EE 5098 – Digital Image Processing

6. Color Image Processing: Fundamentals

Source: [F. Liu], [O. Alkadi]

Color Image Processing

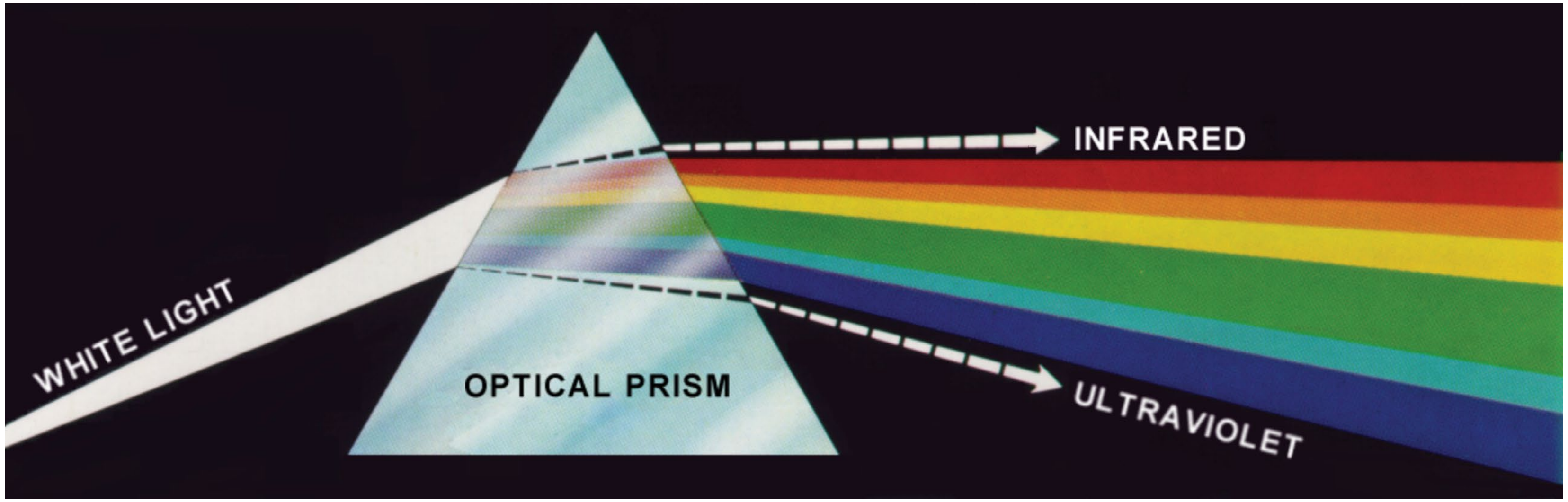
- Motivations for color image processing
  - Color is a powerful descriptor that often simplifies object identification and extraction from a scene.
  - Humans can discern thousands of color shades and intensities (compared to only two dozen shades of gray!).
- Two major areas
  - Full-color processing: images are acquired with a full-color sensor
  - Pseudo-color processing: a color is assigned to a particular monochrome intensity or range of intensities
- In the past, most digital image color processing was done at the pseudo-color level
- Today, full-color image processing techniques are used in a broad range of applications
- Stress the importance of color appearance models for image processing

Color Fundamentals

- Perception and interpretation of color is a physiopsychological phenomenon that is not fully understood
- Sir Isaac Newton discovery in 1666 that color spectrum can be divided into 6 broad regions
  - Violet, blue, green, yellow, orange, and red.
- The colors that human perceive in an object are determined by the nature of the light reflected from that object.
  - Green objects reflect light with wavelengths in 500-570nm while absorbing most of the energy at other wavelengths
- Characterization of light is central to the science of color
  - Achromatic light
  - Chromatic light

Color Spectrum

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



Chromatic Light

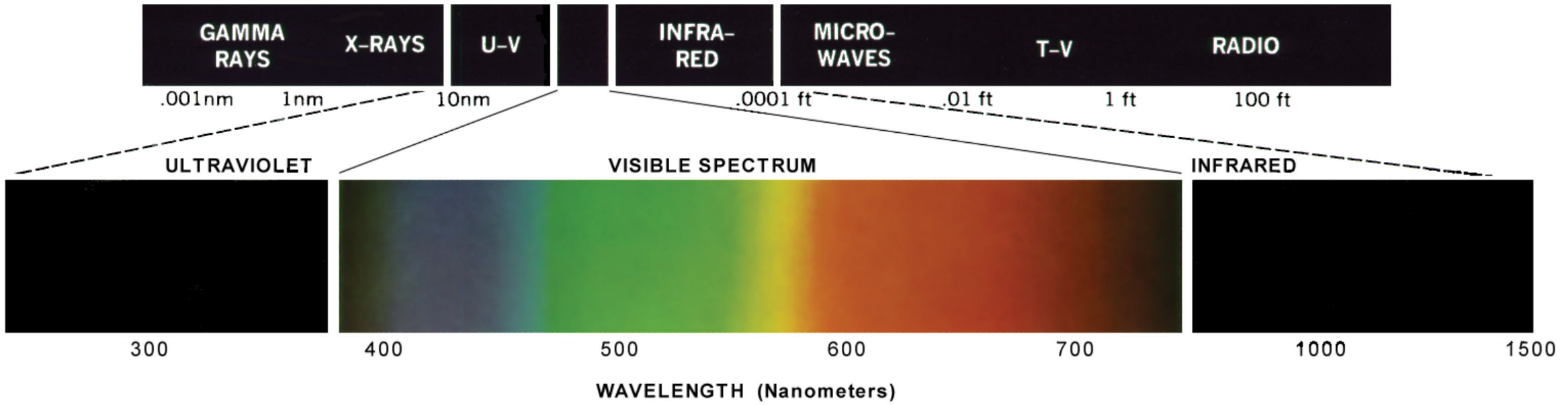
- Chromatic light spans the EM spectrum from 400nm to 700nm
- 3 basic quantities to describe the quality of a chromatic light source
  - Radiance(W): total amount of energy that flows from the light source.
  - Luminance(lm): the amount of energy an observer perceives from a light source.
  - Brightness: a subjective descriptor that is impossible measure in partice.
- Example: light emitted from a source operating in the far infrared region
  - Radiance: significant!
  - Luminance: hardly perceived!
- The cones are responsible for color vision
  - 65% are sensitive to red light.
  - 33% are sensitive to green light.
  - 2% are sensitive to blue light (blue cones are the most sensitive)

source發出多少能量

人看到多少能量

Visible Spectrum

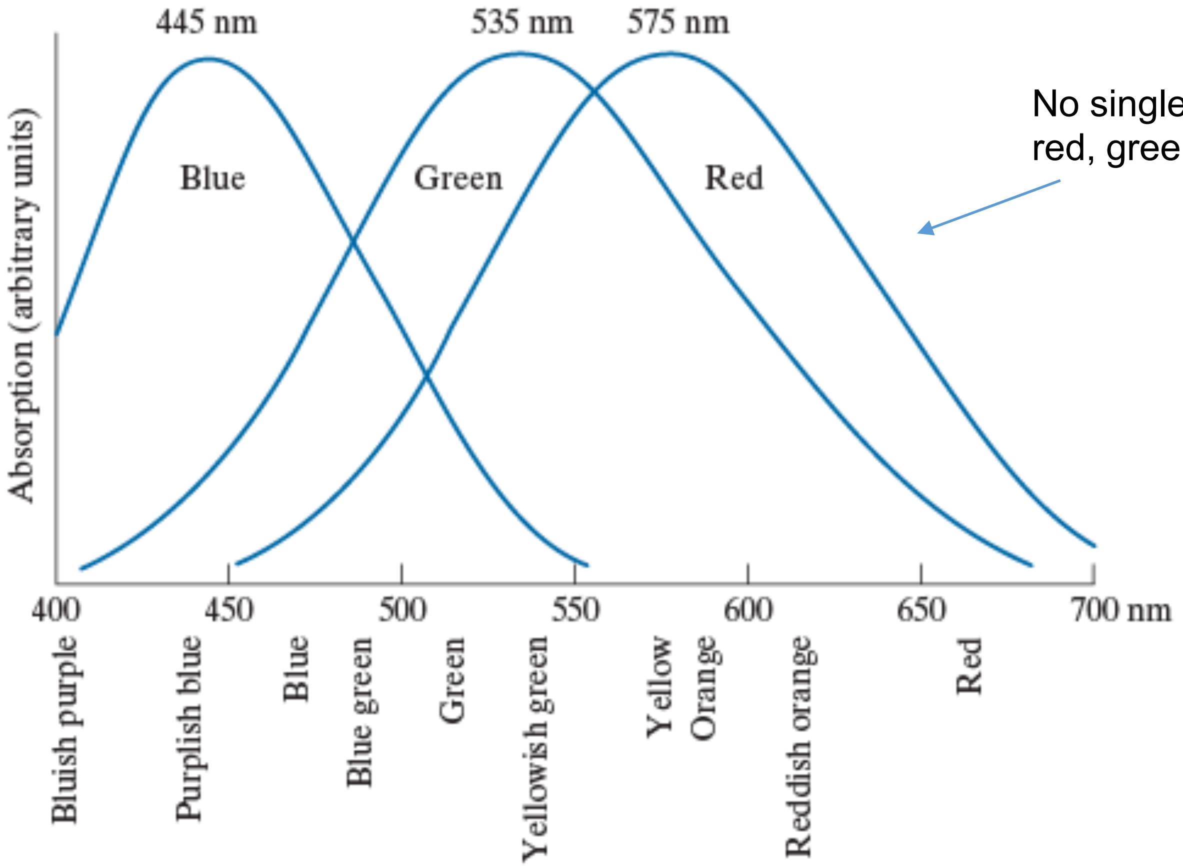
FIGURE 6.2
Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)



Absorption of Light by the Cones

- 6 to 7 million cones in the human eye can be divided into three principal sensing categories, corresponding roughly to red, green, and blue.

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

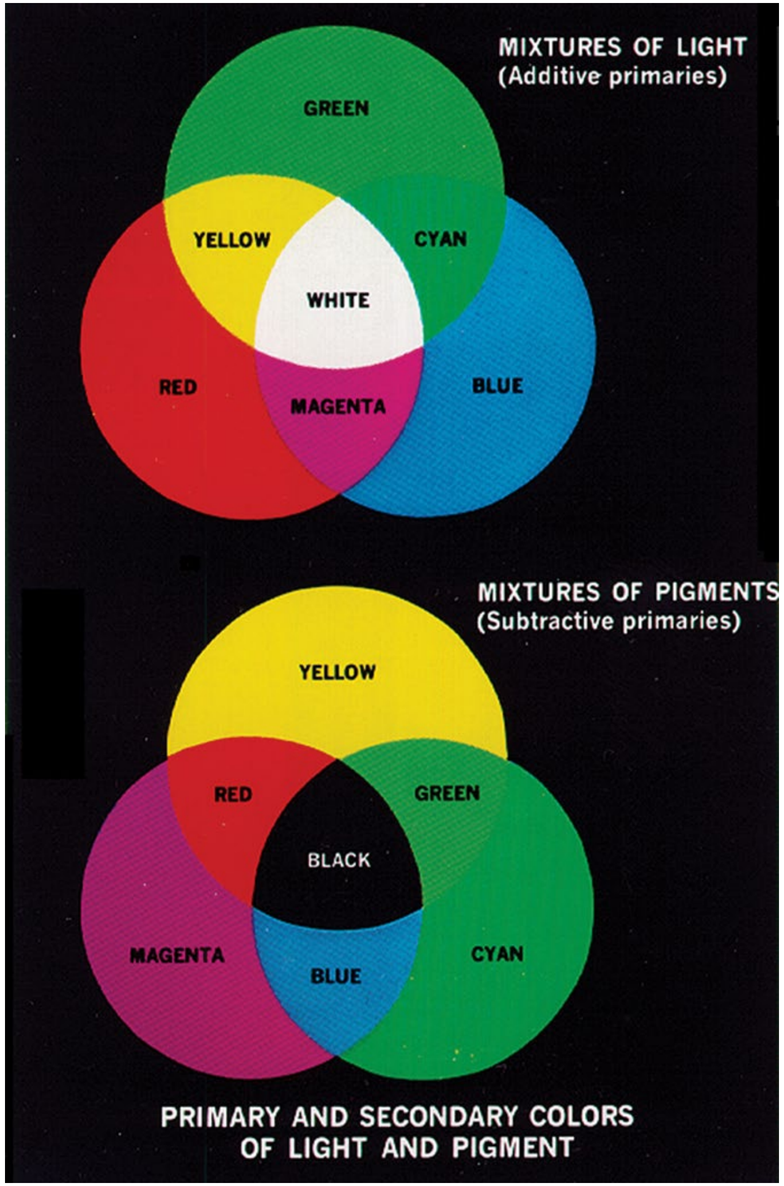


No single color may be called red, green, or blue.

Primary and Secondary Colors of Light

a
b

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



Primary colors are mixed to produce secondary colors of light (magenta, cyan, yellow).

Secondary colors are mixed to produce primary colors of light (red, green, blue).

Tristimulus

- The amounts of red, green, and blue needed to form any particular color are denoted X, Y, and Z, respectively. A color is then specified by its trichromatic coefficients, defined as

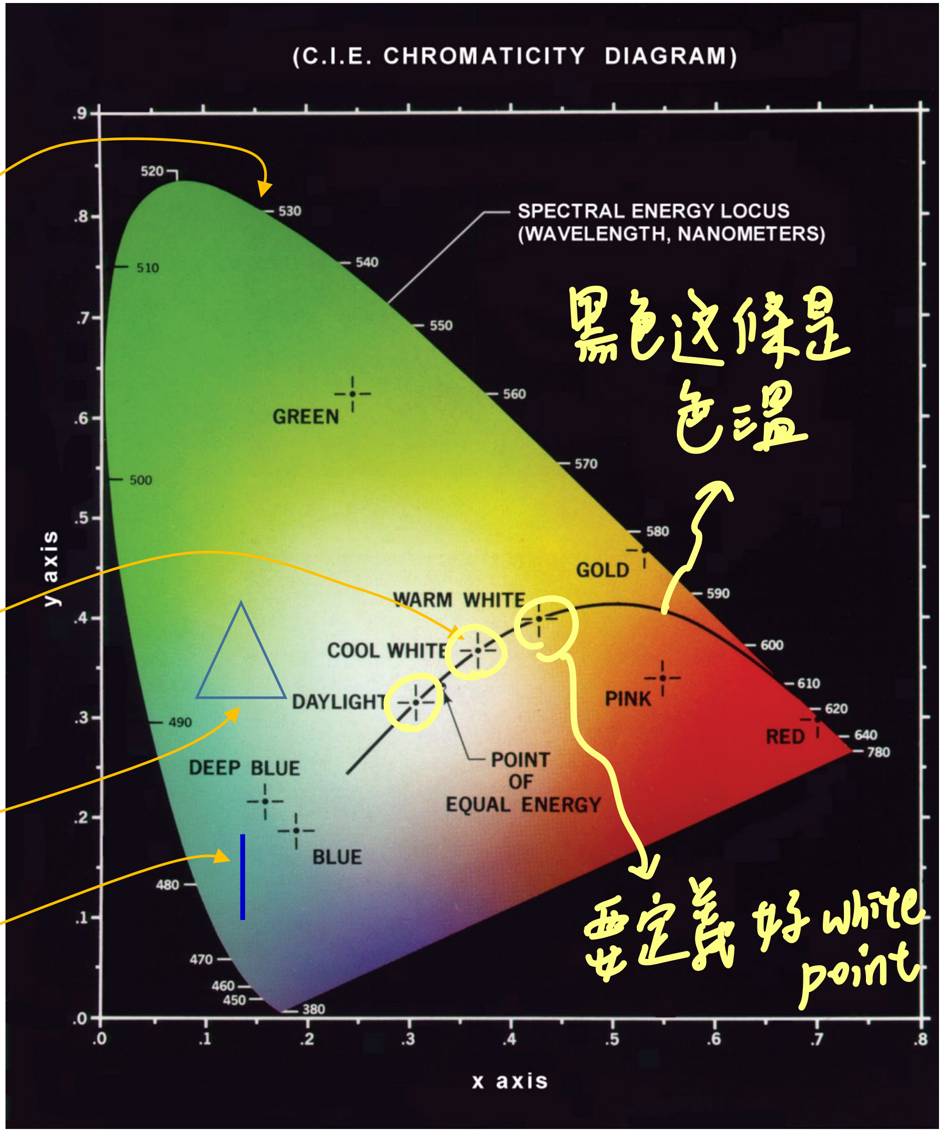
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

CIE Chromaticity Diagram

- It shows color composition as a function of x (red) and y (green)
- The positions of various spectrum colors –from violet at 380 nm to red at 780 nm—are indicated around the boundary. These are the “pure colors” shown in Fig. 6.2.
- Any point on the boundary is fully saturated. As a point leaves the boundary and approaches the white point, it becomes less saturated.
- The point of equal energy in the chromaticity diagram represents the CIE standard for white light.
- Any color in the triangle can be produced by various combinations of the corner colors.
- A straight line segment joining any two points in the chromaticity diagram defines all color variations that cab be obtained by combining the two colors.



