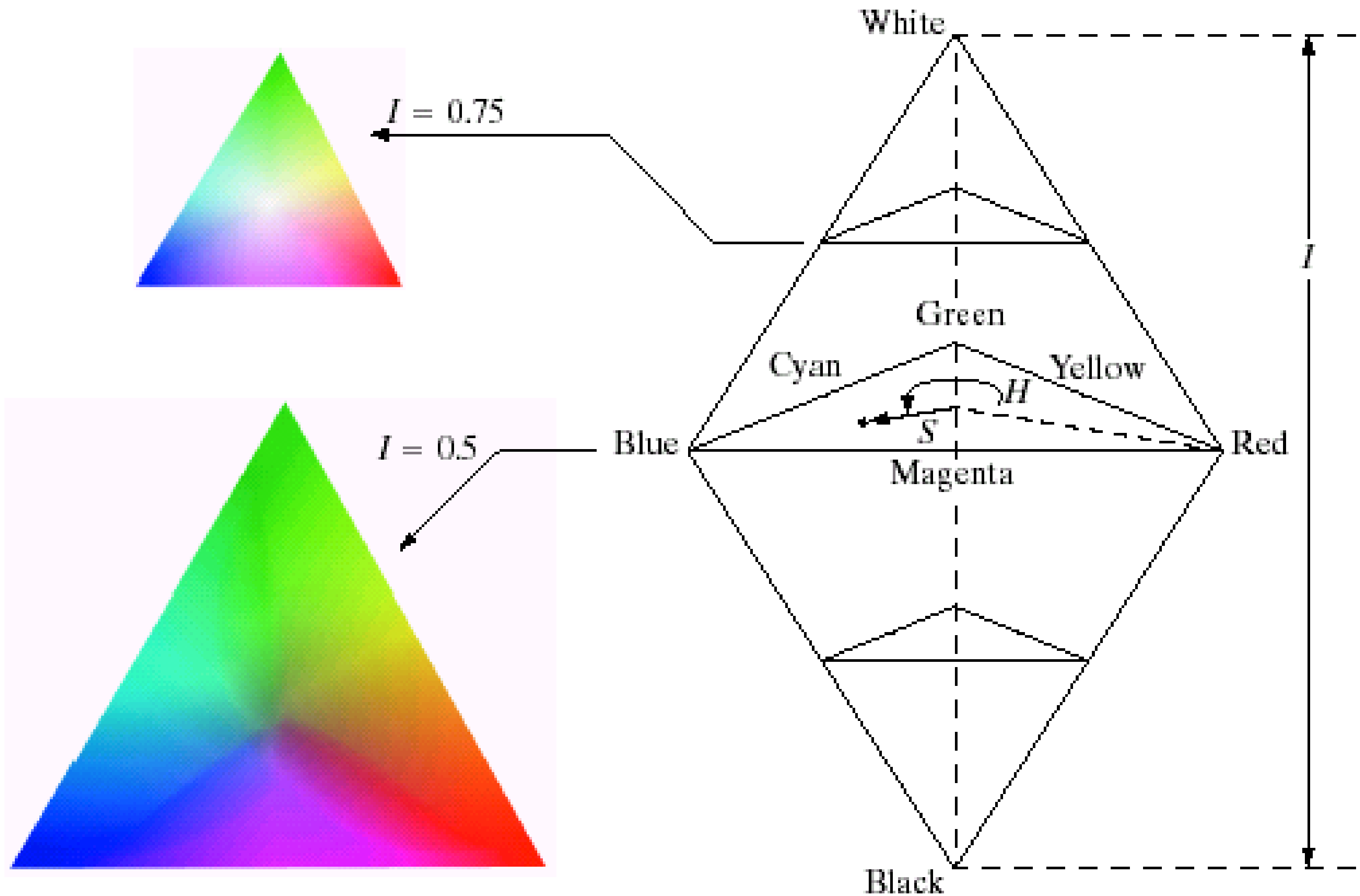
– The intensity is determined by how far up the vertical intenisty axis this hexagonal plane sits (not apparent from this diagram

The HSI Color Model (cont…)

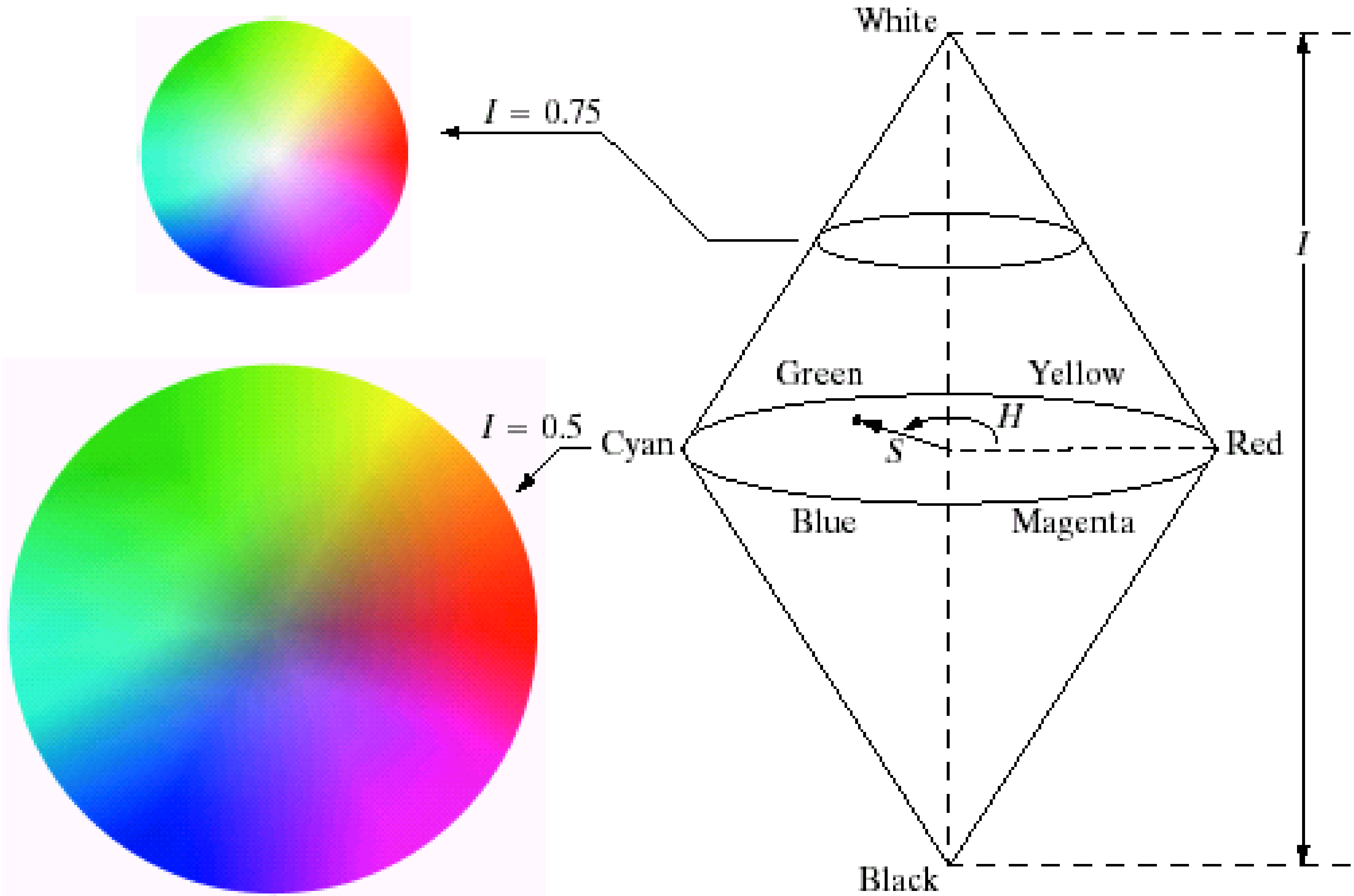
Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle



