Advanced Digital Image Processing

Chapter 6: : Color Image Processing

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Outline

Color Image Processing

Two areas of color image processing:

Definition

________________:

- Image aquired by a **full-color sensor**, ex: color camera/ color scanner.
- Pulishing visualization, Internet.

Definition

____________________:

- Assigning a color to a partuciular **monochrome** intensity or range of intensities.
- Not important as before becauese of color tech in hardware.

Color Fundamental

Primary Colors - CIE 1931

Definition

CIE (Commission Internationale de lÉclairage - the International Commission on Illumination) 1931 defined

- Red $\triangleq$ 700 nm
- Green $\triangleq$ 546.1nm
- Blue $\triangleq$ 435.8nm

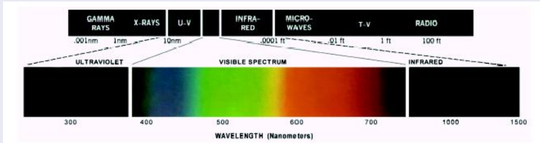


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Why

Cones(6 7 million) can be divided into **3 principal sensing catergories** by their sensitivity

- Red: 65%
- Green: 33%
- Blue: 2% (but **most sensitive**)

Color Fundamental
Primary Colors - CIE 1965

Definition

CIE 1965 : **No single (frequency) color** may be called red, green, or blue.⇒ Bell shape

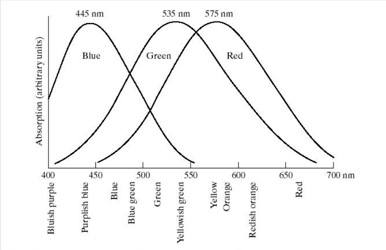


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Why

Use the CIE 1931 primary colors cannot produce **all** visible colors when mixed in various intensity proportions, unless *the wavelength also is allowed to vary*

Primary Color and Secondary Color
Additive and Subtractive

Definition

____________:

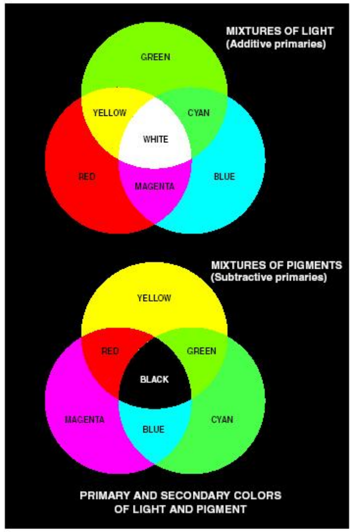
- Primary color: ,Green,
- Secondary color: Magenta (red + blue),Cyan (green + blue),Yellow (red + green)

Definition

________________________:

- Primary color: Magenta (white - green),Cyan (white - red), Yellow (white - blue)
- Secondary color: (white-green-blue), Green (white-red-blue), (whilte-red-green)

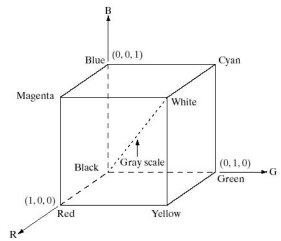
Primary Color and Secondary Color
Additive and Subtractive



RGB Color Space

- Human eye is strongly perceptive to R,G,B primaries
- All values of R, G, and B usually are **normalized** to be in the range $[0, 1]$ / __________
- Used in color monitors and a broad class of color video cameras.
- The number of bits used to represent each pixel in RGB spaces is called the pixel depth.
  - Pixel pixel depth = 24 bits (R8,G8,B8): ______________.
    Total color = $(2^8)^3 = 16,777,216$

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).



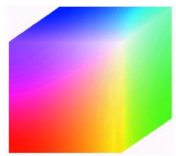


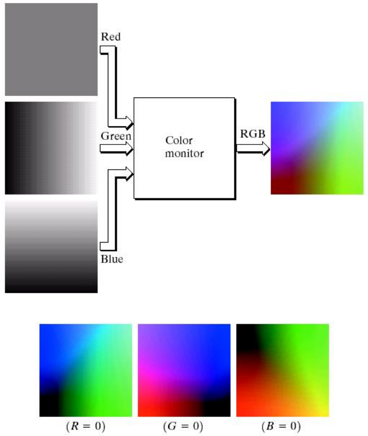
FIGURE 6.8 RGB 24-bit color cube.

RGB Color Space
Color Image Acquisition

Color image can be acquired by using three filters, sensitive to red, green, and blue, respectively.

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.



RGB Color Space
safe RGB colors

Many systems do not need 24-bit RGB image, 256-color is enough. (say, pseudo-color image).