Color Gamut of Color Monitors

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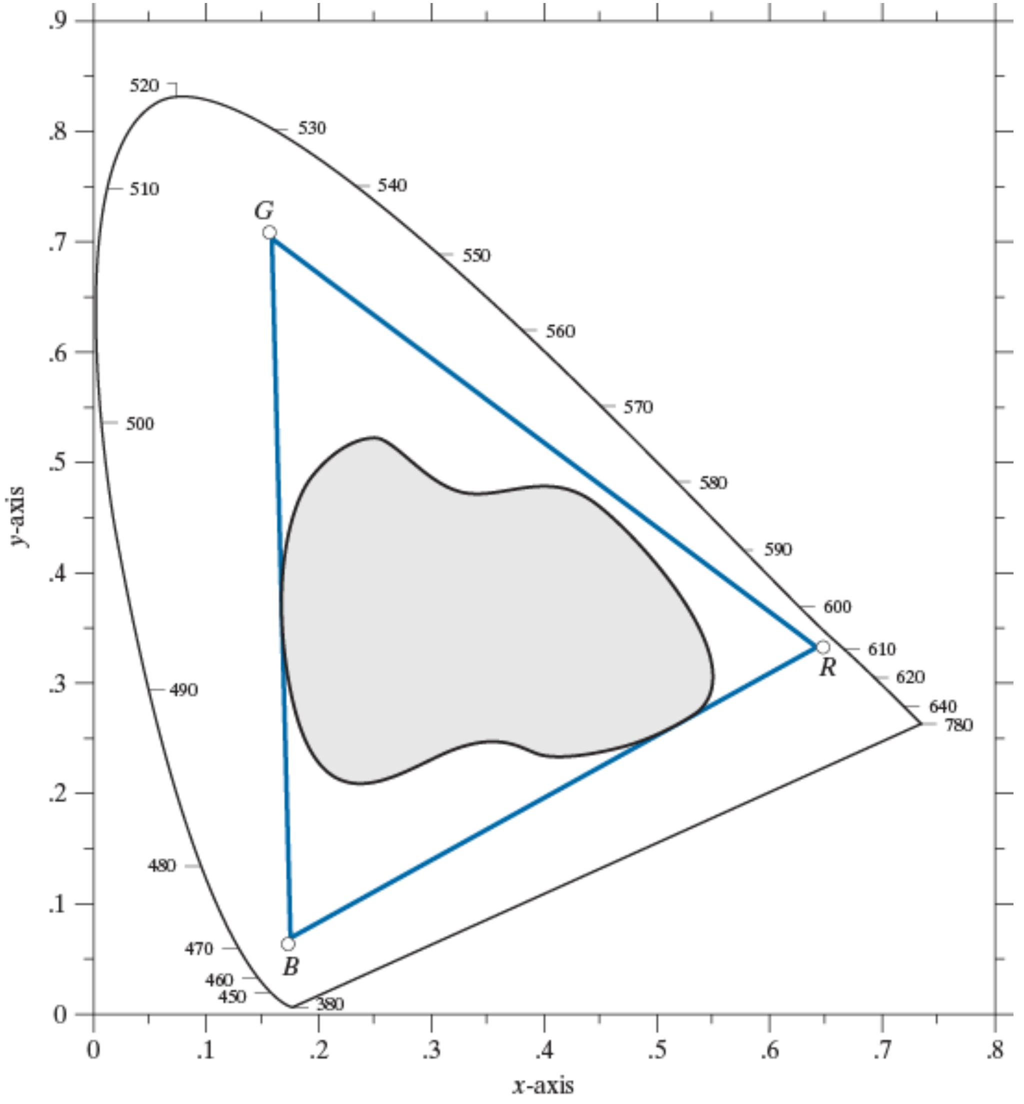
FIGURE 6.6 Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).



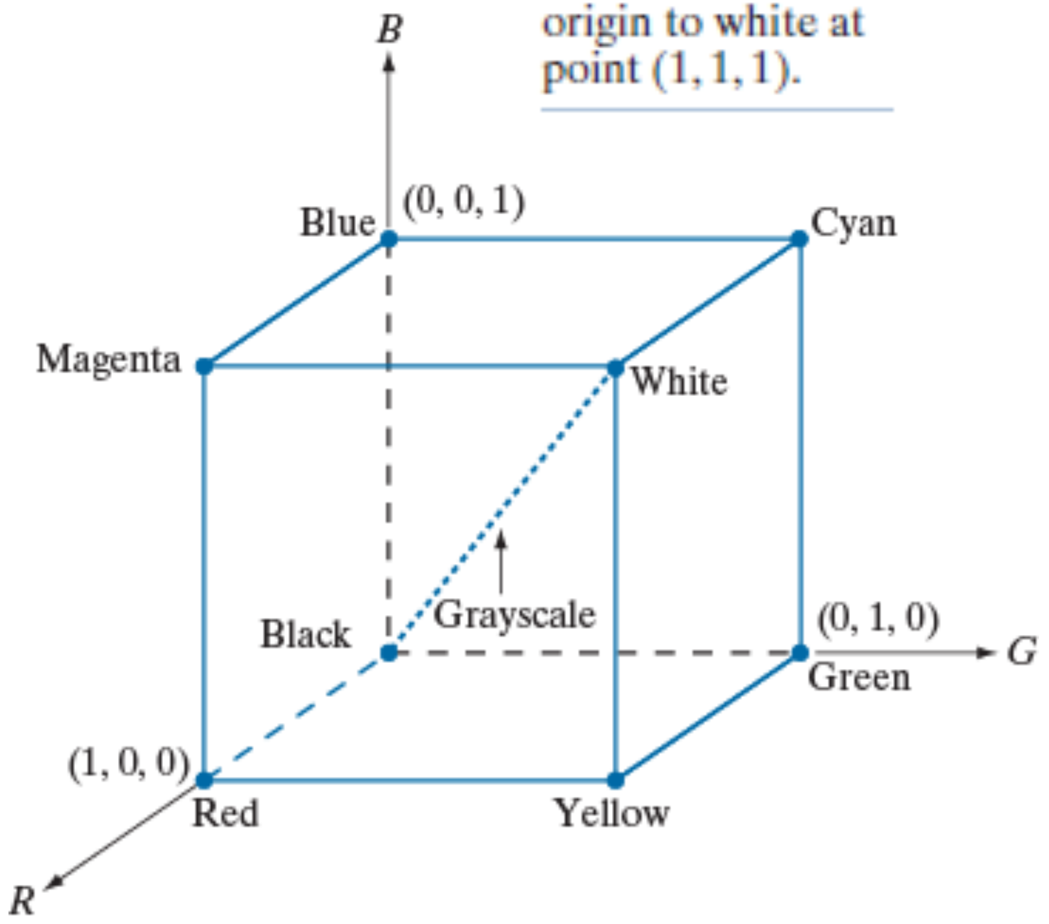
Color Models

- A color model (aka color space or color system) is a specification of colors in a standard way
  - A coordinate system and a subspace where each color is represented by a single point
- Most color models are oriented towards hardware or applications where color manipulation is needed.
- Hardware-oriented color models for DIP
  - RGB (red, green, blue) model for color monitors and cameras
  - CMY (cyan, magenta, yellow) model for printing
  - CMYK (cyan, magenta, yellow, black) model for printing
  - HSI (hue, saturation, intensity) model for color interpretation

RGB Color Model

- The color subspace is a unit cube (Fig. 6.7)
- Different colors represented in this model are on or inside the cube
- RGB primary colors are at three corners
- Black is at the origin; white at the opposite corner
- The secondary colors are at the other three corners
- Points of equal RGB values (grayscale) are along the diagonal line segment joining black and white

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).

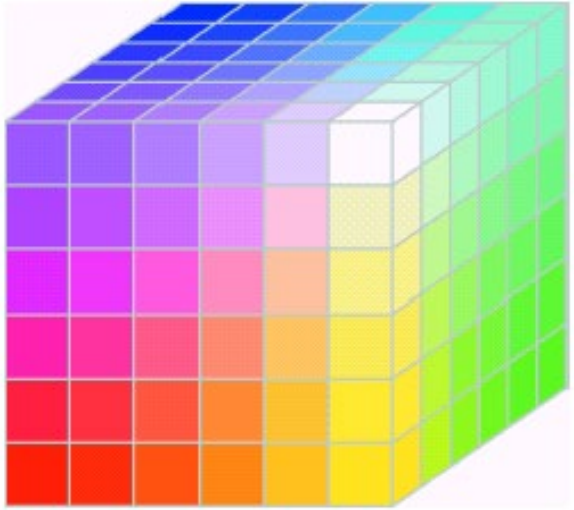


RGB Color Cube

FIGURE 6.8
A 24-bit RGB color cube.

Pixel depth: the number of bits used to represent each pixel

The total number of colors in a 24-bit RGB image is $(2^8)^3 = 16{,}777{,}216$



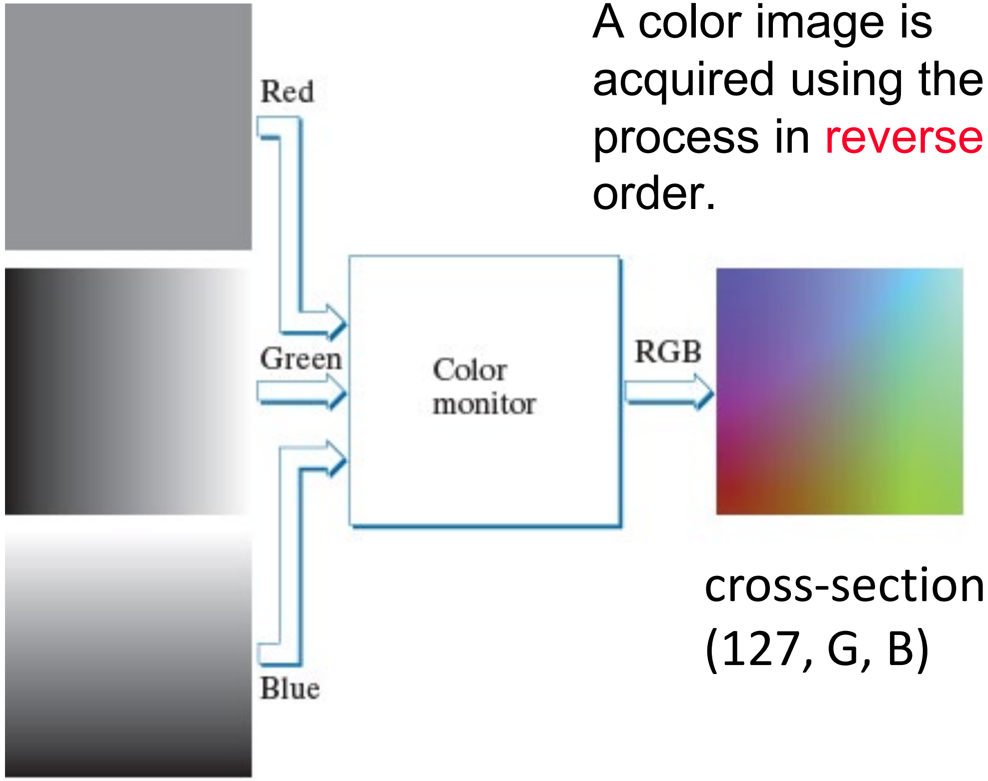
Safe RGB color cube

Each surface has 36 colors.
Total 6x36 = 216 colors

Generating a Cross-Section of the RGB Color Cube

Three monochrome images

In general, a color image is represented by three monochrome images



A color image is acquired using the process in reverse order.

cross-section (127, G, B)

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

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.

CMY and CMYK Color Models

- Most devices (color printers, copiers, etc.) that deposit color pigments on paper require CMY data input or perform an internal RGB to CMY conversion.
- Equal amounts of the pigment primaries, cyan, magenta, and yellow should produce black. In practice, however, combining these colors for printing produces a muddy-looking black.
- To produce true black, the predominant color in printing, the fourth color, black, is added, giving rise to the CMYK color model.
- RGB to CMY conversion (all color values are in the range [0,1])

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

Light reflected from a surface coated with pure cyan does not contain red

Light reflected from a surface coated with pure magenta does not contain green

Light reflected from a surface coated with pure yellow does not contain blue

K就是printer print的黑色

CMY vs. CMYK

Original color image

Conversion from CMY to CMYK:

$$K = \min(C, M, Y)$$

$$\text{If } K = 1 \;\Rightarrow\; C = M = Y = 0$$

Otherwise,

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \frac{1}{1-K} \begin{bmatrix} C-K \\ M-K \\ Y-K \end{bmatrix}$$

CMY

CMYK

Source: http://en.wikipedia.org/wiki/CMYK

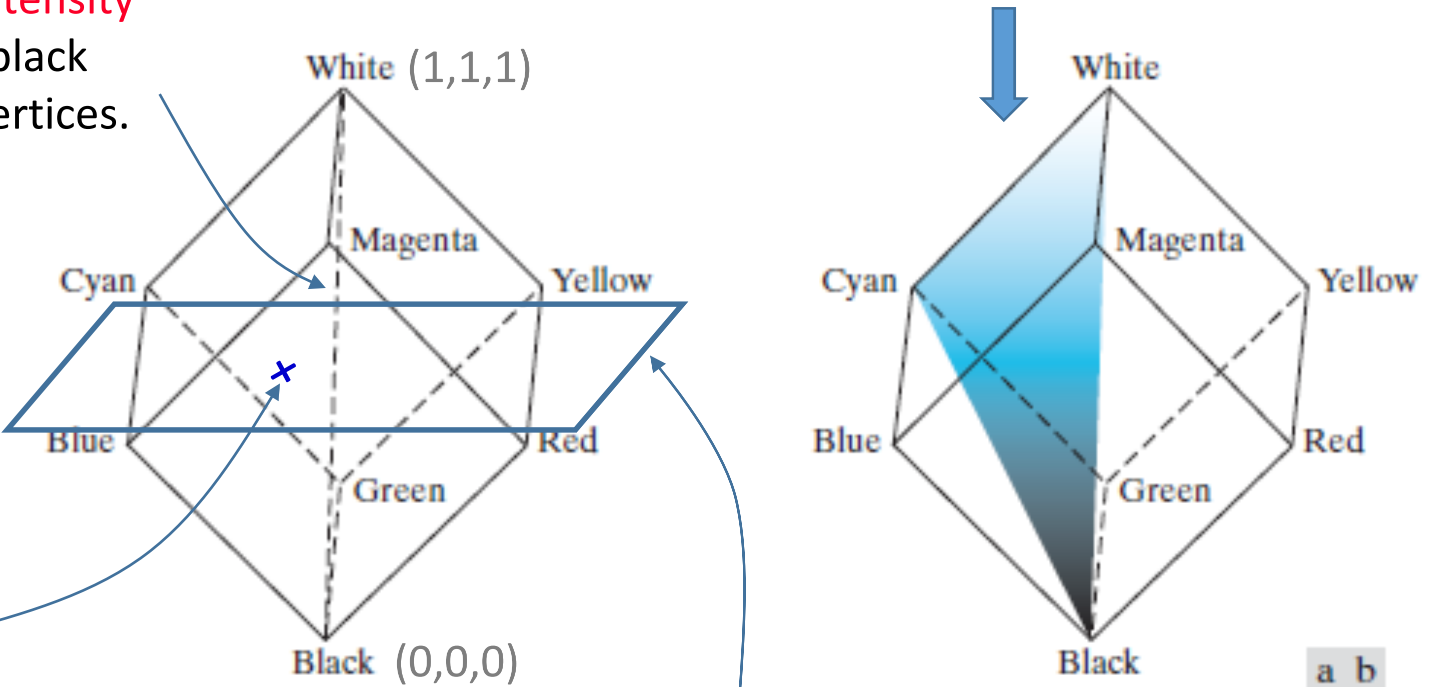
HSI Color Model

- RBG and CMY are suitable for hardware implementations. Unfortunately, they are not good for describing colors for human interpretation. (One does not refer to the color of a car by giving the % of each of the primaries!)
- Humans describe a color object by its hue, saturation, and brightness.
  - Hue: a color attribute that describes a pure color; dominant color as perceived by an observer
  - Saturation: gives a measure of the degree to which pure color is diluted by white light
  - Brightness: a subjective descriptor that is practically impossible to measure
- The HSI model decouples the intensity component from the color-carrying information (hue & saturation).

Conceptual Relationship between RGB and HSI

In this plane segment, all the points have the same hue but different saturation and intensity.

This is the intensity axis joining black and white vertices.



The intensity component of this color point can be determined by passing a plane perpendicular to the intensity axis and containing the point.

As the plane moves up and down, the boundary defined by the intersection of each plane with the faces of the cube have either a triangular or hexagonal shape.

a b

FIGURE 6.10 Conceptual relationships between the RGB and HSI color models.