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:

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

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

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

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

Converting From HSI To RGB

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

– RG sector ($0 <= H < 120°$)

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

– GB sector ($120° <= H < 240°$)

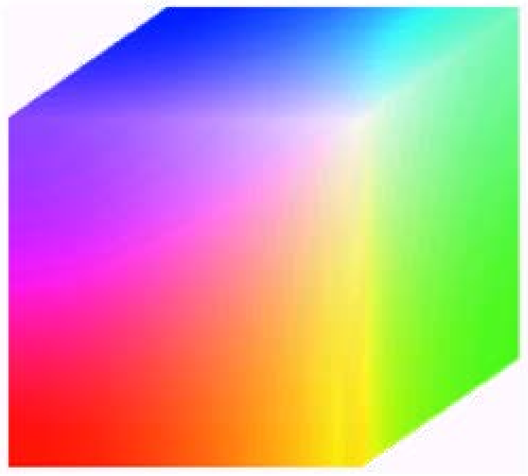
$$R = I(1 - S) \quad G = I\left[1 + \frac{S\cos(H - 120)}{\cos(H - 60)}\right] \quad B = 3I - (R + G)$$

Converting From HSI To RGB (cont…)

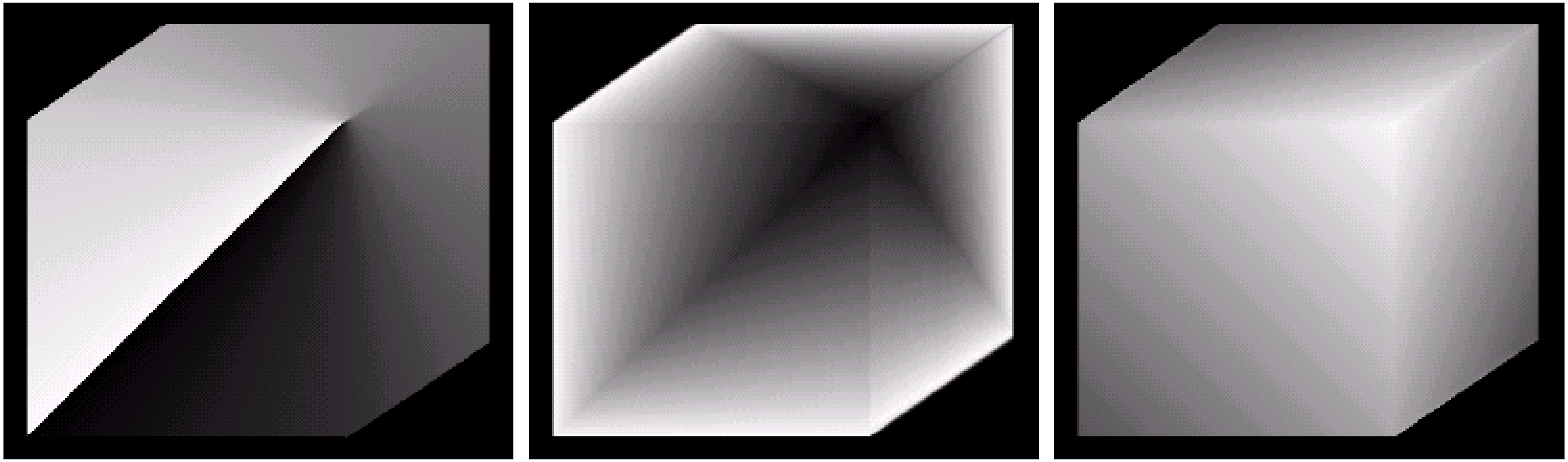
– BR sector ($240° <= H <= 360°$)

