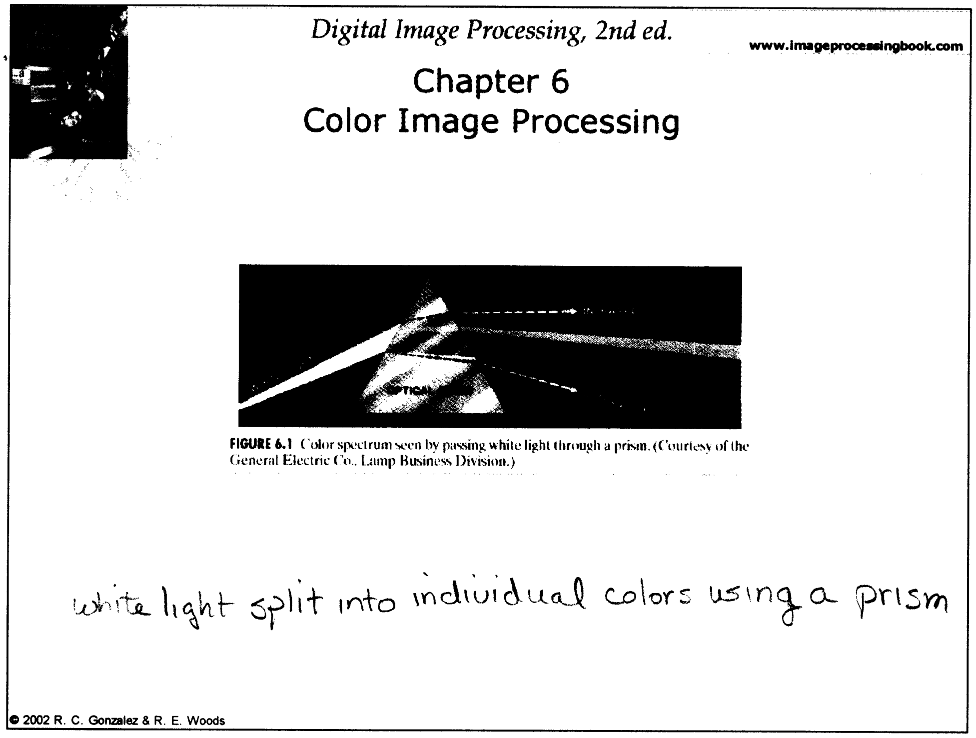

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FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

white light split into individual colors using a prism

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full-color – image acquired with a full-color sensor

pseudocolor – color assigned to a intensity value or range

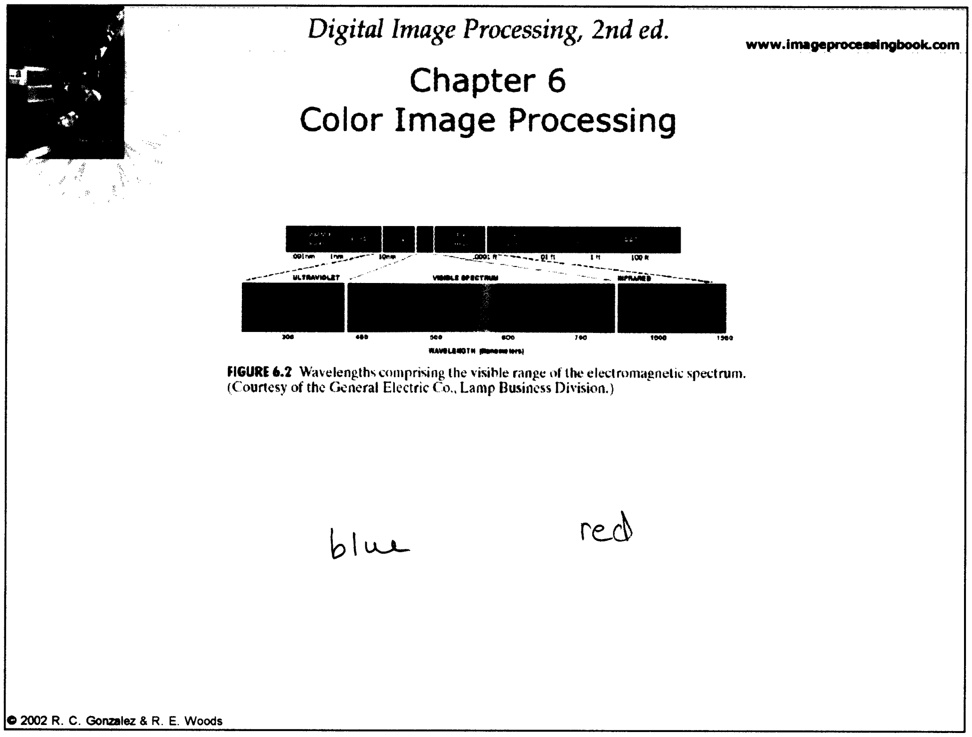

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FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

blue red

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physical units

radiance (watts) - total energy emitted by a light source

luminance (lumens) - incoming energy as measured by the detector

subjective units

brightness

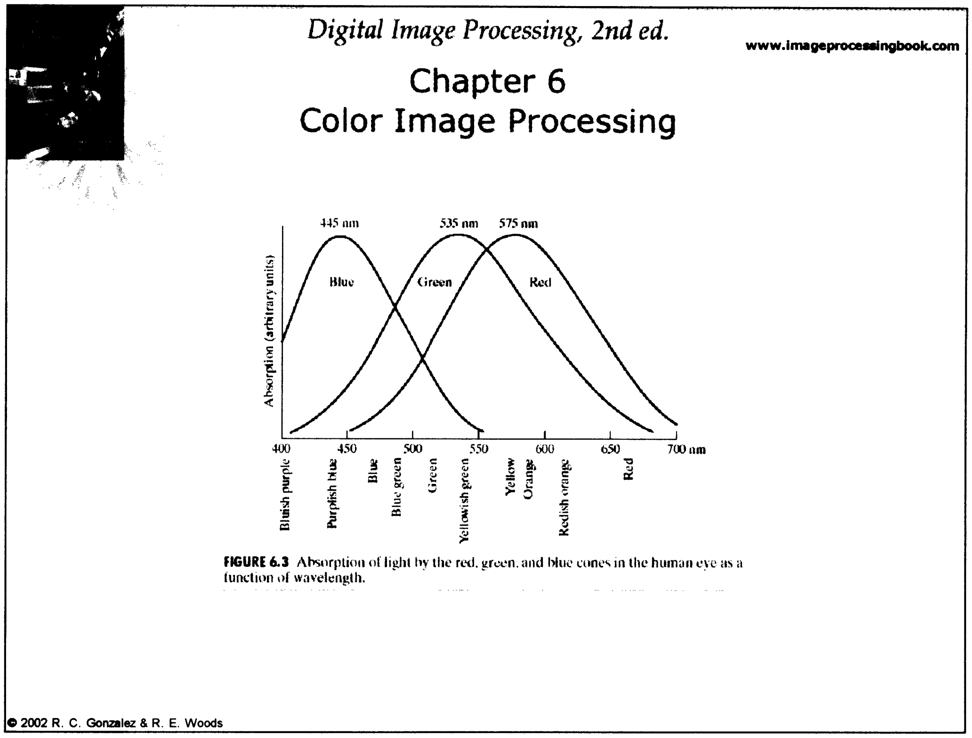
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FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Spectral response of human eye

primary colors do not quite correspond to human eye sensitivity

red (700nm) — 65% of all cones sensitive to red

green (546.1nm) — 33% " green

blue (435.8nm) - 2% " blue

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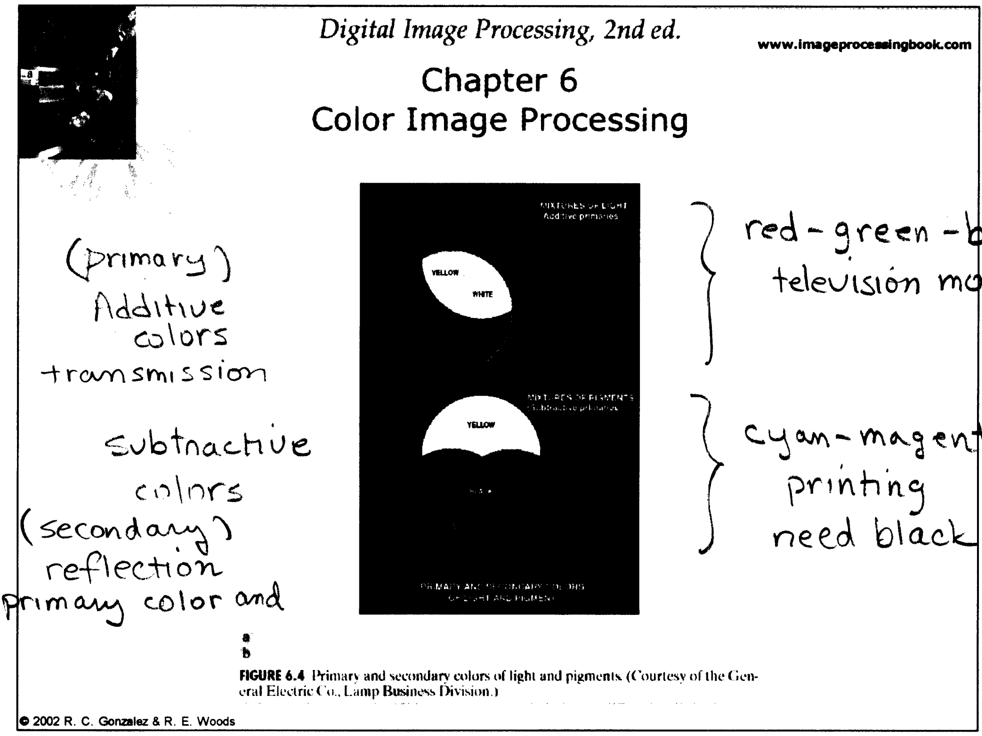

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

(primary)
Additive
colors
transmission

red - green - blue
television monitors

subtractive
colors
(secondary)
reflection
absorbs a primary color and

cyan - magenta - yellow
printing
need black in printing

yellow – absorbs blue
and transmits
red + green = yellow

characteristics of color

brightness

chromaticity {
hue — dominant color seen by an observer
saturation — amount of white light mixed with the color
}

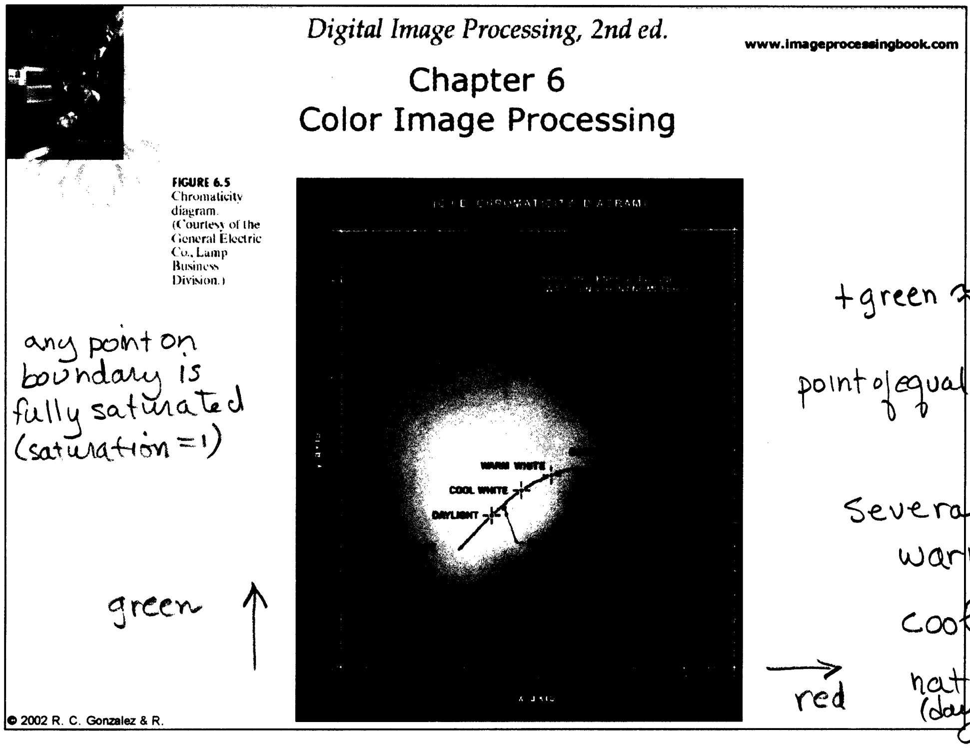

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FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

any point on boundary is fully saturated (saturation = 1)

green ↑

→ red

+ green ≈ (.25red, .62green)

point of equal energy – white (.33red, .33green)

several kinds of white

warm – more red

cool –

natural – (daylight)

A color can be specified by its tristimulus values

red $x = \dfrac{X}{X+Y+Z}$

green $y = \dfrac{Y}{X+Y+Z}$

blue $z = \dfrac{Z}{X+Y+Z}$

where $x+y+z=1$

where X, Y, Z are the amounts of red, green, and blue needed to form a color

CIE chromaticity diagram
just specify x, y (red, green) since blue is then determined by $1-x-y$.

point of equal energy = CIE standard for white light (saturation = 0 here)

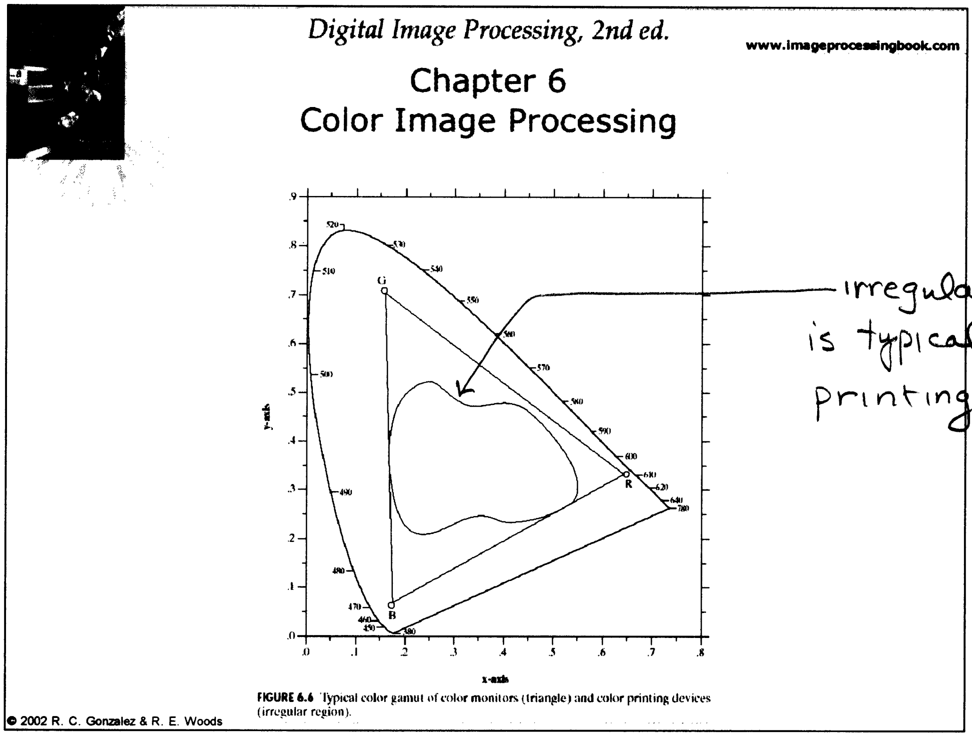

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FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

irregular area is typical color printing area.

The RGB points represent the maximum RGB values of an RGB monitor. Since a monitor is an additive process this RGB monitor can create any color within the triangle.