Hue and Saturation in the HSI Color Model

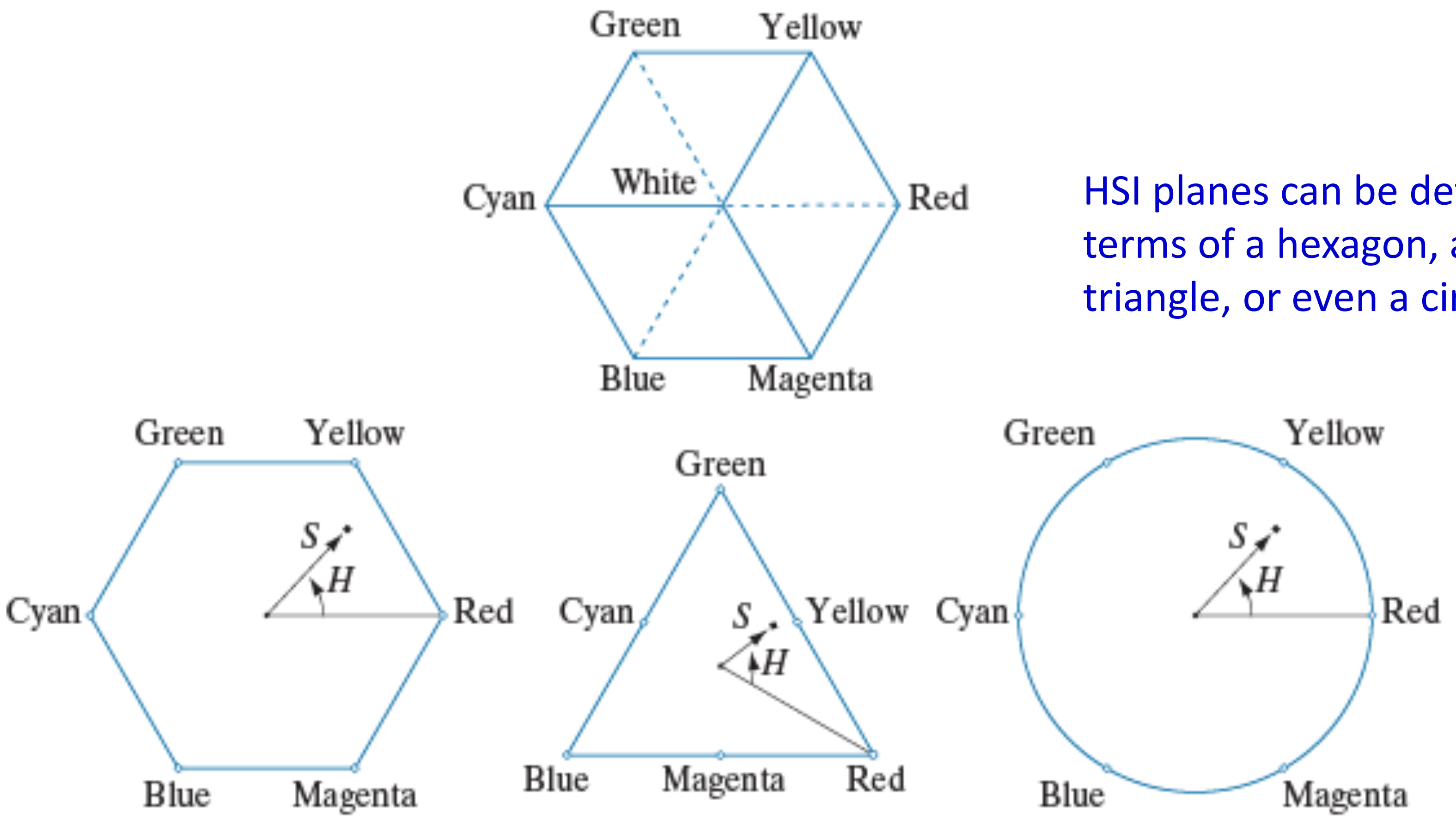


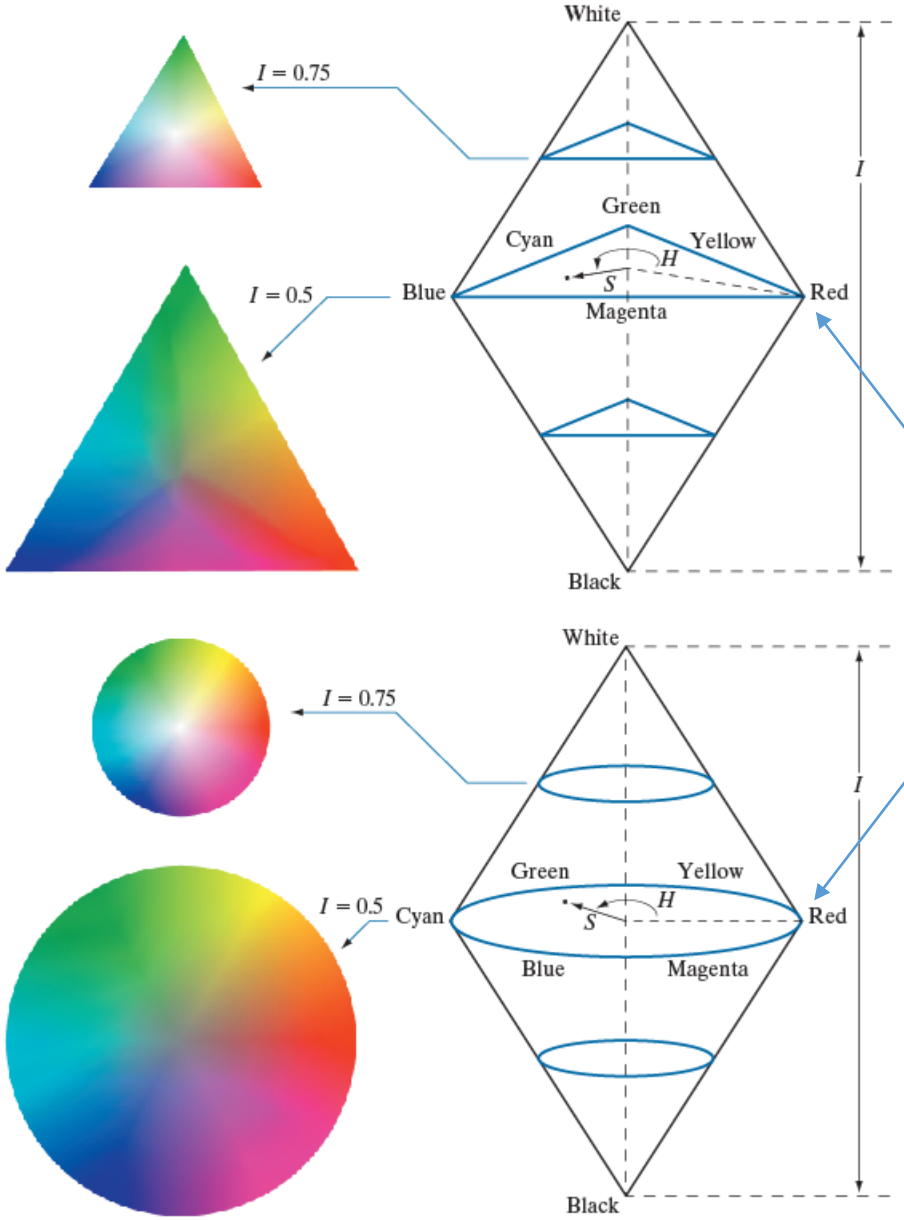
FIGURE 6.11 Hue and saturation in the HSI color model. The dot is any color point. The angle from the red axis gives the hue. The length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

HSI planes can be defined in terms of a hexagon, a triangle, or even a circle.

Triangular and Circular Color Planes in the HSI Model

a
b

FIGURE 6.12 The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.



mid-point of the vertical intensity axis

RGB to HSI Conversion

- The RGB values have been normalized to the range [0, 1]

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

Can be normalized to the range [0,1] by diving all the values by 360.

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

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

HSI to RGB Conversion

- The HSI values are given in the interval [0,1]. The applicable equations depend on the values of H.
- RG sector ($0° \le H < 120°$)

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

- GB sector ($120° \le H < 240°$)

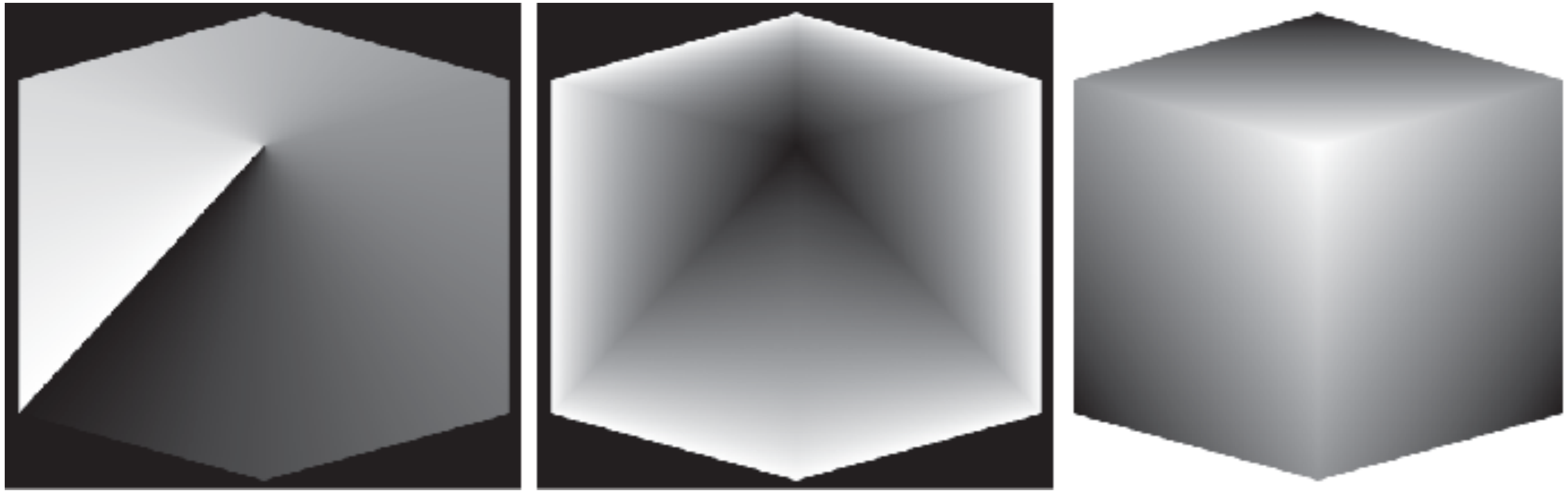
$$H = H - 120^\circ$$

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

- BR sector ($240° \le H < 360°$)

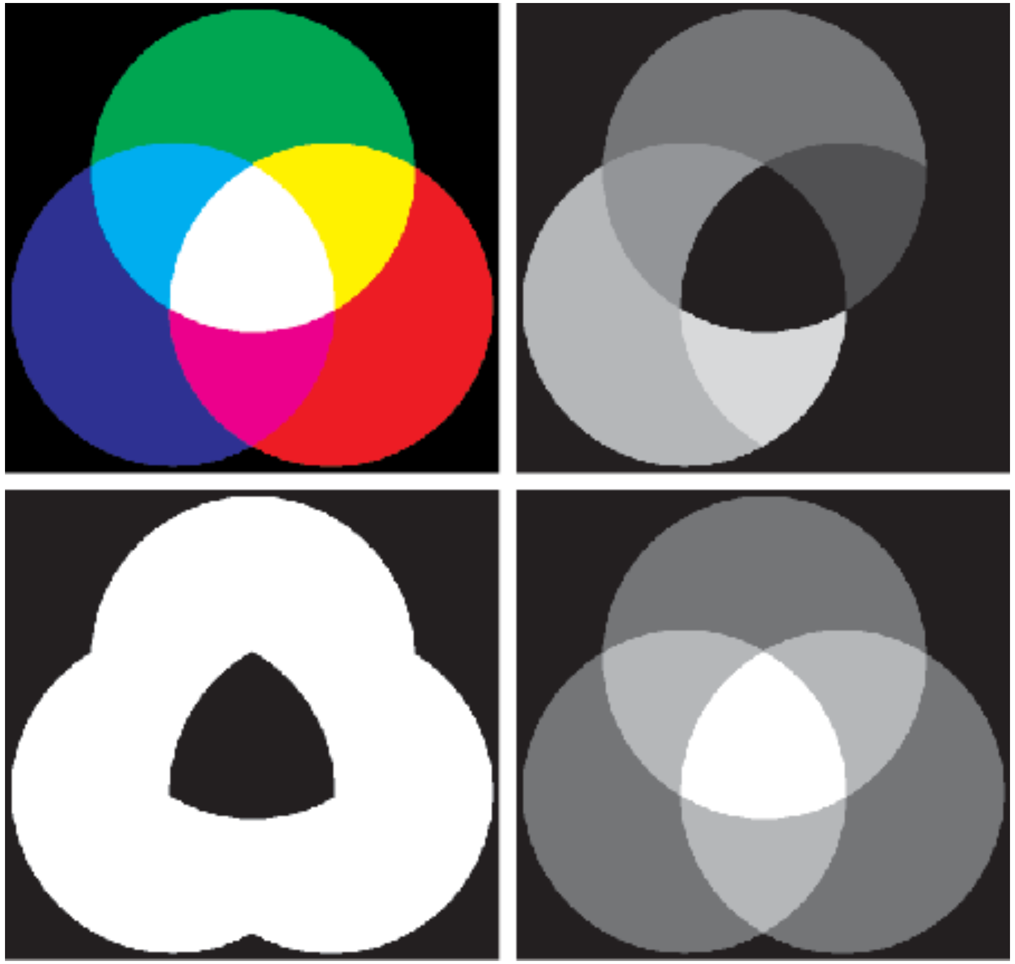
$$H = H - 240^\circ$$

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



a b c

FIGURE 6.13 HSI components of the image in Fig. 6.8: (a) hue, (b) saturation, and (c) intensity images.



a b
c d

FIGURE 6.14 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

CIE L*a*b* Model

- **Device-independent**

  Maintain color consistency between monitors and the eventual output devices (e.g. printers)

- **Colorimetric**

  Colors perceived as matching are encoded identically

- **Perceptually uniform**

  Color differences between various hues are perceived uniformly

From CIE XYZ to CIE L*a*b*:

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

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

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

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

X_W, Y_W, Z_W : reference white tristimulus values

L^*: intensity

a^*: the red–green opponent colors

b^*: the yellow–blue opponent colors

Pseudocolor Image Processing

- Pseudo-color image processing: assignment of colors to gray values based on a specified criterion.
- The principal use of pseudo-color is for human visualization and interpretation of gray-scale events in images because humans can discern thousands of color shades and intensities!
- Intensity slicing and color coding is a simple example of pseudo-color image processing.
  - Treat an image as a 3-D function.
  - Planes parallel to the coordinate plane are used.
- More general transformations achieve a wider range of pseudo-color enhancement results.

Intensity Slicing

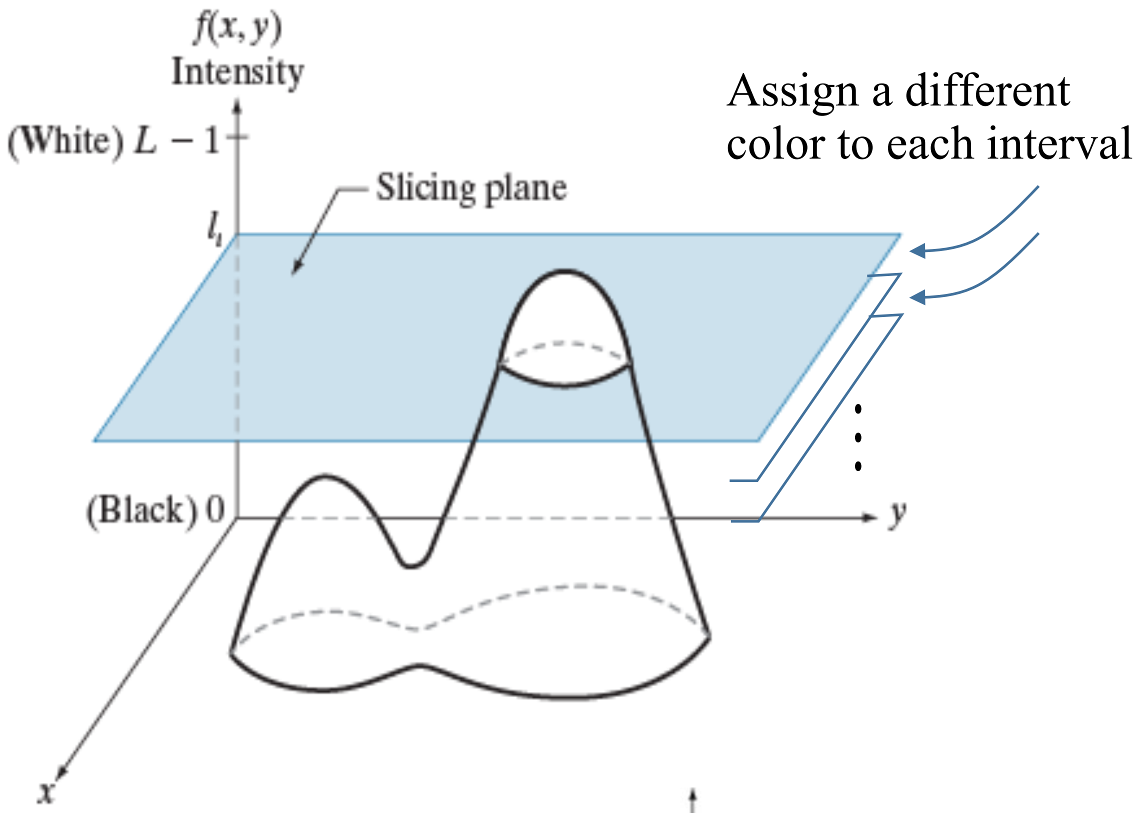


FIGURE 6.16 Graphical interpretation of the intensity-slicing technique.