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

HSI & RGB



RGB Color Cube



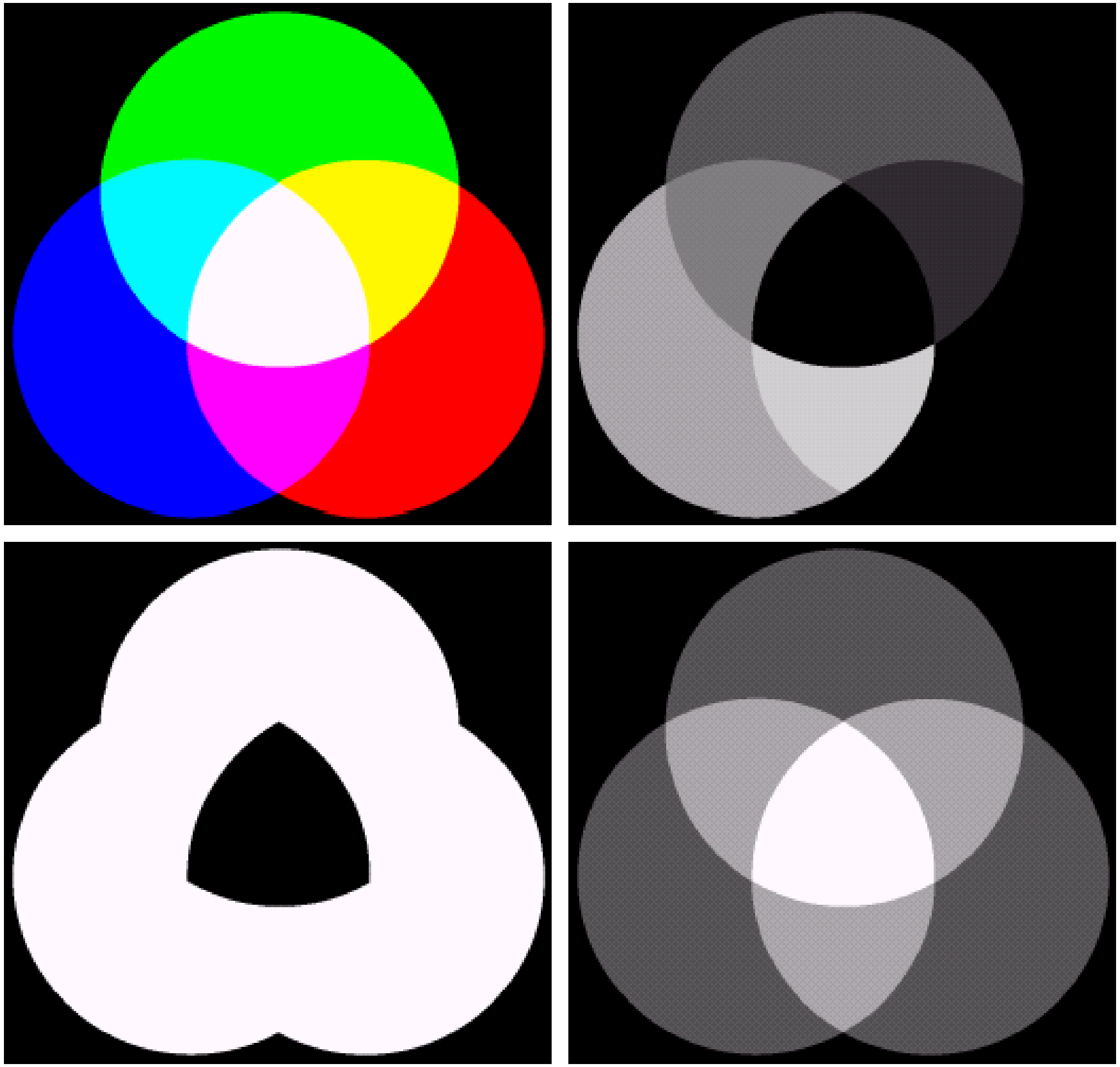
H, S, and I Components of RGB Color Cube

RGB -> HSI

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

RGB Image

Hue



Saturation

Intensity

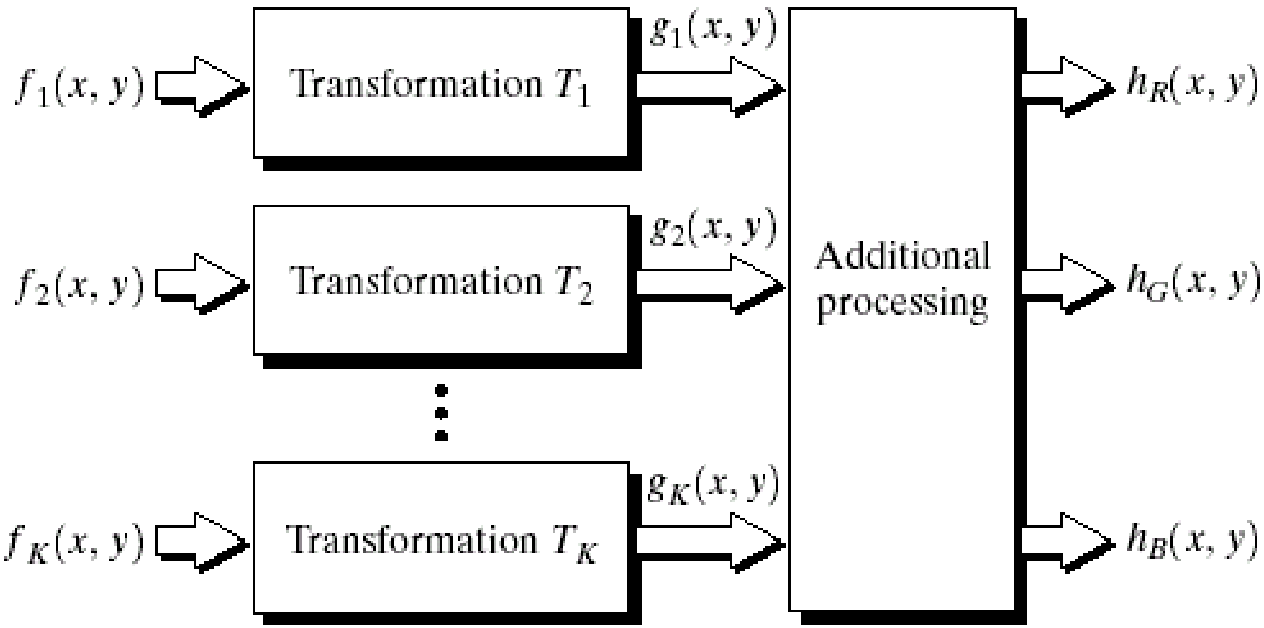
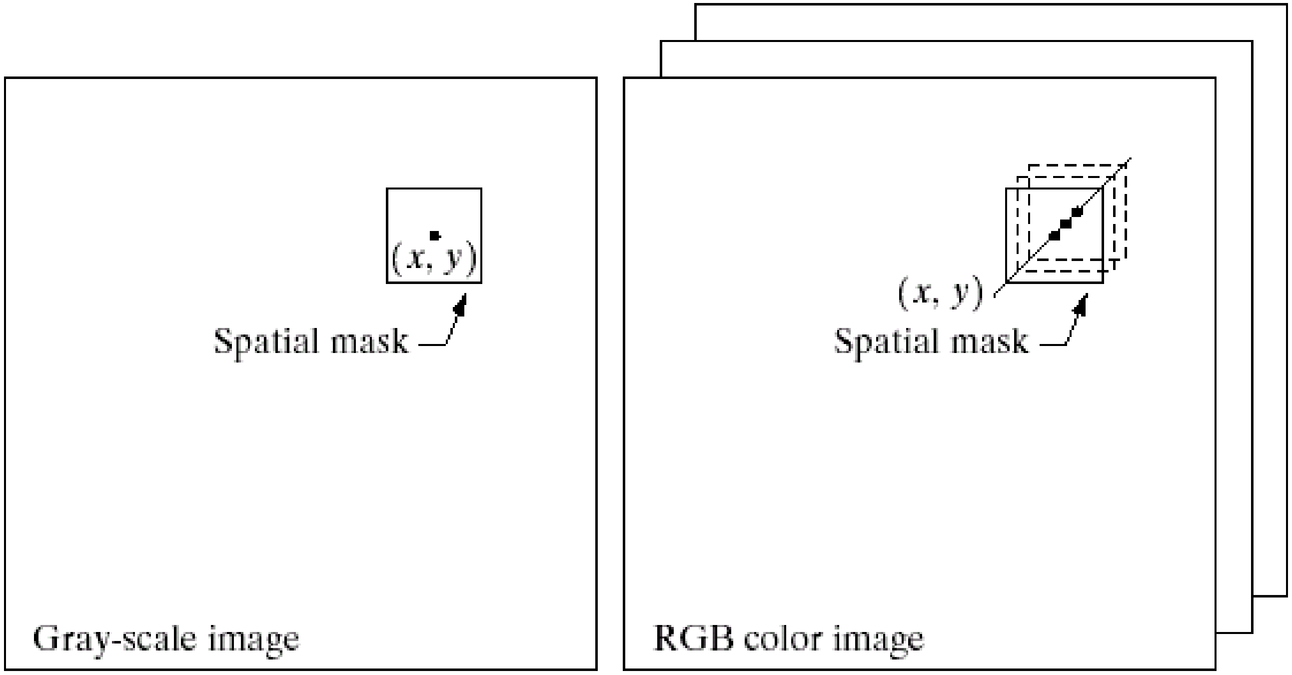