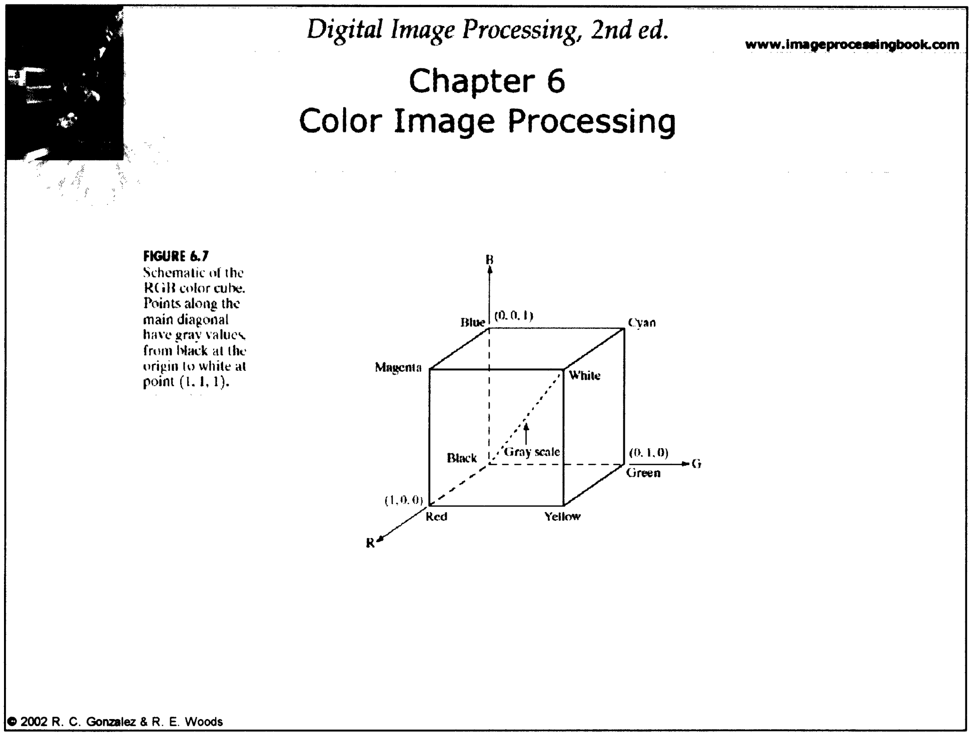

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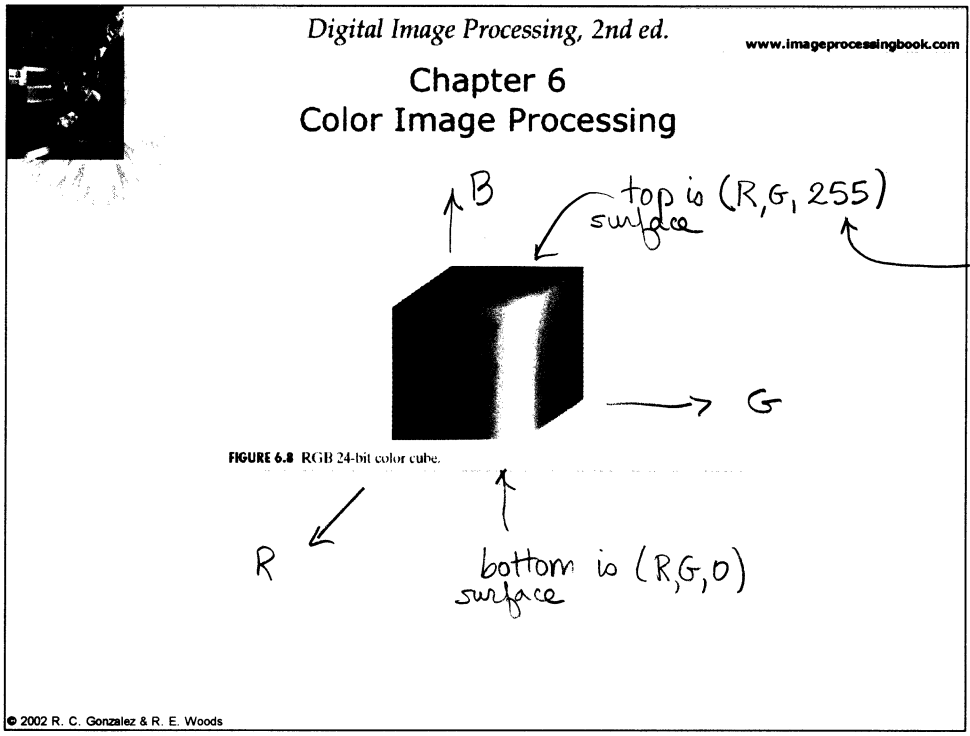
FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB color model

depth is the number of bits used in total

For example, 8-bit RGB is $8 \times 3 = 24$ bit depth.



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top surface is (R,G,255)

bottom surface is (R,G,0)

FIGURE 6.8 RGB 24-bit color cube.

can be represented as [0,255] or [0,1]

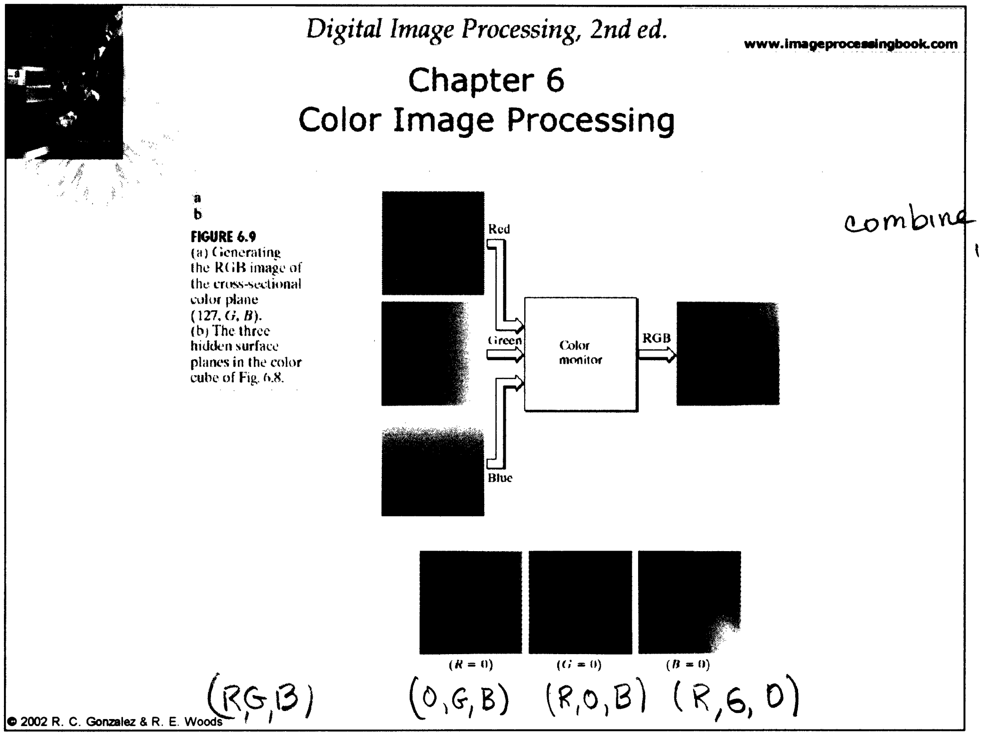

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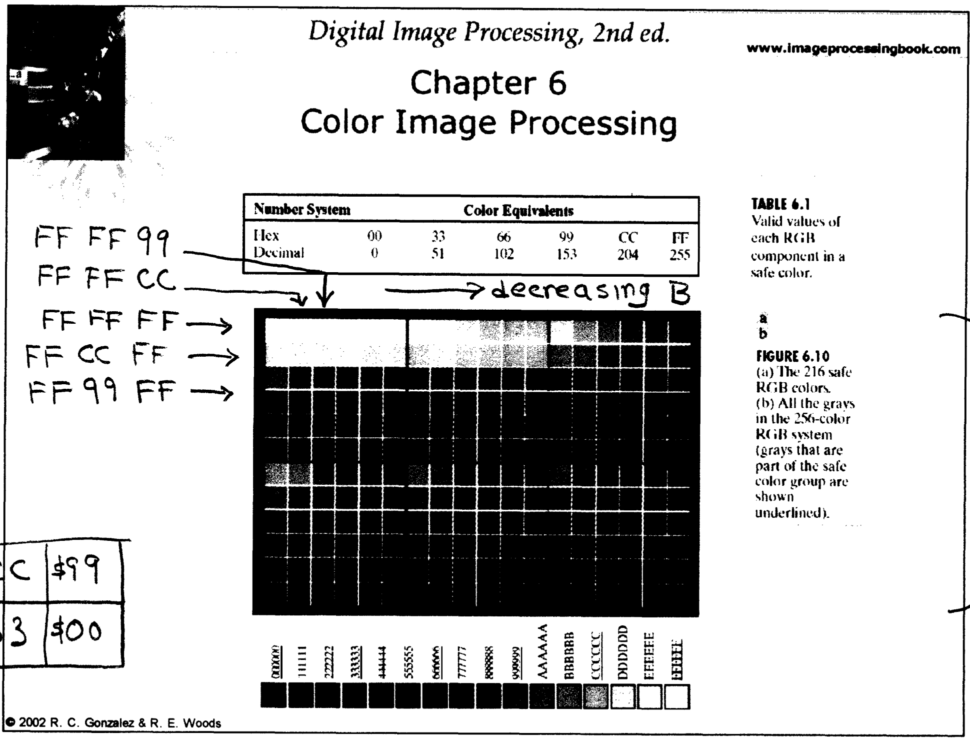
FIGURE 6.9 (a) Generating the RGB image of the cross-sectional color plane (127, G, B). (b) The three hidden surface planes in the color cube of Fig. 6.8.

combine color planes into color image

(R,G,B) (0,G,B) (R,0,B) (R,G,0)

back planes looking inside out



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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).

FF FF 99
FF FF CC
→ decreasing B
FF FF FF →
FF CC FF →
FF 99 FF →

decreasing G

Red:

$FF	$CC	$99
$66	$33	$00

includes Internet "safe" colors

Many systems in use today restrict themselves to 256 colors for simplicity and speed of generation.
Of the only 216 Internet "safe" colors are reliably reproduced by the operating system.

(R, G, B)

each value can only be 00, 33, 66, 99, CC or FF

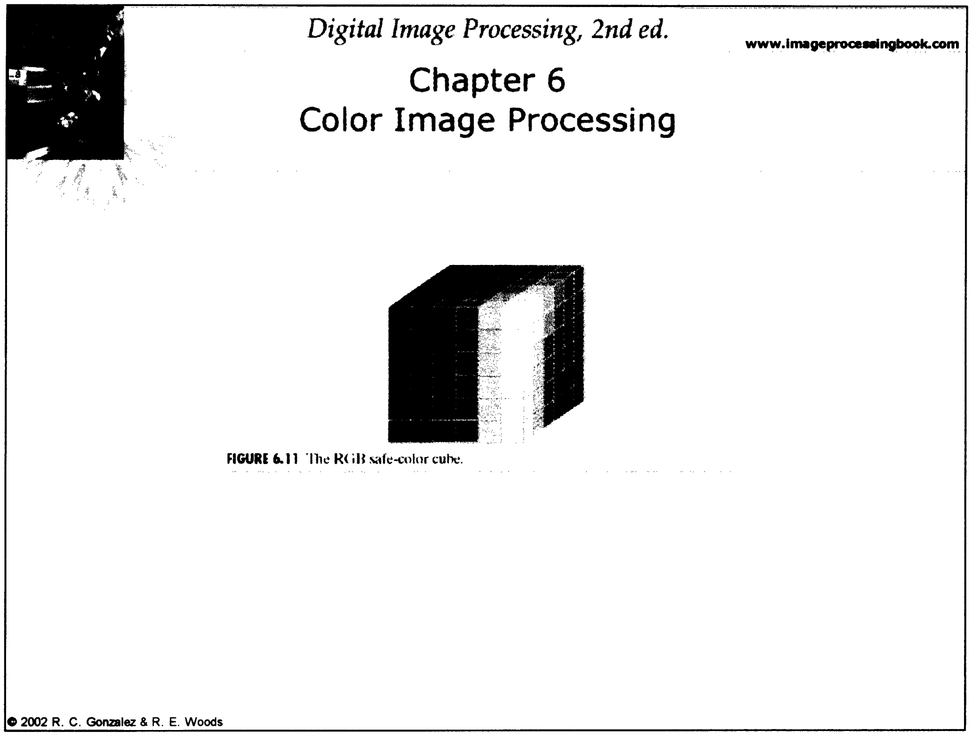

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FIGURE 6.11 The RGB safe-color cube.

"safe" colors are only on the surfaces (faces). No interior colors are "safe".

Color printers & copiers convert RGB to CMY

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

To get a good black on color printers we add "black" as a fourth color.

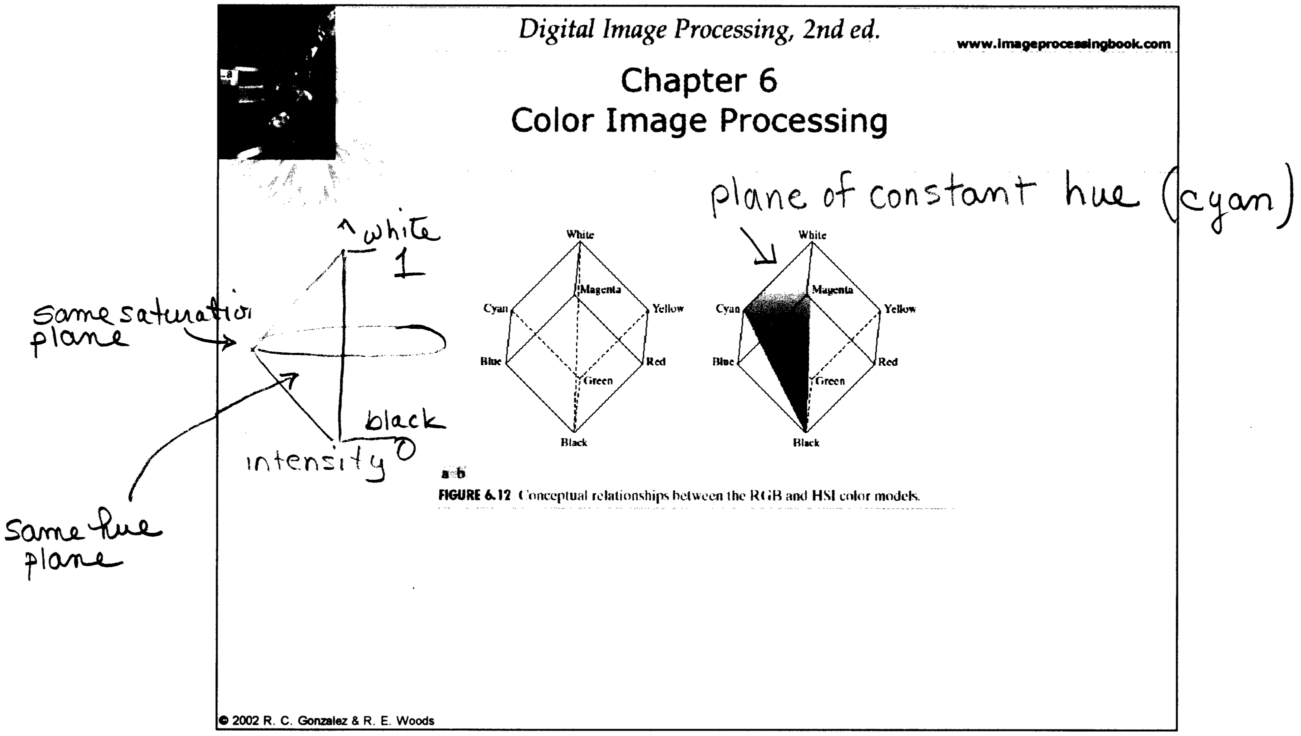

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FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

Although RGB is good for generating colors it is not good for describing colors as humans interpret them.

H - hue } color information decoupled
S - saturation } from intensity
I - intensity } gray scale image

For an RGB color cube the intensity I is the diagonal from (0,0,0) black to (1,1,1) white. The intensity of any RGB color is its projection onto this intensity diagonal.

The plane perpendicular to the gray diagonal in the RGB cube will contain all colors of the same saturation since white does not change.

The plane defined by the gray diagonal and the cube boundaries will contain all colors of the same hue.

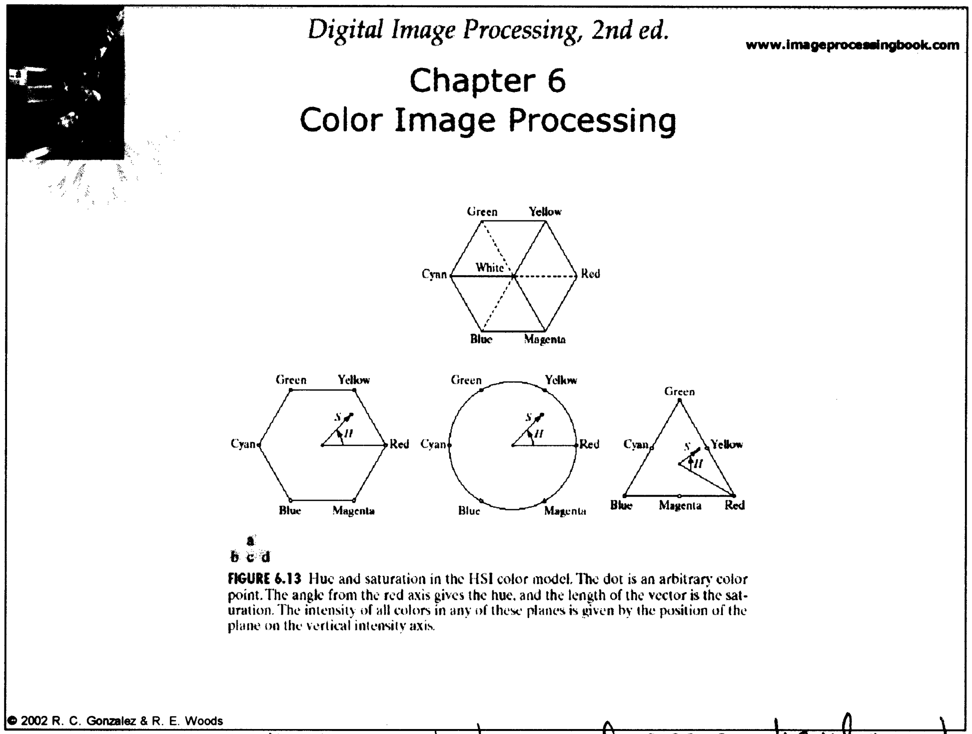

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FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

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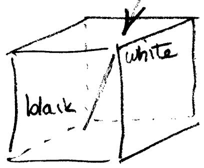
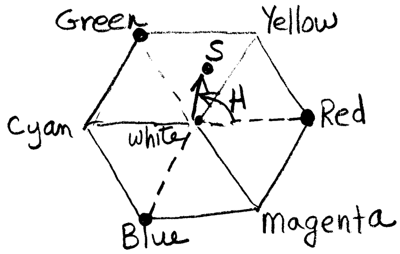
looking at diagonal perpendicular planes are hexagonal.