- L grayscales $[0, L-1]$.
- P plaines at levels $l_1, l_2, \ldots, l_P$.
- P+1 intervals $I_1, I_2, \ldots, I_{P+1}$.
- Assign color c_k to the kth intensity interval I_k defined by the planes at $l = k-1$ and $l = k$. That is,

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

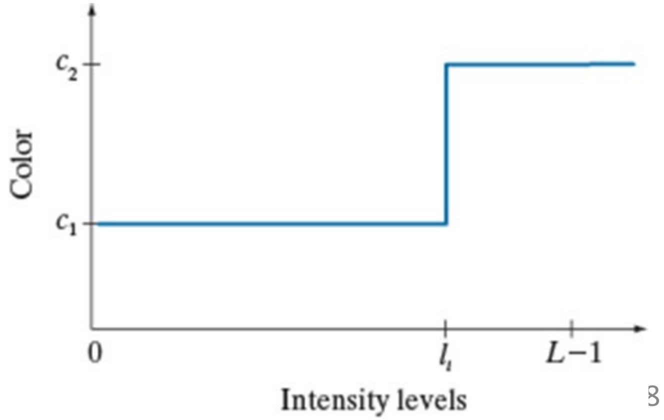
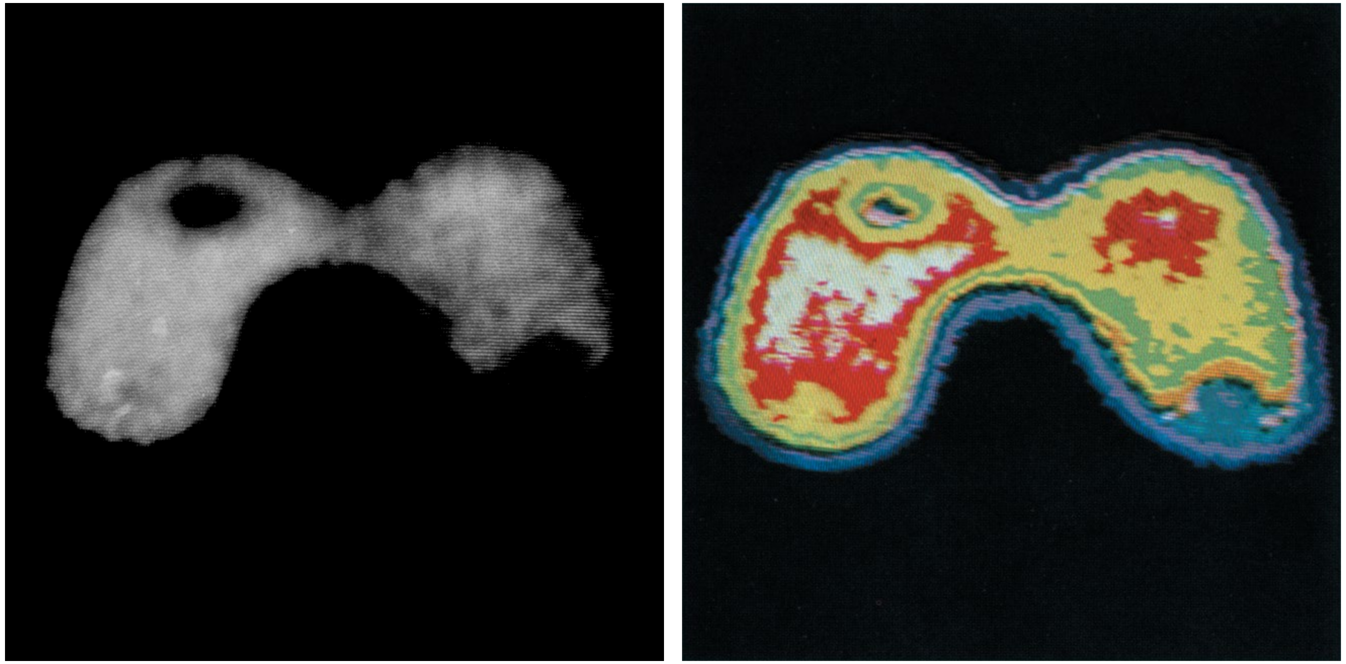


FIGURE 6.17 An alternative representation of the intensity-slicing technique.

a b

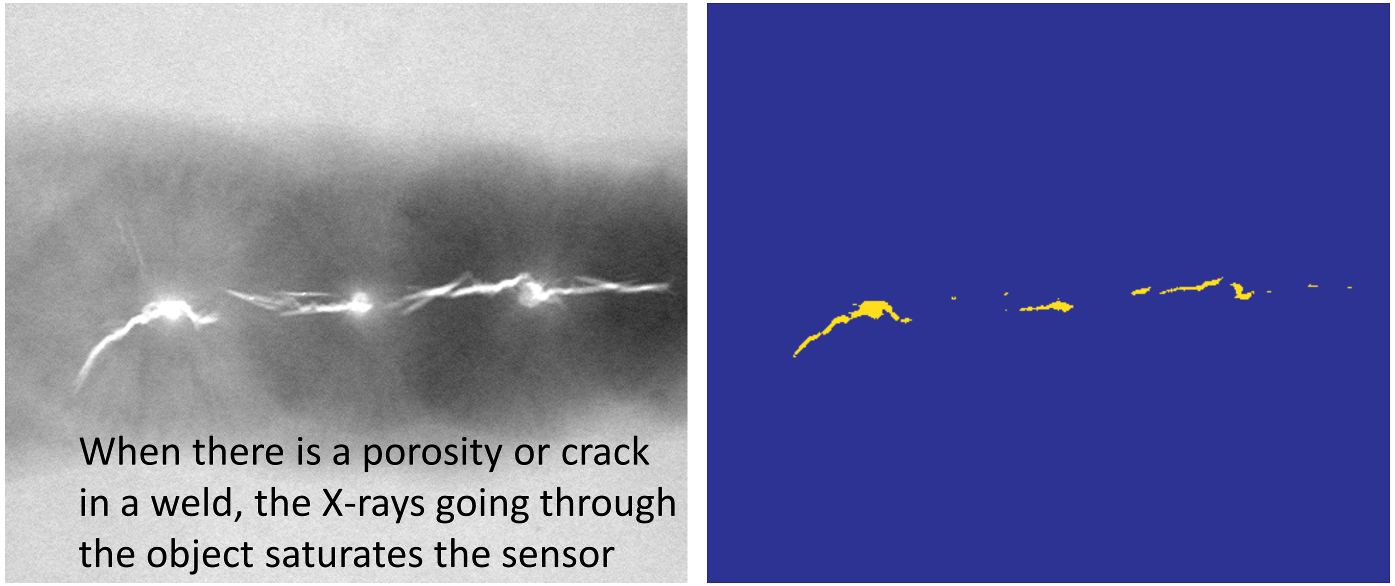
FIGURE 6.18 (a) Grayscale image of the Picker Thyroid Phantom. (b) Result of intensity slicing using eight colors. (Courtesy of Dr. J. L. Blankenship, Oak Ridge National Laboratory.)



A different color is assigned to each region without regard for the meaning of the gray levels in the image.

a b

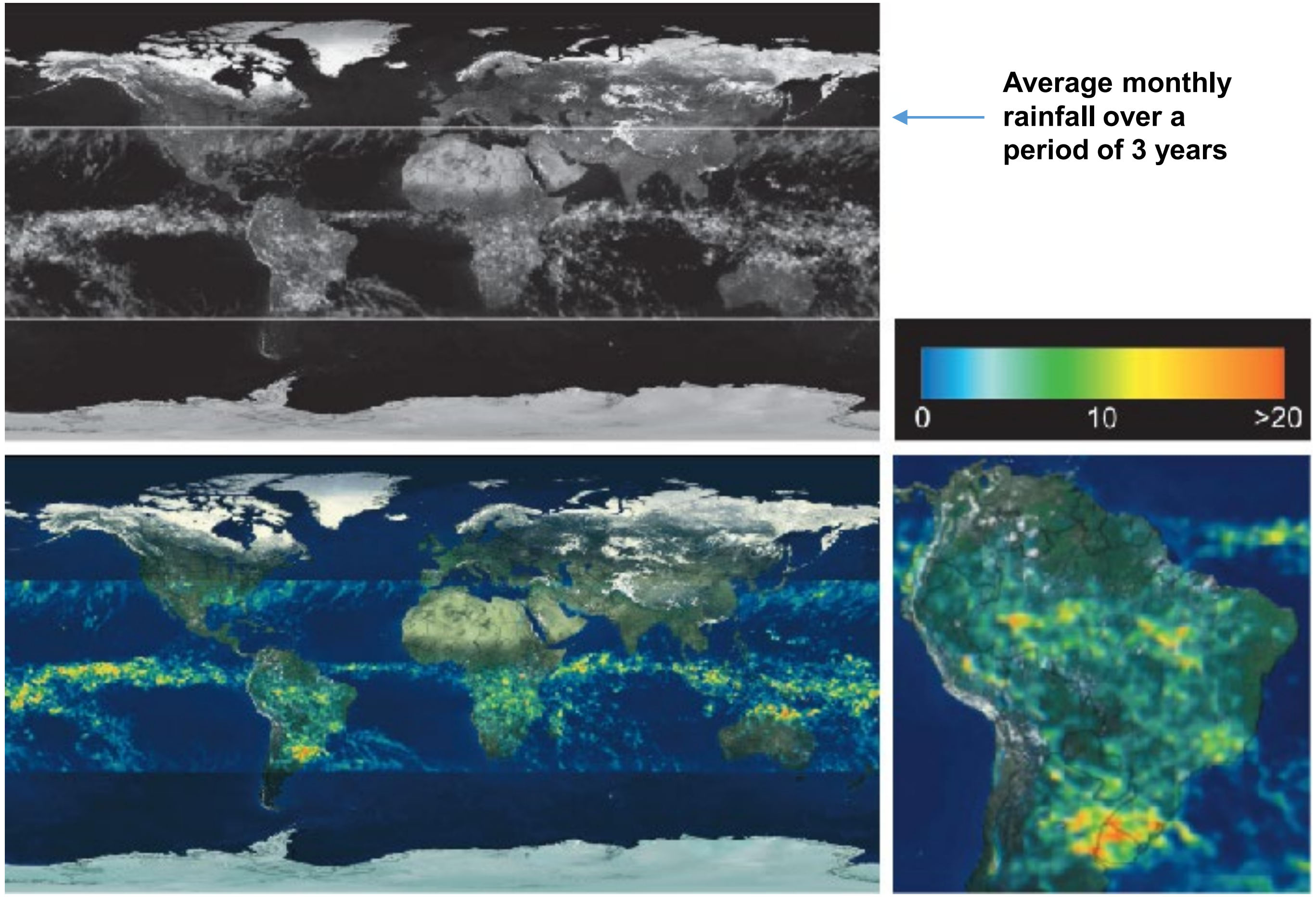
FIGURE 6.19 (a) X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)



If a human is the ultimate judge in inspecting welds, this simple color coding would result in lower error rates!

Using Color to Highlight Rainfall Levels

Average monthly rainfall over a period of 3 years



Much easier to interpret

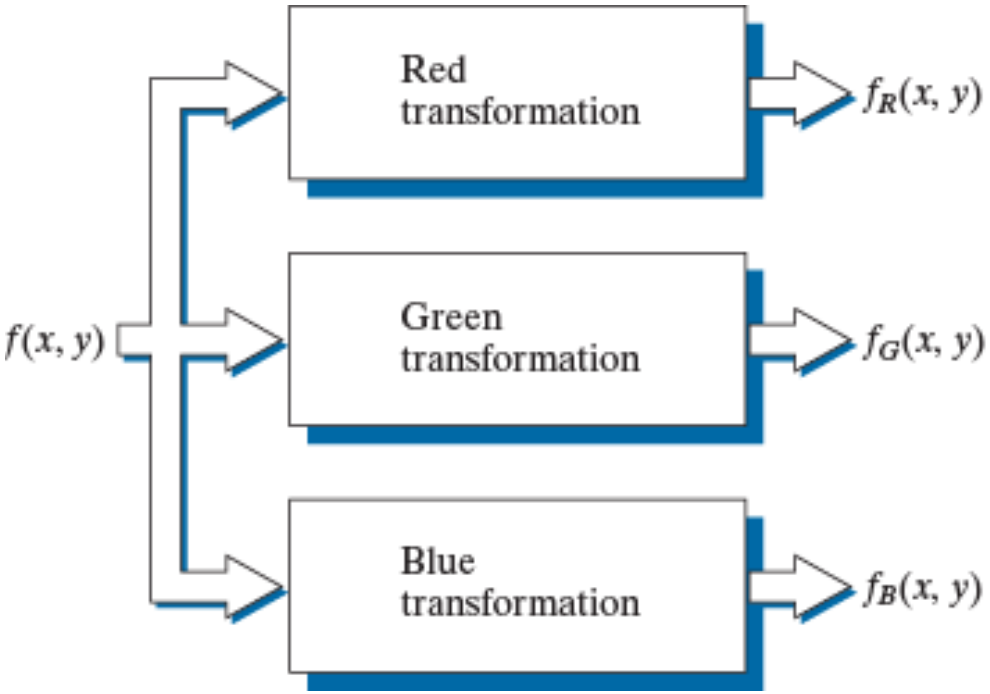
a b
c d

FIGURE 6.20 (a) Grayscale image in which intensity (in the horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

General Pseudocolor Image Processing

Three independent transformations

FIGURE 6.21 Functional block diagram for pseudocolor image processing. Images f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

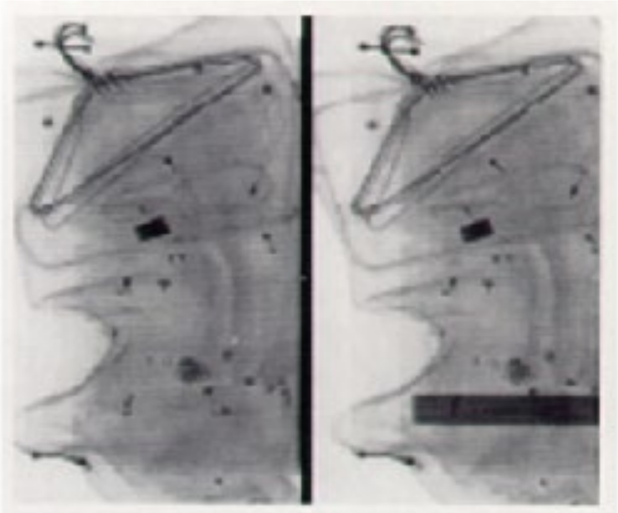


Pseudocolor Enhancement Example

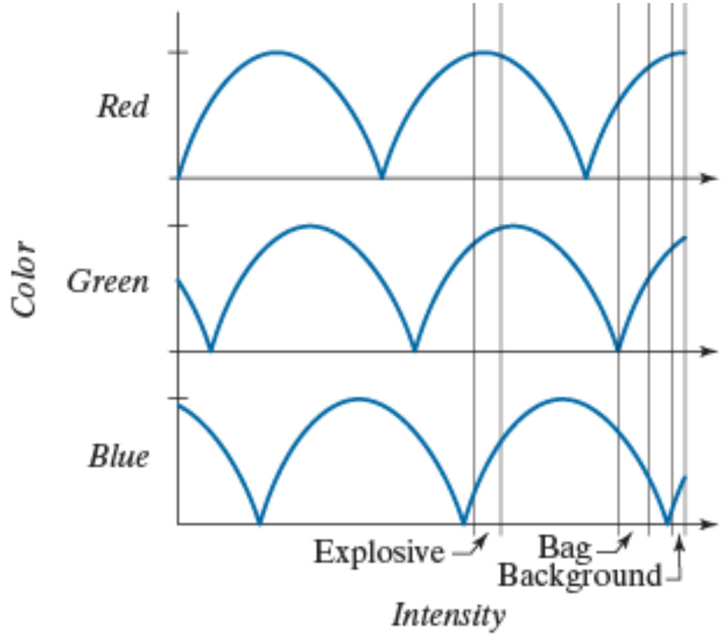
a
b c

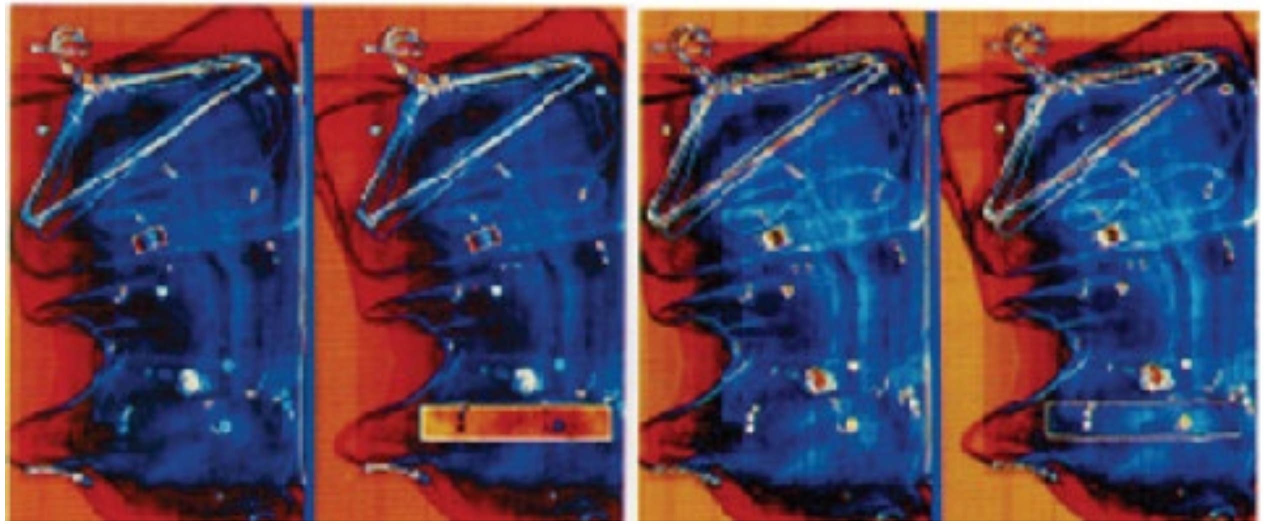
FIGURE 6.22 Pseudocolor enhancement by using the gray level to color transformations in Fig. 6.23. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

