CHAPTER 6

COLOR IMAGE PROCESSING

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- **The use of color image processing is motivated by two factors:**
  - **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 2 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.**

COLOR FUNDAMENTALS

- Perception and interpretation of color is a physiopsychological phenomenon that is not fully understood.
- Sir Isaac Newton discovery in 1666.
- 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

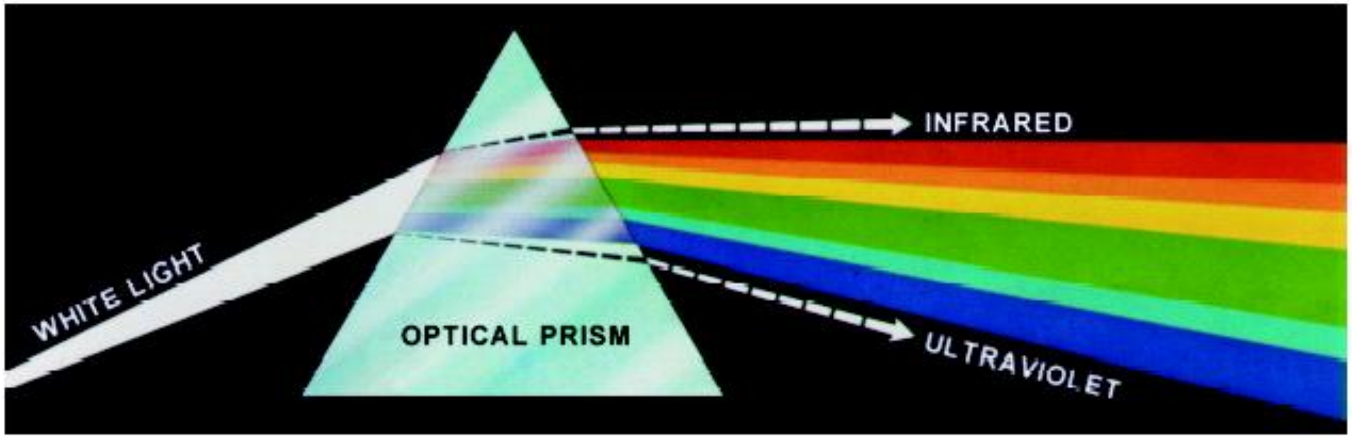


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

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)

VISIBLE SPECTRUM

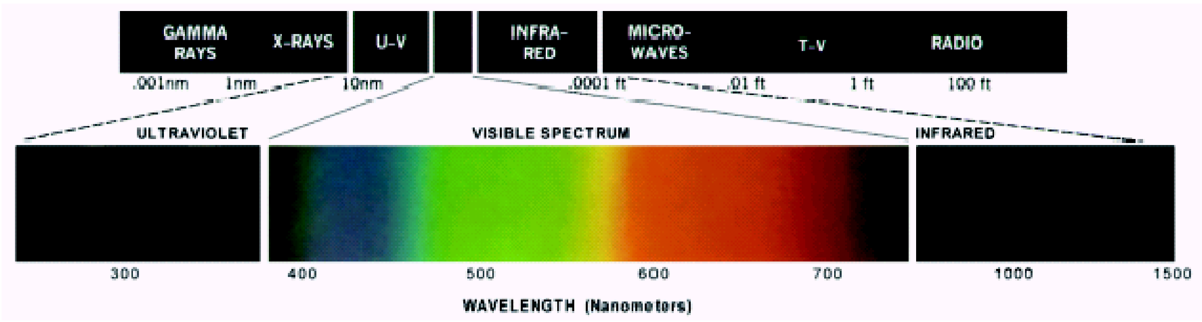


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

ABSORPTION OF LIGHT BY THE CONES

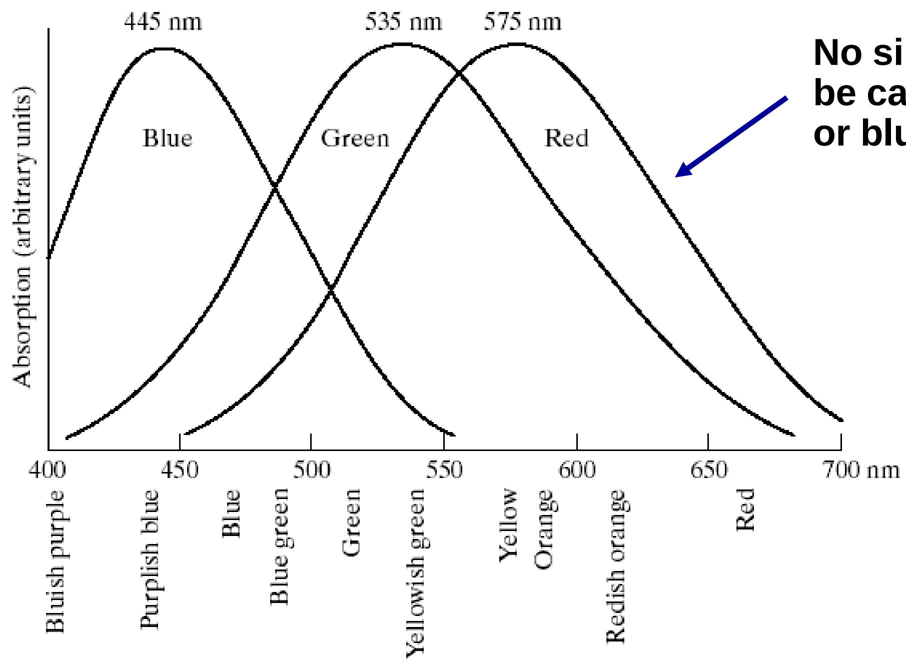
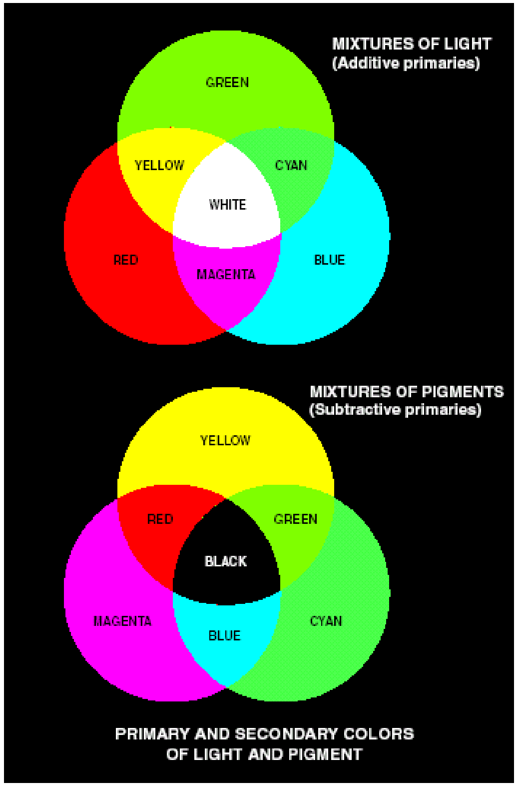


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

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

PRIMARY AND SECONDARY COLORS OF LIGHT



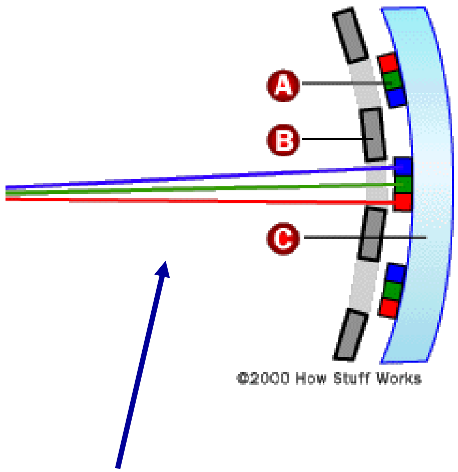
Primary colors are mixed to produce secondary colors of light (magenta, cyan, yellow).

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

a
b

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

COLOR TV



When a color TV needs to create a red dot, it fires the red beam at the red phosphor. Similarly for green and blue dots.

To create a white dot, red, green and blue beams are fired simultaneously -- the three colors mix together to create white.