Definition

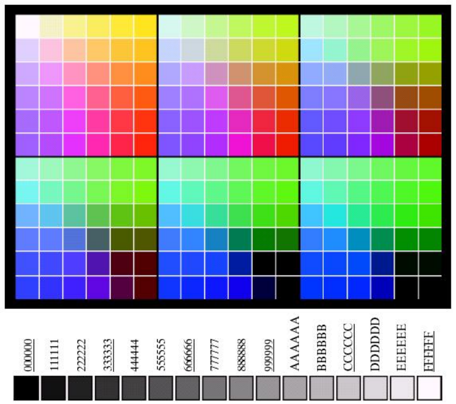
:

- Define 216 colors that are common to most systems for safe colors.(Reserve 40 colors from 256 colors for system.)
- Each value of three RGB values can only be 0, 51, 102,153,204, or 255. That is, RGB triples will give $(6)^3 = 216$ possible values.
- Not all possible 8-bit graycolors are included in the 216 safe colors. Only $(KKKKKK)_{16}$ for $K = 0, 3, 6, 9, C, F$. $(FFFFFF)_{16}$ is white.

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.

RGB Color Space
RGB 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).

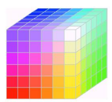


FIGURE 6.11 The RGB safe-color cube.

CMY/CMYK Color Space

- ⇒Ex: Cyan pigments: illuminated with white light, no red light is reflected.
- Color models for color printing and copier, which deposit colored pigmenets on paper.
-
  - Color ink is **expensive**
  - Printing three ink layers causes printed paper quite **wet**.
  - Black edges suffer **colored tinges** (due to mechanical tolerances)
- $$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

HSI Color Space

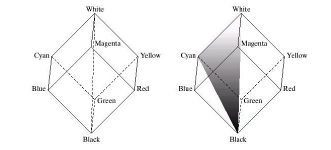
Why

- RGB,CMY and other similar color models are not well suited for describing colors from human interpretation.
- Human describe the color by its
  ______________________ $\Rightarrow$ ____

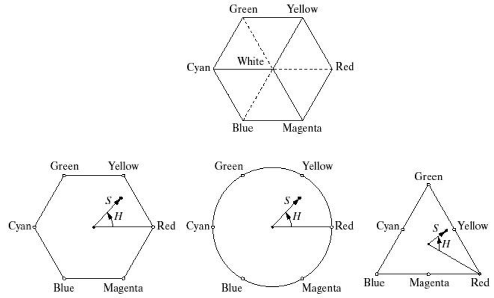
Definition

- ____: The dominant wavelenght of an ______________________ **shifts**, the hue of the associated color will shift.
- _________: The more an SPD is **concentrated** at one wavelength, the more saturated will be the associated color.
- Decouples the ______________ form color-carrying information. (HS) (intuitive to human)

HSI Color Space



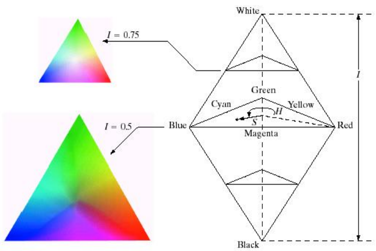
a b
FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

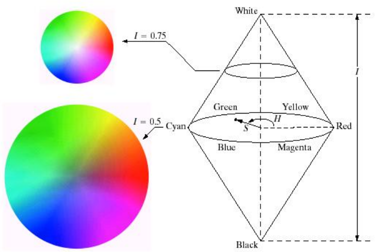


- ___________ is normalized to $[0, 1]$ and is perpendicular to the color plane
- ____: Angle of the vector in color plane, and can be normalized to $[0, 1]$ by $/360^\circ$
- _________: Length of the vector in color plane.

b c d
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.

HSI Color Space





HSI Color Space
RGB to HSI

______________:

$$
\begin{aligned}
I &= \frac{1}{3}(R+G+B) \\
S &= 1 - \frac{3}{R+G+B}\{\min(R,G,B)\} \\
H &= \begin{cases} \theta & \text{if } B \le G \\ 360-\theta & \text{if } B > G \end{cases}
\end{aligned}
$$

with

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

- H can be normalized to $[0, 1]$ by dividing 360°.
- S and I are already in $[0, 1]$ if RGB is in $[0, 1]$.

HSI Color Space

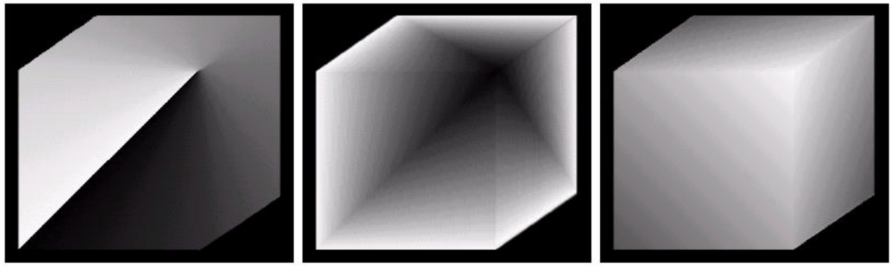
HSI to RGB

$$
\begin{aligned}
B &= I(1-S) \\
R &= I\left(1+\frac{S\cos H}{\cos(60^\circ - H)}\right) \\
G &= 1-(R+B)
\end{aligned}
$$