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

a b

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



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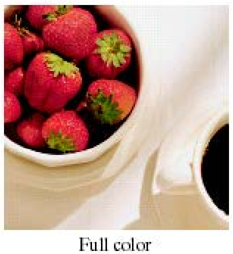
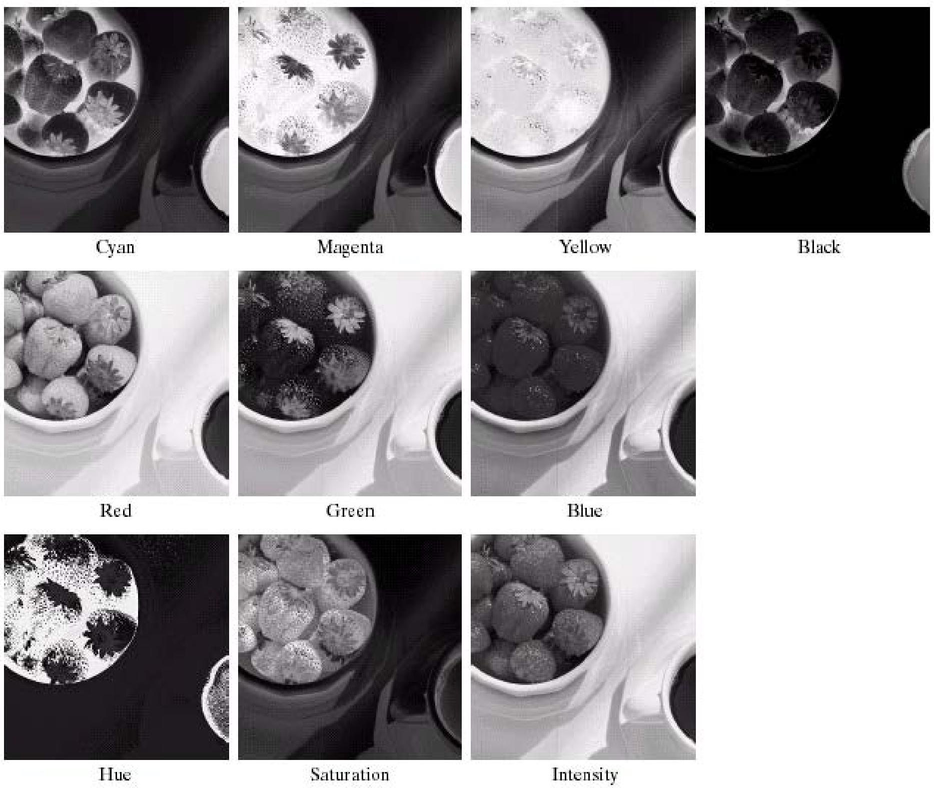
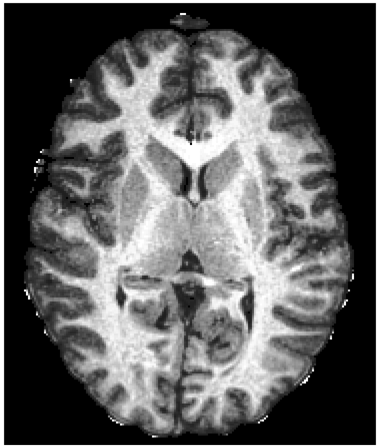
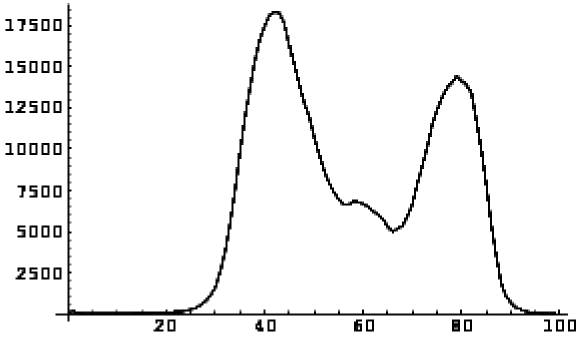


FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)

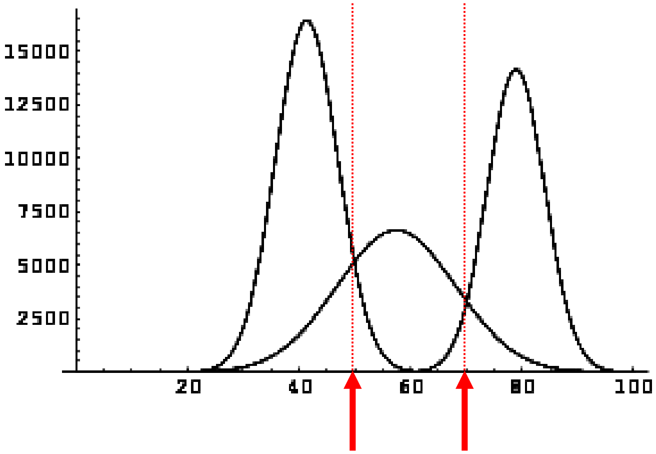


MRI Segmentation: Intensity Classification

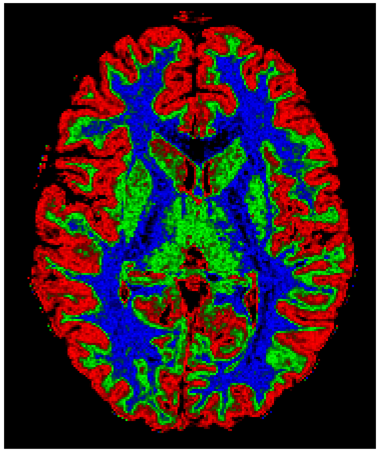




MRI scan (3D GRE) (top) and histogram (bottom)



Estimation of parameters for wm, gm and subcortical structures using Gaussian Mixture Model (GMM).