Images obtained from an airport X-ray scanning system



Plastic explosives





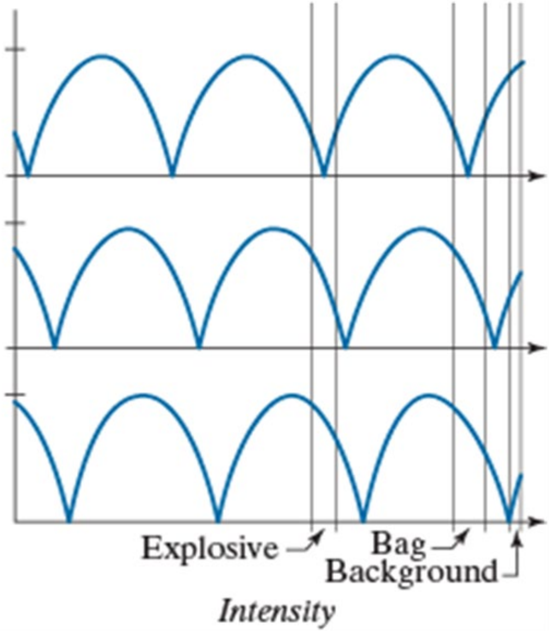
Same color for the explosives and background

Same color for the explosives and garment bag

a b

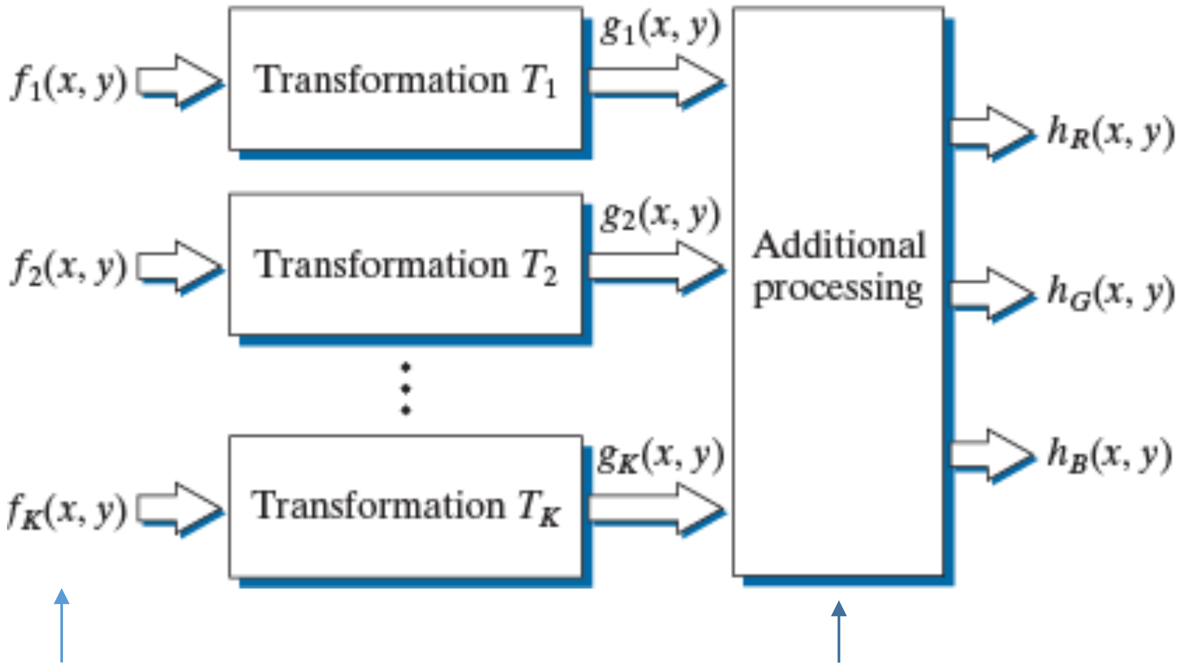
FIGURE 6.23 Transformation functions used to obtain the pseudocolor images in Fig. 6.22.

Change freq. and phase of these functions



Combination of Monochrome Images into One Color Image

FIGURE 6.24 A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.



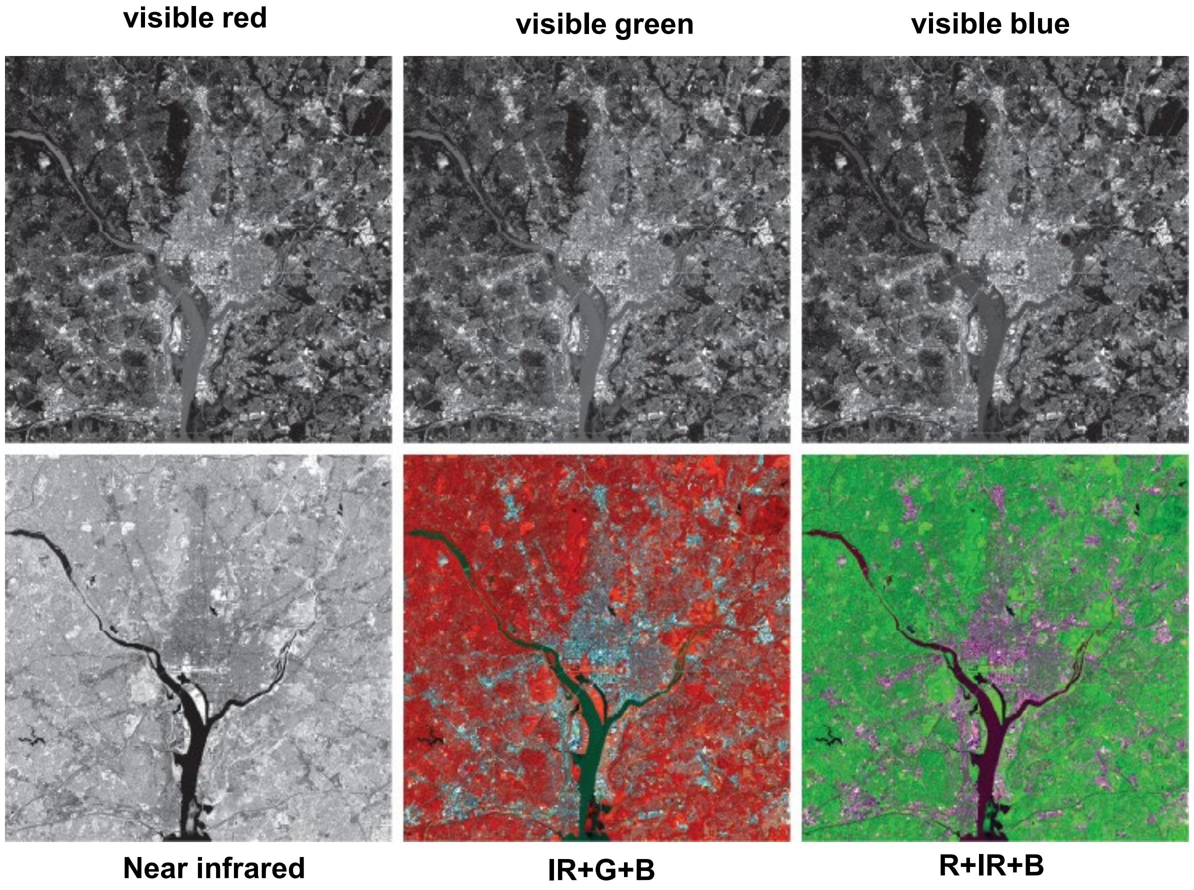
Produced, for example, by multispectral sensors

Color balancing, spatial filtering, etc.

Three Monochrome Images Are Combined

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.



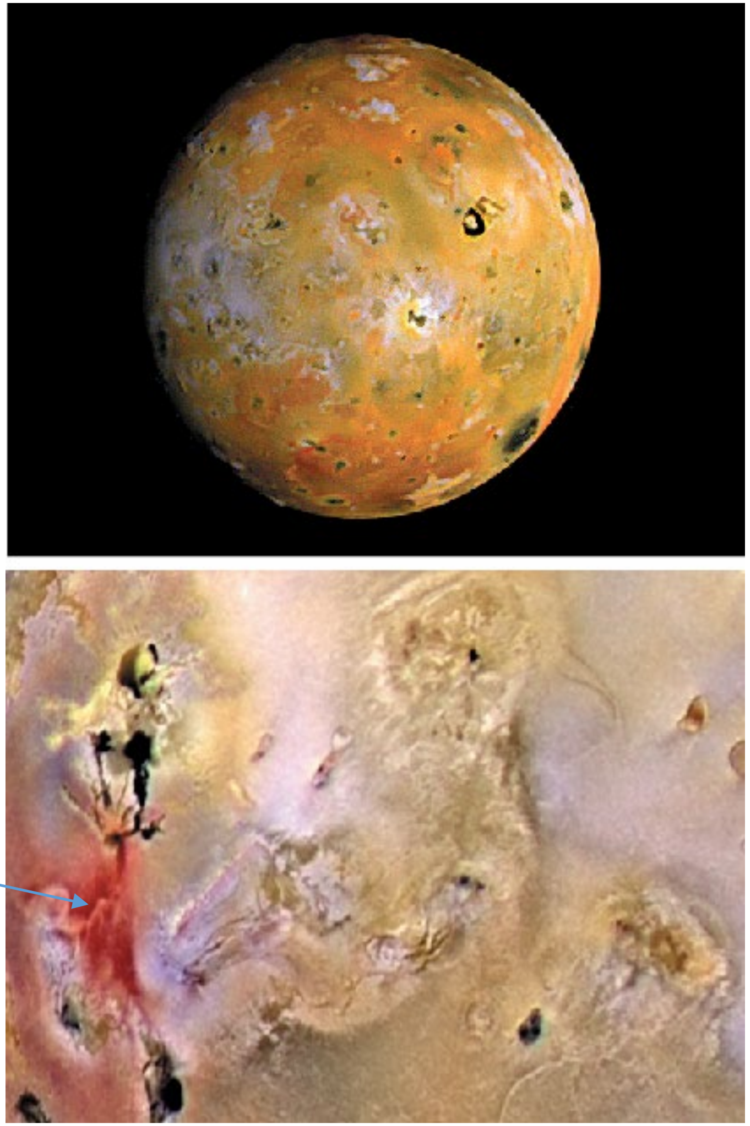
Note that the infrared band is strongly responsive to the biomass components in a scene

a b c
d e f

FIGURE 6.25 (a)–(d) Red (R), green (G), blue (B), and near-infrared (IR) components of a LANDSAT multispectral image of the Washington, D.C. area. (e) RGB color composite image obtained using the IR, G, and B component images. (f) RGB color composite image obtained using the R, IR, and B component images. (Original multispectral images courtesy of NASA.)

Combining Images from a Spacecraft

Combining several sensor images from the Galileo spacecraft, some of which are in spectral regions not visible to the eye.



a
b

FIGURE 6.26 (a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)

Bright red depicts materials newly ejected from an active volcano.

Surrounding yellow materials are older sulfur deposits.

Basics of Full-Color Image Processing

- Two major categories
  - Process each component image individually and form a composite color image from the components
  - Work directly with color pixels (which are vectors).
- For scalar- and vector-based processing to be equivalent, two conditions have to be met
  - The process has to be applicable to both scalars and vectors
  - The operation on each component of a vector must be independent of the other components

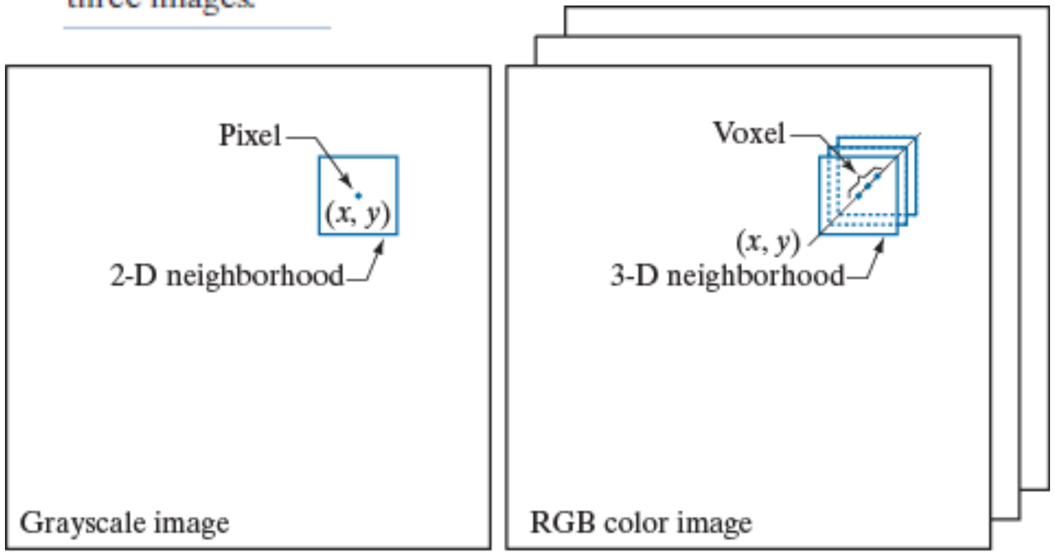
a b

FIGURE 6.27 Spatial neighborhoods for grayscale and RGB color images. Observe in (b) that a *single* pair of spatial coordinates, (x, y), addresses the same spatial location in all three images.

Example:

Suppose the process is neighborhood averaging.

Same result would be obtained using the scalar and vector methods.