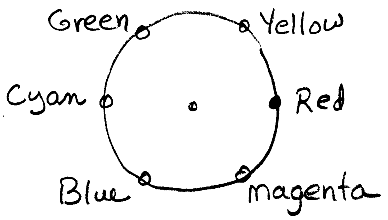


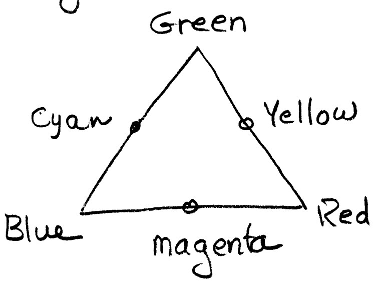
looking along axis



The hue of any point in each plane
is it's angle from a referance point.
The saturation is the distance from the origin.

Various simplifications of this hexagon are circles and triangles.





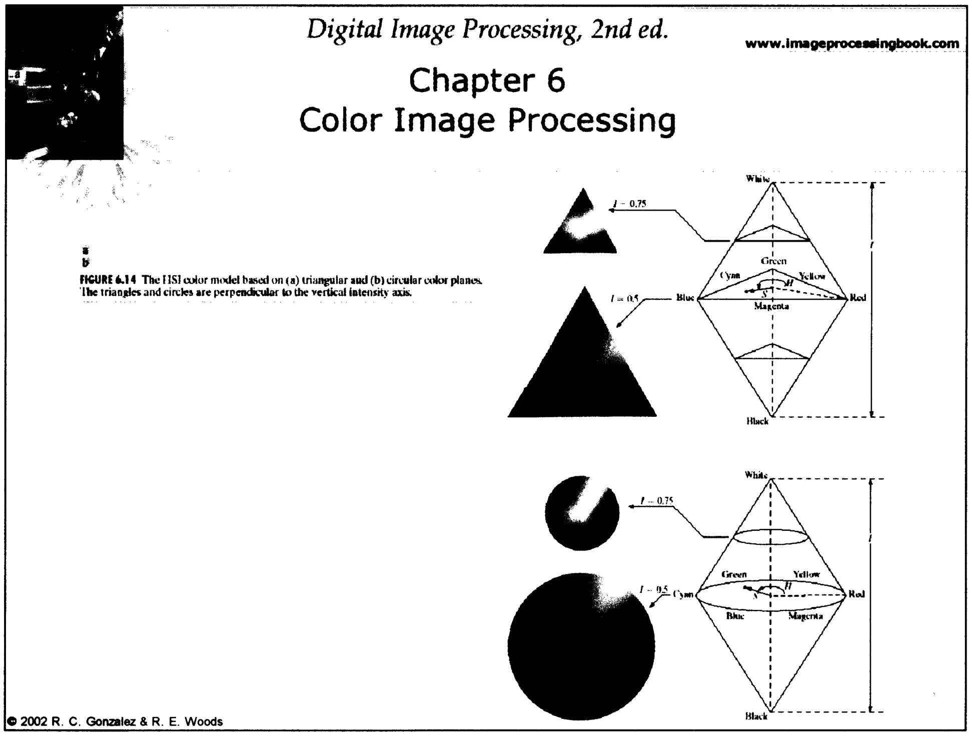


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FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

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↑ This is the gray diagonal, i.e. the intensity axis.

From Figure 6.13 we can use trigonometry to derive the relationships between RGB and an HSI point.

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

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

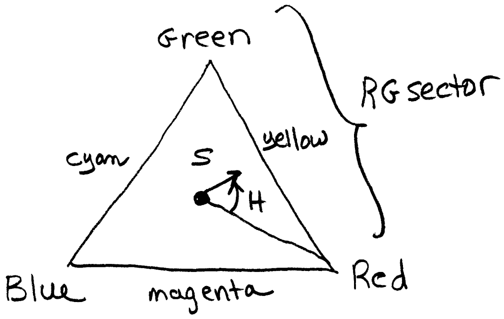
saturation $$S = 1 - \frac{3}{R+G+B} \min(R,G,B)$$

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

See book's Web site for derivation

Converting colors from HSI to RGB

Multiply H by 360°: to convert it back to an angle. H is usually normalized to [0,1].



RG Sector $(0° \le H \le 120°)$

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

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

$$G = 1-(R+B)$$

GB sector $(120° \le H \le 240°)$

compute $H = H - 120°$

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

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

$$B = 1-(R+G)$$

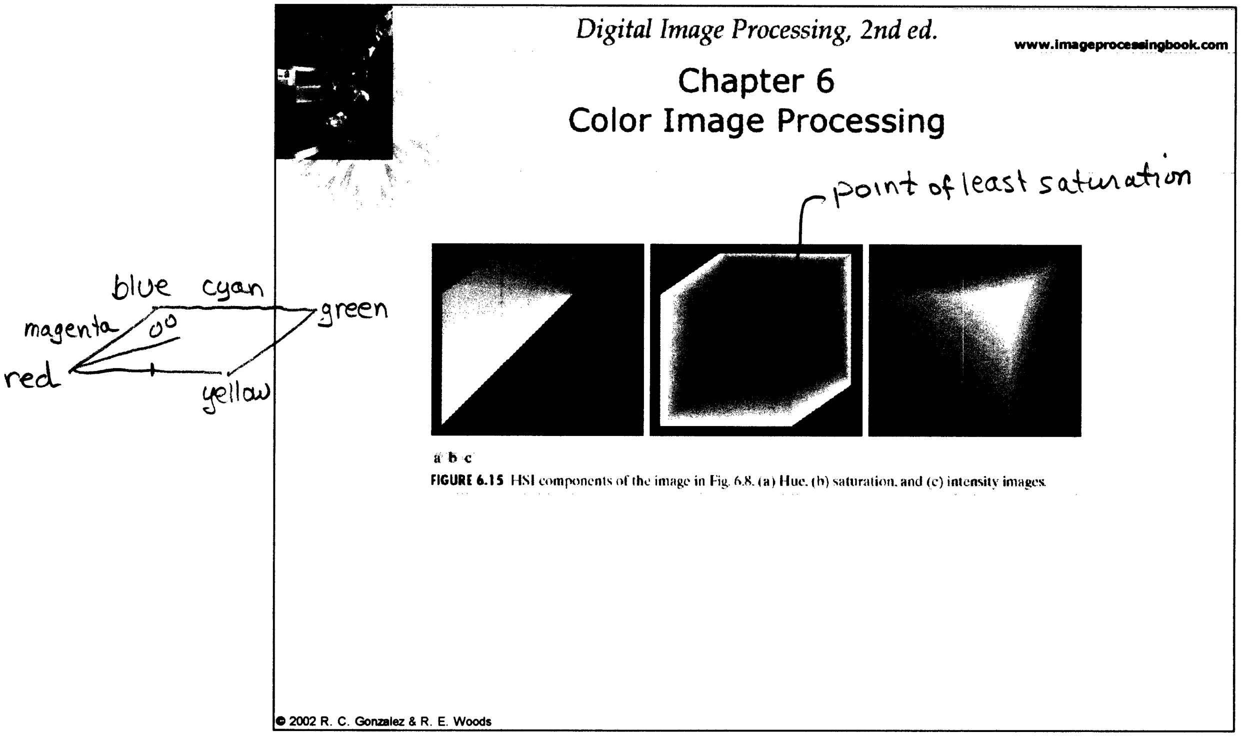
BR Sector $(240° \le H \le 360°)$

compute $H = H - 240°$

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

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

$$R = 1-(G+B)$$



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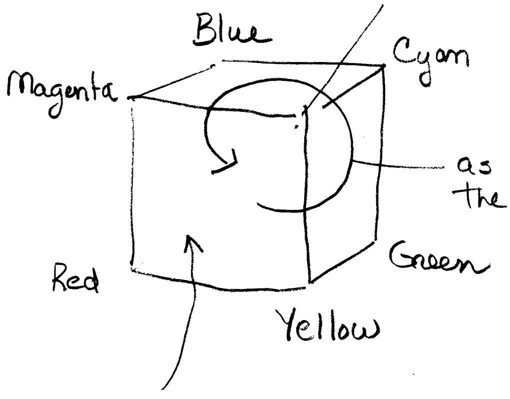
a b c

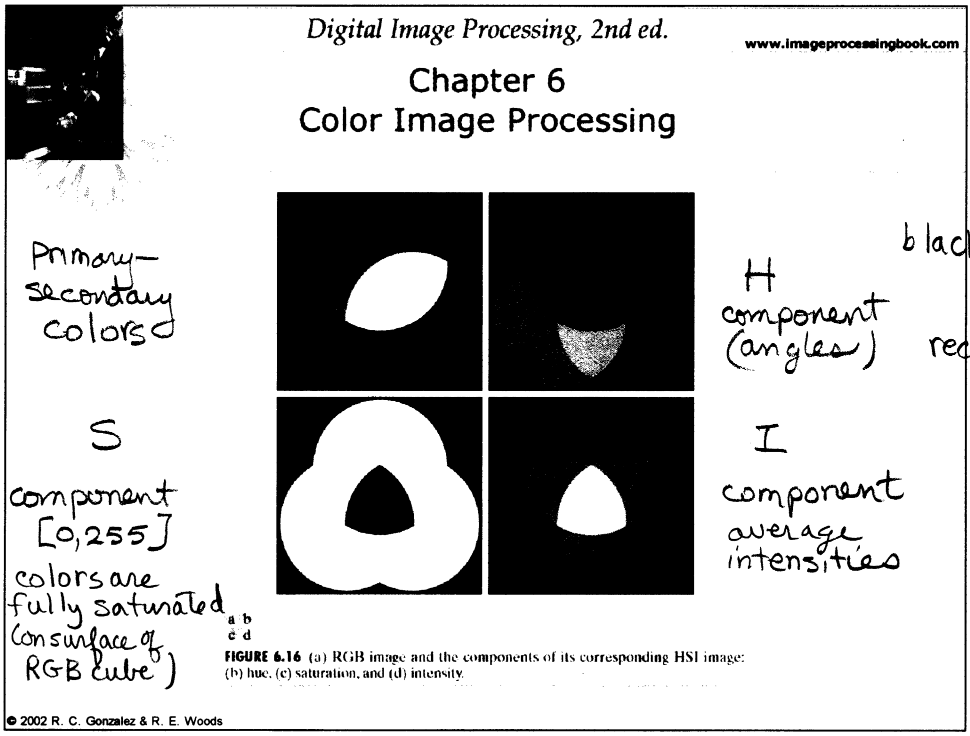
FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

discontinuity because H is going from 1 (bright) to 0 (dark)	shows decreasing value, i.e. less saturation as you approach white	$I = \frac{1}{3}(R+G+B)$ is just average of R, G, B values



as seen looking back along the gray axis we have a discontinuity from 1 to zero along the red-white line.

this is the H=0 plane where H switches from 0°(black) to 360° (white)



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Primary-secondary colors

H component (angles)

black and white have zero hue

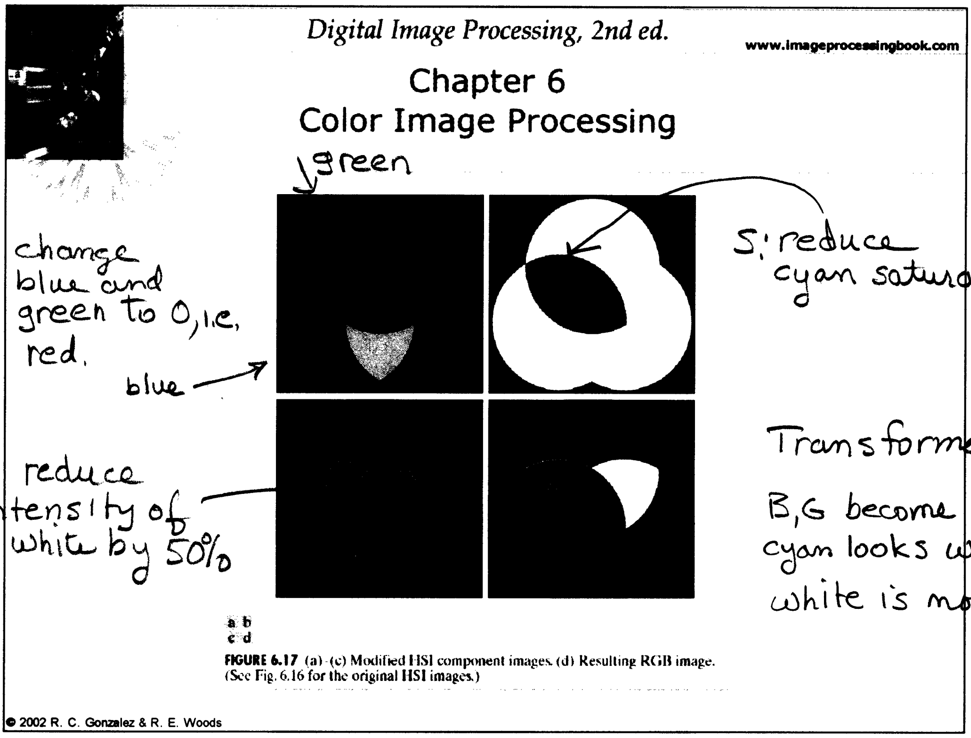
red is 0° or black.

S component [0,255]

colors are fully saturated (on surface of RGB cube)

I component average intensities

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



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green

H: change blue and green to 0, i.e., red.

blue

S: reduce cyan saturation by 50%

I: reduce intensity of white by 50%

Transformed color image

B,G become red

cyan looks washed out

white is now 50% gray

a b
c d

FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

To change color in HSI simply change the hue value and convert back to RGB without changing S and I.

To change saturation modify only S.

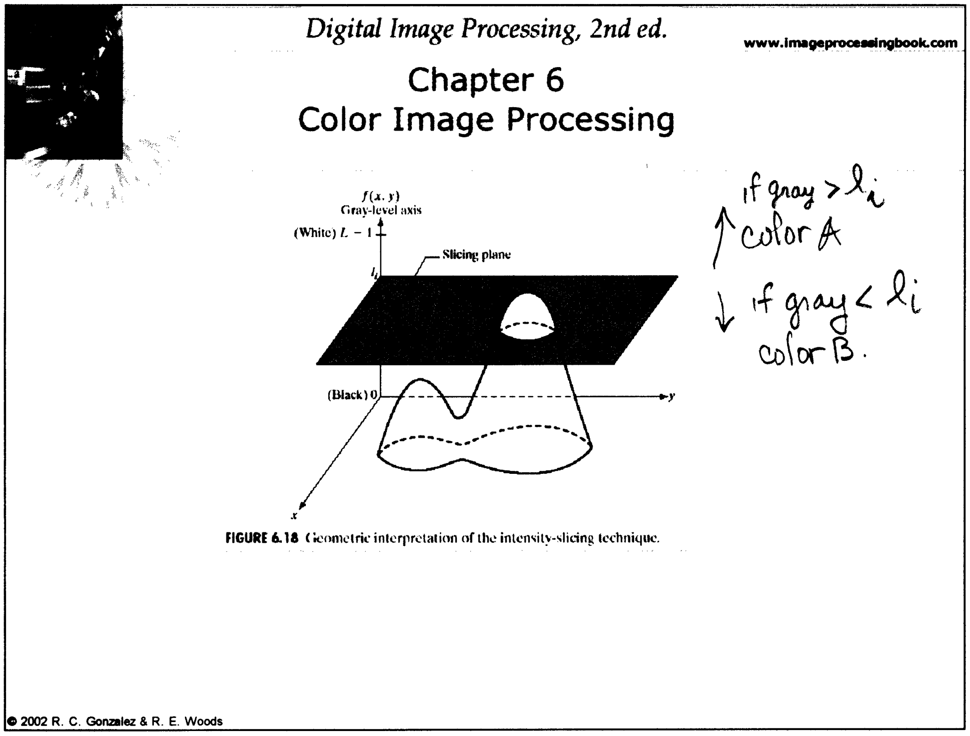

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FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

if gray $> l_i$
↑ color A
↓ if gray $< l_i$
color B.

pseudo color (false color) – assign colors to gray values using some criterion
– used a lot in data visualization