Fuzzy Classification of wm, gm, subcort.

WM Classification

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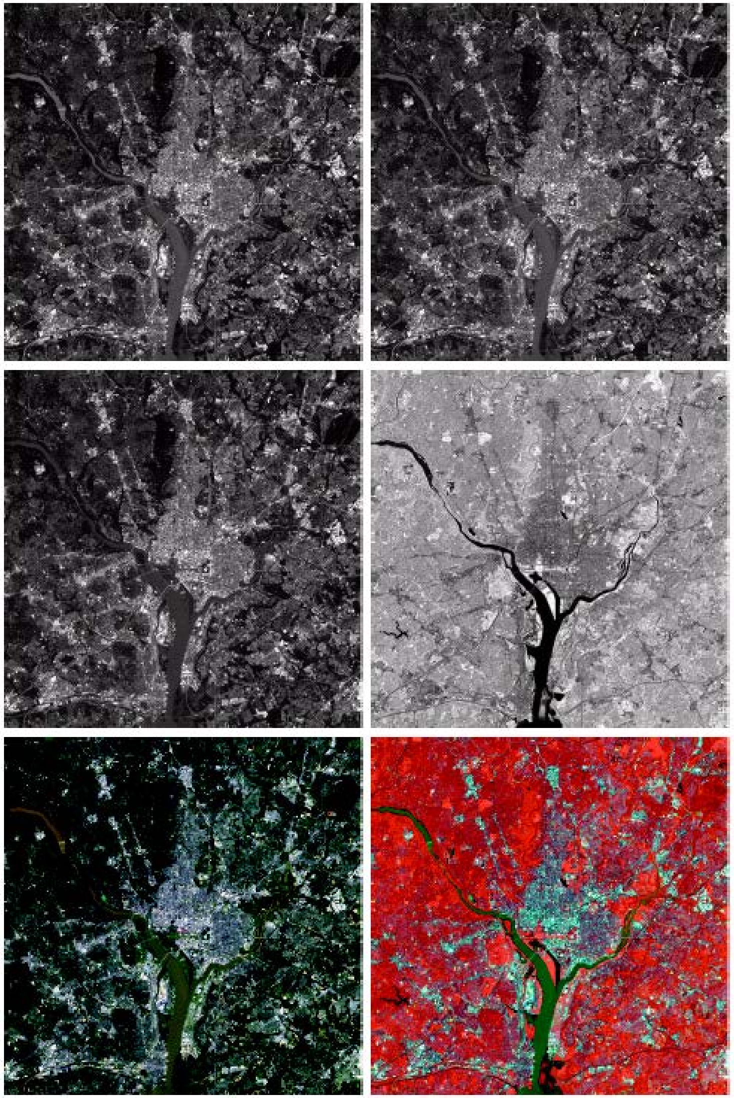
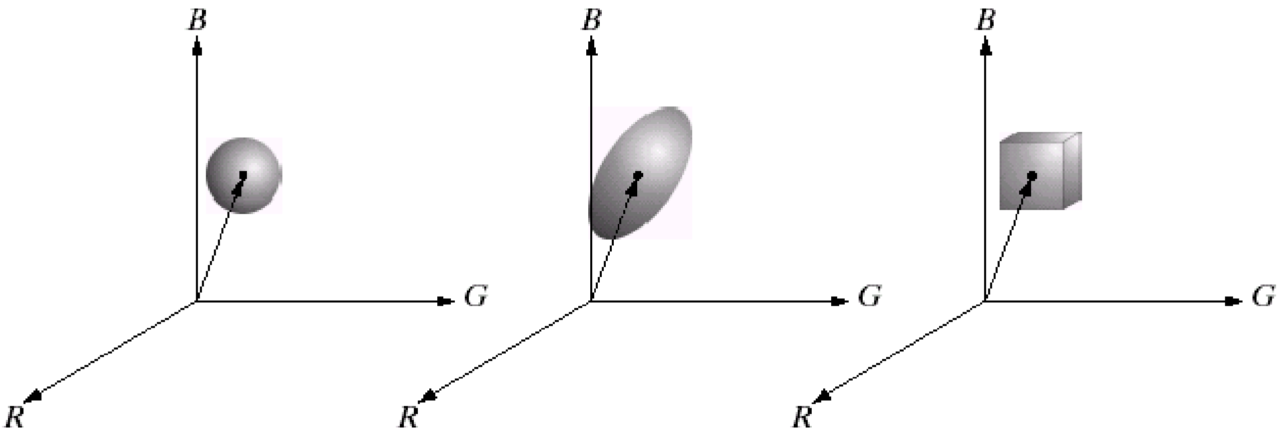
a b
c d
e f

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.)