To create a black dot, all three beams are turned off as they scan past the dot. All other colors on a TV screen are combinations of red, green and blue.

A color TV screen differs from a black-and-white screen in three ways:

There are three electron beams that move simultaneously across the screen. They are named the red, green and blue beams.

The screen is not coated with a single sheet of phosphor as in a black-and-white TV. Instead, the screen is coated with red, green and blue phosphors arranged in dots or stripes. If you turn on your TV or computer monitor, and look closely at the screen with a magnifying glass, you will be able to see the dots or stripes.

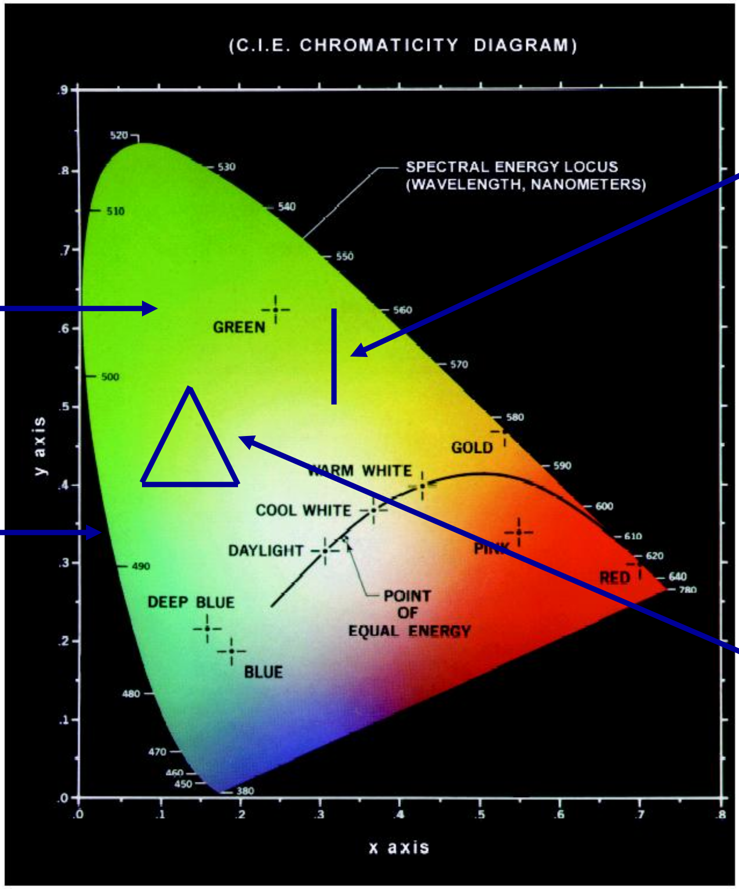
On the inside of the tube, very close to the phosphor coating, there is a thin metal screen called a shadow mask. This mask is perforated with very small holes that are aligned with the phosphor dots (or stripes) on the screen.

CIE CHROMATICITY DIAGRAM

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

Any point within the diagram represents some mixture of spectrum colors.

Points on the boundary are pure colors in the visible spectrum.



A straight line segment joining any 2 points defines all the different color variations that can be obtained by mixing these 2 colors additively.

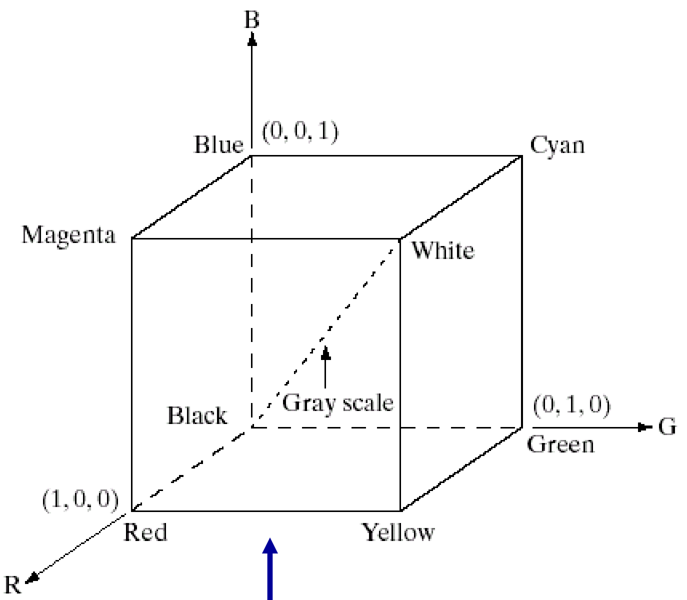
Any color in the triangle can be produced by various combinations of the corner colors.

COLOR MODELS

- A color model 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 toward hardware or applications.
- Hardware oriented models for DIP
  - RGB (red, green, blue) model for color monitors and color video cameras
  - CMY (cyan, magenta, yellow) model for color printing
  - CMYK (cyan, magenta, yellow, black) model for color printing
  - HSI (hue, saturation, intensity) model that corresponds to the way humans describe and interpret color

RGB MODEL

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).



Images represented with the RGB color model have 3 component images:

Red component
Green component
Blue component

If 8 bits are used for each pixel, we have a 24-bit RGB image.

Each color is represented by a point in or on the unit cube.

RGB 24-BIT COLOR CUBE

$(2^8)^3$ = 16,777,216 colors

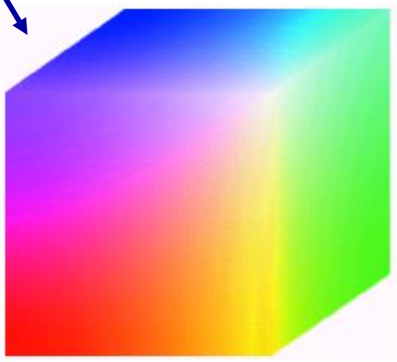


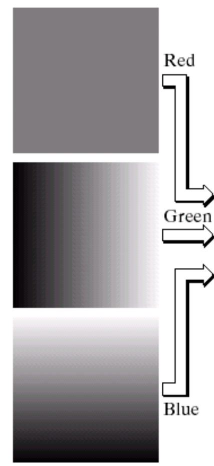
FIGURE 6.8 RGB 24-bit color cube.

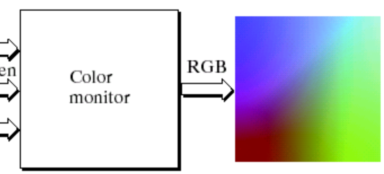
COLOR PLANES

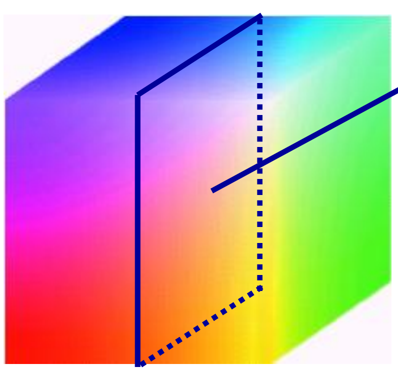
A color image is acquired using the process in reverse order.

a
b

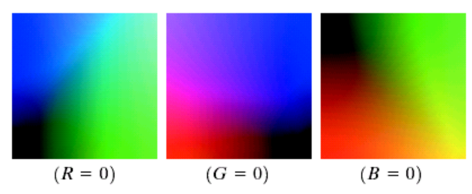
FIGURE 6.9 (a) Generating the RGB image of the cross-sectional color plane (127, *G*, *B*). (b) The three hidden surface planes in the color cube of Fig. 6.8.