$$
\begin{aligned}
H &= H-120^\circ \\
R &= I(1-S) \\
G &= I\left(1+\frac{S\cos H}{\cos(60^\circ - H)}\right) \\
B &= 1-(R+G)
\end{aligned}
$$

$$
\begin{aligned}
H &= H-240^\circ \\
G &= I(1-S) \\
B &= I\left(1+\frac{S\cos H}{\cos(60^\circ - H)}\right) \\
R &= 1-(G+B)
\end{aligned}
$$

HSI Color Space

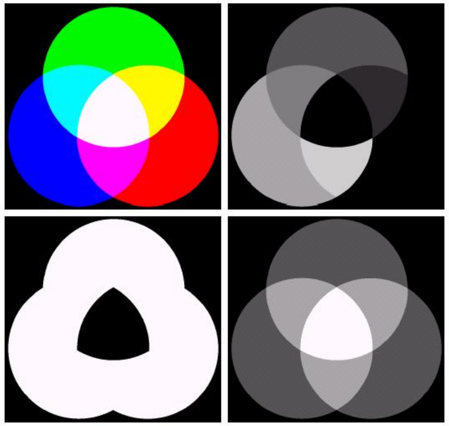


a b c

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

HSI Color Space

Example

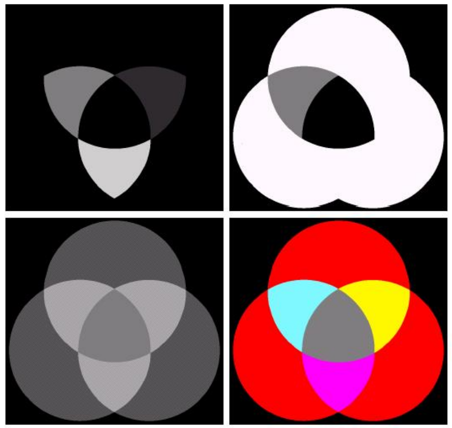


a b
c d

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

HSI Color Space

Example



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.)

HSI Color Space
Drawbacks

From Color FAQ:

- Lightness/brighntess/intensity $(R+G+B)/3$:
  - Conflicts badly with the properties of **color visions**
    Ex: Compute **yellow** to be about **six times** more intense than **blue** with the same "lightness" value (say $L^* = 50$). (next slide)
- Discontinuity of hue at 360 degree.
- Cannot perform arithmetic mixtures of colors expressed in polar coordinates.
- Should be **abandoned**

Luminance

Definition

________: Measure over some interval of the EM spectrum of the flow of power that is radiated from (incident on) a surface. (Candelas)

Definition

__________: Radiant power weighted by a spectral sensitivity (luminance efficiency) (Candelas/meter^2)

Example

________________: The results of integrating an SPD (Spectraum of Power Distribution) using the curve of **luminance efficiency** as a weighting function.

- __________________ (Defined by CIE) everywhere postive, and peaks at about **555 nm** (close to green).

Luminance, YUV and YIQ Color Spaces

CIE Luminance: $Y = K_r \cdot R + K_g \cdot G + K_b \cdot B$

Recommendation	K_r	K_g	K_b	white point
ITU-R BT.601 (1953 for SD) (Older phosphor)	0.299	0.587	0.114	C illuminat $(0.3101; 0.3162)$
ITU-R BT.709 (1990 for HD) (Modern phosphor)	0.213	0.715	0.072	D65 $(0.3127, 0.3290)$

Definition

________________________________:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- YUV: PAL, YIQ: NTSC, rotate 33° each other
- $U = 0.492(B-Y)$
  $V = 0.877(R-Y)$
- Y is **normalized to** $[0,1]$ if input RGB is normalized. (Y=1 refers to **white**)
- U, V, I, Q can be $+$ or $-$
- Easily Discard some color infos to reduce bandwidth

Luma

________ (NTSC, 1953) is the weighted sum of the **non-linear R'G'B' components** after **gamma correction** has been applied

- Why: A CRT converts a video signal/voltage to light in a nonlinear way (Electron gun is nonlinear)
- Cf: Luminance is the weighted sum of the **linear RGB components** of a color video signal, proportional to **intensity**