↓

false since these are not real color

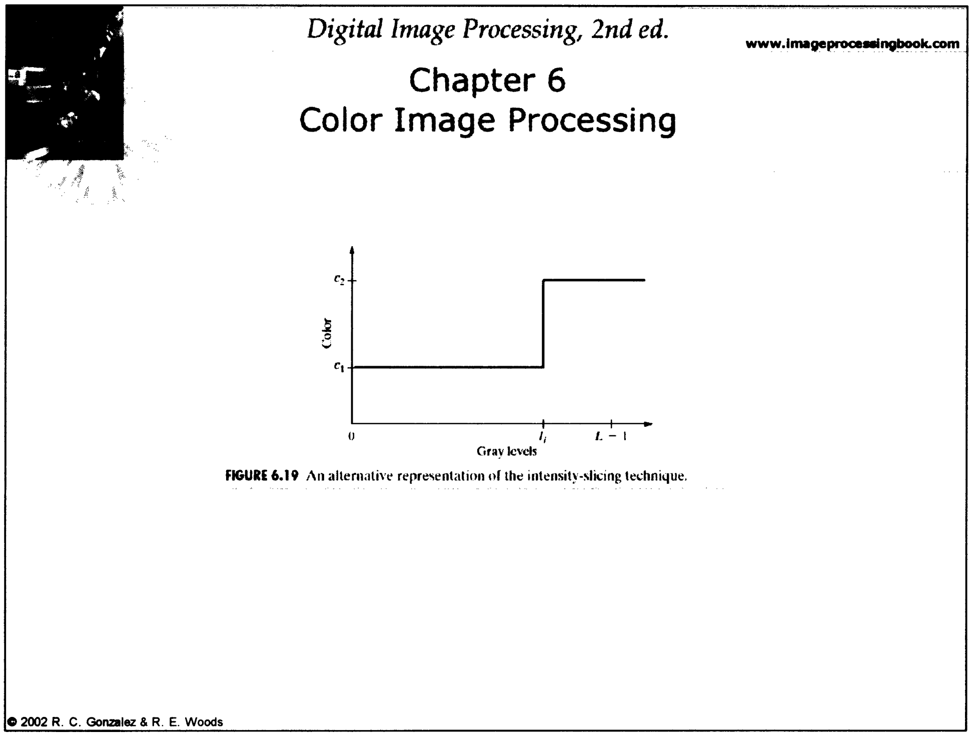

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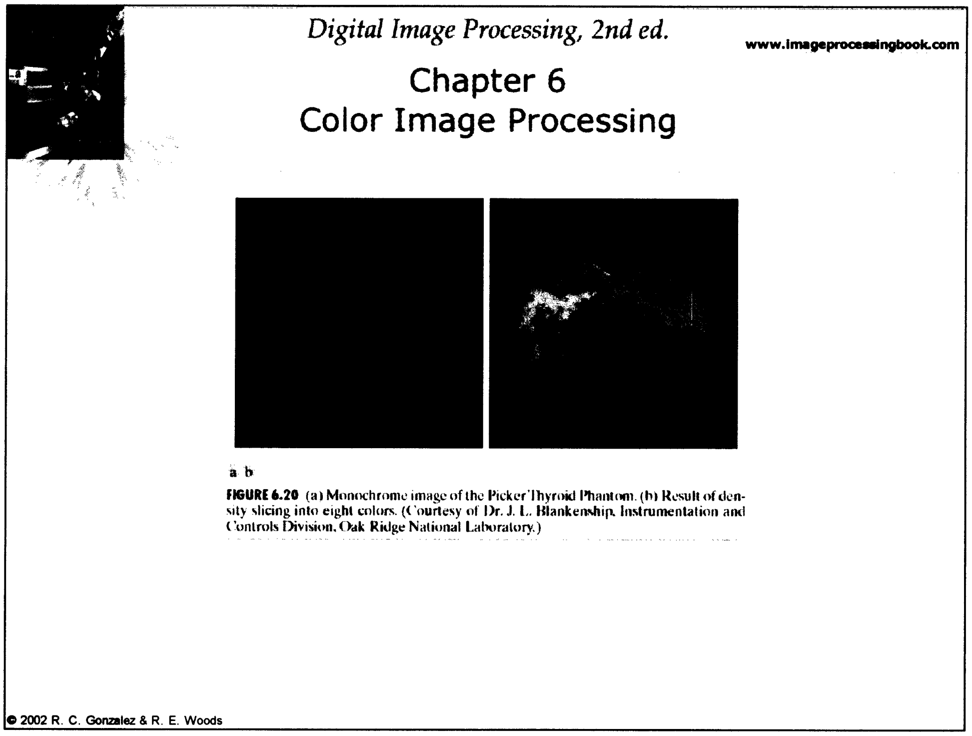
FIGURE 6.19 An alternative representation of the intensity-slicing technique.

Simply another way of describing what is done in Figure 6-18.



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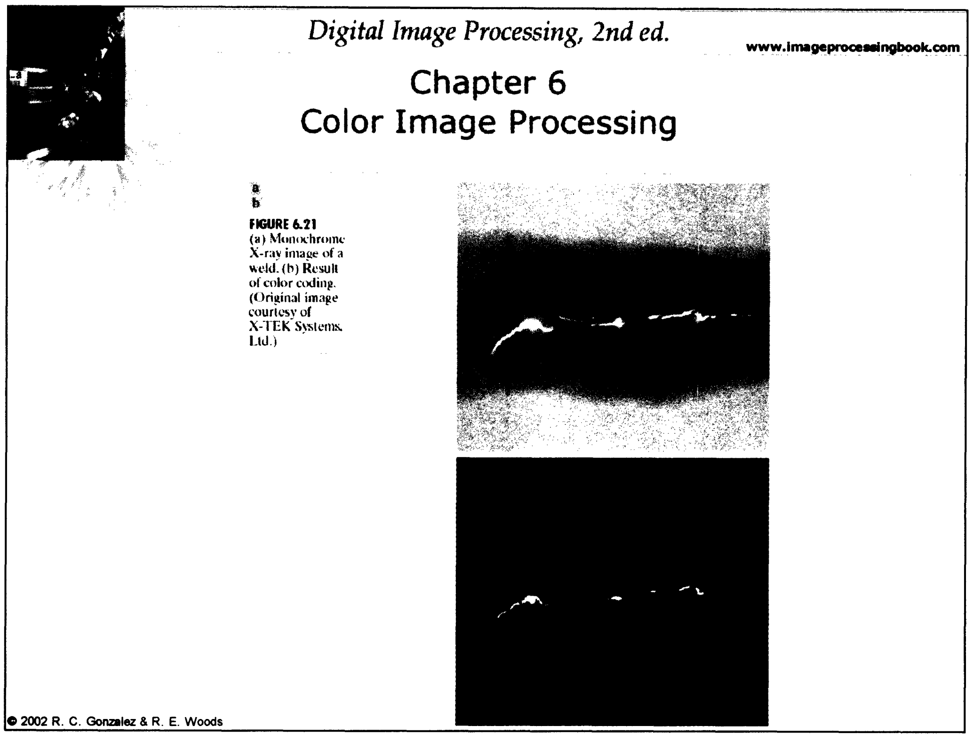
a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

intensity slicing with multiple color slices



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a
b

FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)

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Simple application in X-ray analysis.
Cracks allow full X-ray intensity through metal.
Image simply codes 255 as yellow and all others as blue for inspection.

intensity values correspond to rainfall →

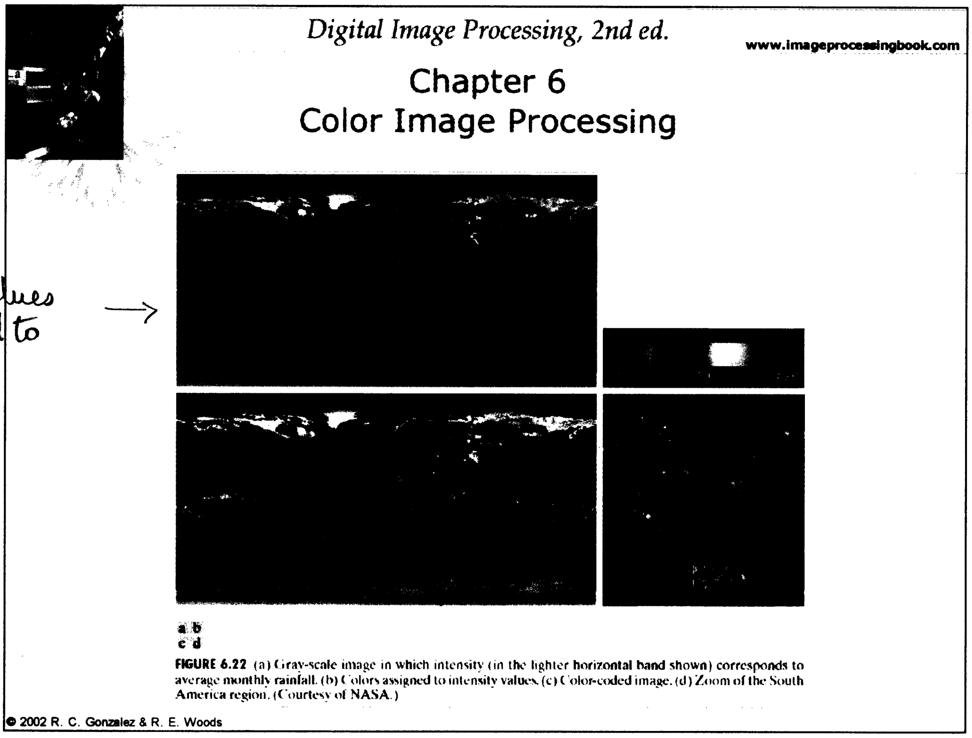

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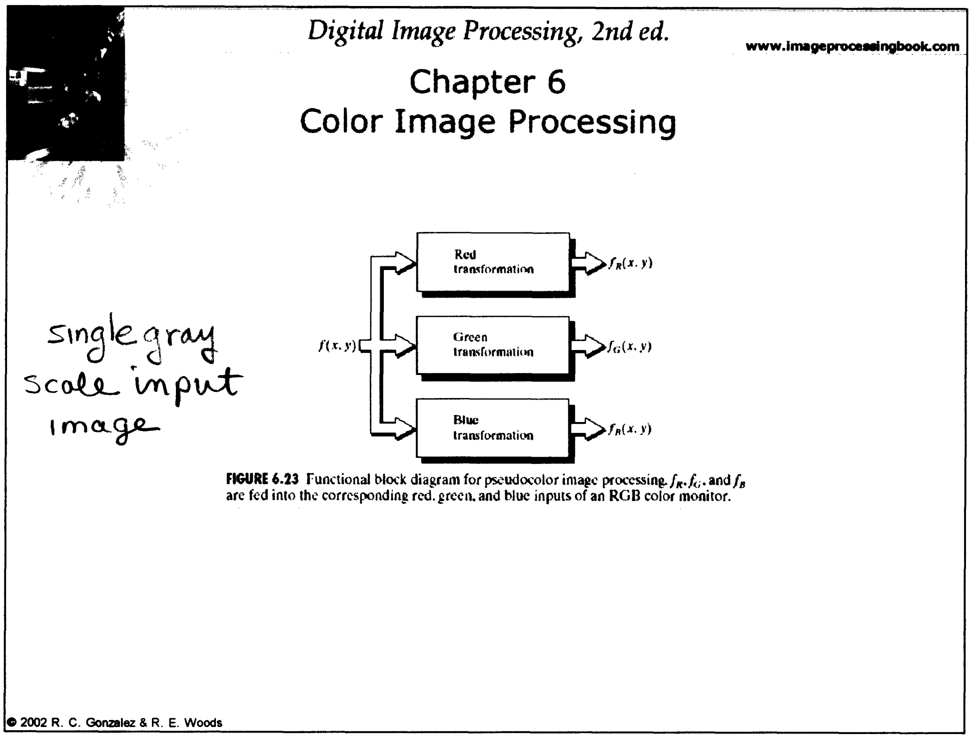
FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South America region. (Courtesy of NASA.)

Combine signals from (Tropical Rainfall Measuring Mission satellite)
- precipitation radar
- micro-wave imager
- visible/IR scanner.

to estimate average monthly rainfall.

Difficult to see patterns in grayscale. Much easier to see in pseudocolor.



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single gray scale input image

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.

We can use simultaneous non-linear transforms to drive a color camera.

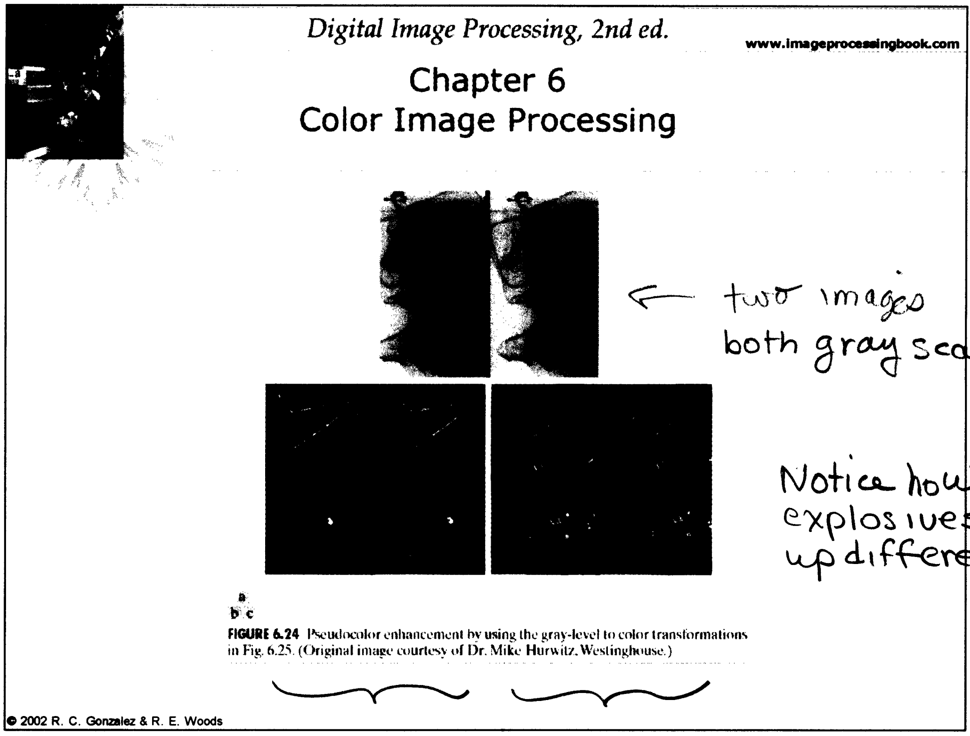

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FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

← two images
both gray scale.

Notice how
explosives show
up differently.

transform
6.25(a)

transform
6.25(b)

2 different transforms.

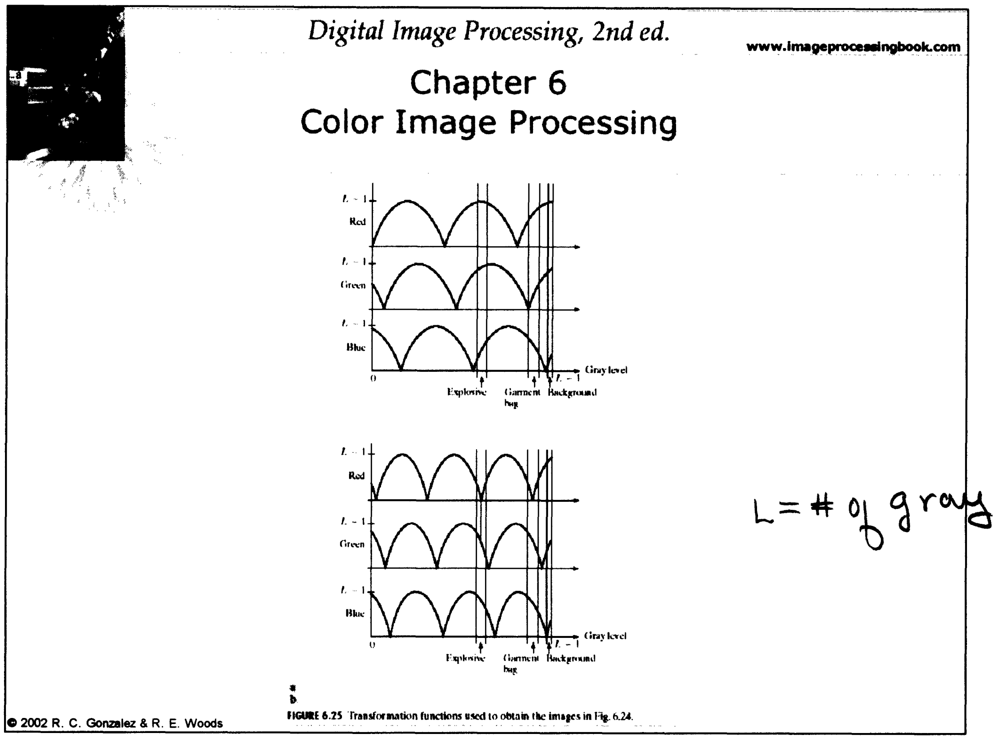

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FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

L = # of gray levels

transformations used to make explosives in 6.24 visible.