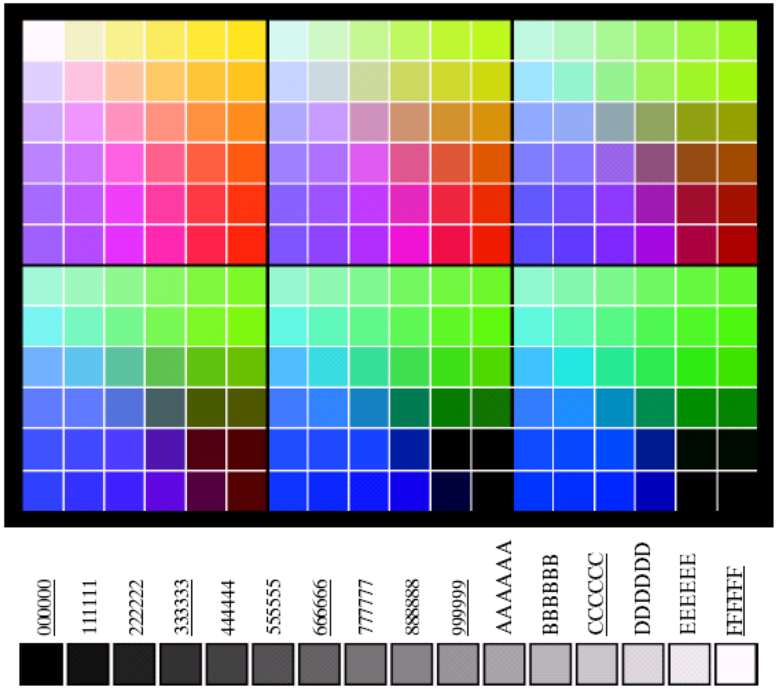
R = 127
G = 0-255
B = 0-255



SAFE RGB COLORS

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).

RBG SAFE-COLOR CUBE

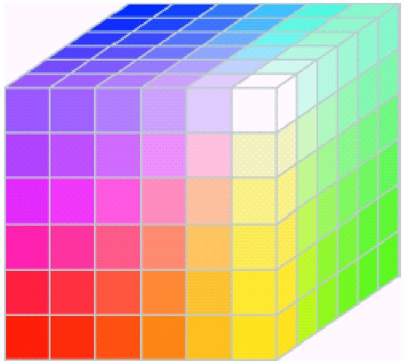


FIGURE 6.11 The RGB safe-color cube.

Each surface has 36 colors: 6x36 = 216

CMY & CMYK COLOR MODELS

Secondary colors of light : Cyan, magenta, yellow
(primary colors of pigments)

Most devices (color printers, copiers, etc.) that deposit color pigments on paper require CMY data input or perform an internal RGB to CMY conversion.

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 <u>cyan</u> does not contain <u>red</u>
light reflected from a surface coated with pure <u>magenta</u> does not contain <u>green</u>
light reflected from a surface coated with pure <u>yellow</u> does not contain <u>blue</u>

Equal amounts of cyan, magenta, and yellow should produce black.
In practice, this combination produces muddy-looking black.
In order to produce true black, a fourth color is added to the model.

CMYK color model: cyan, magenta, yellow, and black

HSI COLOR MODEL

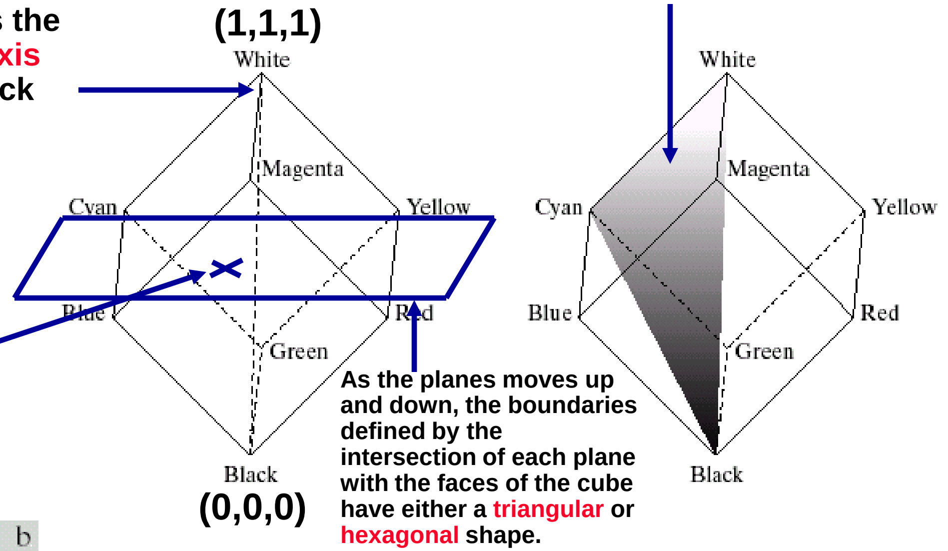
- RBG and CMY are suitable for hardware implementations.
- Unfortunately, they are not good for describing colors for human interpretation.
- One does not refer to the color of a car by giving the % of each of the primaries!
- Humans describe a color object by its hue, saturation, and brightness.
  - <u>Hue</u>: a color attribute that describes a pure color.
  - <u>Saturation</u>: gives a measure of the degree to which pure color is diluted by white light.
  - <u>Brightness</u>: 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 COLOR MODELS

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

This line 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 axis and containing the point.



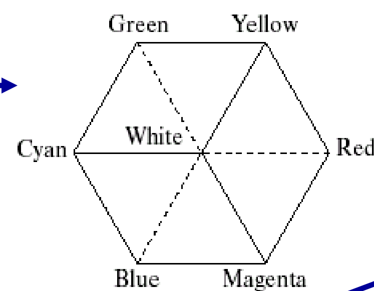
As the planes moves up and down, the boundaries defined by the intersection of each plane with the faces of the cube have either a triangular or hexagonal shape.

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

Conclusion: H, S, and I values required to form the HSI space can be obtained from the RGB cube.

HUE AND SATURATION IN THE HSI MODEL

View obtained by looking at the RBG cube down its gray-scale axis.



It is not unusual to see HSI planes defined in terms of a hexagon, a triangle, or even a circle.

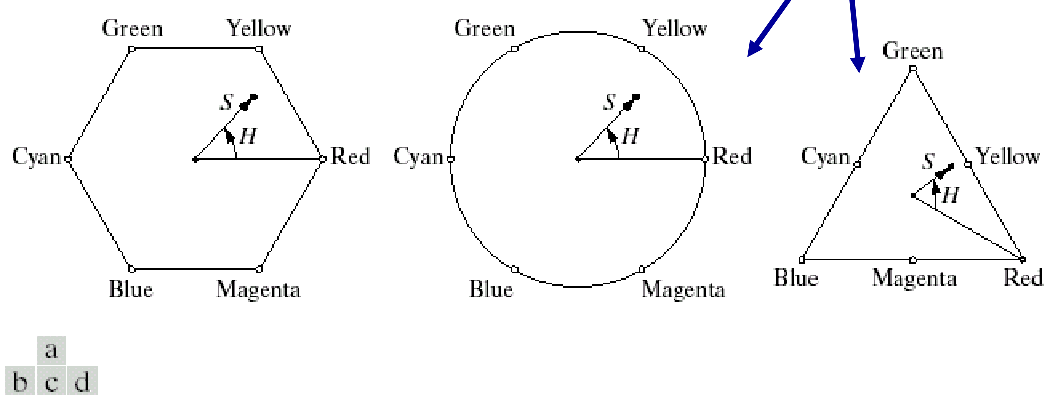
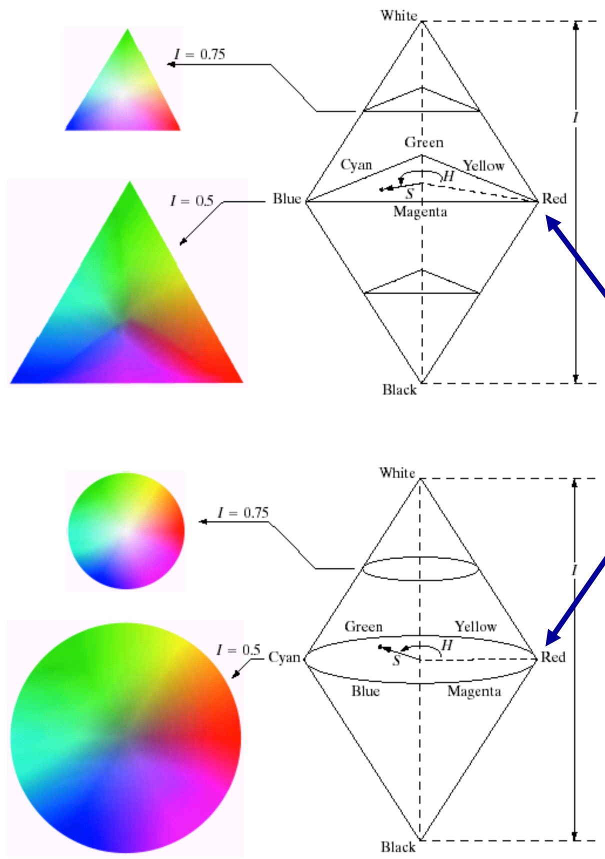


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

TRIANGULAR AND CIRCULAR COLOR PLANES IN THE HSI MODEL



mid-point of the vertical intensity axis

CONVERTING COLORS FROM RGB TO HSI

The RBG values have been normalized to the range [0,1].