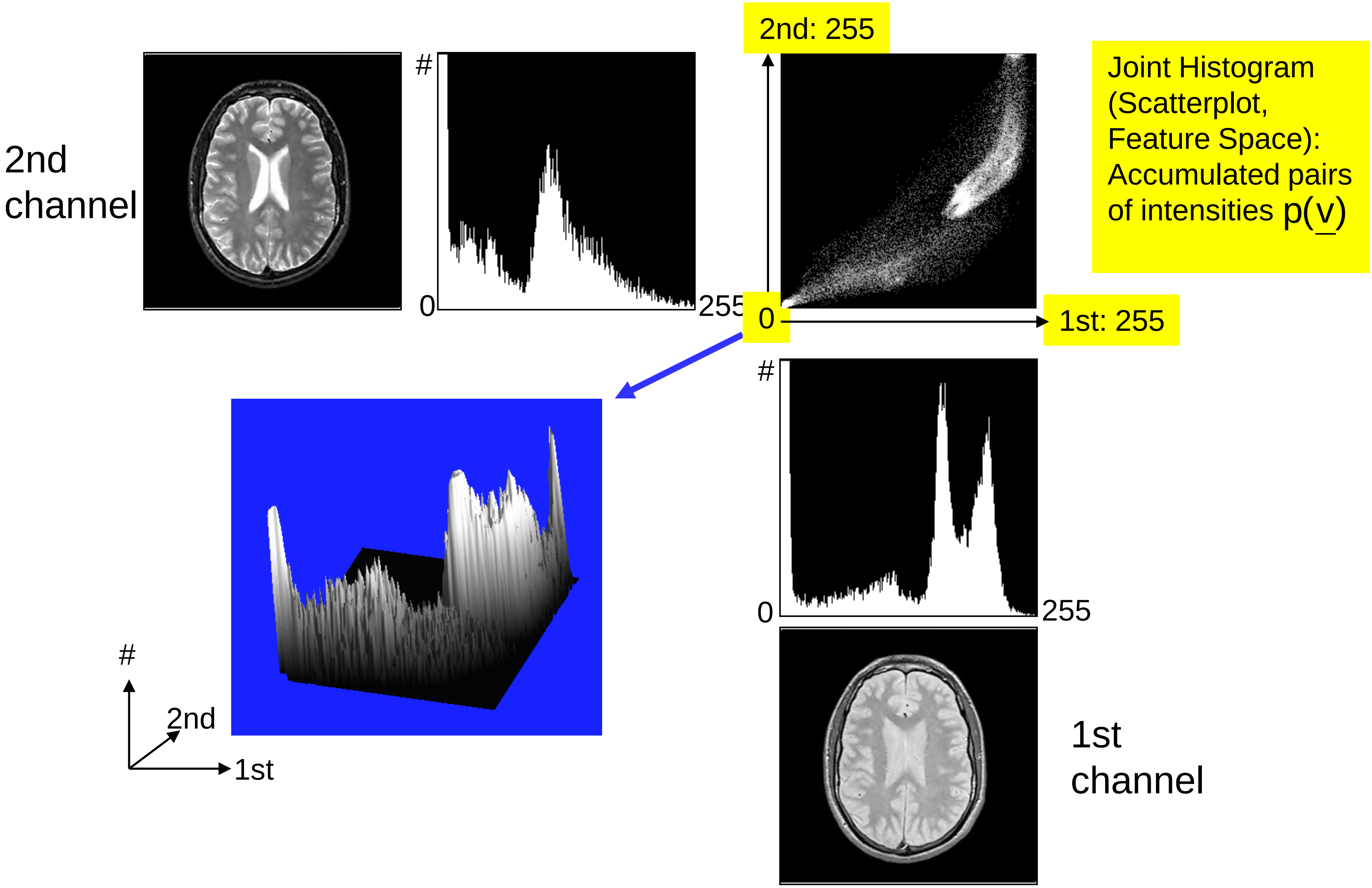




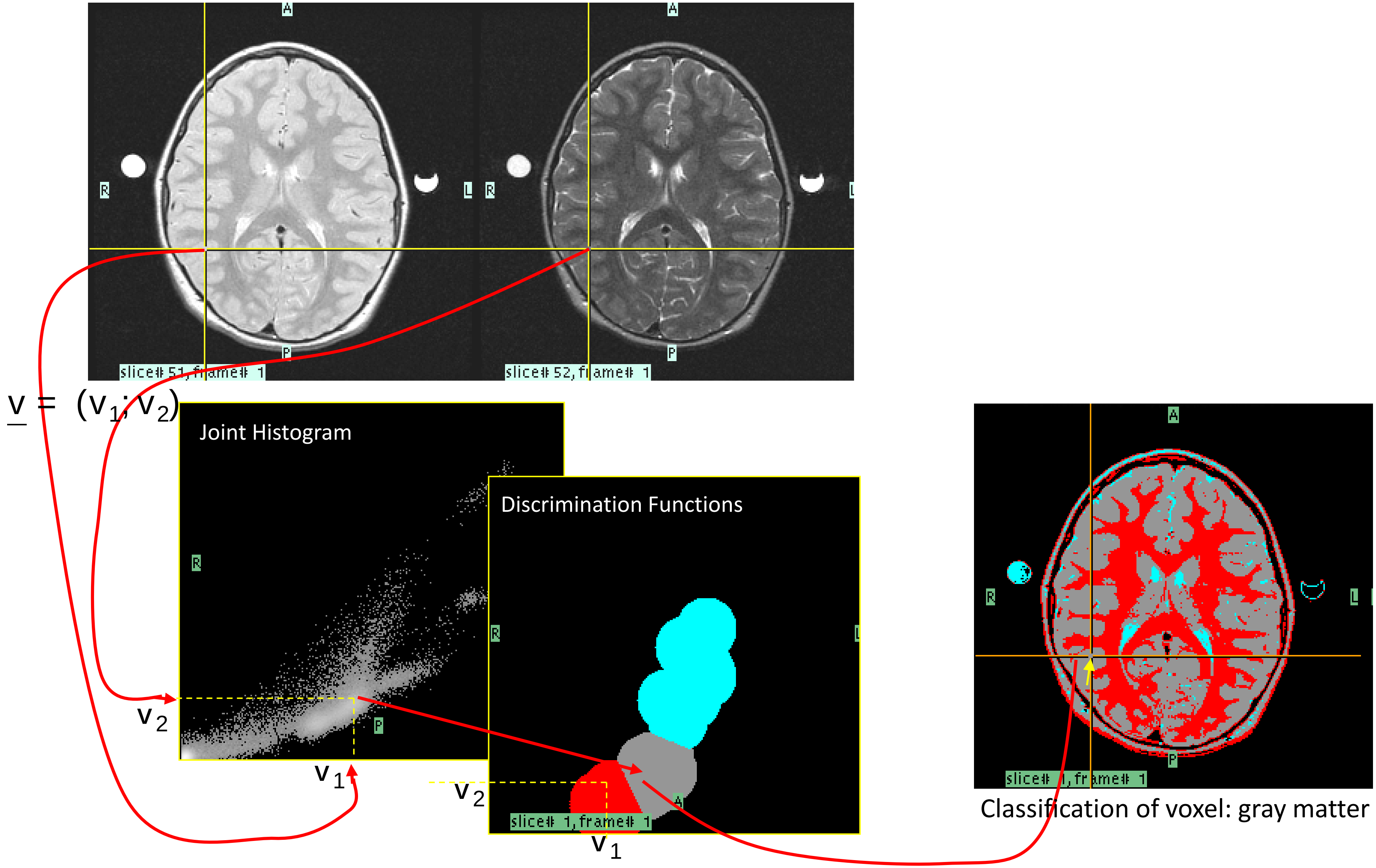
a b c

FIGURE 6.43 Three approaches for enclosing data regions for RGB vector segmentation.