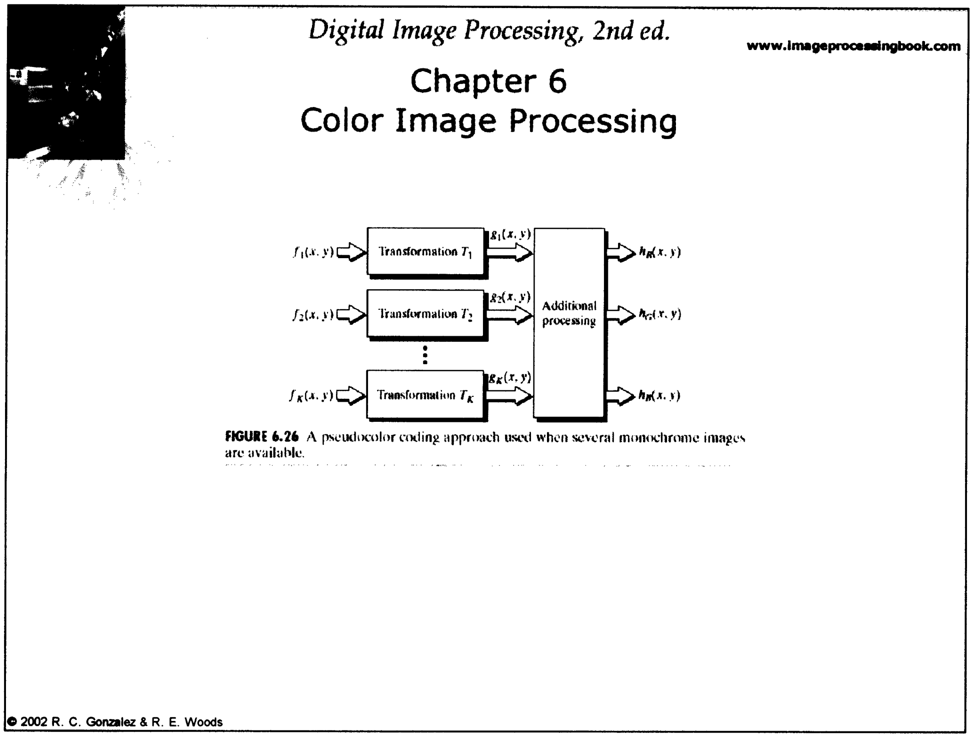

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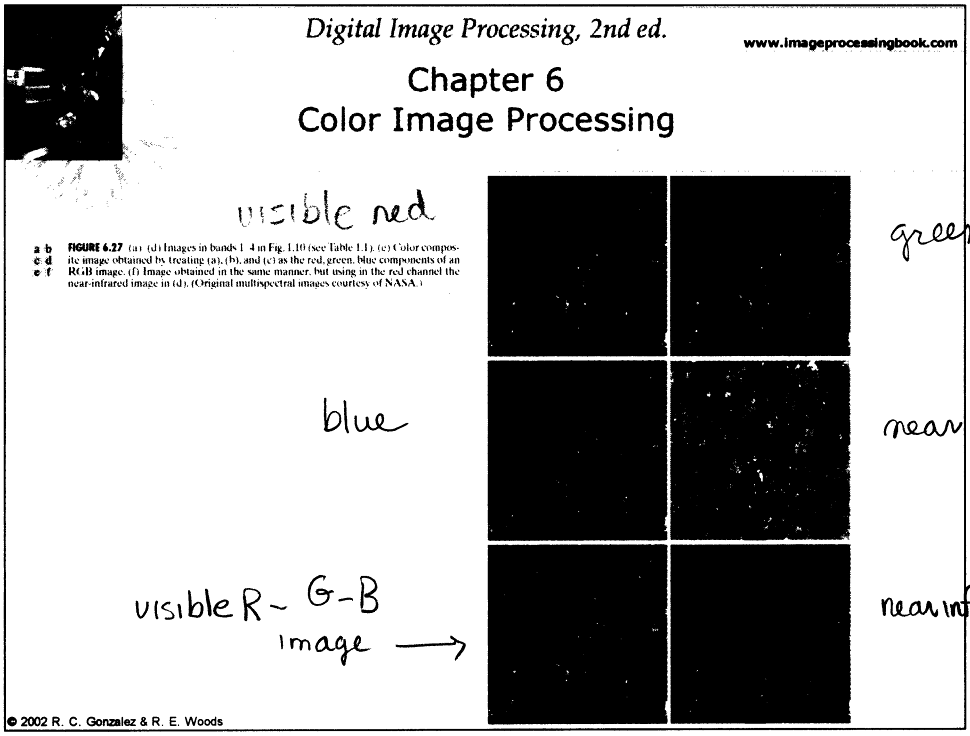
FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

more sophisticated color transformations.
can be used to combine grayscale images
from different sensors as an example.



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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.)

visible red

green

blue

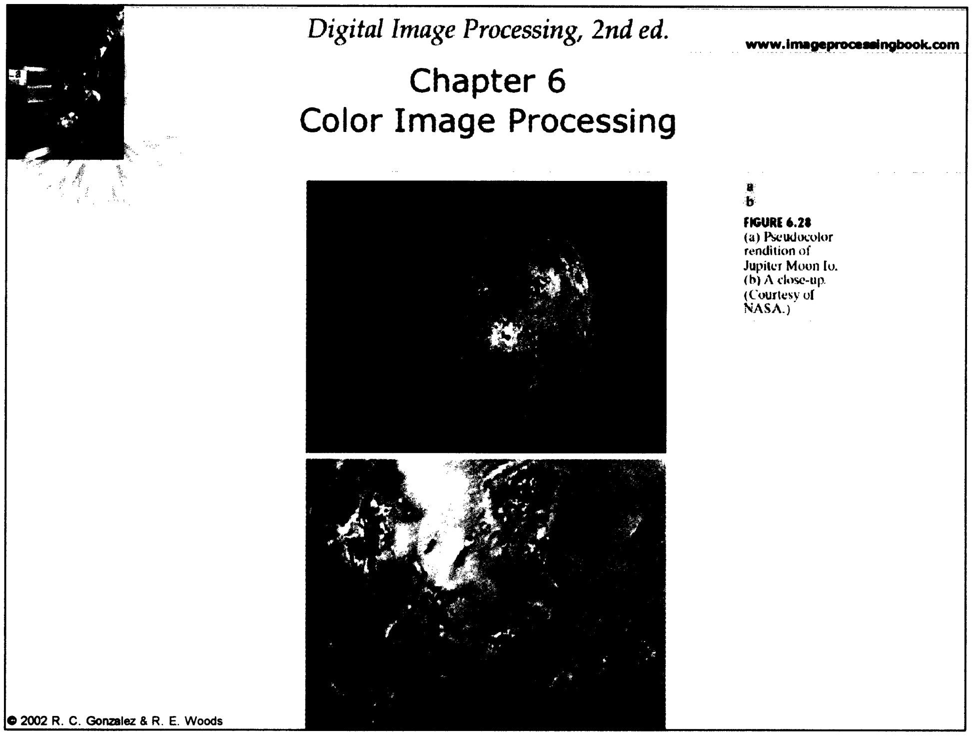
near-infrared

visible R - G-B
image →

near infrared - G - B
image

↑
used visible red
for R

↑
used near infrared
for R.



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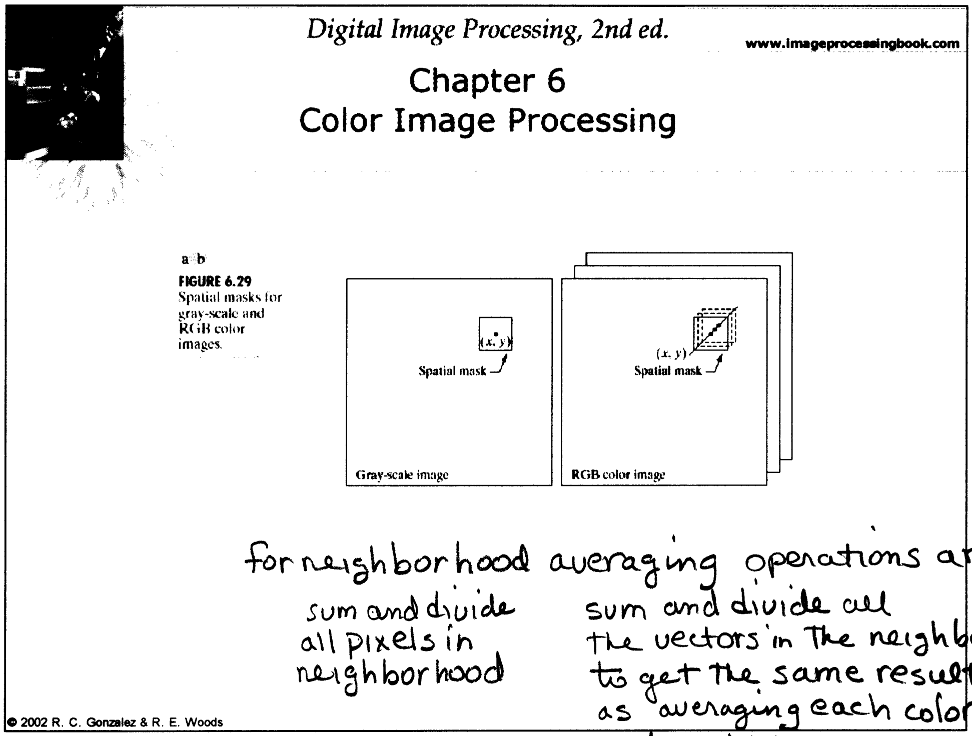
a
b

FIGURE 6.28
(a) Pseudocolor rendition of Jupiter Moon Io.
(b) A close-up.
(Courtesy of NASA.)

used a variety of different wavelengths

The newly ejected material is red (different material)

The older material is yellow. (sulfur)



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

for neighborhood averaging operations are equivalent

sum and divide all pixels in neighborhood

sum and divide all the vectors in the neighborhood to get the same result as averaging each color component and combining

full-color image processing

- process each component image separately and combine to form a composite image
- process color vectors (pixels) directly.

$$\underline{c}(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

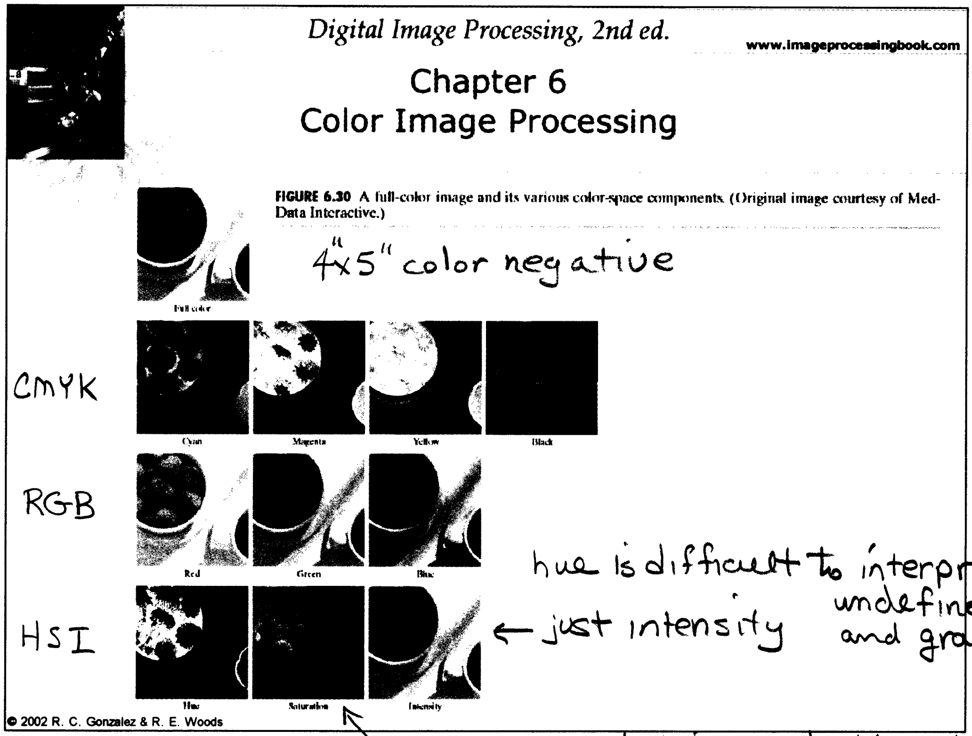

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FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)

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4"x5" color negative

CMYK

RGB

HSI

hue is difficult to interpret since its undefined for white, black and gray

← just intensity

straw berries are highly saturated

color transformations

$$\underbrace{s_i}_{\text{new color components}} = T_i(\underbrace{r_1, r_2, \ldots, r_n}_{\text{color components, i.e., R, G, B}}) \quad i=1,\ldots,n = \#\text{ of color components}$$

T_i = set of color transformations

There are different costs associated with image processing in the different color spaces

to do intensity modification $g(x,y) = k\,f(x,y)$ $0 \le k \le 1$

HSI color space $s_3 = k r_3$

$s_1 = r_1$, $s_2 = r_2$

RGB color space $s_i = k r_i$, $i = 1,2,3$

CMY color space $s_i = k r_i + (1-k)$, $i = 1,2,3$

We didn't show it but $I = \frac{1}{3}\left[3-(c+m+y)\right] = 1-\frac{1}{3}(c+m+y)$ which is why this formula looks a little odd.

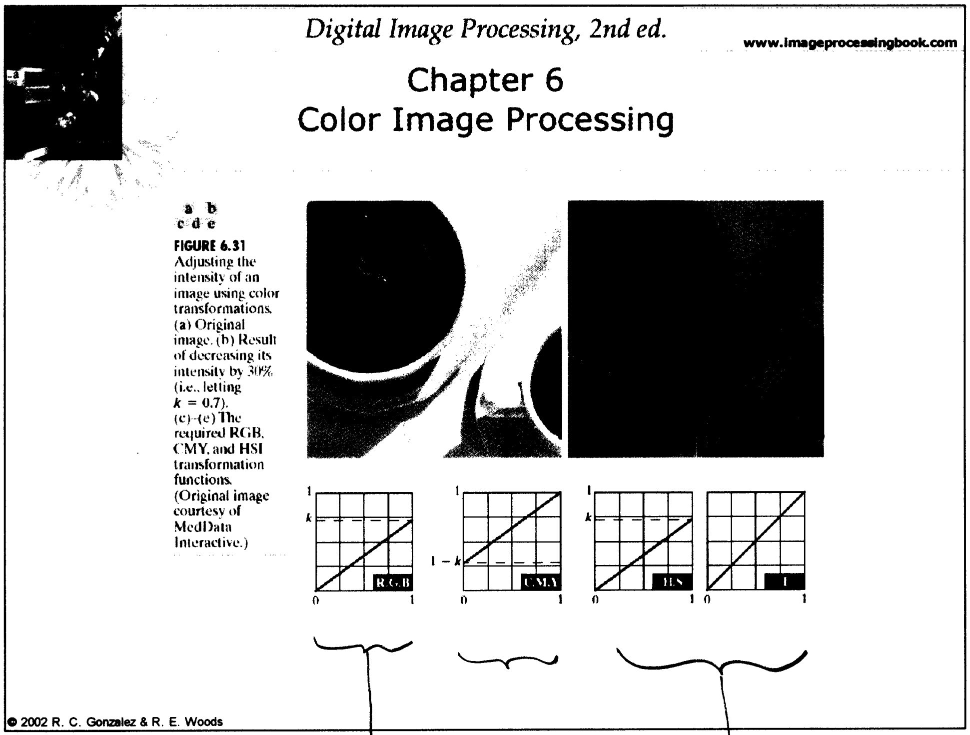

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FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image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

Scale each component in RGB

Since $C = 1 - R$, etc. This is simply a linear transformation.

these are reversed I is decreased H,S remain the same.

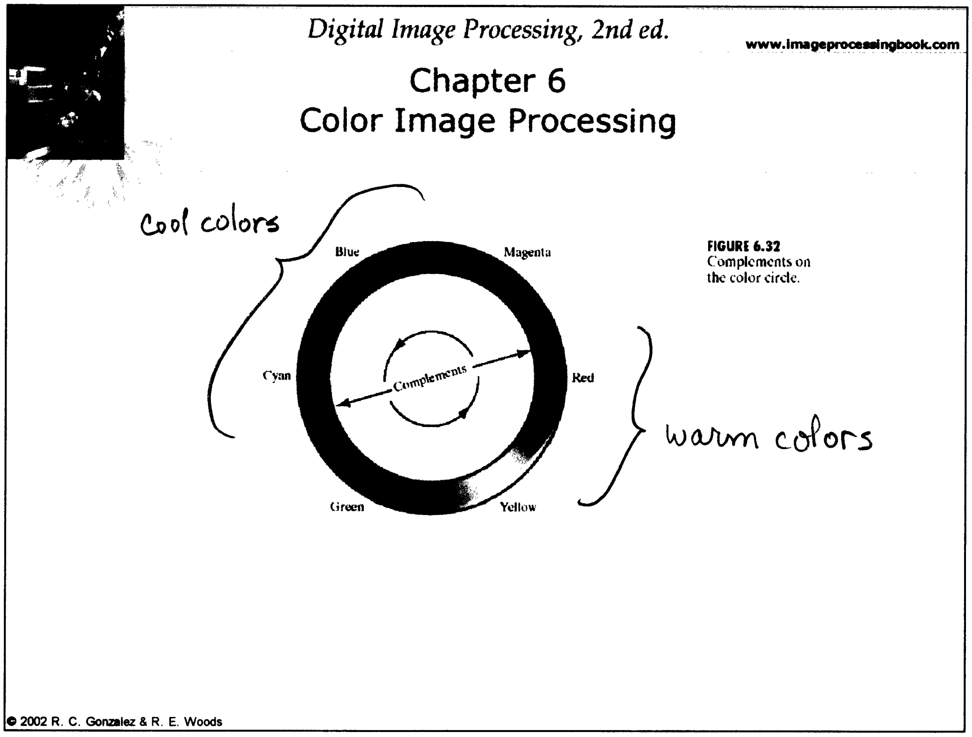

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FIGURE 6.32 Complements on the color circle.