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

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

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

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

CONVERTING COLORS FROM HSI TO RGB

The HSI values are given in the interval [0,1].

The applicable equations depend on the values of *H*.

***RG* sector ($0^0 \leq H < 120^0$):**

$$B = I(1-S) \qquad R = I\left[1+\frac{S\cos H}{\cos(60^0 - H)}\right] \qquad G = 3I - (R+B)$$

***GB* sector ($120^0 \leq H < 240^0$): first subtract 120^0 from it.**

$$R = I(1-S) \qquad G = I\left[1+\frac{S\cos H}{\cos(60^0 - H)}\right] \qquad B = 3I - (R+G)$$

***BR* sector ($240^0 \leq H \leq 360^0$): first subtract 240^0 from it.**

$$G = I(1-S) \qquad B = I\left[1+\frac{S\cos H}{\cos(60^0 - H)}\right] \qquad R = 3I - (G+B)$$

PSEUDO-COLOR 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.
- A principal motivation for using color is that humans can discern thousands of color shades and intensities!
- Intensity slicing and color coding is a simple example of pseudo-color image processing.
  - The image is 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

A different color is
assigned to each side of
the plane.

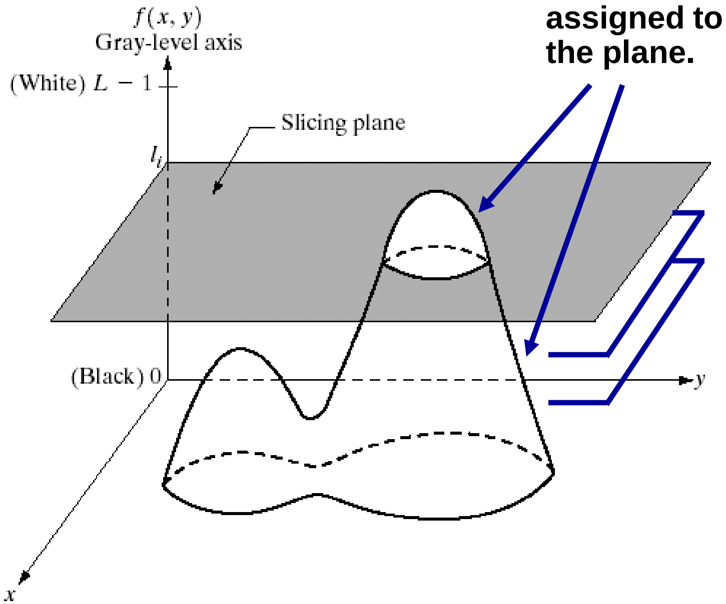


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

Algorithm:

[0,L-1]: gray-scale

L_0: black
l_{L-1}: white

P planes: $l_1, l_2, \ldots, l_P$

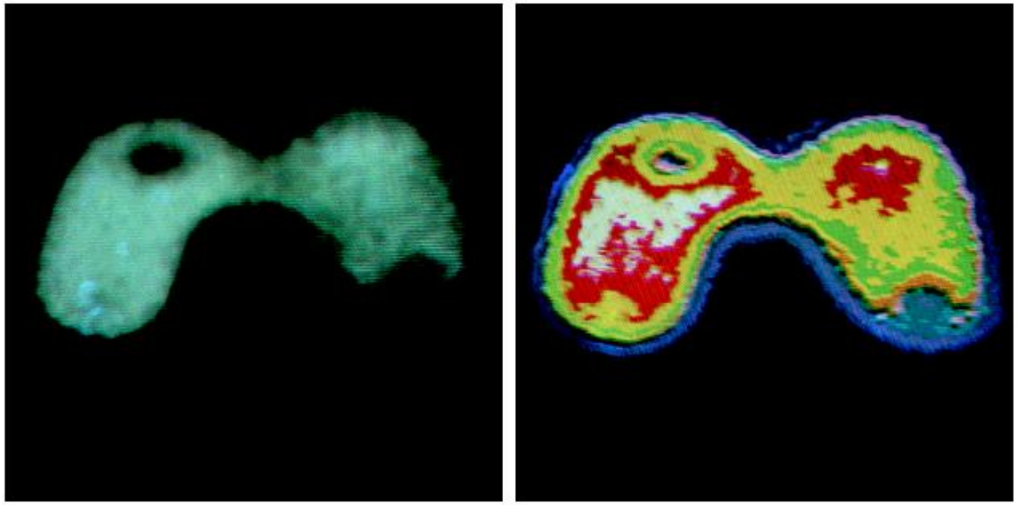
P planes partition the gray-scale into P+1 intervals: $V_1, V_2, \ldots, V_{P+1}$

Color assignments:

$f(x,y) = c_k$ if $f(x,y) \in V_k$

INTENSITY SLICING INTO 8 COLORS

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



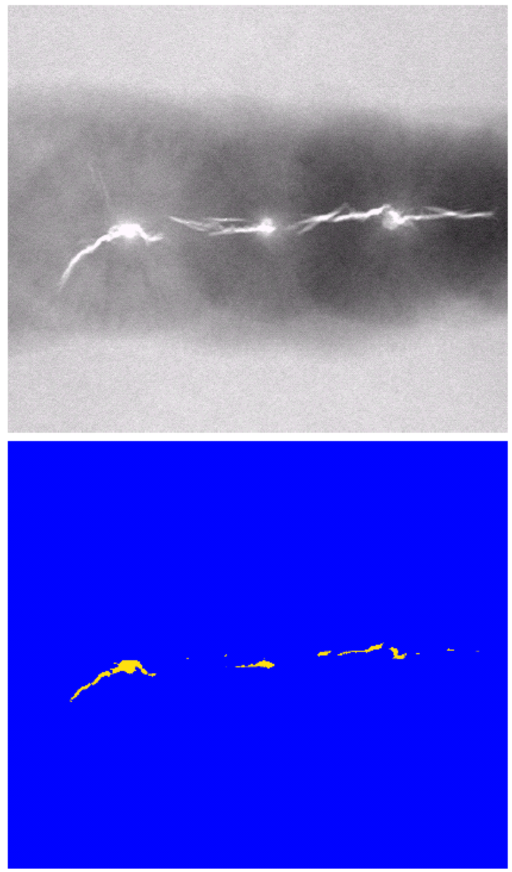
a b

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 INTO 2 COLORS

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.)



When there is a porosity or crack in a weld, the full strength of the X-rays going through the object saturates the sensor on the other side of the object.