Basics of Full-Color Image Processing

Let c represent an arbitrary vector in RGB color space:

$$c = \begin{bmatrix} c_R \\ c_G \\ c_B \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

At coordinates (x, y),

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

Color Transformation of an Image

- Color transformation within the context of a color model, not between color models
- $g(x,y) = T[f(x,y)]$: pixels values are triplets or quartets
- $s_i = T_i(r_1, r_2, \ldots, r_n)$
  - s_i and ri: variables denoting the color components
  - $\{T_1, T_2, \ldots, T_n\}$: set of transformation functions
  - For RGB color space, n=3.
  - For CMYK color space, n=4.
- Example:
  - $g(x,y)=kf(x,y)$, $0<k<1$: intensity modification
  - HSI color space: $s_3=kr_3$, $s_1=r_1$, $s_2=r_2$
  - RGB color space: $s_i=kr_i$, $i=1,2,3$
  - CMY color space: $s_i=kr_i+(1-k)$, $i=1,2,3$
  - In this case, although the HSI transformation involves **the fewest # of operations**, the computations required to convert an RGB or CMY(K) image **offsets more than the advantages!**

Color Space Components of a Full Color Image

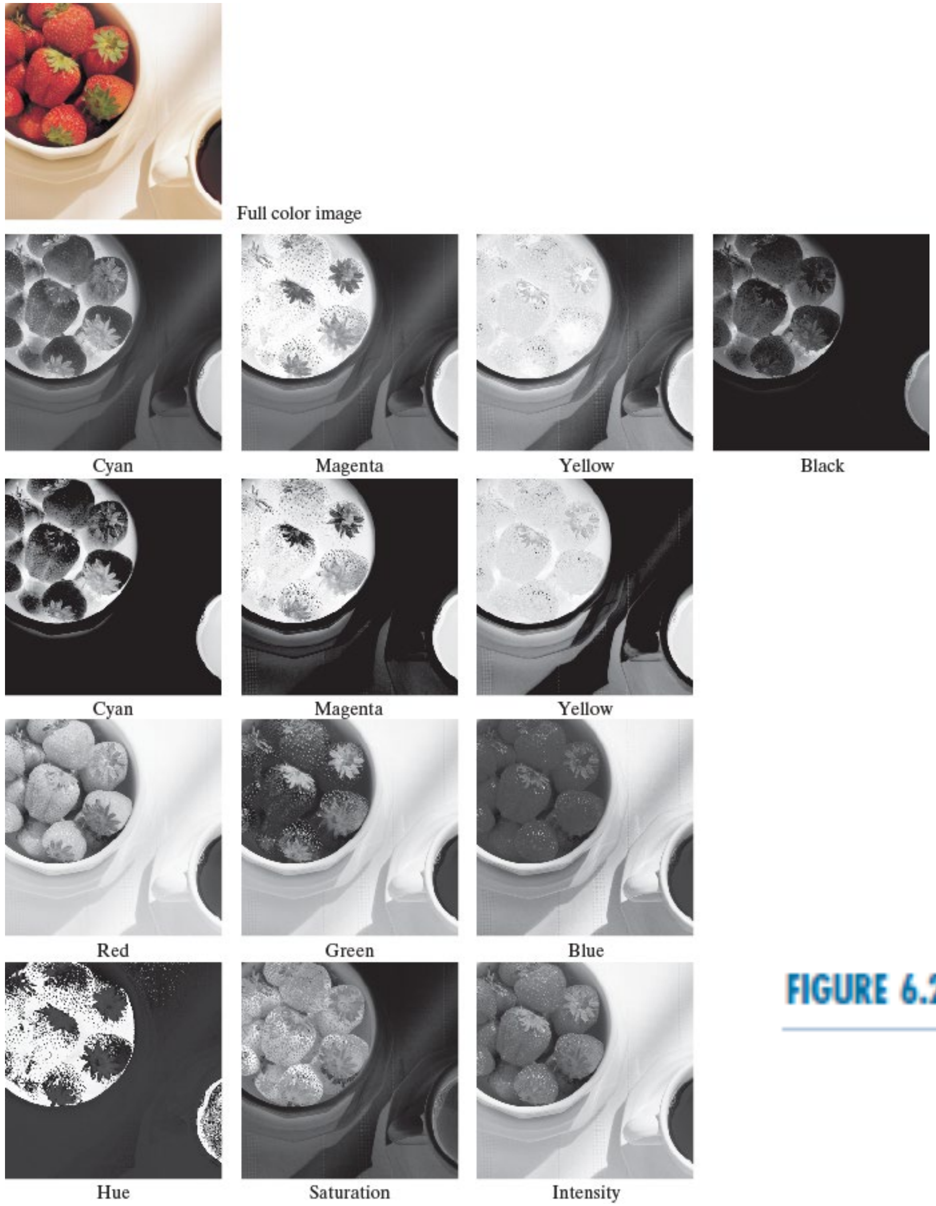


FIGURE 6.28 A full-color image and its various color-space components

(Original image courtesy of MedData Interactive.)

Modified Intensity of the Full Color Image

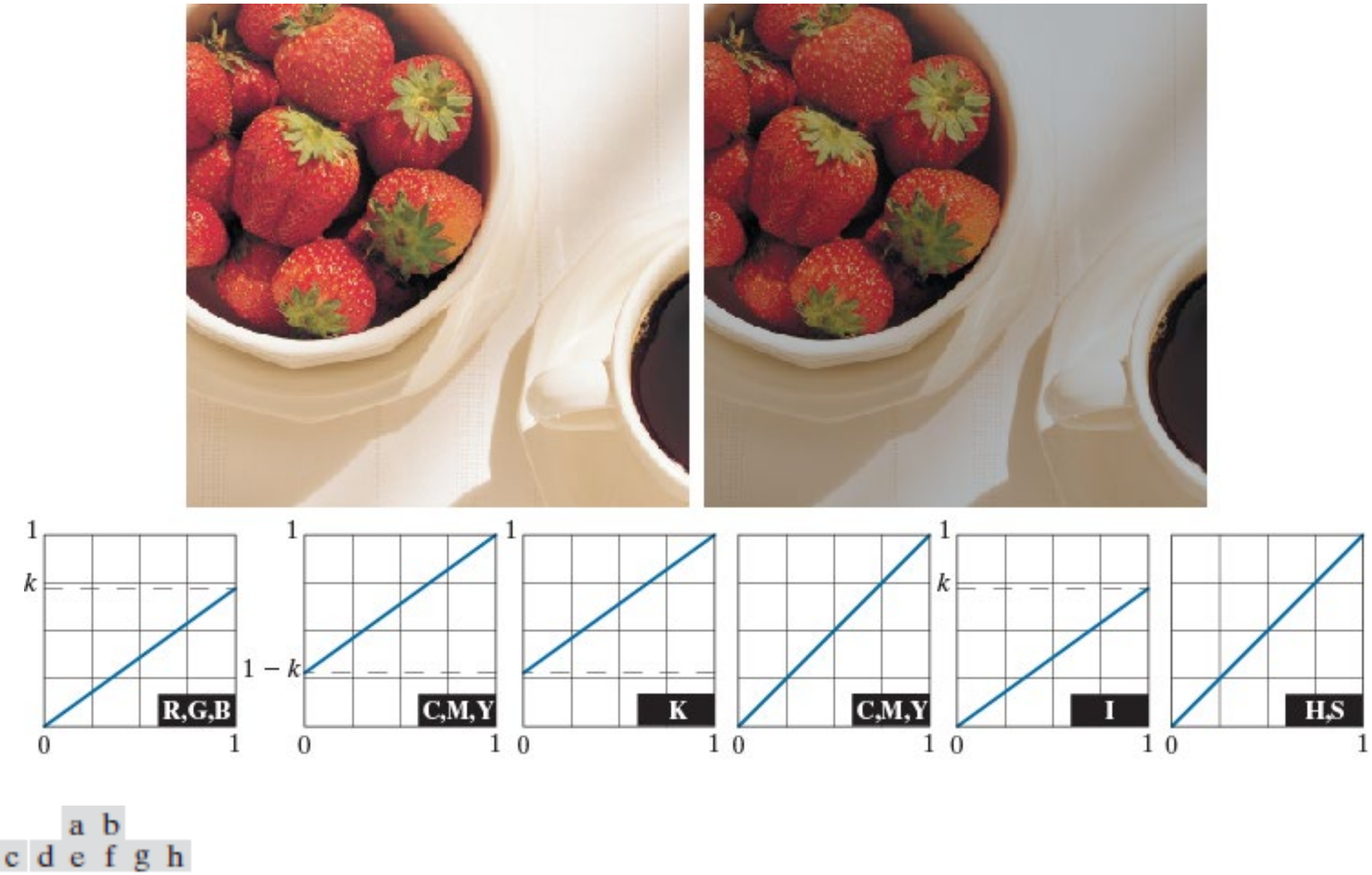


FIGURE 6.29 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c) The required RGB mapping function. (d)–(e) The required CMYK mapping functions. (f) The required CMY mapping function. (g)–(h) The required HSI mapping functions. (Original image courtesy of MedData Interactive.)

$$g(x, y) = kf(x, y),\ k = 0.7$$

RGB:

$$s_i = kr_i, \quad i = 1, 2, 3.$$

CMY:

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

$$C = 1 - R,\quad C' = 1 - R',\ R' = kR, \cdots$$

$$\Rightarrow\ C' = 1 - kR = 1 - k(1 - C)$$

$$\Rightarrow\ C' = kC + (1 - k)$$

$$\Rightarrow\ s_i = kr_i + (1 - k),\quad i = 1, 2, 3.$$

Similarly, for CMYK:

$$s_i = \begin{cases} r_i & i = 1, 2, 3 \\ kr_i + (1 - k) & i = 4 \end{cases}$$

Color Complements

- The color circle is formed by placing the primary colors equidistant from each other
- Then the secondary colors are placed between the primary colors, also in an equidistant manner
- Hues opposite one another on the color circle are complements
- Color complements are useful for enhancing details in dark regions

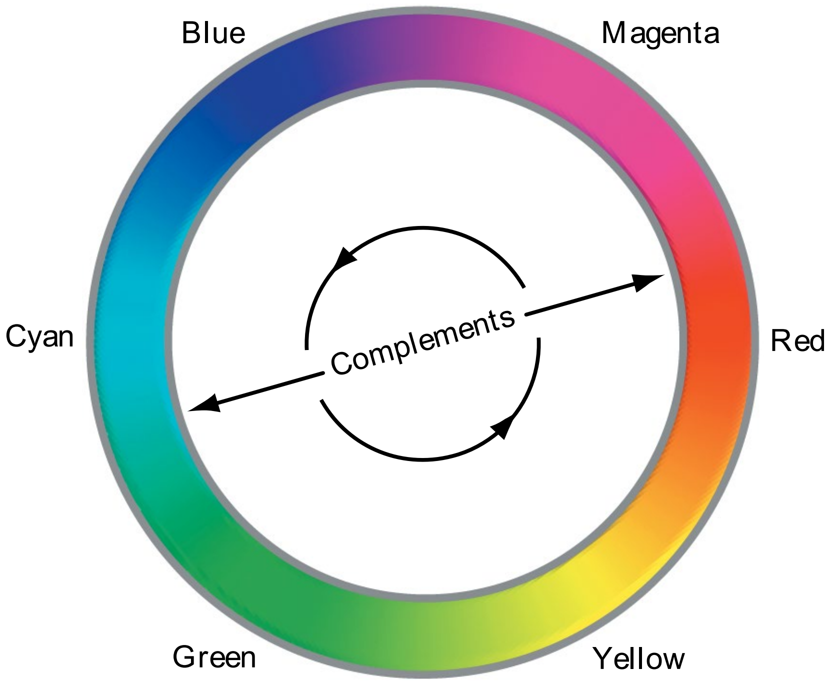
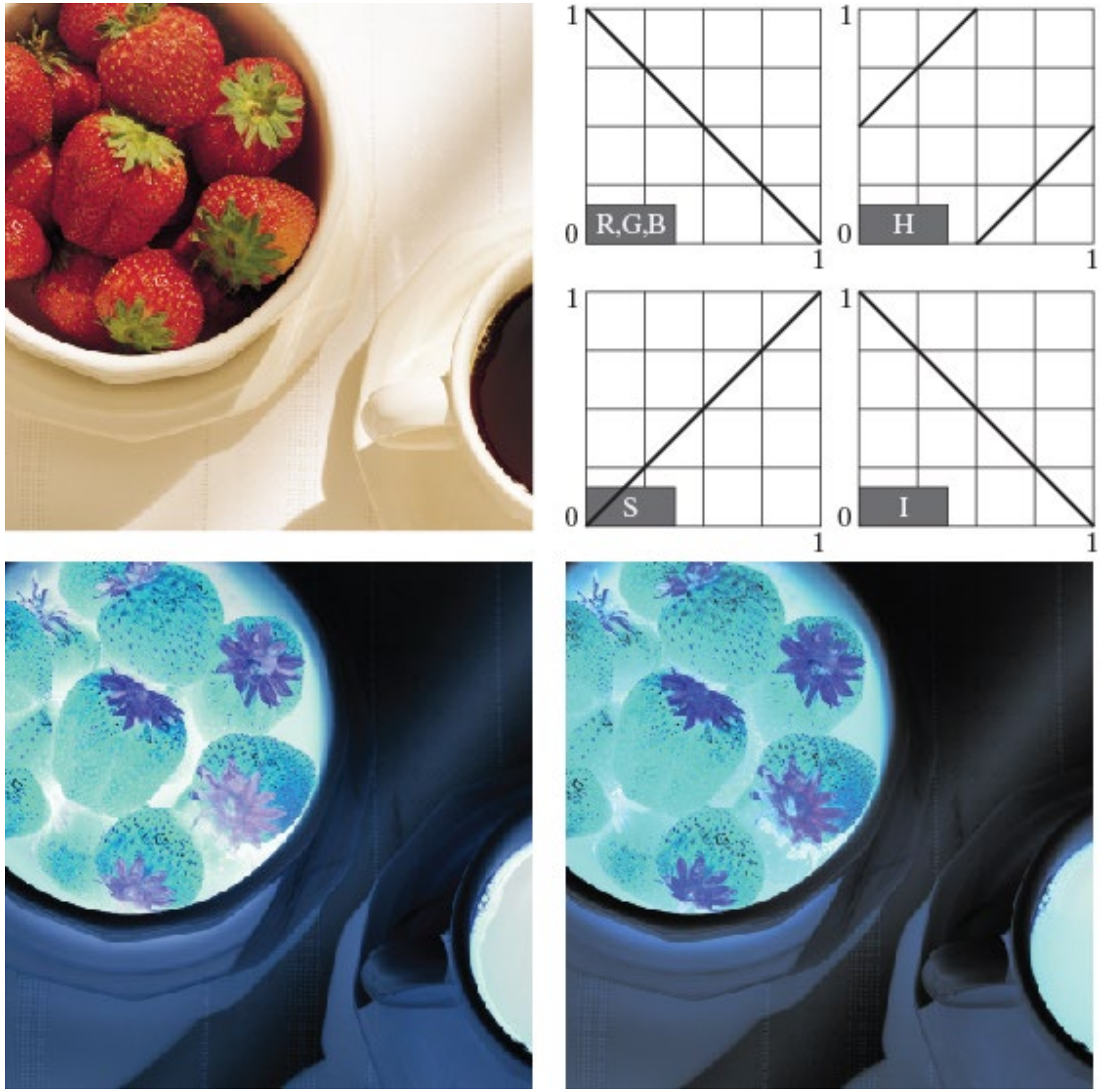


FIGURE 6.30 Color complements on the color circle.

Color Complements: An Example

a b
c d

FIGURE 6.31 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.



The RGB complement transformation functions used here do not have a straightforward HSI color space equivalent.

Color Slicing

- Highlighting a specific range of colors in an image is useful for separating objects from their surroundings
- The most straightforward approach is to extend the gray-level slicing techniques
- $s_i = T_i(r_1, r_2, \ldots, r_n)$: s_i is a function of all r_i.
- Colors of interest are enclosed by a cube of width W and centered at $\mathbf{a}$

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

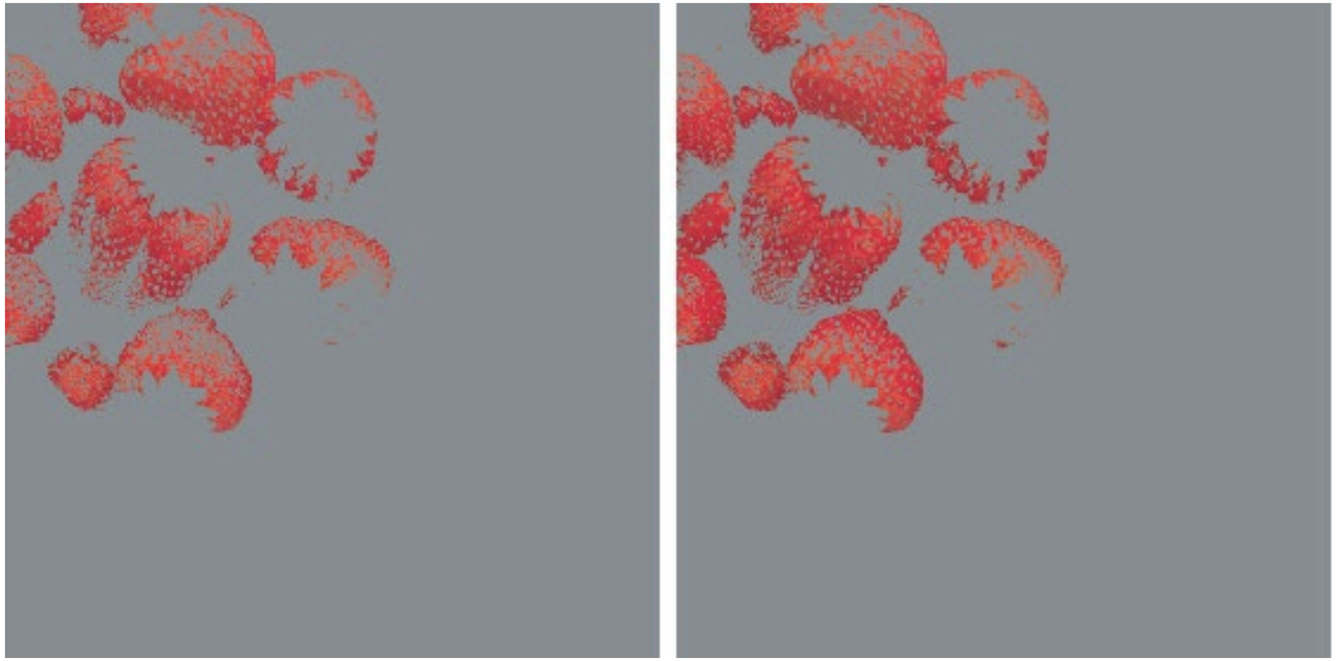
- Colors of interest are enclosed by a sphere with Radius R_0 and center at $\mathbf{a}$

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

- The width of the cube and the radius of the sphere were determined interactively

Color Slicing: An Example

Edible parts of the strawberries are separated!
In each of the 2 cases below, a prototype red with RGB color coordinates (0.6863,0.1608,0.1922) was selected from the most prominent strawberry.