Cool colors

warm colors

Newton's color circle summarizes the additive properties of colors

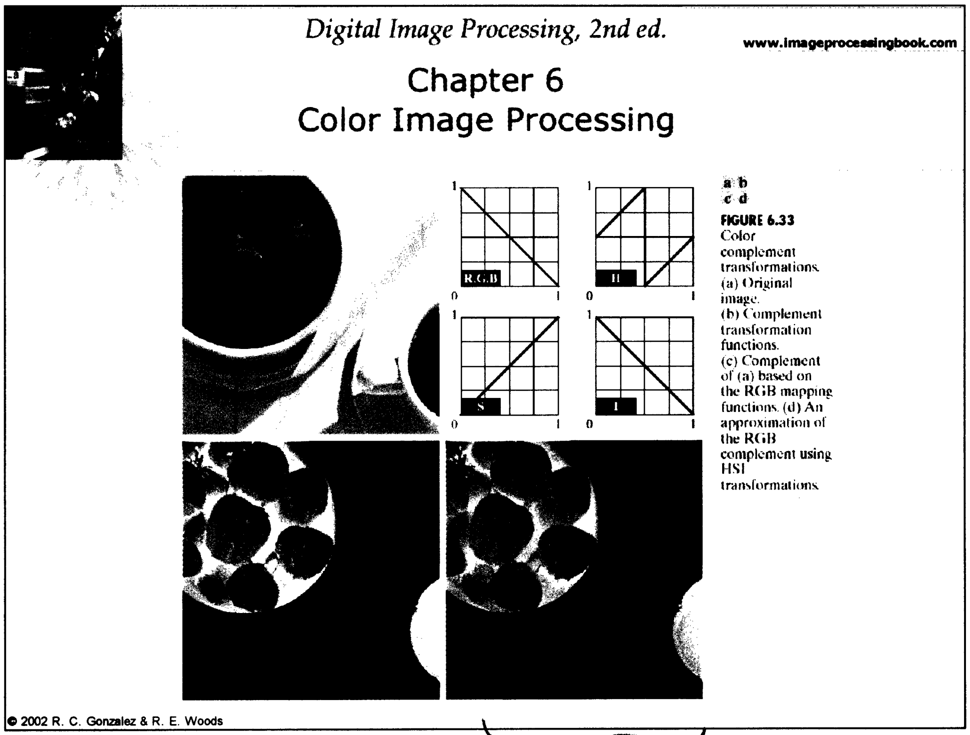

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FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

RGB complement

HSI complement.

As you decrease each color (R, G, B) its complement becomes evident.

R ⟷ cyan
G ⟷ magenta
B ⟷ yellow

complement not straight forward
See problem 6.18

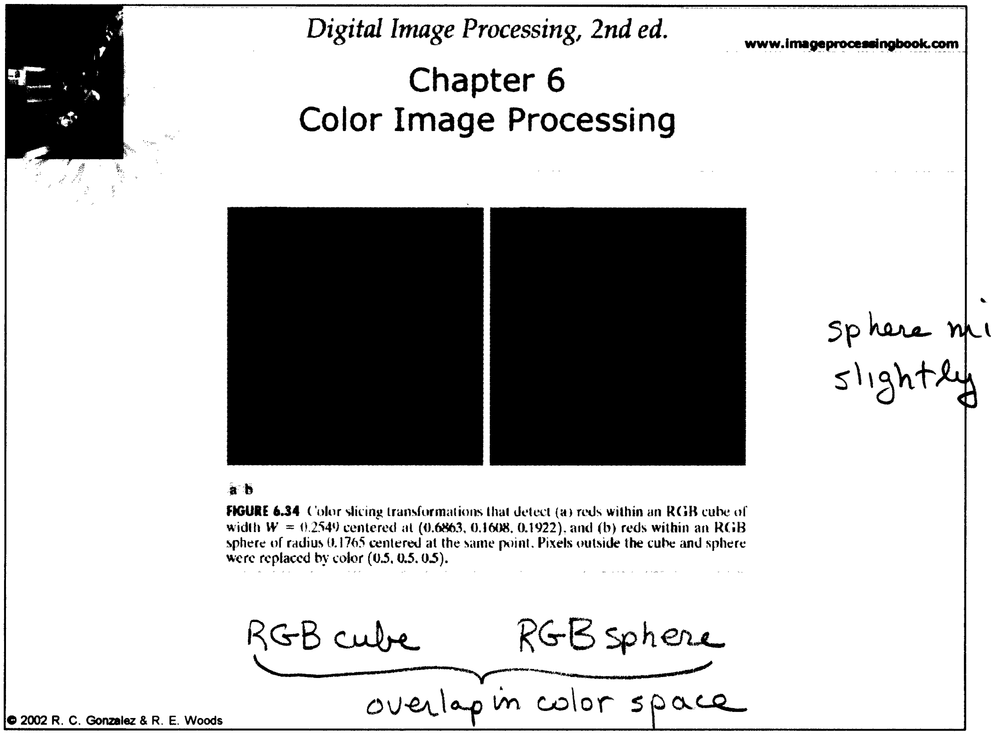

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FIGURE 6.34 Color slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at (0.6863, 0.1608, 0.1922), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color (0.5, 0.5, 0.5).

RGB cube RGB sphere

overlap in color space

sphere might be slightly better

Color slicing - map colors outside a range of interest to a neutral color

neutral color

cube, hypercube

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

cube of width W centered at (a_1, a_2, a_3)

sphere

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

$i = 1, 2, \ldots, n$

6.5.4. Tone/Color correction

need a device-independent color model to get color consistency between monitors & output devices

color management systems

Pantone (used by Adobe)

CIE L*a*b

similar to HSI by separating color from intensity

$$L^* = 116 \cdot h\left(\frac{Y}{Y_w}\right) - 16$$

lightness

$$a^* = 500\left[h\left(\frac{X}{X_w}\right) - h\left(\frac{Y}{Y_w}\right)\right]$$

Red – Green

$$b^* = 200\left[h\left(\frac{Y}{Y_w}\right) - h\left(\frac{Z}{Z_w}\right)\right]$$

Green – Blue

$$\text{where } h(q) = \begin{cases} \sqrt[3]{q} & q > 0.008856 \\ 7.787q + \frac{16}{116} & q \le 0.008856 \end{cases}$$

X_w, Y_w, Z_w – reference white tristimulus, perfect diffused illuminated with CIE D65 light. (this is defined to be daylight)

X, Y, Z – R, G, B tristimulus values

L*a*b* is

colorimetric – colors perceived as identical have identical values

perceptually uniform – color differences are perceived uniformly

device independent

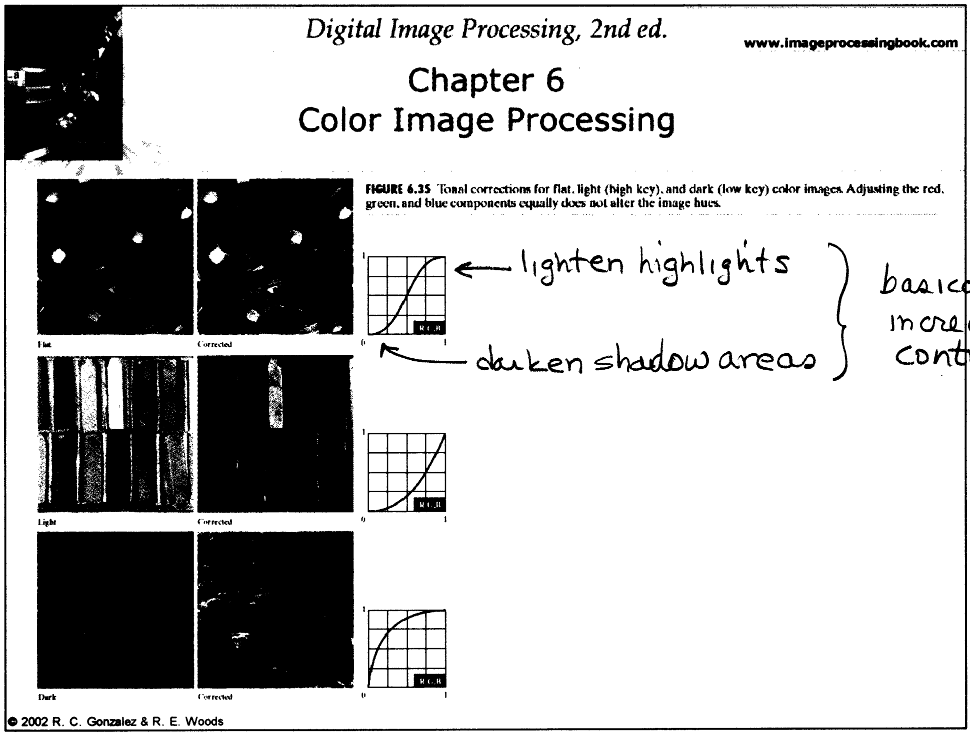

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FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.

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correction

flat

light

dark

← lighten highlights

← darken shadow areas

basically increases contrast

tonal range – key type

high-key – most information at high (bright) intensities

low-key – " " at low intensities

middle-key – " " at intermediate intensities

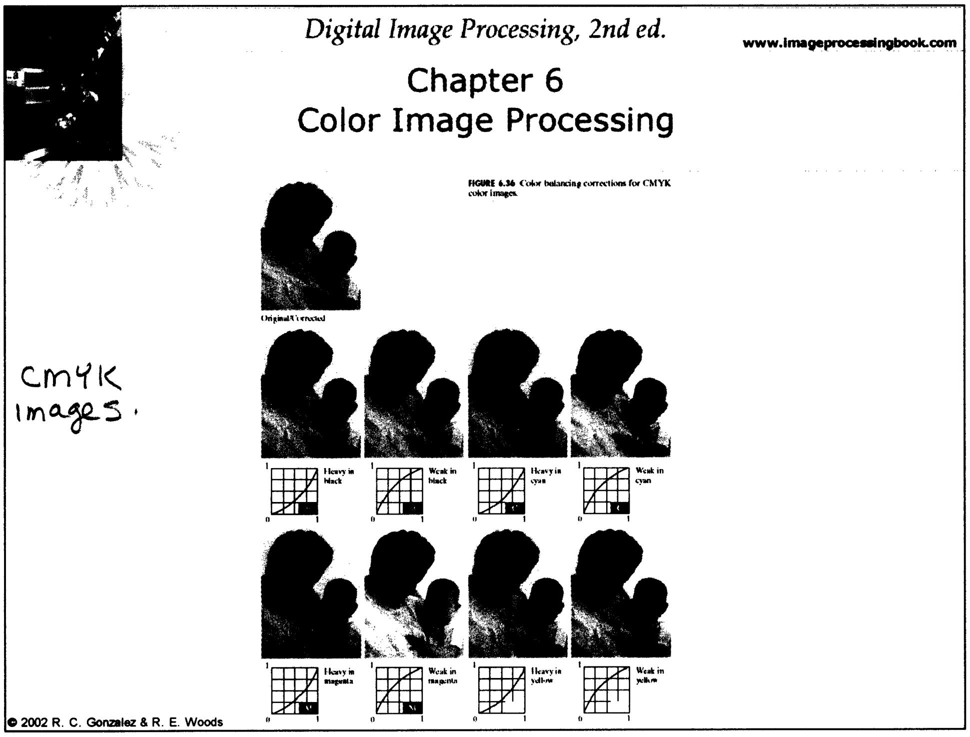

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FIGURE 6.36 Color balancing corrections for CMYK color images.

CMYK images.

Easiest way to evaluate color imbalance in an image is to analyze a known color. such as whites or skin,

Simple transformations to either boost or lighten a CMYK image.

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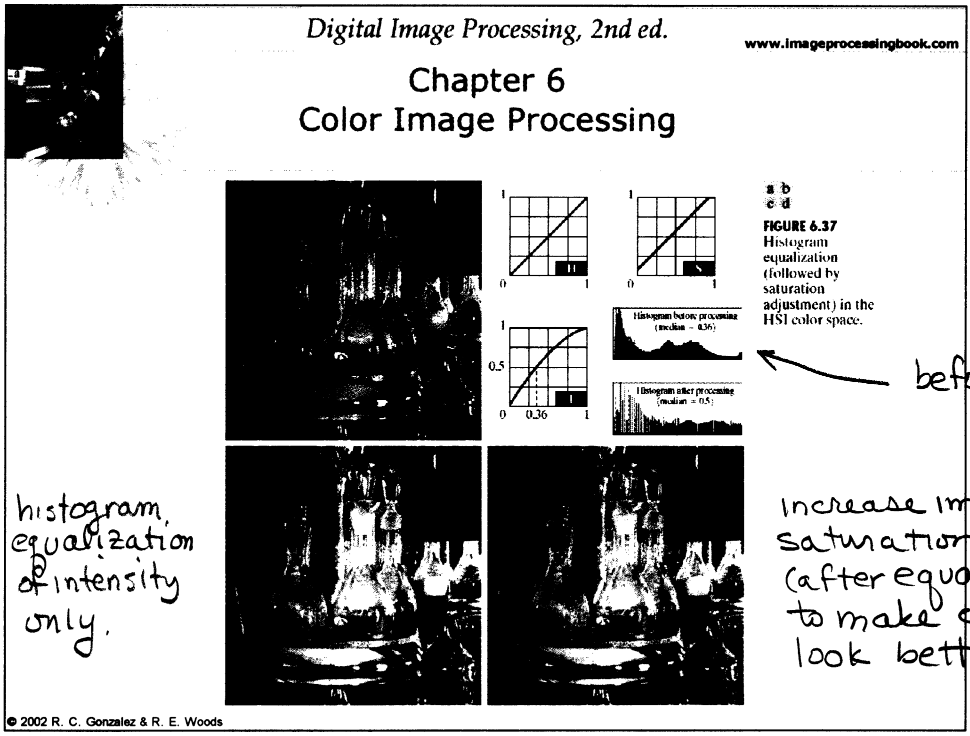

a b
c d

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

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before equalization

histogram equalization of intensity only.

increase image saturation slightly (after equalization) to make colors look better.

How can you apply histogram equalization to a color image?

Don't equalize colors independently,

spread color intensities such as in HSI space.

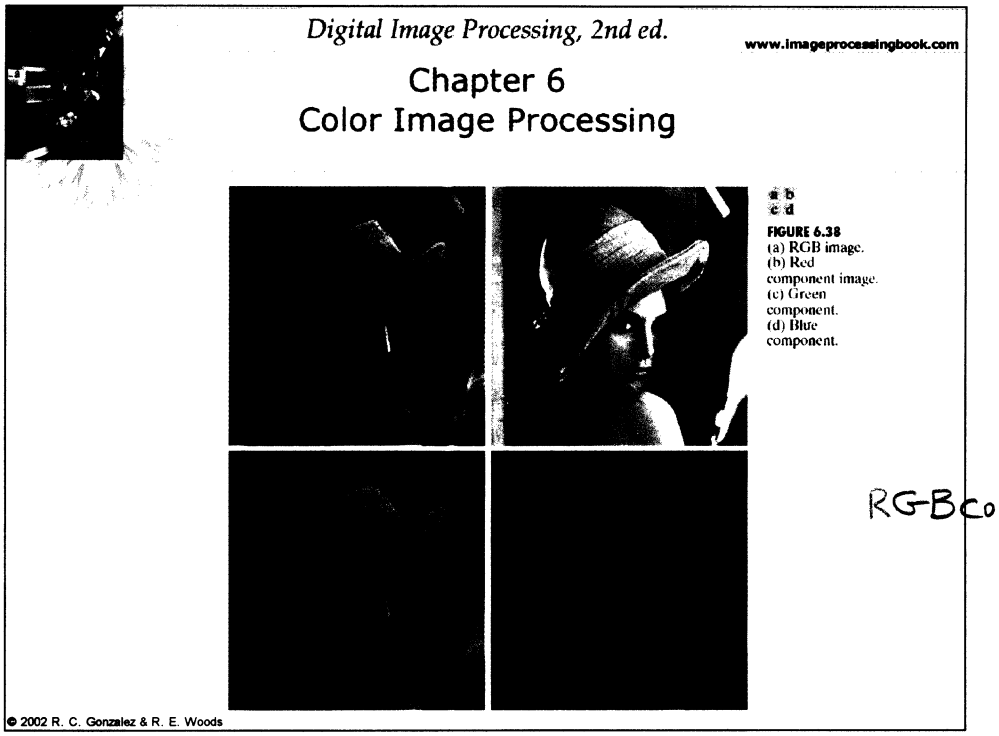

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FIGURE 6.38 (a) RGB image. (b) Red component image. (c) Green component. (d) Blue component.