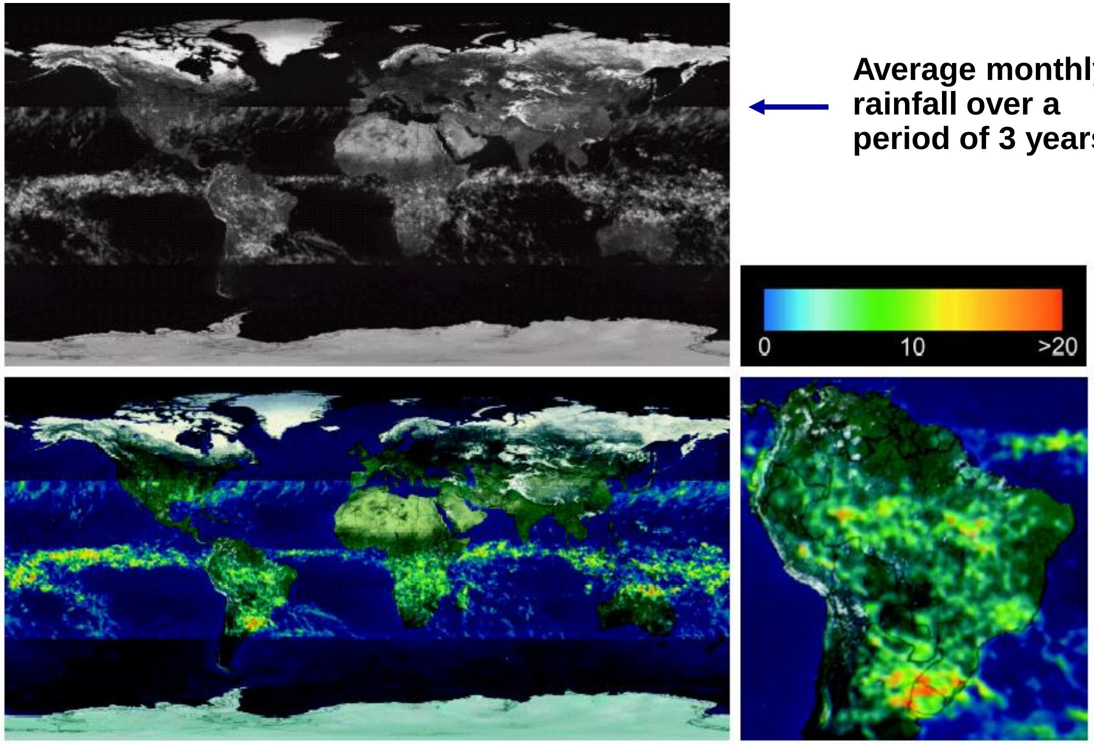
Hence, gray levels of value 255 in an 8-bit image coming from such a system automatically imply a problem with the weld!

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

INTENSITY SLICING INTO 2 COLORS

Average monthly rainfall over a period of 3 years

Much easier to interpret



a b
c d

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.)

3 INDEPENDENT COLOR TRANSFORMATIONS

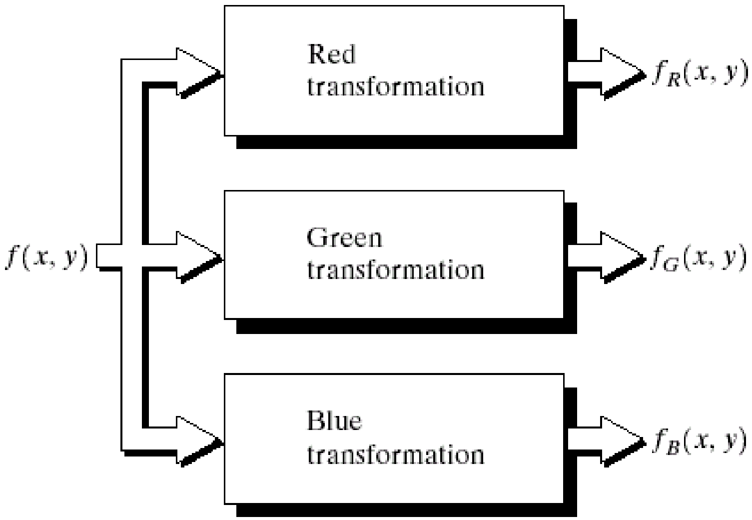


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

PSEUDO-COLOR ENHANCEMENT: AN EXAMPLE

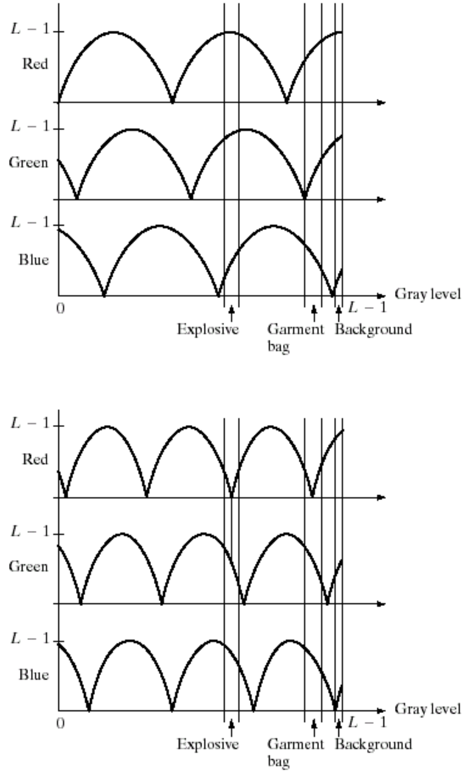


FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

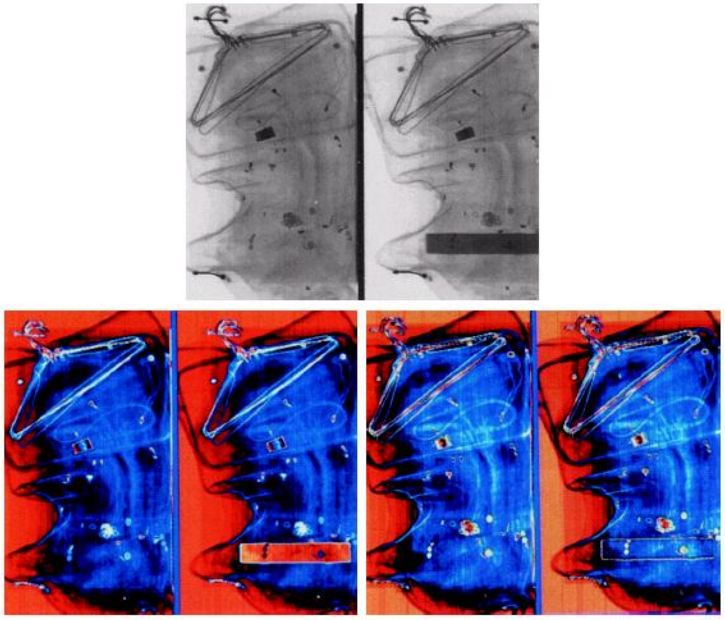


FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

Why do we have the same color for the explosives and background?

Why do we have the same color for the explosives and garment bag?