Two MRI Channels: Joint Histogram

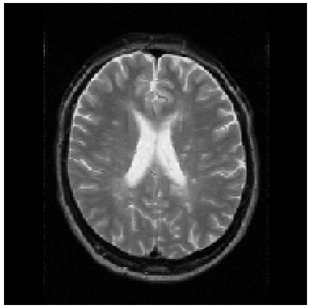


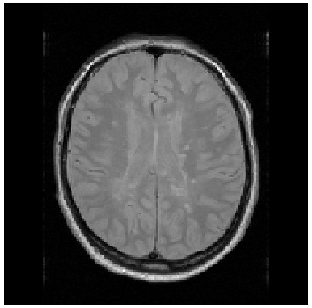
Two-Channel Segmentation

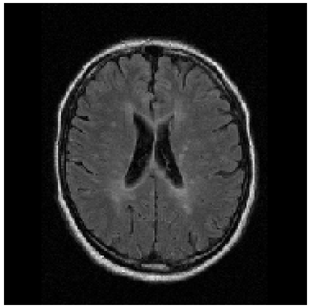


Three-Channel Segmentation

3channel classification using T2-weighted, PD-weighted and FLAIR MR for the segmentation of a multiple sclerosis dataset.





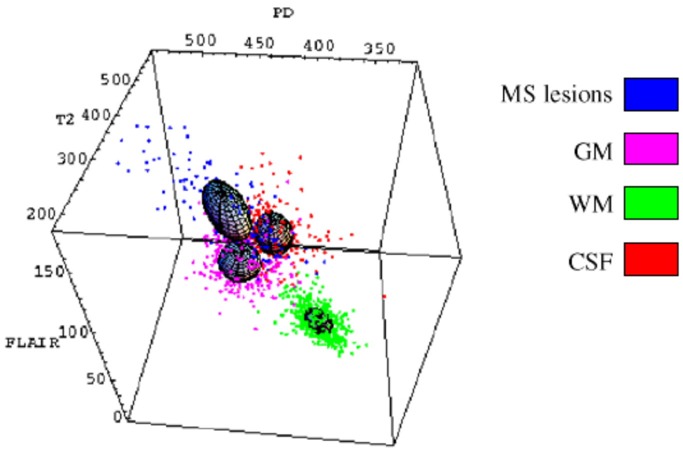


Parametric Classifier: Gaussian Mixture Model and Maximum Likelihood Classifier.

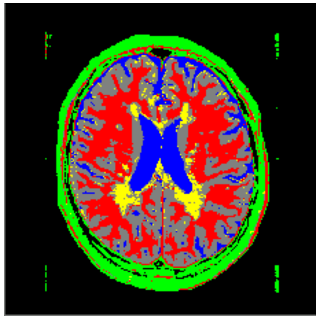
Training samples: User-defined typical regions for each class.

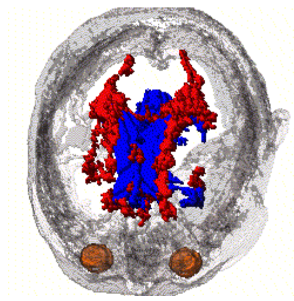
Expert-user needs to define seed regions to train classifier.

Training samples and probability density functions in 3D feature space



Segmentation Result:
WM (red),
GM (gray),
CSF (blue),
Lesions (yellow),
skin/fat/muscles (green)





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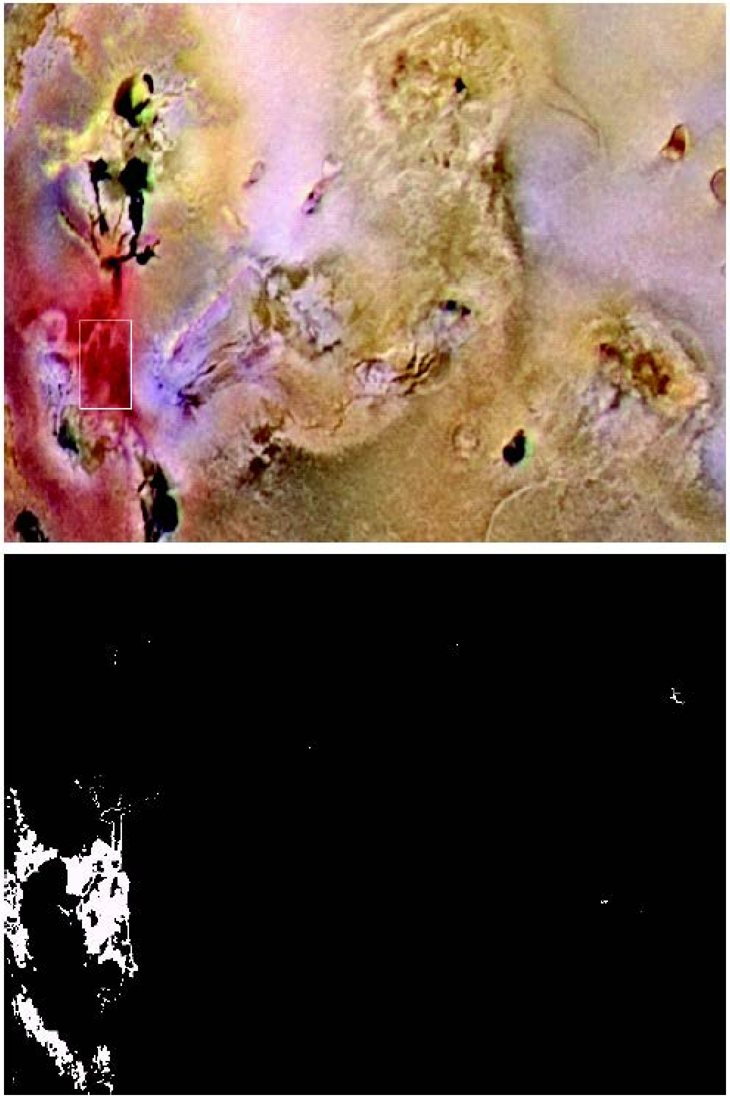

a
b

FIGURE 6.44 Segmentation in RGB space. (a) Original image with colors of interest shown enclosed by a rectangle. (b) Result of segmentation in RGB vector space. Compare with Fig. 6.42(h).

Edge Detection

3 categories: Output fusion methods, multi-dimensional gradient methods, and vector methods.