Reds within an RGB cube **Reds within an RGB sphere**

a b

FIGURE 6.32 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 $(0.5, 0.5, 0.5)$.

Tone and Color Corrections

- ❑ Tonal range (key type)
  - General distribution of colors intensities
- ❑ Desirable to distribute the intensity of color images equally
- ❑ Adjust brightness and contrast while leaving the color unchanged
  - RGB and CMYK: mapping all color components except K with the same transformation function
  - HSI: only the I component is modified

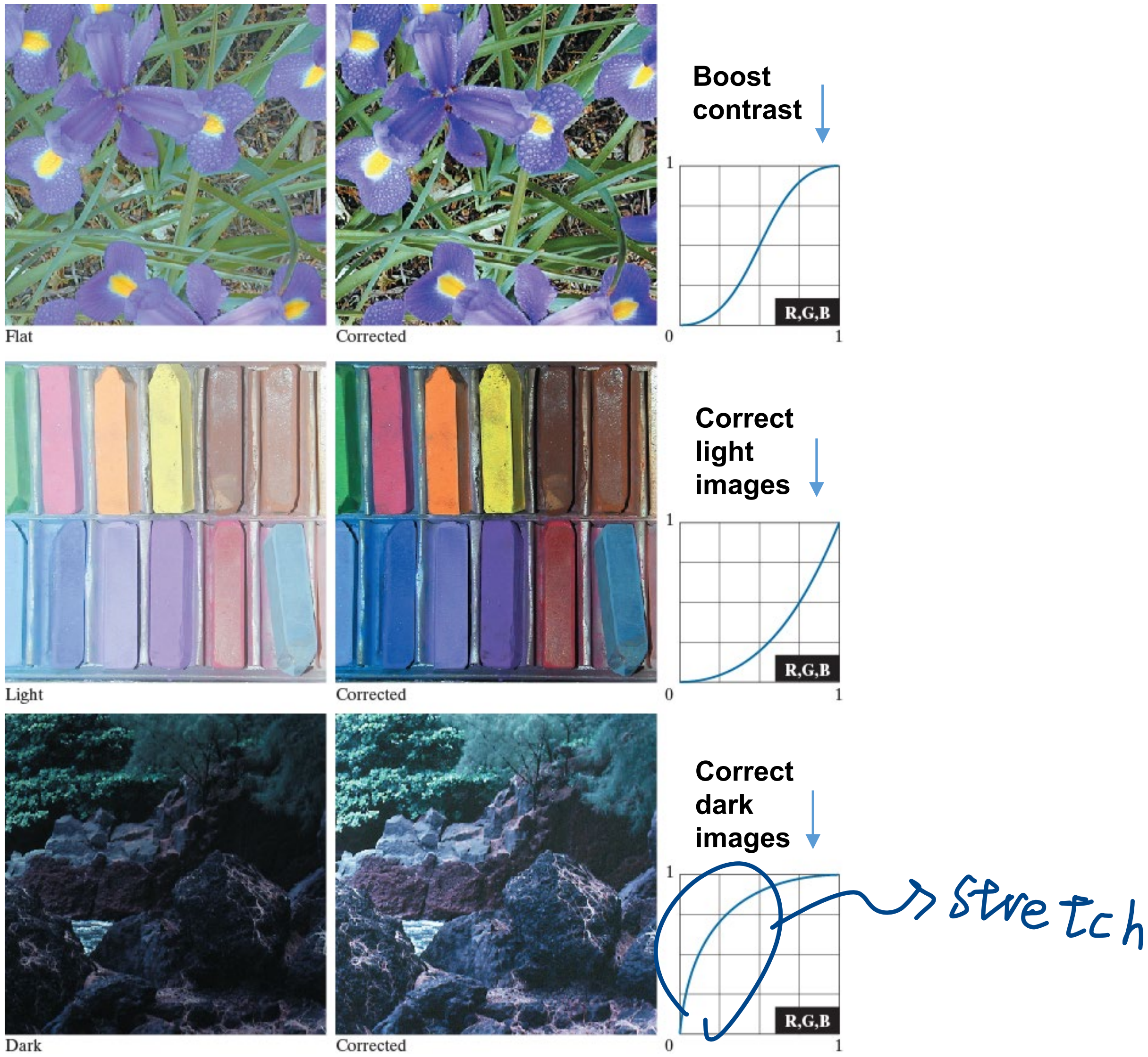
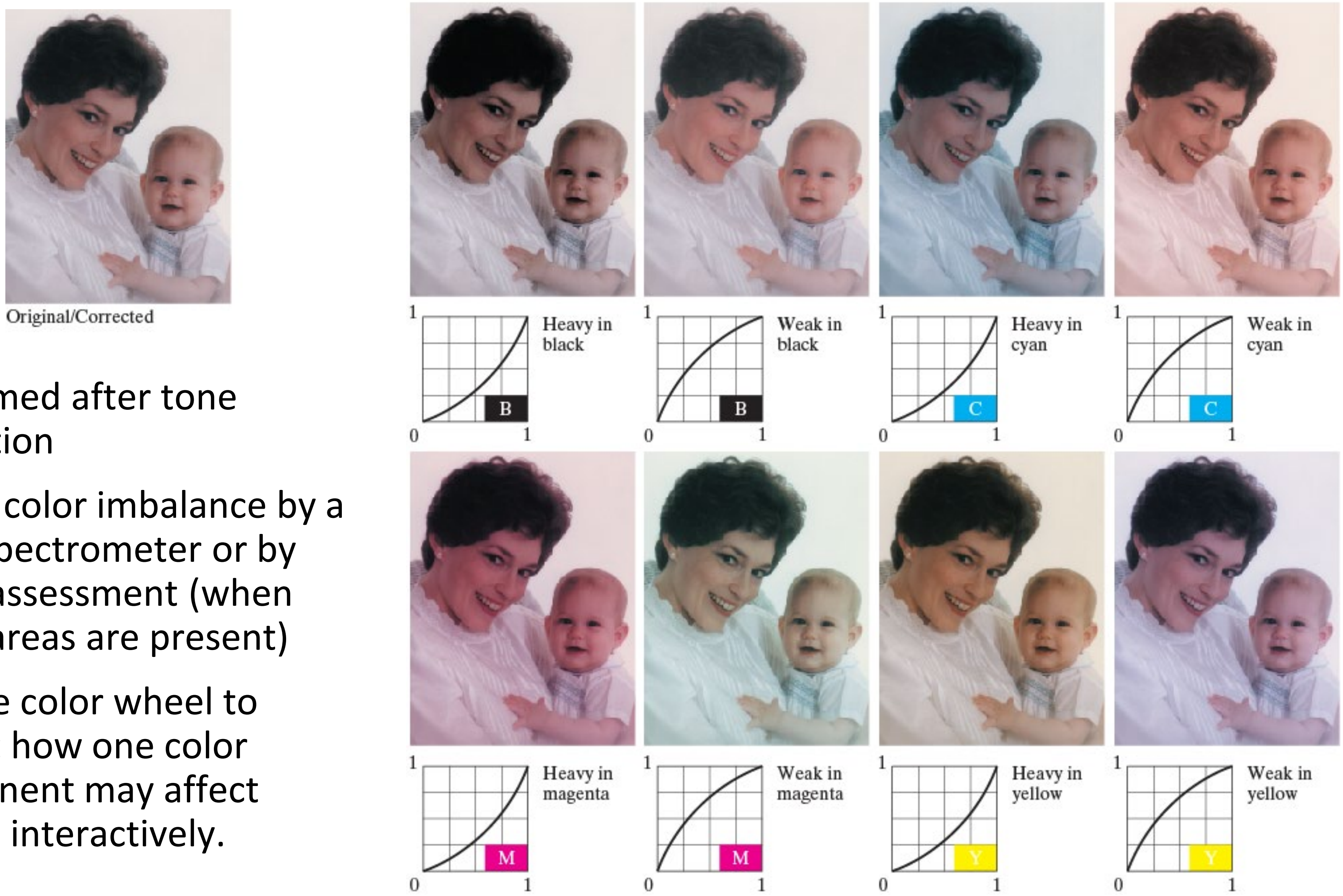


FIGURE 6.33 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Color Balancing

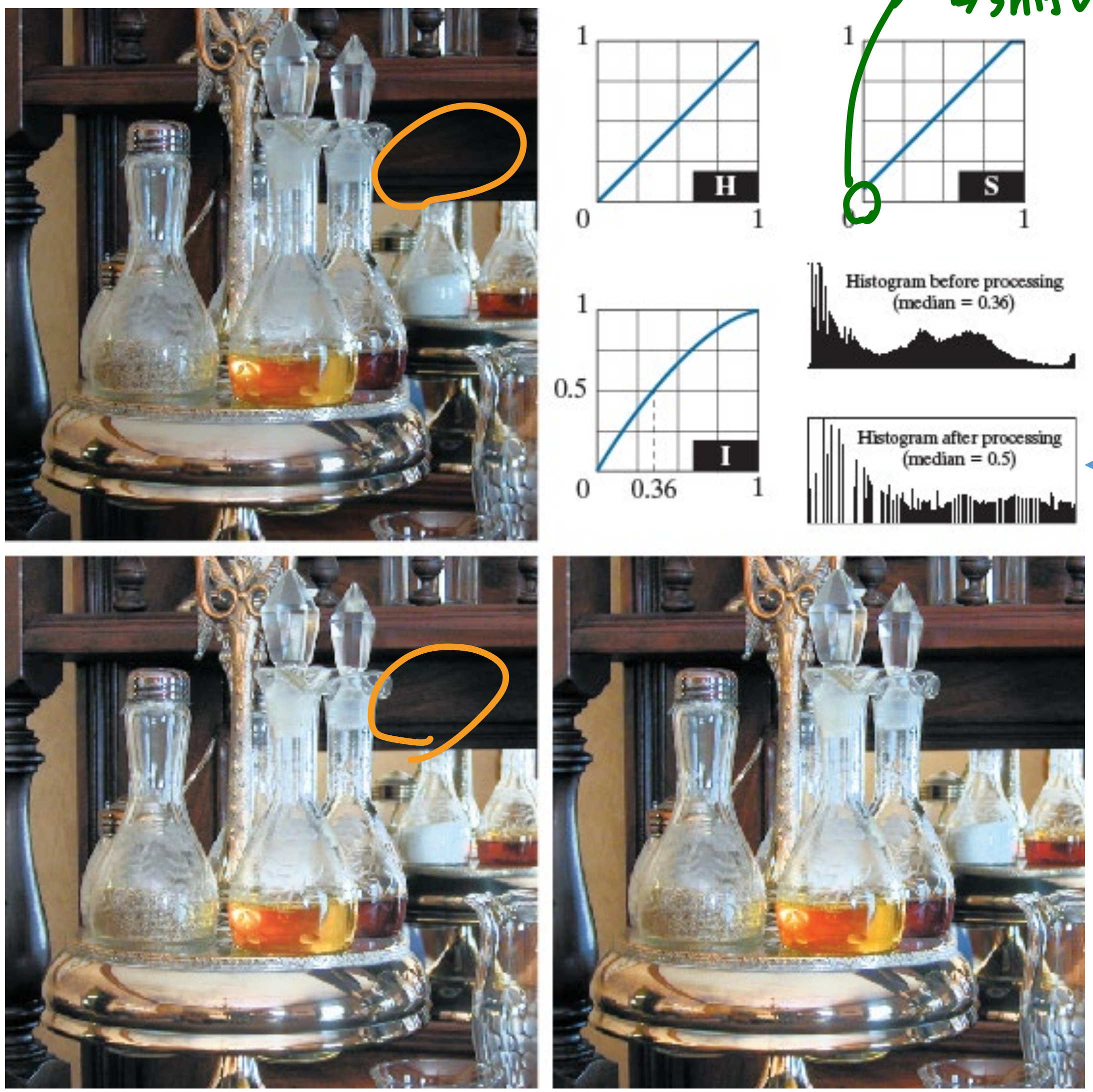


- Performed after tone correction
- Detect color imbalance by a color spectrometer or by visual assessment (when white areas are present)
- Use the color wheel to predict how one color component may affect others, interactively.

FIGURE 6.34 Color balancing a CMYK image.

Histogram Equalization

- It is generally unwise to histogram equalize the components of a color image independently. This results in erroneous color.
- A more logical approach is to spread the color intensities uniformly, leaving the colors themselves (e.g., hues) unchanged.
- The HSI color space is ideally suited to this approach.



saturation
↳ shift

WHY on HSI ?

Why not on RGB ?

∵ intensity

a b
c d

FIGURE 6.35 Histogram equalization (followed by saturation adjustment) in the HSI color space.

The intensity component is histogram equalized.

The saturation component is increased after histogram equalization

Color Image Smoothing

Let S_{xy} denote the set of coordinates defining a neighborhood centered at (x, y) in an RGB color image. The average of the RGB component vectors in this neighborhood is

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

Smoothing by neighborhood averaging can be carried out using either individual color planes or the RGB color vectors

a b
c d

FIGURE 6.36 (a) RGB image. (b) Red component image. (c)Green component. (d) Blue component.

a b c

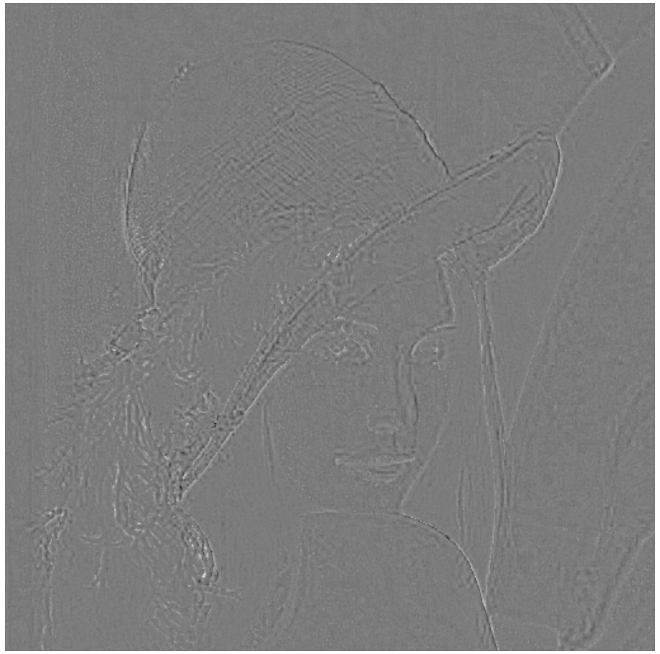
FIGURE 6.37 HSI components of the RGB color image in Fig. 6.36(a). (a) Hue. (b) Saturation. (c) Intensity.

Color Image Smoothing

By smoothing only the intensity, the pixels in the smoothed image maintain their original hue and saturation!

In RGB Color space

In HSI color space



Difference

a b c

FIGURE 6.38 Image smoothing with a 5×5 averaging kernel. (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.

Color Image Sharpening

The Laplacian of vector c is $$\nabla^2[c(x,y)] = \begin{bmatrix} \nabla^2 R(x,y) \\ \nabla^2 G(x,y) \\ \nabla^2 B(x,y) \end{bmatrix}$$

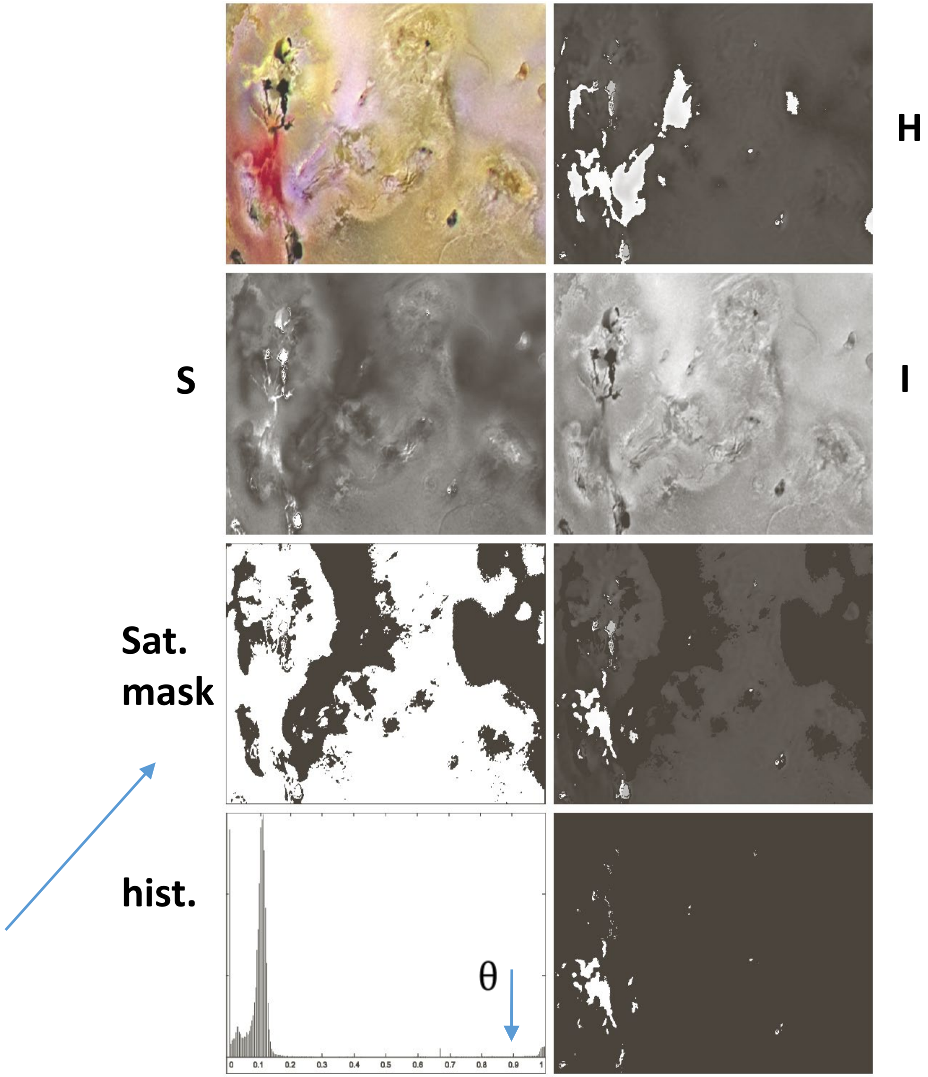
In RGB Color space | **In HSI color space (with hue and saturation planes unmodified)** | **Difference**

a b c

FIGURE 6.39 Image sharpening using the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the HSI intensity component and converting to RGB. (c) Difference between the two results.