COMBINATION OF SEVERAL MONOCHROME IMAGES INTO A SINGLE COLOR COMPOSITE

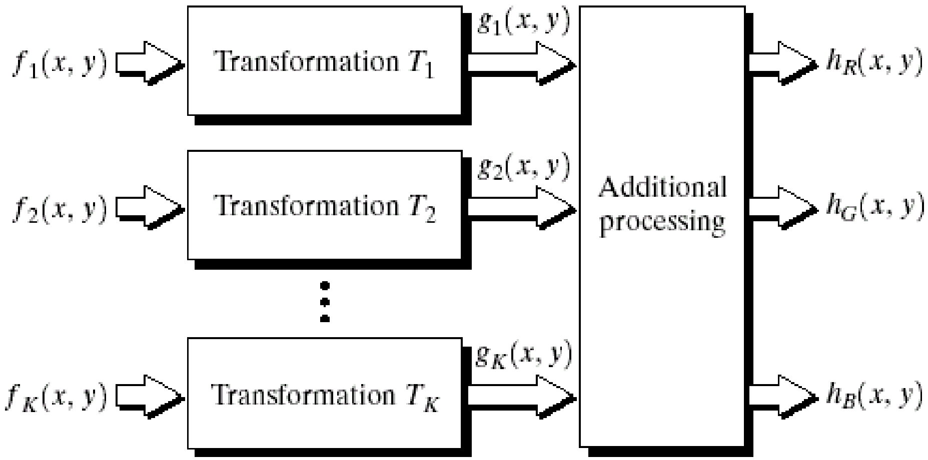


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

3 MONOCHROME IMAGES ARE COMBINED

visible red

visible green

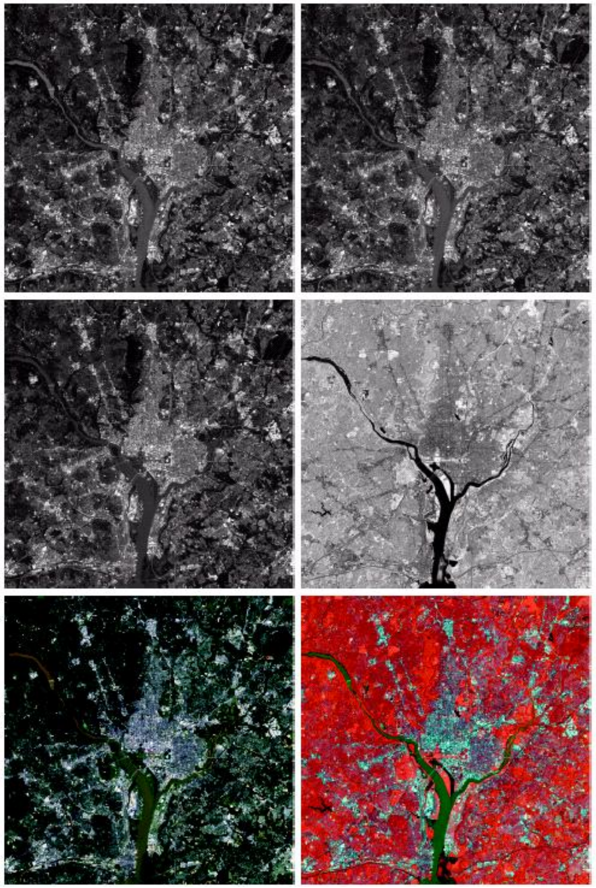
visible blue

near infrared

First 3 images are combined into an RGB image

Red component was replaced with the infrared image

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



a b
c d
e f

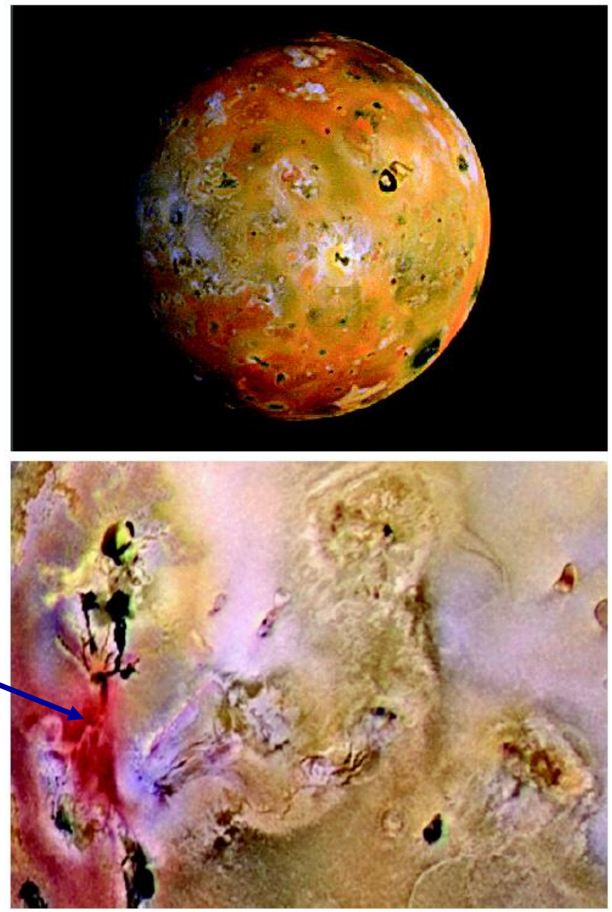
FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral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

COMBINING IMAGES FROM A SPACECRAFT

One way to combine the sensed image data is by how they show differences in surface chemical composition.

Bright red depicts material newly ejected from an active volcano.

Surrounding yellow materials are older sulfur deposits.



a
b

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

This image was obtained by combining several of the sensor images from the Galileo spacecraft.

BASICS OF FULL-COLOR IMAGE PROCESSING

Two major categories of full-color IP approaches

- **Each component image is processed individually, and a composite color image is formed from the components.**
- **Color pixels (which are vectors) are directly processed.**

Two conditions have to be satisfied for per-color-component and vector-based processing to be equivalent.

- **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.**

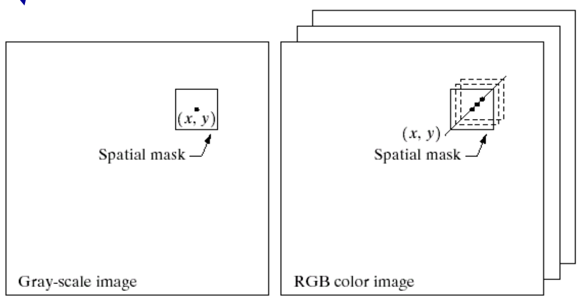
<u>Example</u>:

Suppose the process is neighborhood averaging.

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

a b

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



COLOR TRANSFORMATIONS - FORMULATION

- $g(x,y) = T[f(x,y)]$: pixels values are triplets or quartets.
- $s_i = T_i(r_1, r_2, \ldots, r_n)$:
  - s_i and r_i: 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
  - Any color space can be used.
  - 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 more than offsets the advantages!

COLOR-SPACE COMPONENTS OF A FULL-COLOR IMAGE

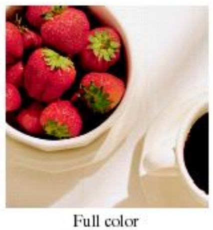
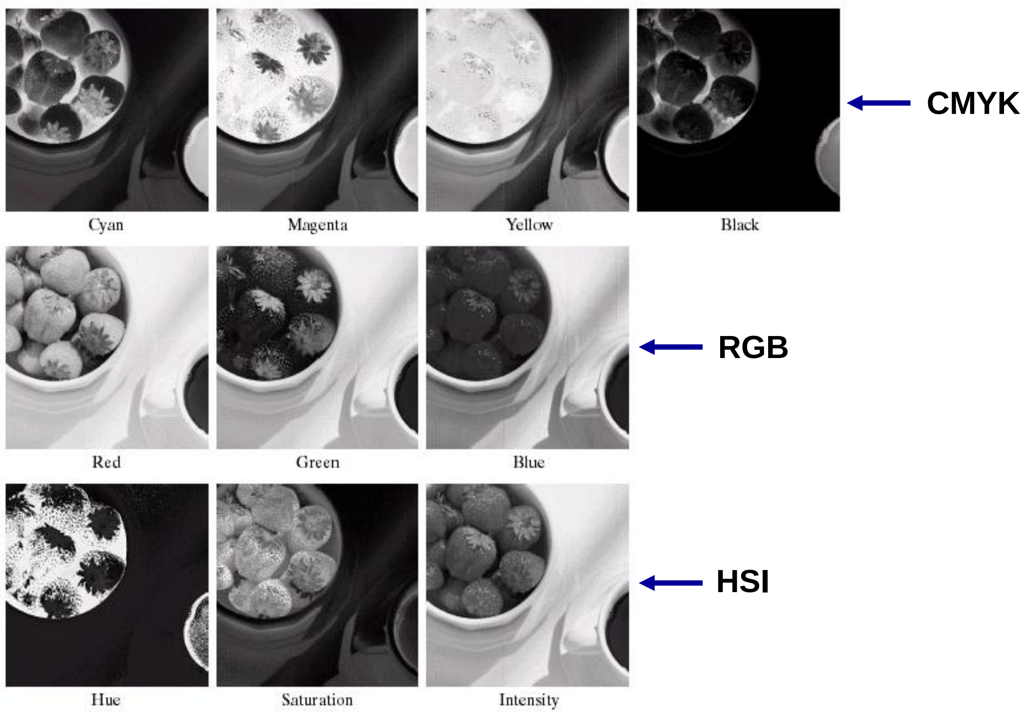


FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)