Output fusion:

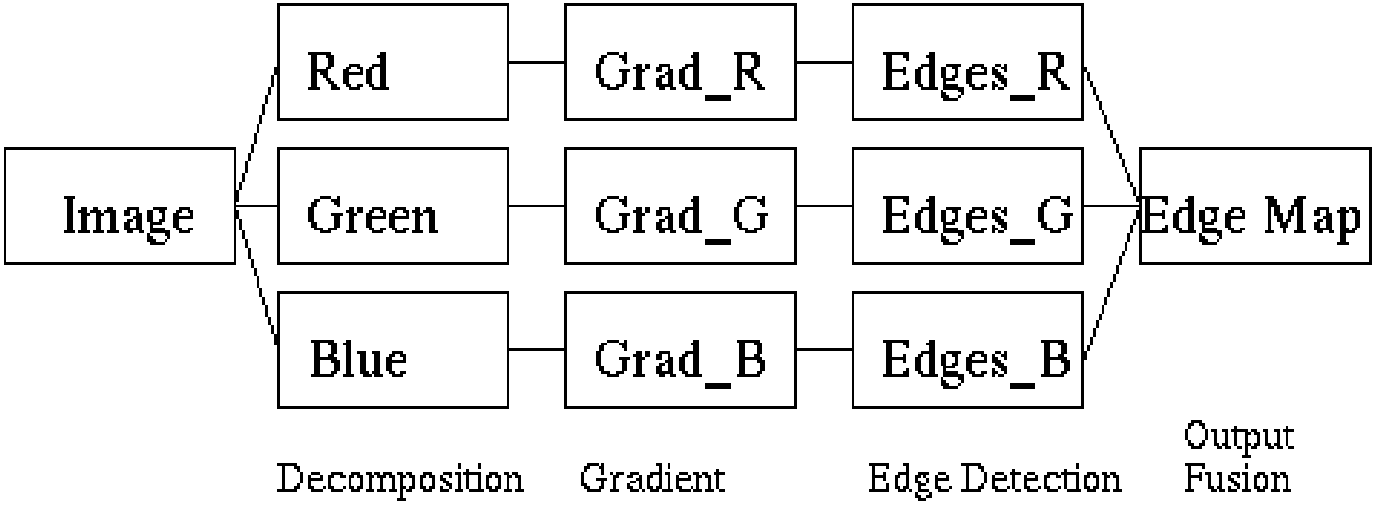

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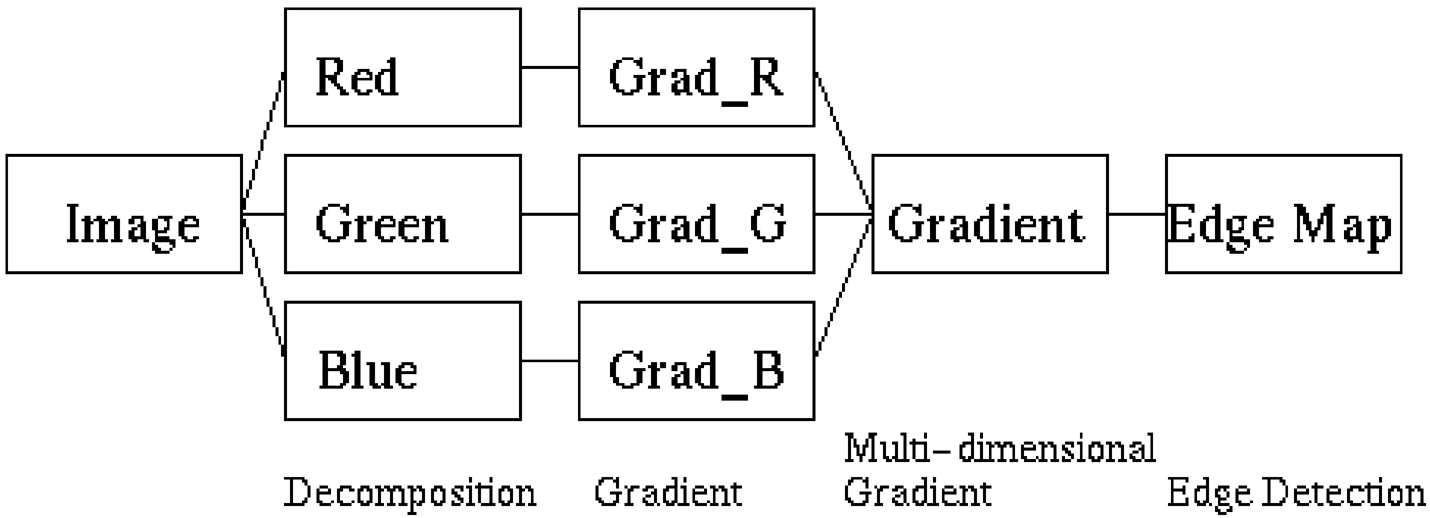
FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

Edge Detection

Multi-dimensional gradient methods:



Edge Detection

Let **r**, **g**, and **b** be unit vectors along the R, G, and B axis of RGB color space (Fig. 6.7), and define the vectors

$$\mathbf{u} = \frac{\partial R}{\partial x}\mathbf{r} + \frac{\partial G}{\partial x}\mathbf{g} + \frac{\partial B}{\partial x}\mathbf{b} \qquad (6.7\text{-}3)$$

and

$$\mathbf{v} = \frac{\partial R}{\partial y}\mathbf{r} + \frac{\partial G}{\partial y}\mathbf{g} + \frac{\partial B}{\partial y}\mathbf{b}. \qquad (6.7\text{-}4)$$

Let the quantities g_{xx}, g_{yy}, and g_{xy} be defined in terms of the dot product of these vectors, as follows:

$$g_{xx} = \mathbf{u} \cdot \mathbf{u} = \mathbf{u}^T\mathbf{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2 \qquad (6.7\text{-}5)$$

$$g_{yy} = \mathbf{v} \cdot \mathbf{v} = \mathbf{v}^T\mathbf{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2 \qquad (6.7\text{-}6)$$

and

$$g_{xy} = \mathbf{u} \cdot \mathbf{v} = \mathbf{u}^T\mathbf{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}. \qquad (6.7\text{-}7)$$

Edge Detection

Keep in mind that R, G, and B, and consequently the g's, are functions of x and y. Using this notation, it can be shown (Di Zenzo [1986]) that the direction of maximum rate of change of $\mathbf{c}(x, y)$ is given by the angle

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{(g_{xx} - g_{yy})}\right] \tag{6.7-8}$$

and that the value of the rate of change at (x, y), in the direction of θ, is given by

$$F(\theta) = \left\{\frac{1}{2}\left[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\theta + 2g_{xy}\sin 2\theta\right]\right\}^{\frac{1}{2}}. \tag{6.7-9}$$

a b
c d

FIGURE 6.46
(a) RGB image.
(b) Gradient computed in RGB color vector space.
(c) Gradients computed on a per-image basis and then added.
(d) Difference between (b) and (c).