YPbPr and YCbCr Color Spaces

- ______________ : **Analog** System
- ______________ : **Digital** Video
- YPbPr is **numerically equivalent** to YCbCr.
- YPbPr is a **scaled version (gamma correction)** of YUV
- YCbCr is often confused with the YUV: When referring to signals in digital form, the term YUV probably really means YCbCr more often than not.
- $$\begin{cases} Y' &= K_r * R' + K_g * G' + K_b * B' & , Y' \in [0,1] \\ C_b &= 0.5 * (B' - Y')/(1 - K_b) & , Cb \in [-0.5, 0.5] \\ C_r &= 0.5 * (R' - Y')/(1 - K_r) & , Cr \in [-0.5, 0.5] \end{cases}$$
  - ______ with $Kb = 0.114, Kr = 0.299$

$$\begin{bmatrix} Y' \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

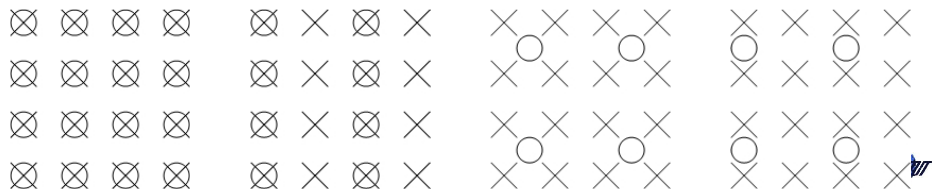
  - Similar to ______ with $Kb = 0.072, Kr = 0.213$

YUV Down-sampling

Chroma can be down-sampled without affecting subjective visual quality

Definition

- _____ : No down-sampling on chroma
- _____ : 2:1 in Hori, no in Vert
- _____ : 2:1 in Hori, 2:1 in Vert (**MPEG-1 vs MPEG-2**)(**MPEG-2 style** easily converted to other formats, ex:4:2:2))
- _____ : 4:1 in Hori, no in Vert (**Seldom used**)



Lightness

Definition

____

- Human vision is a **nonlinear perceptual response to brightness**
- **The perceptual response to luminance** of human vision is called ____________
- $L^* = -16 + 116(h(\frac{Y}{Y_W}))$ where Y_W is _____________
- CIE definition: $h(q) = \begin{cases} \sqrt[3]{q} & \text{if } q > 0.008856 \\ 7.787q + 16/116 & \text{if } q \le 0.008856 \end{cases}$
- L^*: $[0, 100]$

Lightness
Reference White

Definition

____ means a temperature at about **xx00 Kelvins**.

- _________ used as reference for **reflective copy (print industry)**
- _________ used as reference for **photography**
- _________ used as reference for **emissive devices** $(x, y) = (0.3127, 0.3290)$ (talk later)
- _________ used as an approximative reference for **phosphors of a computer monitor**

Note: 3200K to 9300K ⇔ (yellow of tungsten) to (2*blue of daylight)

CIE-XYZ

Definition

______ can describe **any color** by Lumniance Y and two additional components X,Z

- Related to **primary colors**: X (red), Y (green/luminance), Z (blue).
  - From Rec.709 RGB to CIE XYZ

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.35758 & 0.180423 \\ 0.212671 & 0.71516 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

  - From CIE XYZ to Rec.709 RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.240479 & -1.53715 & -0.498535 \\ -0.969256 & 1.875991 & -0.41556 \\ 0.055648 & -0.204043 & 1.057311 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

CIE Chromaticity Diagram and CIE-xyY Color Space

Definition

______
$$\begin{cases} x = \frac{X}{X+Y+Z} & \text{Red} \\ y = \frac{Y}{X+Y+Z} & \text{Green} \\ z = 1-x-y \quad (\text{ie,} z = \frac{Z}{X+Y+Z}) & \text{Blue} \end{cases}$$

Definition

______: It's convenient to describe "pure" color **in the absence of brightness**, which color is plotted as **a point** in an ______

Definition

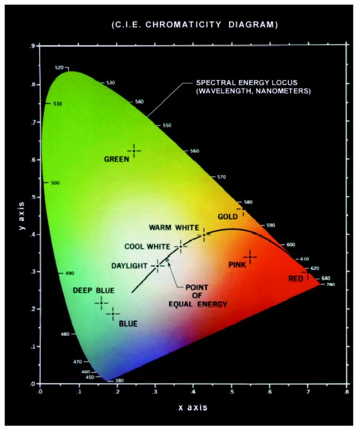
______ specifies a color by its **chromaticity** (x, y) and **Luminance** Y

- An xyY color to XYZ $\begin{cases} X = \frac{x}{y} \cdot Y \\ Z = \frac{1-x-y}{y \cdot Y} \end{cases}$

CIE Chromaticity Diagram

Color composition as a function of x (red) and y (green). z (blue) can be derived by $z = 1-(x+y)$.