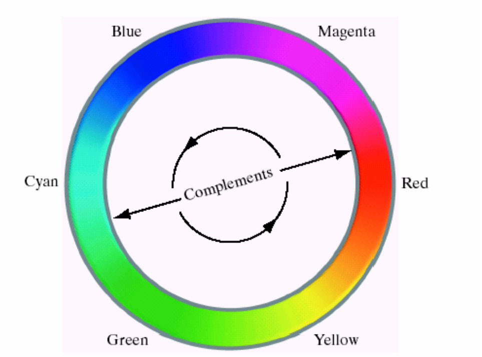
MODIFIED INTENSITY OF THE FULL-COLOR IMAGE

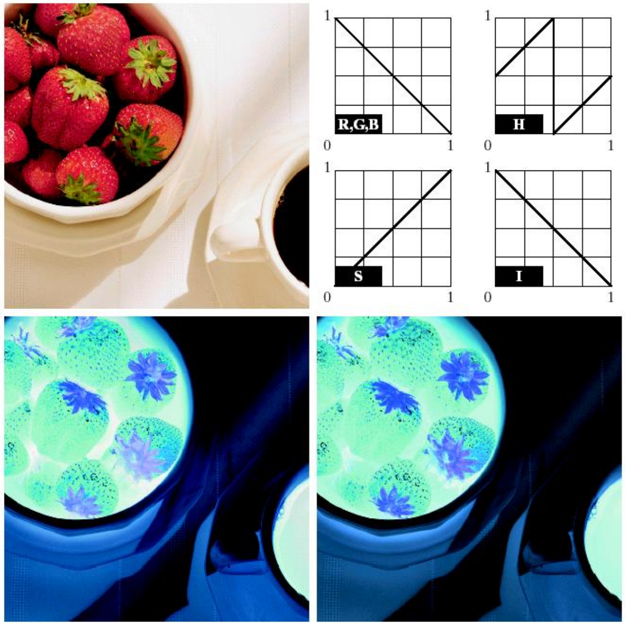
FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

COLOR COMPLEMENTS

The hues directly opposite one another on the color circle are called complements.

Complements are analogous to gray-scale negatives: they are useful in enhancing detail embedded in dark region of a color image.





a b
c d

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.

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:

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

Colors of interest are enclosed by a sphere:

$$s_i = \begin{cases} 0.5 & \text{if } \sum (r_j - a_j)^2 > (R_0)^2 \\ r_i & \text{otherwise} \end{cases} \qquad i = 1, 2, \ldots, n$$

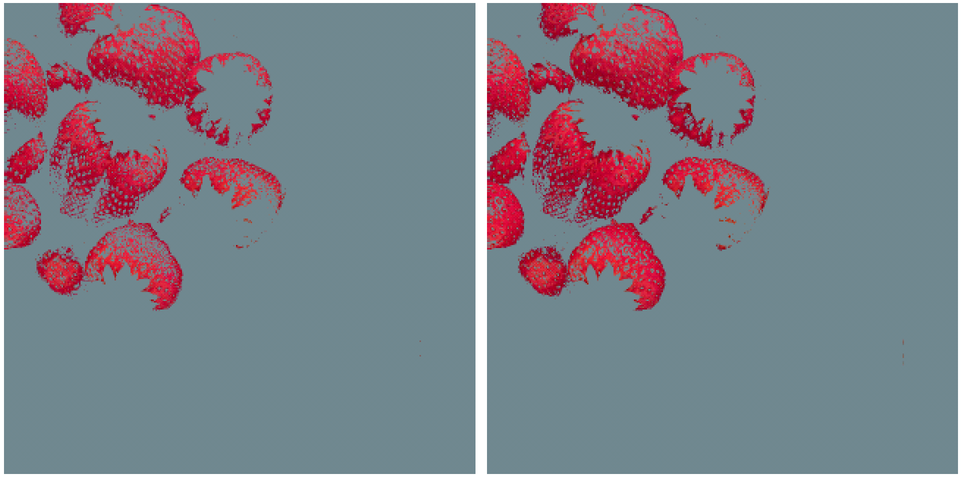
The width of the cube and the radius of the sphere were determined interactively.

AN EXAMPLE OF COLOR SLICING

Edible parts of the strawberries are separated!

In each of the 2 cases below, a prototype red with RGB color coordinate (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

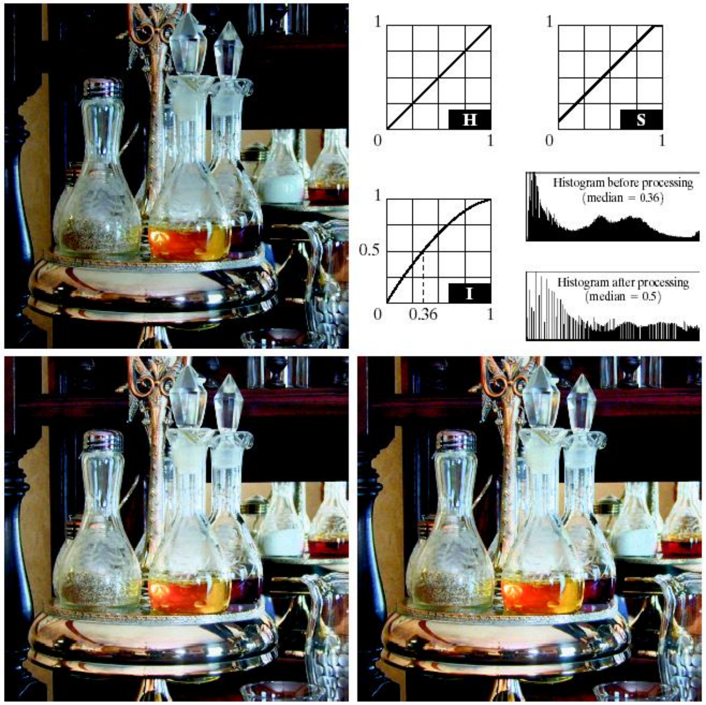
FIGURE 6.34 Color slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at (0.6863, 0.1608, 0.1922), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color (0.5, 0.5, 0.5).

HISTOGRAM PROCESSING

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.



a b
c d

FIGURE 6.37 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

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

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

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

AN RGB IMAGE AND ITS COLOR PLANES

a b
c d

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

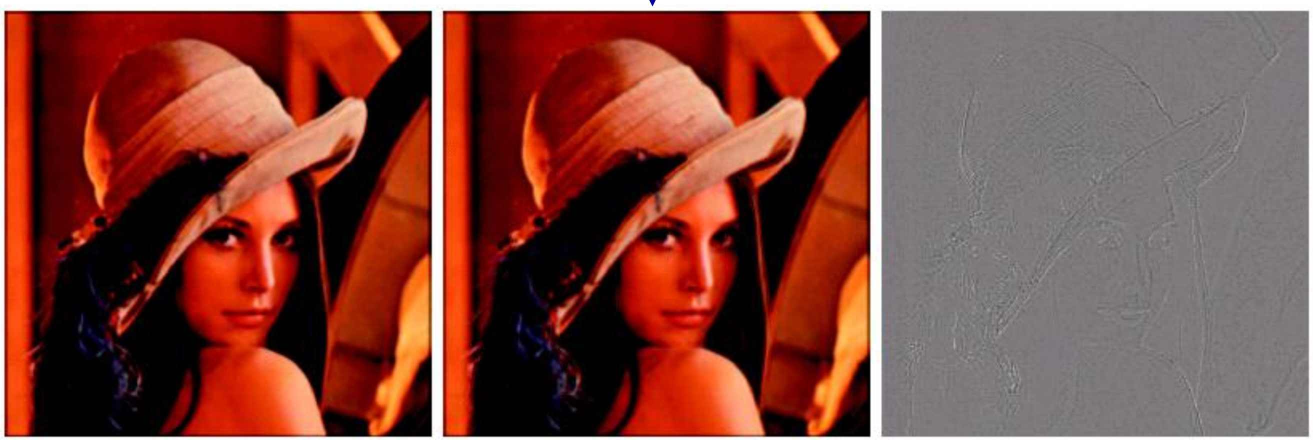
HSI PLANES

a b c

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

SMOOTHED IMAGES

By smoothing only the intensity plane, the pixels in the smoothed image maintain their original <u>hue</u> and <u>saturation</u> – and their original color!