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RGB components

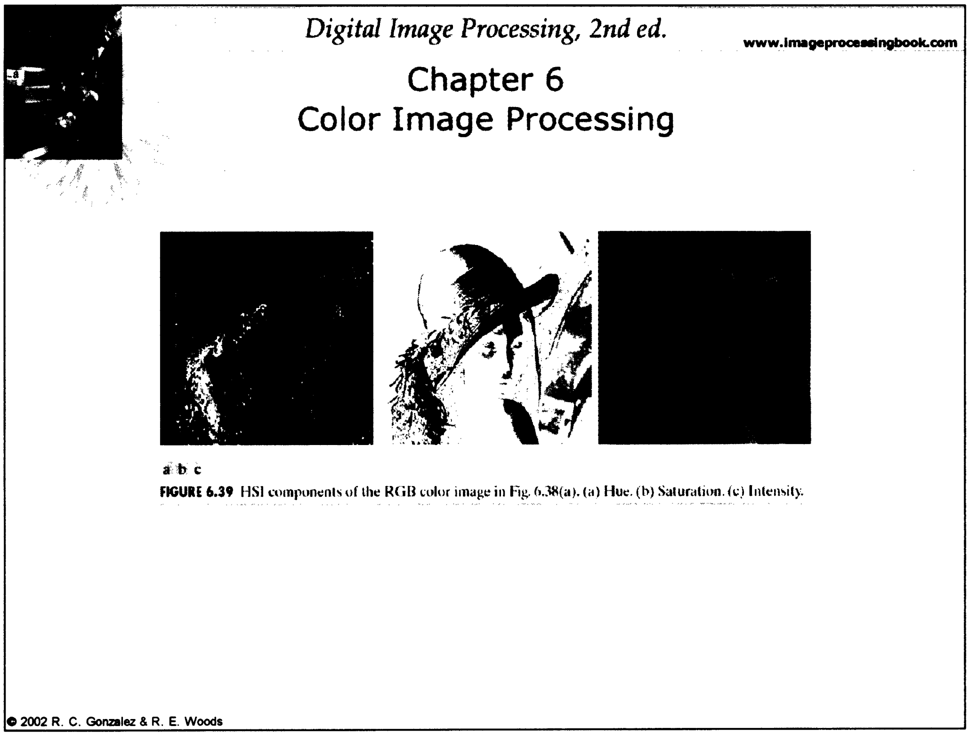
We just considered
pixel transforms
The next level of processing is
neighborhood processing
such as smoothing and sharpening

Consider averaging

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

$K = \#$ of pixels

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



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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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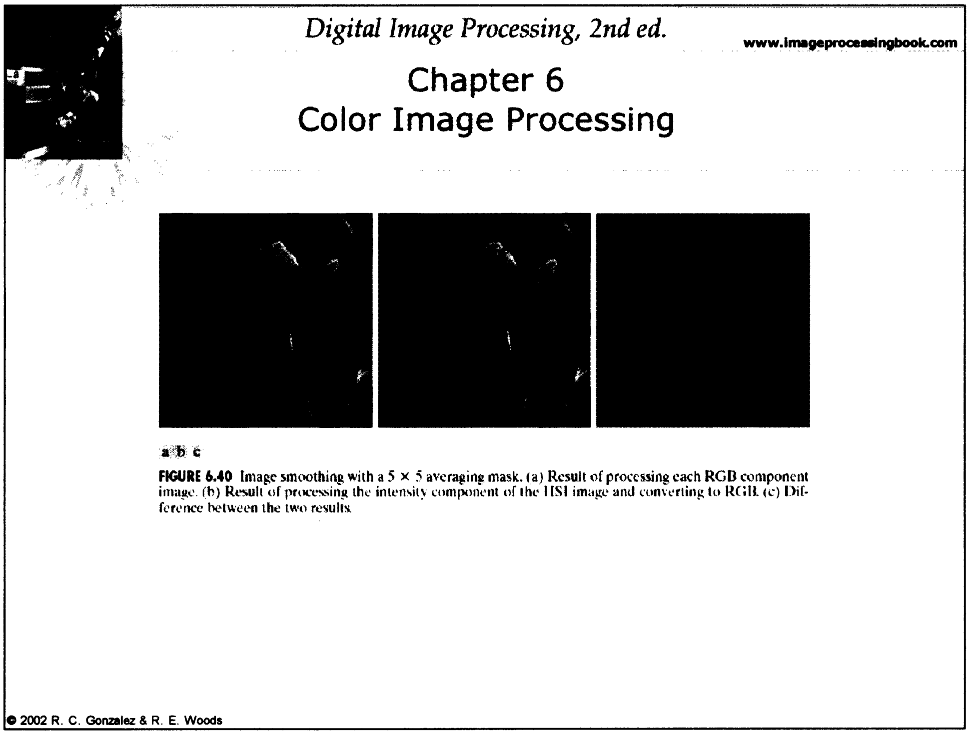
HSI components of previous picture.



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a b c

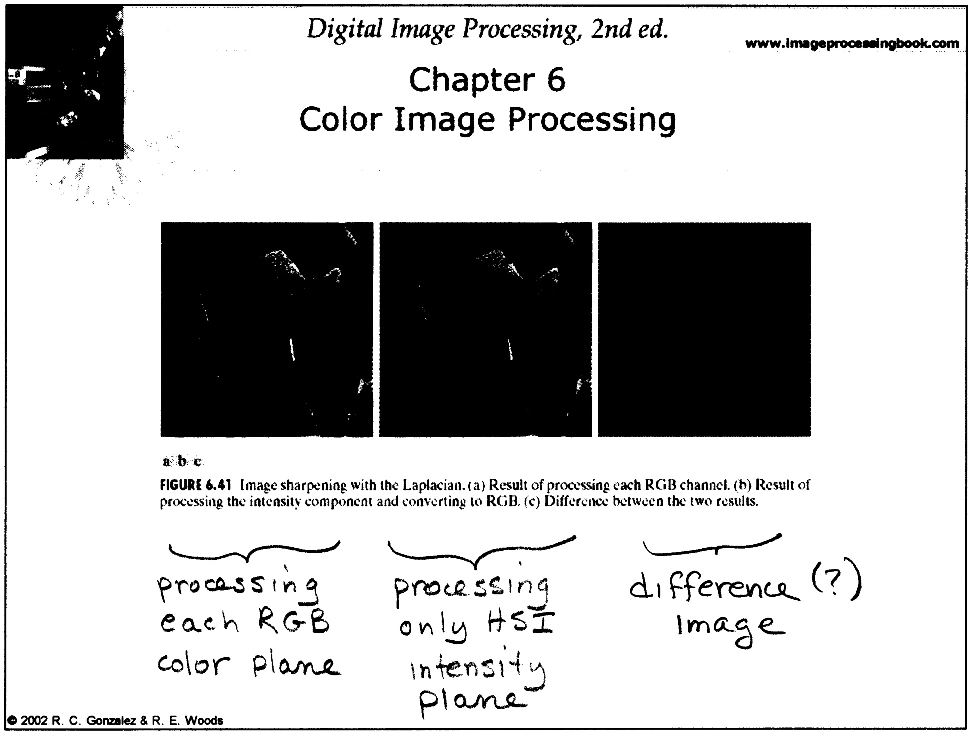
FIGURE 6.40 Image smoothing with a 5 × 5 averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.

Image smoothing using a 5x5 mask.

(a) smoothing each color plane independently

(b) smoothing I (intensity) component of HSI image and conversion to RGB. This keeps color accurate.

(c) No data on how this difference image was computed. Several possibilities



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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.

processing each RGB color plane

processing only HSI intensity plane

difference (?) image

Color image sharpening using Laplacian

$$\nabla^2[\underline{c}(x,y)] = \begin{bmatrix} \nabla^2 R(x,y) \\ \nabla^2 G(x,y) \\ \nabla^2 B(x,y) \end{bmatrix}$$

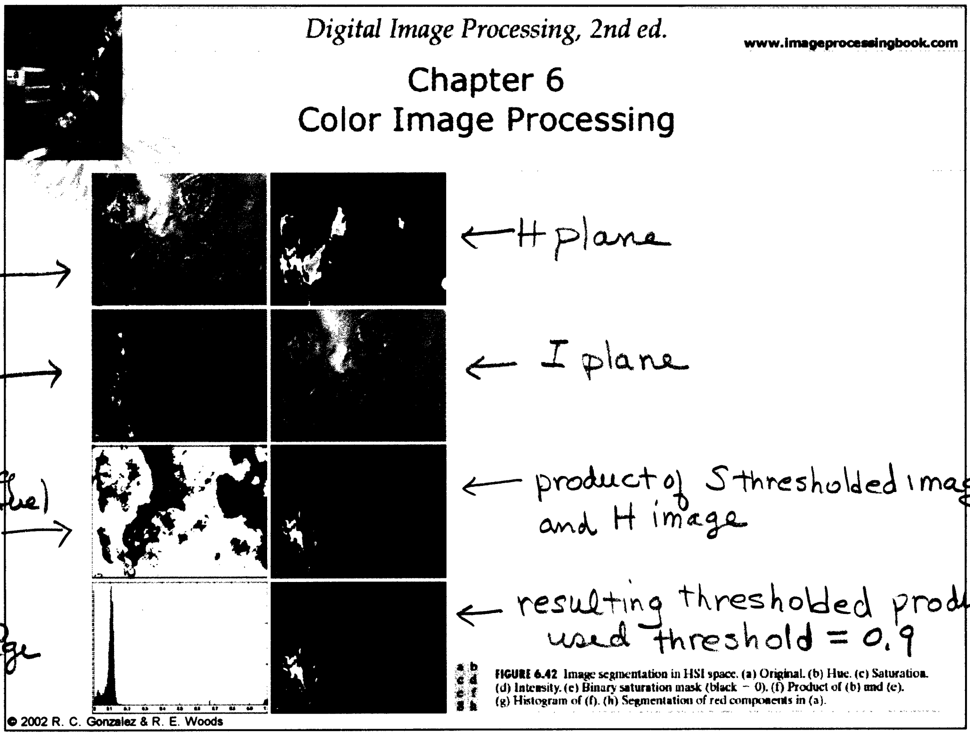

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FIGURE 6.42 Image segmentation in HSI space. (a) Original. (b) Hue. (c) Saturation. (d) Intensity. (e) Binary saturation mask (black = 0). (f) Product of (b) and (e). (g) Histogram of (f). (h) Segmentation of red components in (a).

want to segment this area. →

S plane →

thresholding (0.1 max value) S plane →

histogram of product image

← H plane

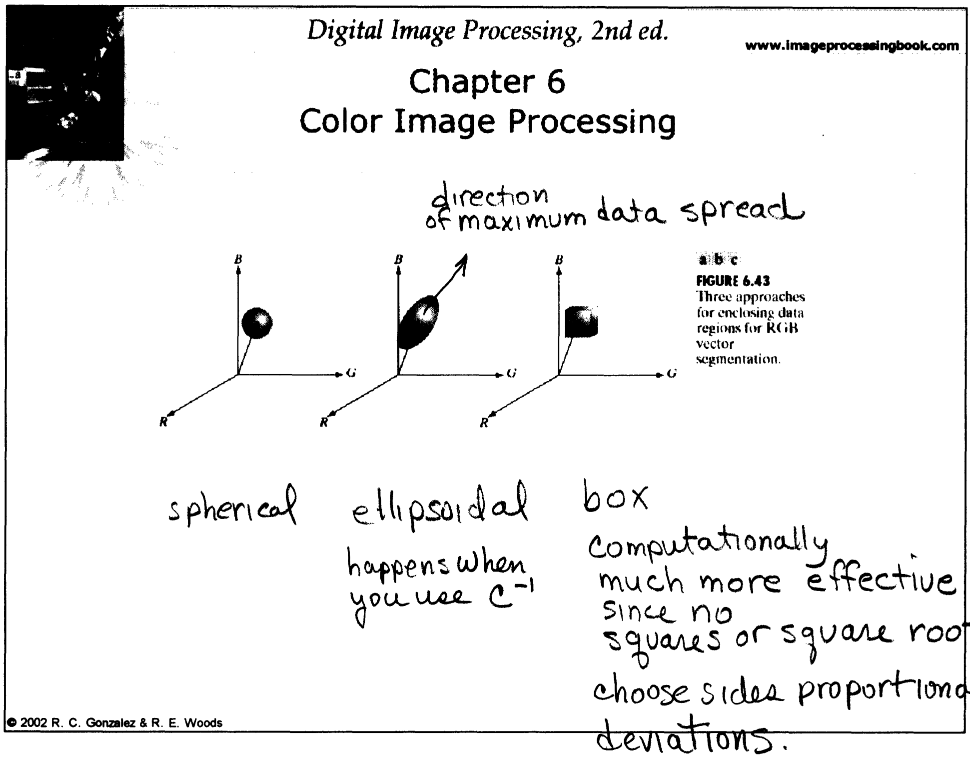
← I plane

← product of S thresholded image and H image

← resulting thresholded product image. used threshold = 0.9

Segmentation (Chap. 10 topic)

If we want to segment an image based on color the hue (H) image is the most natural to use.



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direction of maximum data spread

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

spherical

ellipsoidal
happens when you use C^{-1}

box
computationally much more effective since no squares or square roots
choose sides proportional to standard deviations.

Segmentation divides an image into constituent regions or objects.

Segmentation usually works better in RGB space than in HSI space.

Objective – classify each color pixel as having a color in the specified range or not

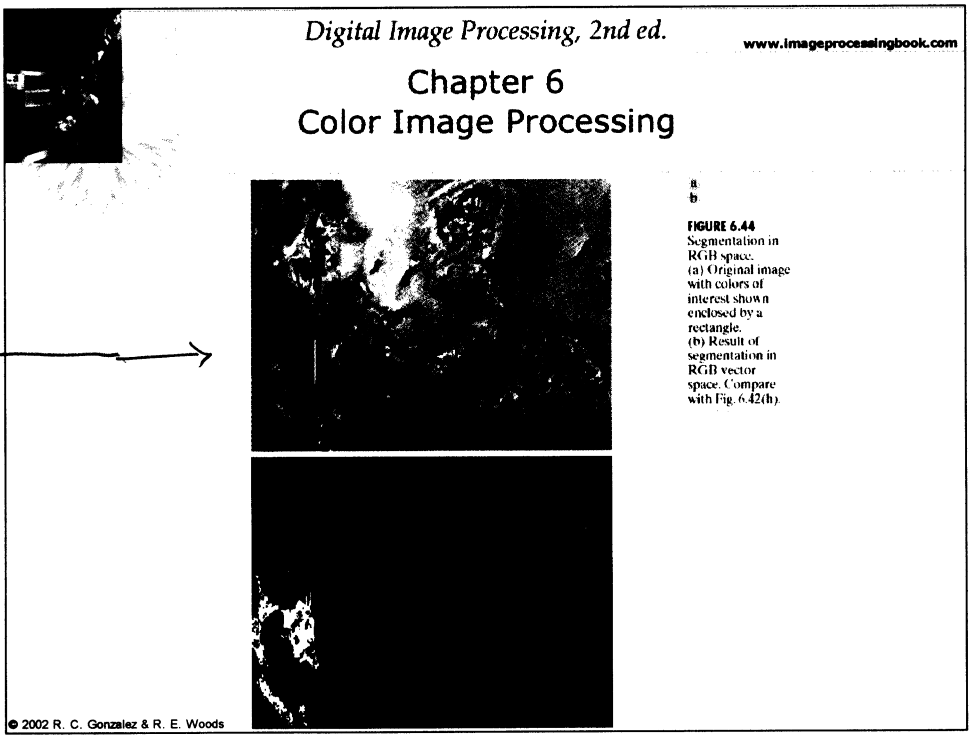
Use Euclidean distance

$$D(\underline{z},\underline{a}) = \|\underline{z}-\underline{a}\| = \sqrt{(\underline{z}-\underline{a})^T(\underline{z}-\underline{a})}$$

$$D(\underline{z},\underline{a}) = \sqrt{(z_R-a_R)^2+(z_G-a_G)^2+(z_B-a_B)^2}$$

A generalized distance measure is

$$D(\underline{z},\underline{a}) = \sqrt{(\underline{z}-\underline{a})^T \underset{\uparrow\text{ covariance matrix}}{C^{-1}} (\underline{z}-\underline{a})}$$



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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).

rectangle shows color we want to segment →

Same image and goal as figure 6.42 but done in RGB space.

Procedure

1. Compute mean and standard deviations of the color contained in the sample rectangle.

   mean $\underline{a}$
   std deviations $\sigma_R, \sigma_G, \sigma_B$

2. using box in color space

   $a_R \pm 1.25\sigma_R$
   $a_G \pm 1.25\sigma_G$
   $a_B \pm 1.25\sigma_B$

   classify pixel as white if inside this box, or white outside

Compare results with 6.42(h)

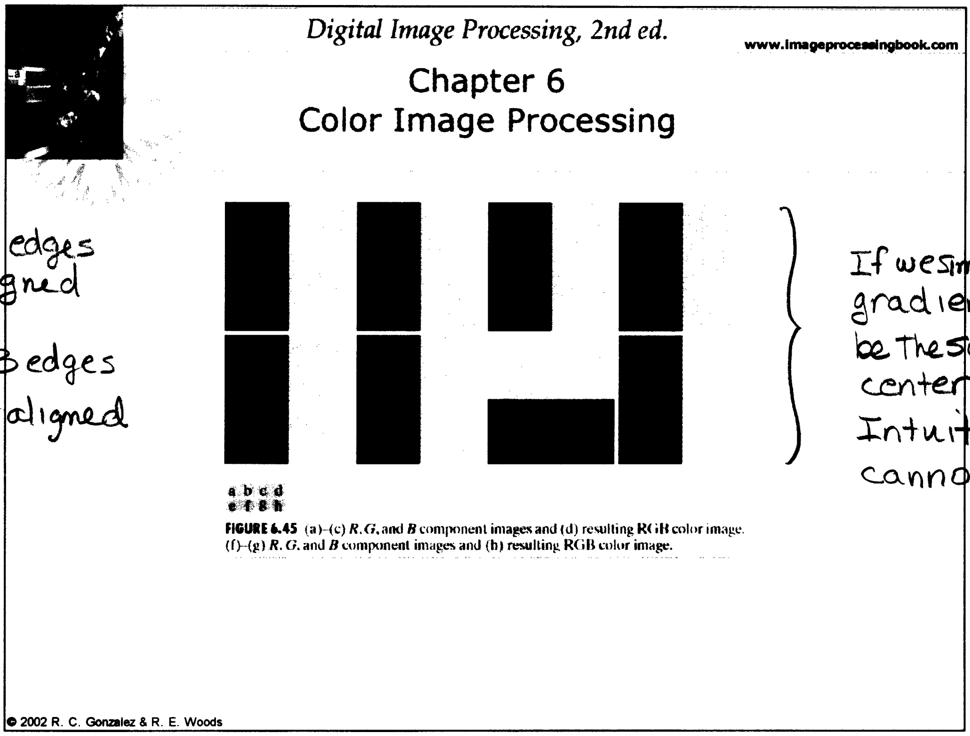

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FIGURE 6.45 (a)–(c) *R*, *G*, and *B* component images and (d) resulting RGB color image. (f)–(g) *R*, *G*, and *B* component images and (h) resulting RGB color image.