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

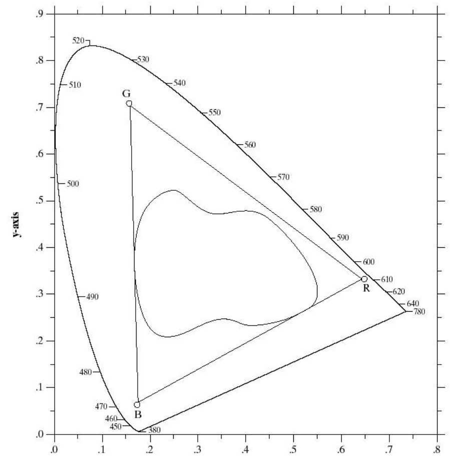


- Points on the boundary of the ______ (Spectral locus + Line of purples) are **pure (fully saturated) colors**.
  Note: Purple cannot be produced by a single wavelength)
- Points not on the boundary represents **the mixture of spectrum colors.**
- ______: Saturation=0
- Points leave the boundary and approach the equal engery point $\Rightarrow$ **More white** and **less saturated**.
- ______: A straight line joining any two points can be ... colors **additively**.

CIE Chromaticity Diagram

Color Gamut

______ (i.e., a typical range of color) of **color printing devices** (irregular region) and **color monitor** (triangle)



(irregular region).

$L^*a^*b^*$ Color Space

Definition

______________ decouples **lightness and color**, which is

$$
\begin{aligned}
L^* &= -16 + 116(h(\tfrac{Y}{Y_W})) \\
a^* &= 500[h(\tfrac{X}{X_W}) - h(\tfrac{Y}{Y_W})] \quad \text{r-g} \\
b^* &= 200[h(\tfrac{Y}{Y_W}) - h(\tfrac{Z}{Z_W})] \quad \text{g-b}
\end{aligned}
\qquad
h(q) = \begin{cases} \sqrt[3]{q} & \text{if } q > 0.008856 \\ 7.787q + 16/116 & \text{if } q \le 0.008856 \end{cases}
$$

where X_w, Y_W, Z_w is reference white tristimulus values

The ______________ has the properties,

- __________: Colors perceived as matching are encoded **identically**
- ________________: Color difference among various **hues** are perceived uniformly
- _______________: Represent accurately colors of any **display/print/input device**

  Note: Device has _________ to **map device to color model**

Pseudocolor

Definition

____________________________________ is to **assign colors to gray values** based on a specified criterion.

There are two techniques:

- __________________________
- _____________________________

Why we need it

Human can discern thousands of color shades and intensities than two dozen or so shades of gray

Intensity Slicing

Definition

- A different color is assigned to each side of the plane. (not continouse gray level in reality)
- Suppose that P planes slice the intensity axis at $l_1, l_2 \ldots l_P$.
  That is, Partition the gray scale into $P+1$ levels $(V_1, V_2 \ldots, V_{P+1})$

  Gray-level to color assigments: $f(x,y) = c_k$ if $f(x,y) \in V_k$

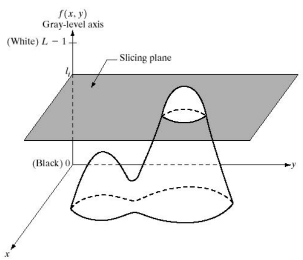


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

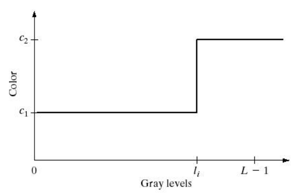
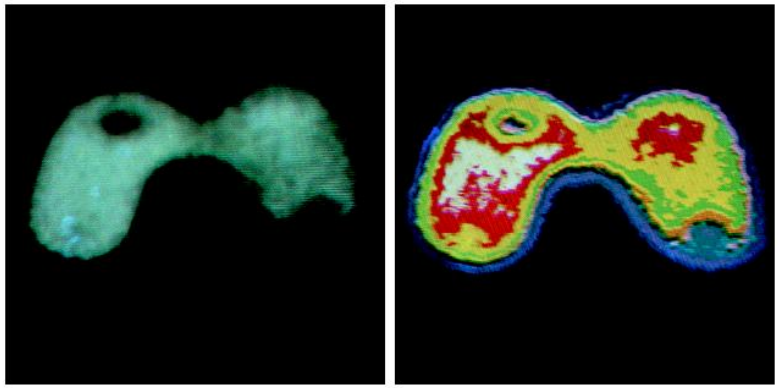


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

Intensity Slicing

Example (8 colors)



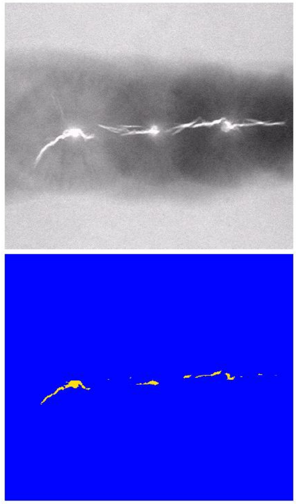
a b

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.)