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.

COLOR IMAGE SHARPENING

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

The Laplacian

The **Laplacian** of a full-color image can be obtained by computing the Laplacian of each component plane separately.

SHARPENED IMAGES

Obtained by combining the Laplacian of the intensity plane with the unmodified <u>hue</u> and <u>saturation</u> planes.

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.

COLOR SEGMENTATION IN HSI COLOR SPACE

Assume we want to segment an image based on color, and to carry out the process on individual planes.

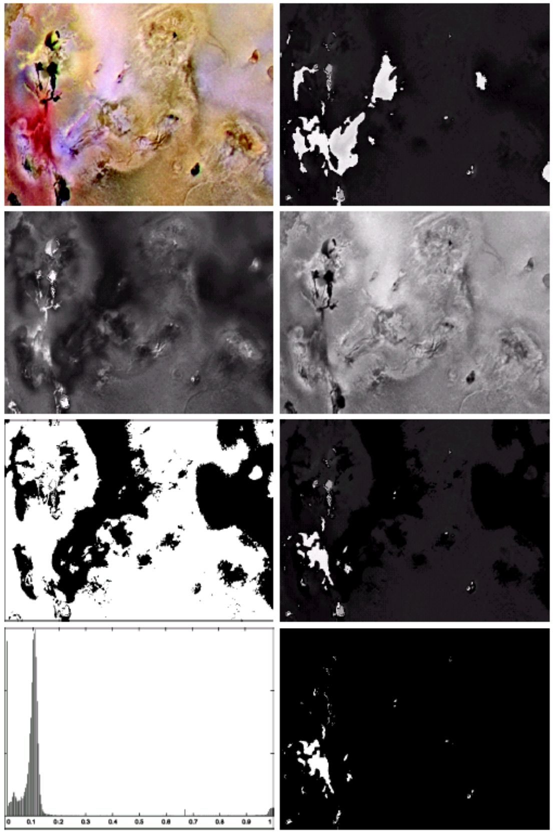
HSI space:

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.

The binary mask is generated by thresholding the saturation plane with *T* = 0.1x(maximum value in the saturation plane).



The product image is thresholded with *T* = 0.9

a b
c d
e f
g h

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).

COLOR SEGMENTATION IN RGB COLOR SPACE

RGB color vectors generally result in better segmentation results.

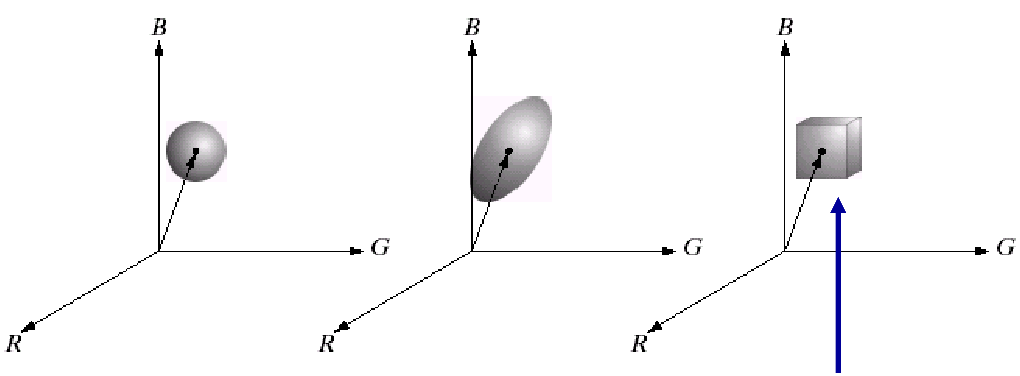
A set of sample points representative of the colors of interest is given.

Obtain an estimate of the average color that will be segmented.

Classify each pixel in the given image with according to the specified range.

One measure of similarity is the Euclidean distance:

$$D(z,a) = \|z-a\| = [(z-a)^T(z-a)]^{1/2} = [(z_R-a_R)^2 + (z_G-a_G)^2 + (z_B-a_B)^2]^{1/2}$$



a b c

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

$D(z,a) \leq D_0$ $\quad$ $D(z,a)=[(z-a)^T C^{-1}(z-a)]^{1/2} \leq D_0$ $\quad$ **Computationally much simpler!**

AN EXAMPLE OF COLOR SEGMENTATION IN RGB COLOR SPACE

Compute the mean vector a using the points contained within the rectangle.

Center the box at a.

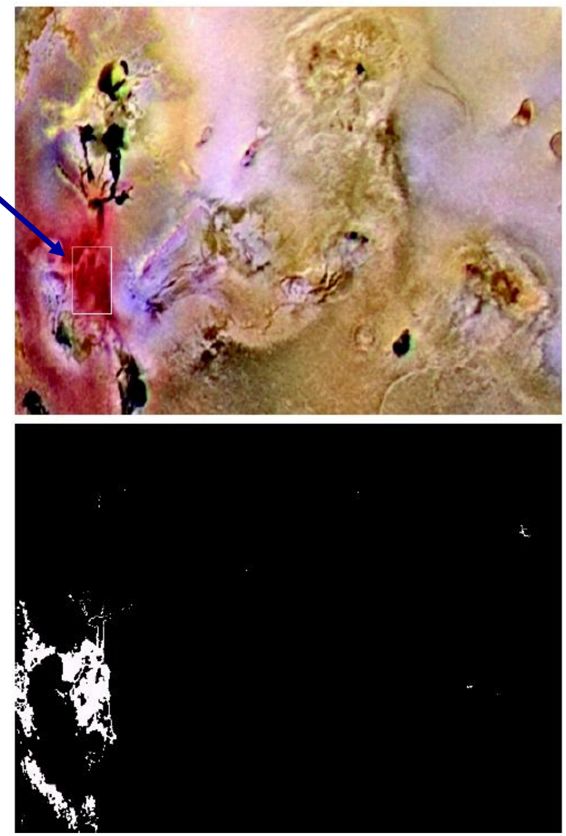
Compute the standard deviation of the R,G,B values of the sample points.

Determine the dimension along each axis by computing 1.25xSD.

$\blacklozenge_R$: **SD of red components**

Dimension along the *R*-axis:

$(a_R - 1.25\blacklozenge_R)$ **to** $(a_R + 1.25\blacklozenge_R)$



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).

COLOR EDGE DETECTION

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*) = [*R*(*x*,*y*) *G*(*x*,*y*) *B*(*x*,*y*)]^T

A method has been proposed by Di Zenzo in 1986:

Direction of max rate of change: $\theta = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{(g_{xx} - g_{yy})}\right]$

Value the rate of change: $F(\theta) = \left\{\frac{1}{2}\left[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\theta + 2g_{xy}\sin 2\theta\right]\right\}^{\frac{1}{2}}$

AN EXAMPLE OF COLOR EDGE DETECTION USING 2 APPROACHES

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).

The edge detail is more complete!

Both approaches yielded reasonable results. Is the extra detail worth the added computational burden of the vector approach?

COMPONENT GRADIENT IMAGES

a b c

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).

NOISE IN COLOR IMAGES

The noise models discussed in Chapter 5 are applicable to color images.

Gaussian noise
Rayleigh noise
Erlang noise
Exponential noise
Uniform noise
Impulse (salt and pepper) noise

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.

GAUSSIAN NOISE IN A COLOR IMAGE

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).]

Fine grain noise tends to be less noticeable in color images.

NOISY RGB IMAGE CONVERTED TO HSI

The degradation in hue and saturation planes is due to the nonlinearity of cos and min operations!

a b c

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

The intensity plane is slightly smoother than any of the 3 RGB noisy planes.

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

Image averaging reduces random noise!

Compare

a b c

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

ONE NOISY RGB CHANNEL AFFECTS ALL HSI PLANES

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.

The noise spreads from the green channel to all the HSI planes.

COLOR IMAGE COMPRESSION

Compression reduces the amount of data required to represent a digital image.

The data that are the object of any compression are the components of each color pixel.

Compressed with JPEG 2000.

The compressed image contains only 1 data bit for every 230 bits of data in the 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).