Using Color for Segmentation

- Segmentation is a process that partitions an image into regions
- Typically performed in the HSI color space
  - Hue plane conveniently represents the color
  - Saturation plane is used as a masking image
  - Intensity plane is seldom used because it carries no color information
- Example:
  - Segment the reddish region
  - Compare (a) and (b) ➔ the reddish region has high saturation value
  - Set the mask by thresholding the S image at 10% of its maximum intensity value



a b
c d
e f
g h

FIGURE 6.40 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 from (a).

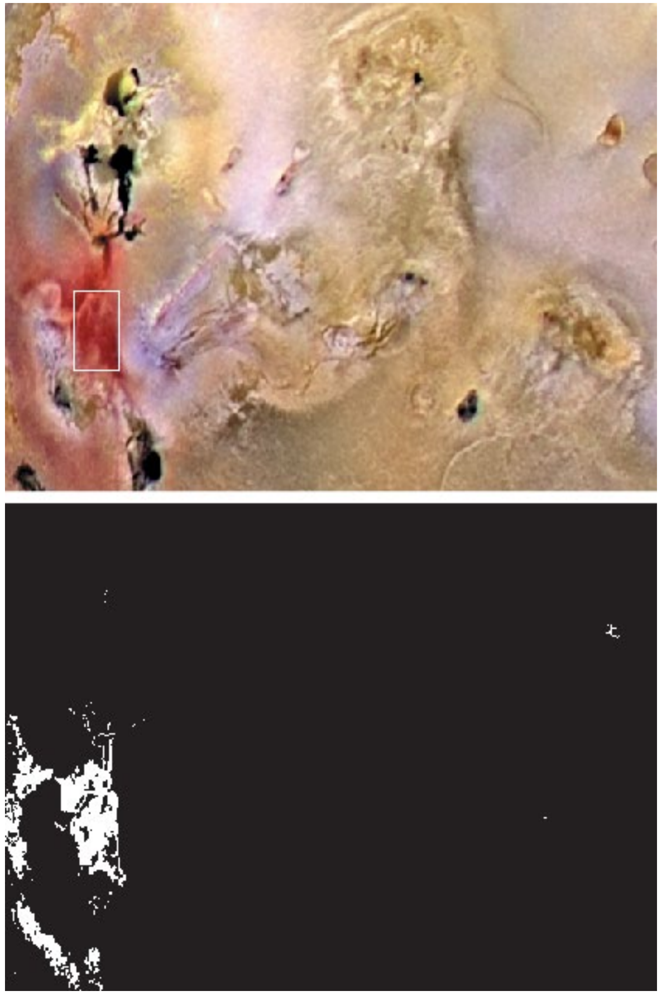
Segmentation in RGB Space

RGB color vectors generally result in better segmentation results.

Denote the average color of interest by **a** and an arbitrary point in the RGB space by **z**.

$$D(\mathbf{z},\mathbf{a}) = \|\mathbf{z}-\mathbf{a}\| = \left[(\mathbf{z}-\mathbf{a})^T(\mathbf{z}-\mathbf{a})\right]^{1/2}$$

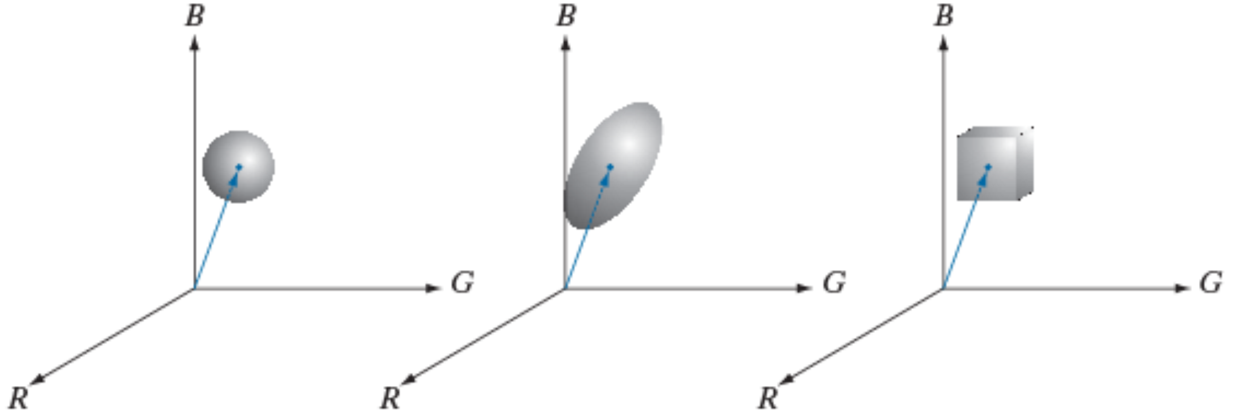
$$= \left[(z_R-a_R)^2+(z_G-a_G)^2+(z_B-a_B)^2\right]^{1/2}$$



a
b

FIGURE 6.42 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. 6.40(h).

More accurate



a b c

FIGURE 6.41 Three approaches for enclosing data regions for RGB vector segmentation.

Color Edge Detection (1)

Let **r**, **g**, and **b** be unit vectors along the R, G, and B axes of RGB color space, and define

$$\mathbf{u} = \frac{\partial R}{\partial x}\mathbf{r} + \frac{\partial G}{\partial x}\mathbf{g} + \frac{\partial B}{\partial x}\mathbf{b}$$

and

$$\mathbf{v} = \frac{\partial R}{\partial y}\mathbf{r} + \frac{\partial G}{\partial y}\mathbf{g} + \frac{\partial B}{\partial y}\mathbf{b}.$$

Then

$$g_{xx} = \mathbf{u} \cdot \mathbf{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

$$g_{yy} = \mathbf{v} \cdot \mathbf{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

and

$$g_{xy} = \mathbf{u} \cdot \mathbf{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}.$$

Note:

- **The gradient introduced in Chapter 3 is not defined for vector quantities.**
- **So, computing the gradient on individual planes, and then using the results to form a color image will lead to erroneous results.**
- **We need to define the gradient for c(*x*,*y*).**
- **A method was proposed by Di Zenzo in 1986.**

Color Edge Detection (2)

The direction of maximum rate of change of c(x, y) is given by the angle

$$\theta(x,y)=\frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{g_{xx}-g_{yy}}\right]$$

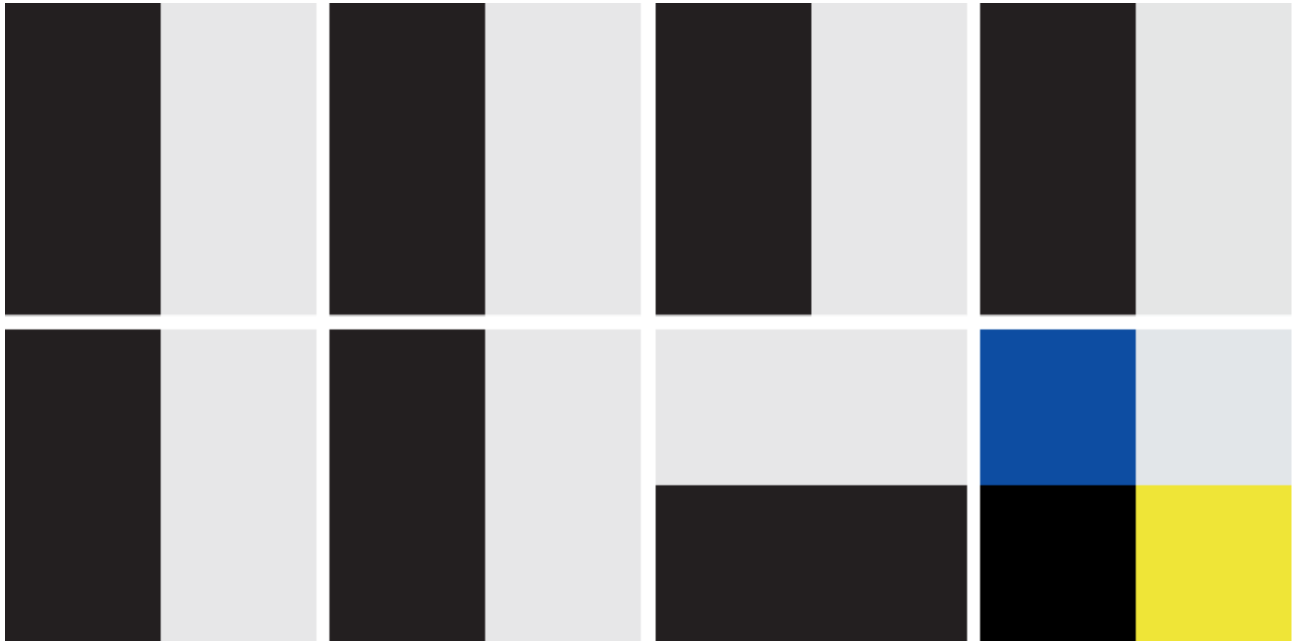
The value of the rate of change at (x, y) in the direction of $\theta(x, y)$ is given by

$$\mathrm{F}_{\theta}(x,y)=\left\{\frac{1}{2}\left[\left(g_{xx}+g_{yy}\right)+\left(g_{xx}-g_{yy}\right)\cos 2\theta(x,y)+2g_{xy}\sin 2\theta(x,y)\right]\right\}^{1/2}$$

-- Di Zeno [1986]

Color Edge Detection (3)

The gradient described in Chapter 3 is not defined for vector quantities. Thus, computing the gradient on individual images and forming a color image from the gradient images lead to erroneous result.



a b c d
e f g h

FIGURE 6.43 (a)–(c) R, G, and B component images, and (d) resulting RGB color image. (e)–(g) R, G, and B component images, and (h) resulting RGB color image.

Color Edge Detection: An Example

a b
c d

FIGURE 6.44
(a) RGB image. (b) Gradient computed in RGB color vector space. (c) Gradient image formed by the elementwise sum of three individual gradient images, each computed using the Sobel operators. (d) Difference between (b) and (c).

The edge detail is more complete!

Both approaches yield reasonable results. Is the extra detail worth the added computational burden of the vector approach (over the Sobel operator)?

Color Edge Detection: An Example

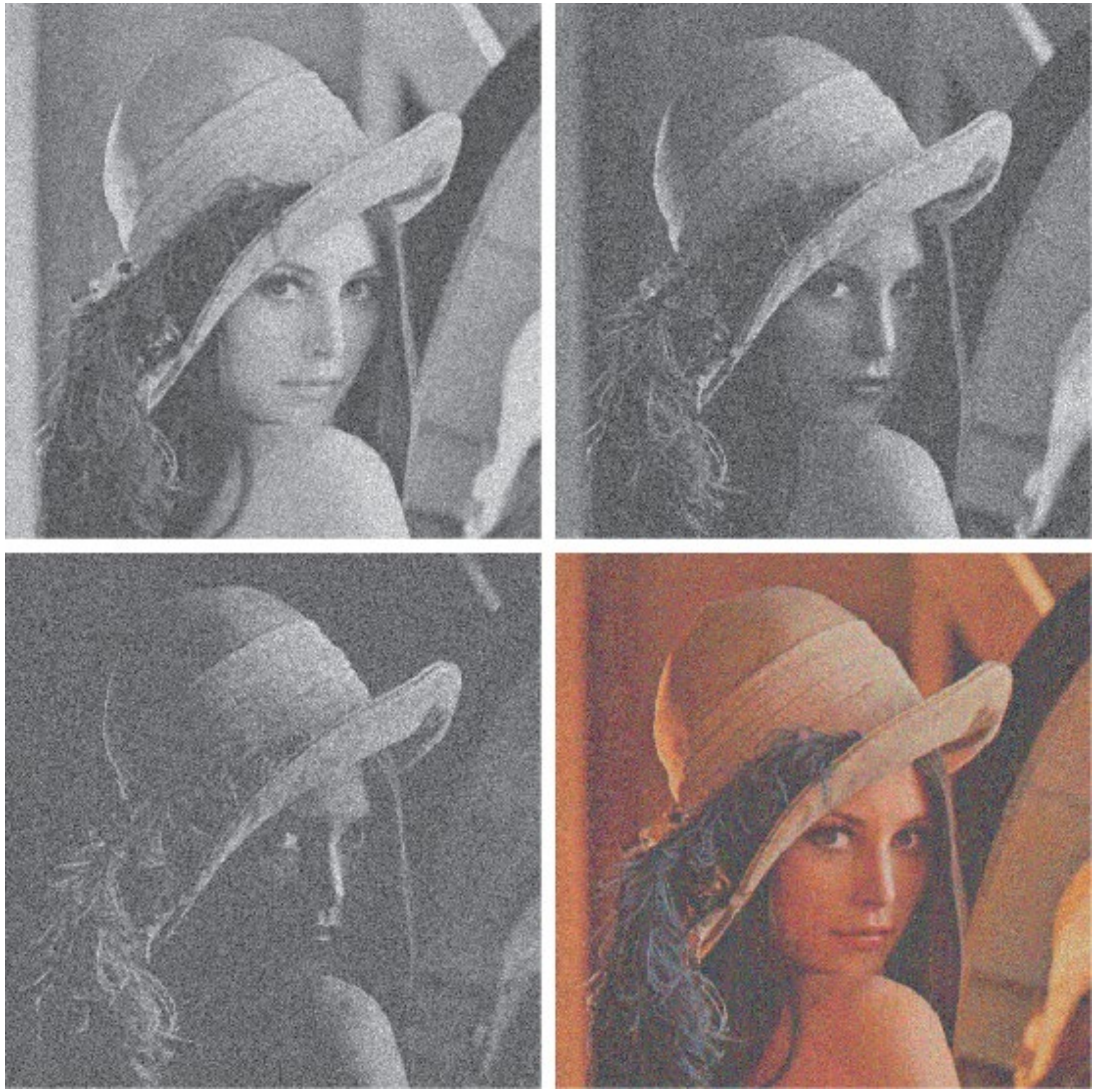
a b c

FIGURE 6.45 Component gradient images of the color image in Fig. 6.44. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.44(c).

Effect of Noise on Color Conversion

a b
c d

FIGURE 6.46 (a)–(c) Red, green, and blue 8-bit component images corrupted by additive Gaussian noise of mean 0 and standard deviation of 28 intensity levels. (d) Resulting RGB image. [Compare (d) with Fig. 6.44(a).]



Note:

- Noise can carry over when converting from one color model to another
- The noise models discussed in Chapter 5 are applicable to color images.
- Usually, the noise content of a color image has the same characteristics in each color channel.
- However, it is possible for color channels to be affected differently by noise.

Fine grain noise tends to be less noticeable in color images ;相加, 類似取avg

Effect of Noise on Color Conversion

Severely degraded

Average of RGB, hence smoother than Figs. 6.46 (a), (b), and (c).

a b c

FIGURE 6.47 HSI components of the noisy color image in Fig. 6.46(d). (a) Hue. (b) Saturation. (c) Intensity.

Noise Spreading due to Color Conversion

a b
c d

FIGURE 6.48
(a) RGB image with green plane corrupted by salt-and-pepper noise.
(b) Hue component of HSI image.
(c) Saturation component.
(d) Intensity component.

H

S

I

Noise spread from the green channel to H, S, and I images.

Color Image Compression

a
b

FIGURE 6.49 Color image compression. (a) Original RGB image. (b) Result of compressing, then decompressing the image in (a).

Original

230:1 by JPEG-2000

Slightly blurred due to lossy compression