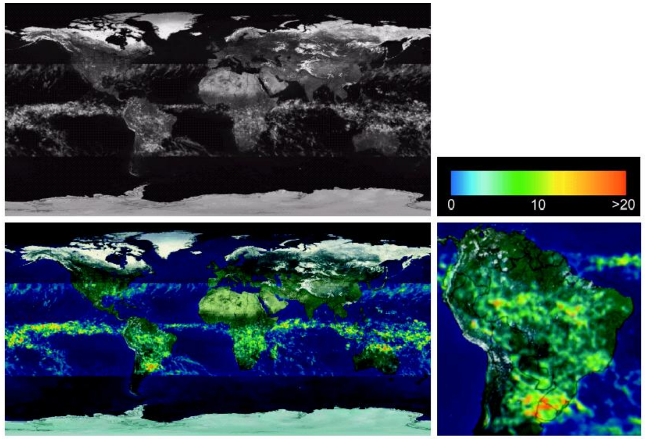
Intensity Slicing
Example (X-ray Image of a Weld)

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.)



Intensity Slicing
Example



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.)

Gray Level to Color Transformations

Definition

________________________ is to perform three independent transformations on the gray level of any input pixel. The three results are then fed separately into the **red, green, and blue channels** to produce a composite image.

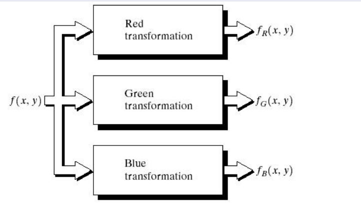
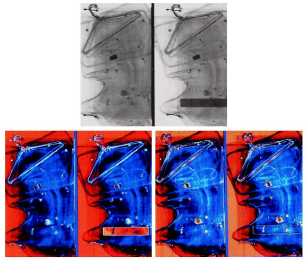


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

- Tranformation is on **gray-level values** but not on position.
- Transformation function can be **nonlinear functions**.
- ____________ is a special case: **piecewise linear functions** of the gray levels to generate color.

Gray Level to Color Transformations
Example

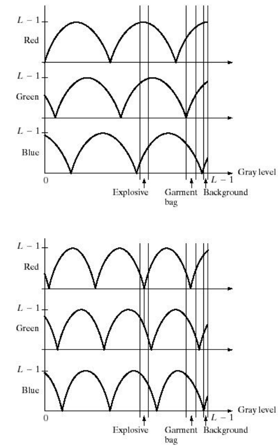


a
b c

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

►Two transformations with **different phase displacement**: the upper transformation can map explosure to orange color and indentify from garment.

►Changing the **phase and frequency** of each sinusoid can emphasize (**in color**) ranges in the gray scale. (**low freq** → **little change**)



a
b

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

Pseudocolor with several mono images

Example

It is often interest to combine several monochrome images into a single color composite. For example:

- ____________________: different sensors produce individual monochrome images, each in a different spectral band.
- ____________: Selecting the three images for display based on knowledge about response characteristics of the acquiring sensors.
- ________

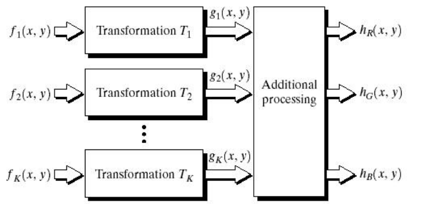
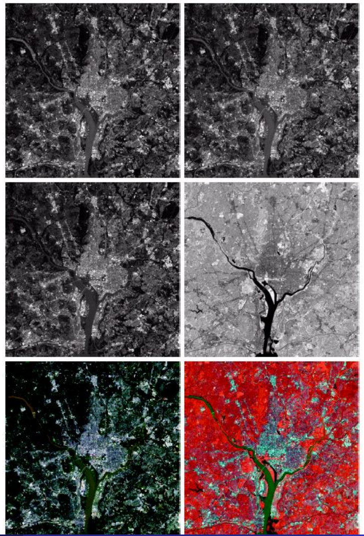
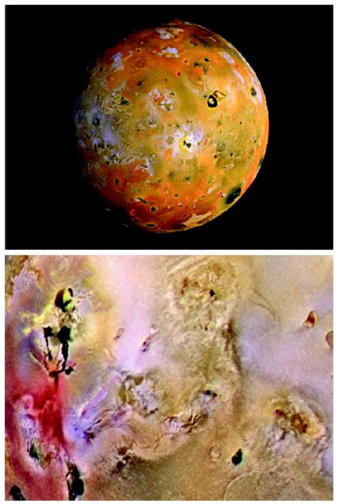


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images

Pseudocolor with several mono images
Example



Pseudocolor with several mono images
Example



a
b

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

- Composition of different mono images from **different sensors**
- Meaningful composition by **understanding the physical and chemical processes** likely to affect sensor response.
  - Red: Material newly ejected from an active volcano
  - Yellow: Older sulfur deposits.