RGB edges aligned

RGB edges not aligned

If we simply add the gradients they would be the same at the center point. Intuitively they cannot be the same.

Computing edges in individual color planes vs. computing directly in color space.

Alternative vector definition

S. Di Zenzo (1986)
A Note on the Gradient of a Multi-Image
Computer Vision, Graphics and Image Processing
Vol. 33, pp. 116-125

We want to define the gradient (magnitude and direction) of the vector $\underline{c}(x,y)$

For a scalar function $f(x,y)$ the gradient is a vector pointing in the direction of maximum rate of change of f at (x,y)

$\hat{r}, \hat{g}, \hat{b}$ be unit vectors along the R, G, B axis of a RGB color space

define
$$\underline{u} = \frac{\partial R}{\partial x}\hat{r} + \frac{\partial G}{\partial x}\hat{g} + \frac{\partial B}{\partial x}\hat{b}$$
$$\underline{v} = \frac{\partial R}{\partial y}\hat{r} + \frac{\partial G}{\partial y}\hat{g} + \frac{\partial B}{\partial y}\hat{b}$$

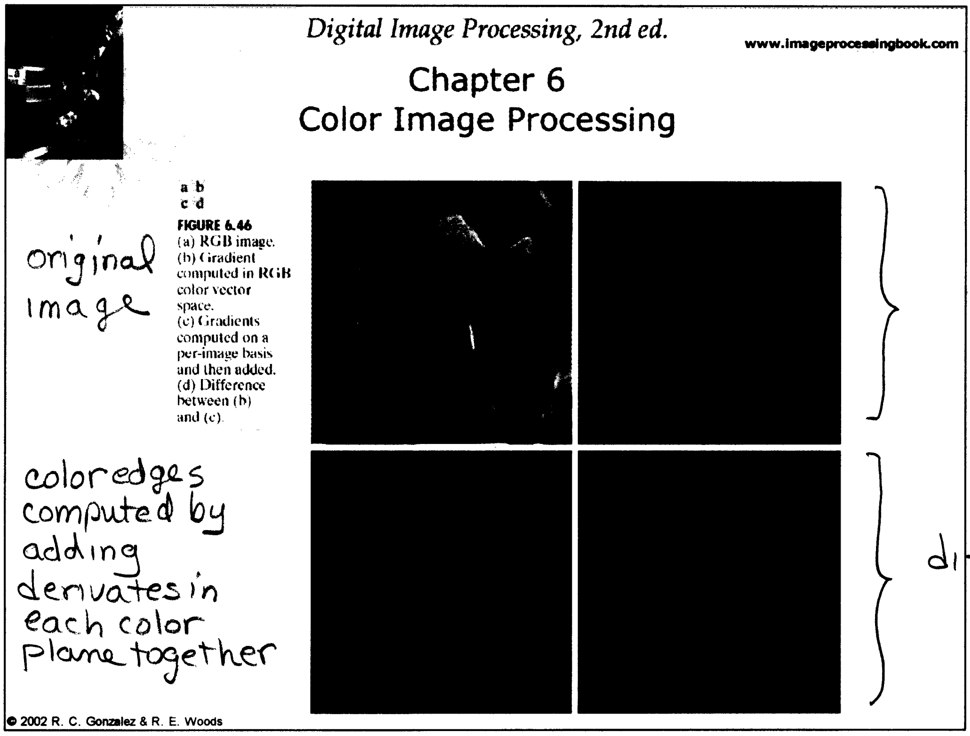
These can be computed using a Sobel operator.

further define
$$g_{xx} = \underline{u}\cdot\underline{u} = \underline{u}^T\underline{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$
$$g_{yy} = \underline{v}\cdot\underline{v} = \underline{v}^T\underline{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$
$$g_{xy} = \underline{u}\cdot\underline{v} = \underline{u}^T\underline{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

The maximum rate of change of $\underline{c}(x,y)$ at (x,y) is in the direction given by
$$\theta(x,y) = \frac{1}{2}\operatorname{Tan}^{-1}\left[\frac{2g_{xy}}{g_{xx}-g_{yy}}\right]$$

and the rate of change in the direction $\theta(x,y)$ is given by
$$F(\theta) = \sqrt{\frac{1}{2}(g_{xx}+g_{yy}) + (g_{xx}-g_{yy})\cos 2\theta + 2g_{xy}\sin 2\theta}$$

θ is given in two orthogonal directions. One is a maximum for F and the other is a minimum.



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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).

original image

coloredges computed by adding derivates in each color plane together

coloredges computed used vector method in RGB color space

difference between (b) and (c)

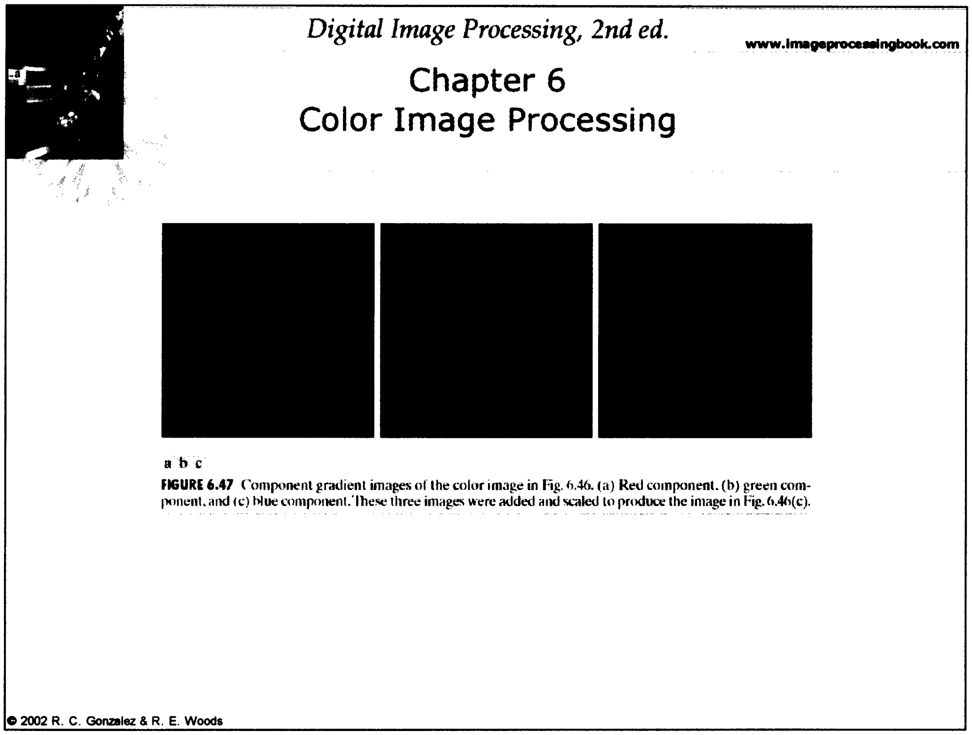
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FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

Individual RGB gradient images

Added and scaled to produce RGB gradient image.

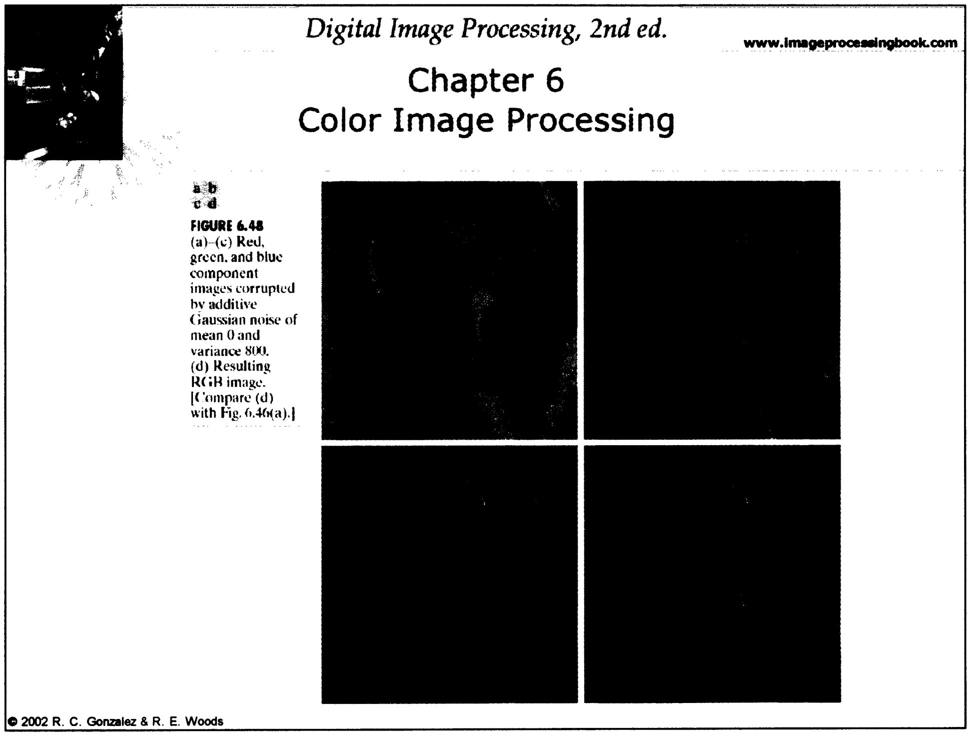

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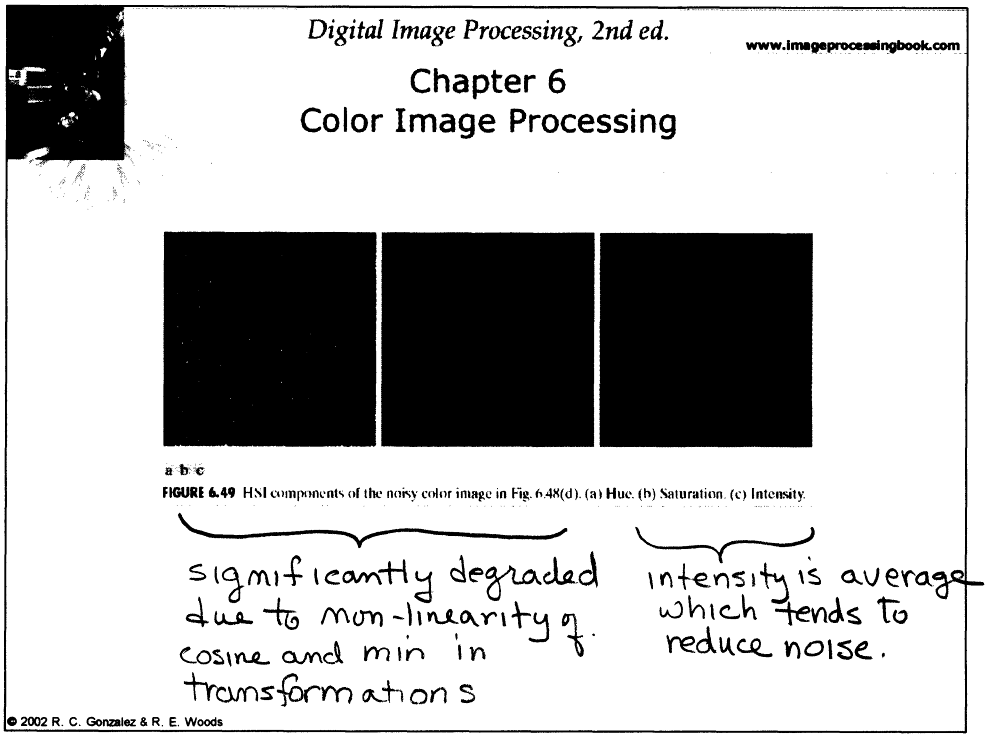
FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]

Added Gaussian noise to the R, G, and B color planes.
RGB image with noise shown in (d).



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a b c

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

significantly degraded due to non-linearity of cosine and min in transformations

intensity is average which tends to reduce noise.

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HSI components of the noisy RGB image.

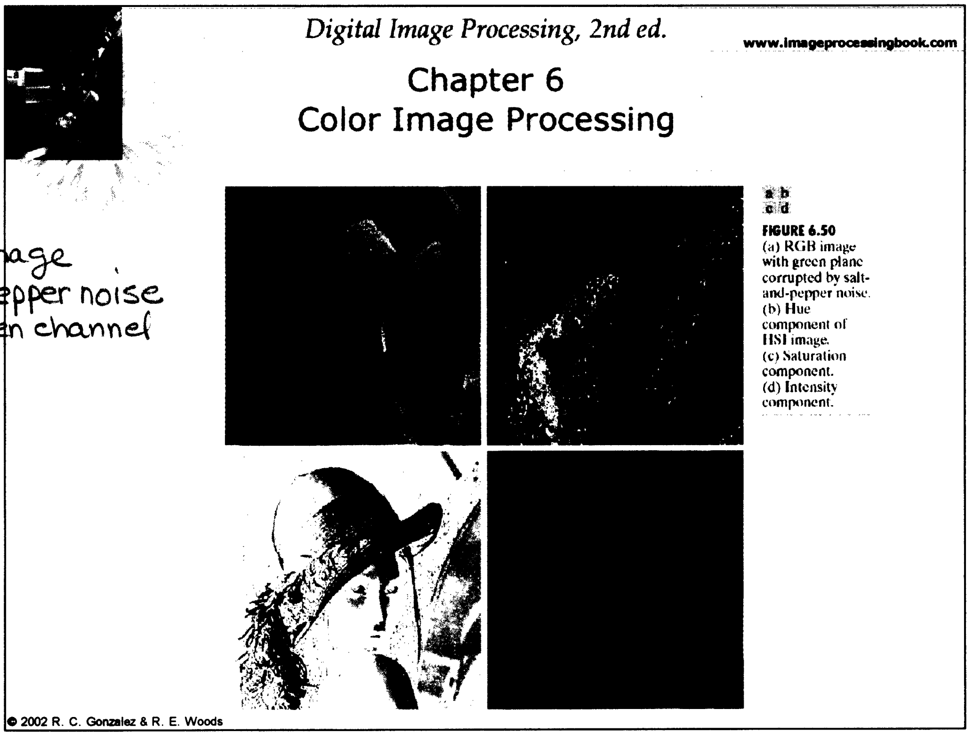

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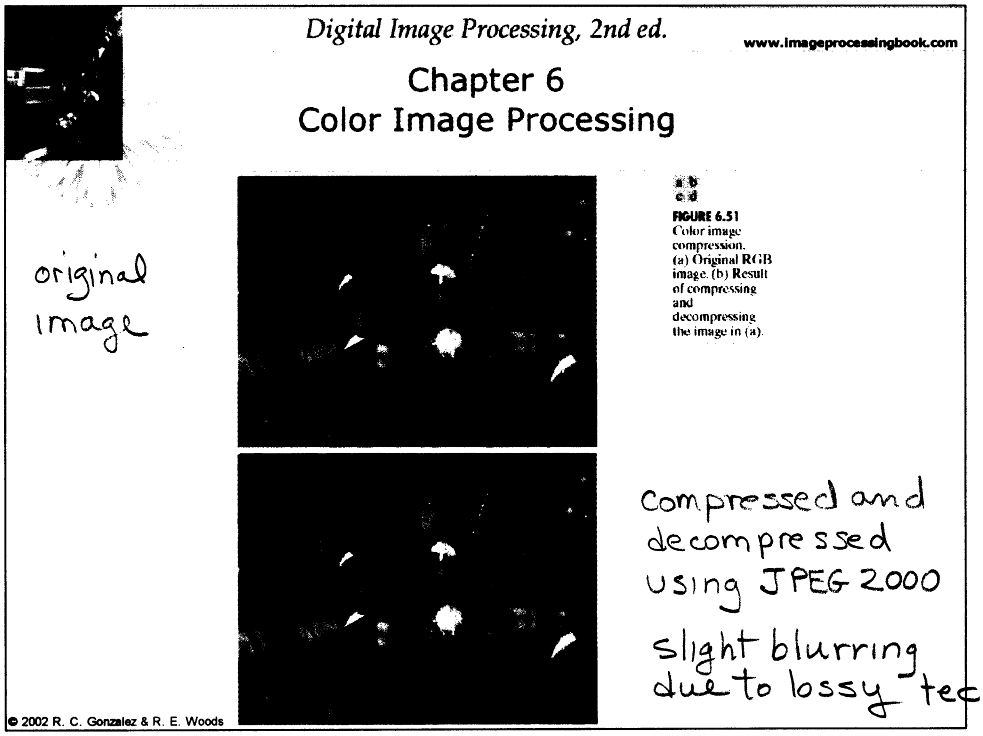
FIGURE 6.50 (a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.

RGB image
Salt & pepper noise
in Green channel

noise spreads to all HSI component images



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original image

a b
c d

FIGURE 6.51 Color image compression. (a) Original RGB image. (b) Result of compressing and decompressing the image in (a).

compressed and decompressed using JPEG 2000

slight blurring due to lossy technique