Basics of Full-color Image Processing

Category

Two categories of ____________________:

- ______________________: Process each component image individually and then form a composite processed color image.
- __________________: Work with color pixels directly.
  - Color pixels are treated as vectors $c(x, y) = \begin{bmatrix} c_R \\ c_G \\ c_B \end{bmatrix} = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix}$

Two processes are **equivalent** if

- The process can be **applicable to both vectors and scalars**.
- The operation on each component of a vector must be **indep of the other component**.

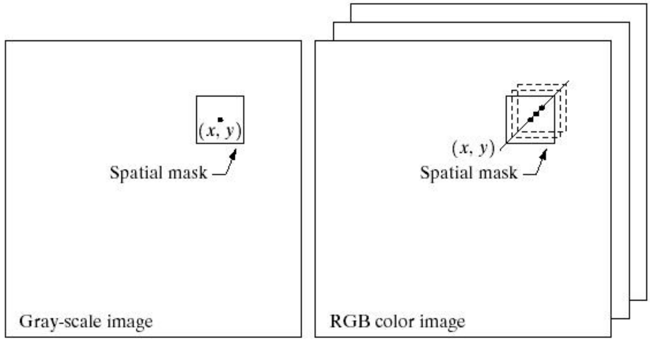
Basics of Full-color Image Processing

Example

Example of equivalent processes between component and vectors processing: Spatial averaging

a b

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



Color Transformation (with a single color model)

Recall ____________________ :

$$g(x, y) = T[f(x, y)]$$

Definition

__________________ :

$$s_i = T_i(r_1, r_2, \ldots, r_n), \ i = 1, 2, \ldots, n$$

where

r_i,s_i: Color components

$\{T_1, T_2, \ldots, T_n\}$: a set of tranformation (____________________)

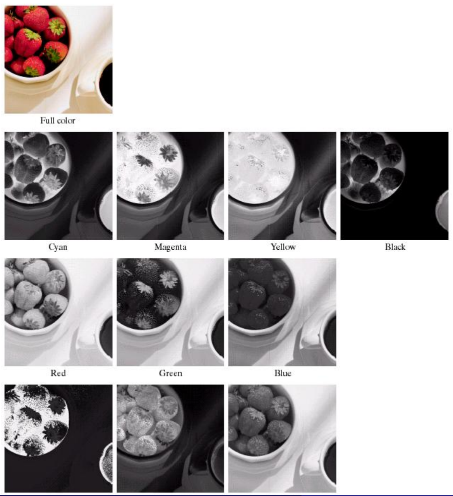
n: Number of components

Example

Work on diff color spaces:

RGB space: n=3, CMYK: n=4, HSI: n=3

Color Transformation
Features in Different Color Spaces



- ______: Strawberry = Large M and Y
- _____: Strawberry = Large R, little G,B
- ____: Strawberry = White S (pure color)

HSI Problem:

  - H is **discontinous** at $0°, 360°$ (red). See strawberry
  - H is **no definition when S=0**

Intensity Transformation

Recall Intensity Transformation in Gray-level image:

$$g(x, y) = k \cdot f(x, y) \ 0 < k < 1$$

Definition

______________________________ :

- _____: $s_i = k \cdot r_i, \ i = 1, 2, 3$
- ____: $s_3 = k \cdot r_3$
- _____: $s_i = 1 - k \cdot (1 - r_i), \ i = 1, 2, 3$

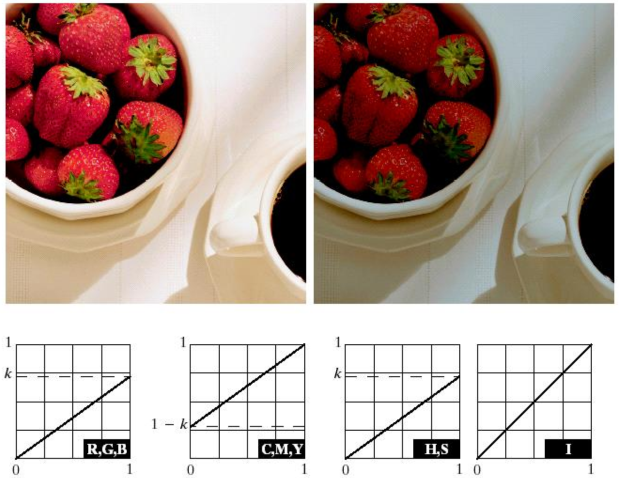
►HSI seems to be with fewer complexity!?

Wrong!!! Don't forget the complexity from color space conversion.

Intensity Transformation
Example

a b
c d e

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 Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations Smoothing and Sharpen

Color Complements

Recall Gray-level Negative.

Definition

__________________ is used in **color film negative**.

___________:

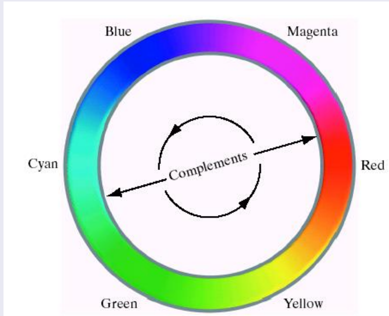
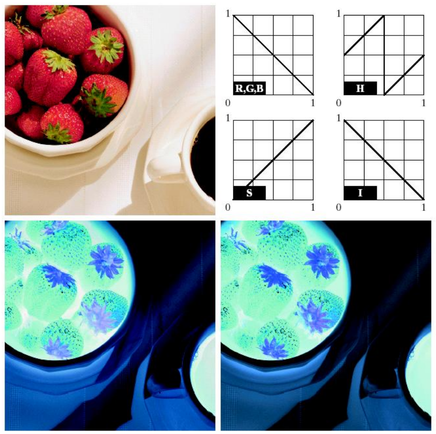


FIGURE 6.32 Complements on the color circle.

Color Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations Smoothing and Sharpen

Color Complements
Example



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.

- RGB complement transform does **not** have a straightforward HSI space equivalent.
  - Reason: **S** of the output image cannot be computed from the S of the input image alone
- **S** represents the **visual differents** in the results of RGB and HSI.

Color Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations Smoothing and Sharpen

Color Slicing

Recall the gray-level slicing technique

Definition

_____________ is to **highlight** a specific range of color

Importance

- Can display **the colors of interest** so that they stand out from the background
- Use the region defined by the colors as a **mask** for further processing.

Color Slicing in RGB Color Space

Method by RGB Cube

Let the **colors of interest** are enclosed by a cube of width W (__________ if $n > 3$)

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

Method by RGB Sphere

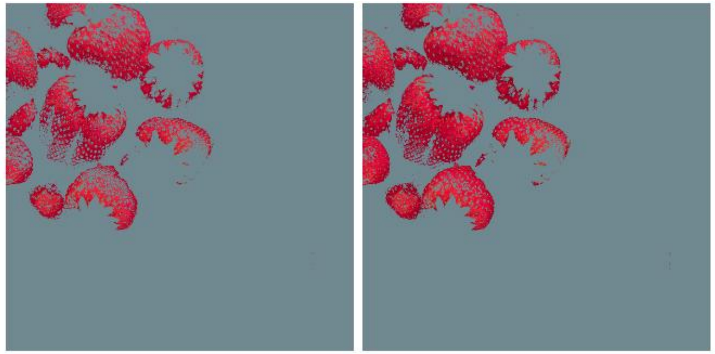
Let the **colors of interest** are enclosed by a Sphere with radius R_0

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

► **0.5**: Forcing all other colors to the **midpoint** of the reference color space.

Color Slicing in RGB Color Space

Example



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 $(0.5, 0.5, 0.5)$.

Tone and Color Corrections

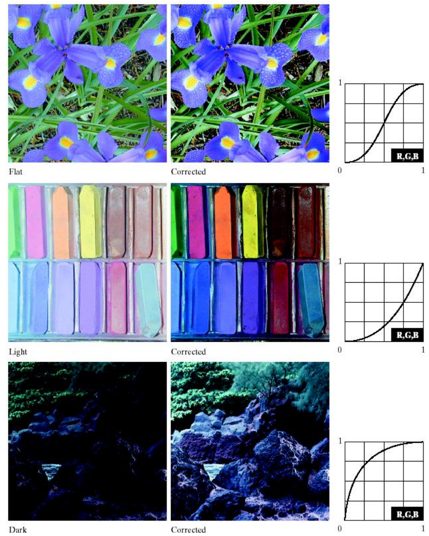
______________: photo enhancement & color reproduction

Two common operations in Digital Darkroom:

- ______________:
  Key Type: General distribution of color intensities.
  - ________: Image is concentrated at high (or light) intensity
  - __________: In between
  - ________: Low intensities
- ______________:

Tone Adjustment

Example



Color Correction
Example

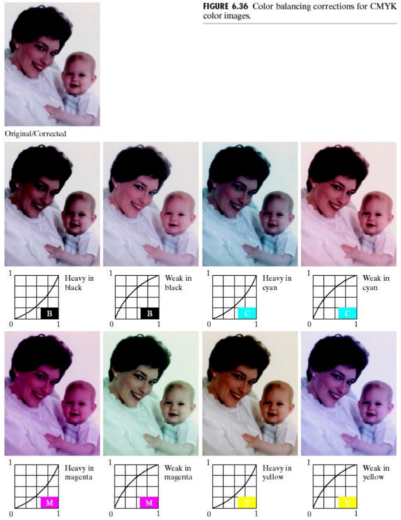


FIGURE 6.36 Color balancing corrections for CMYK color images.

- Since the perception of one color is affected by its surrounding colors, we can correct color by +/- the amount of **the opposite**, or +/- the **adjacent color**.
- **Color circle** can be used.
- Ex: Decrease magenta by **removing r/b** or **adding g**

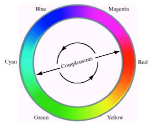
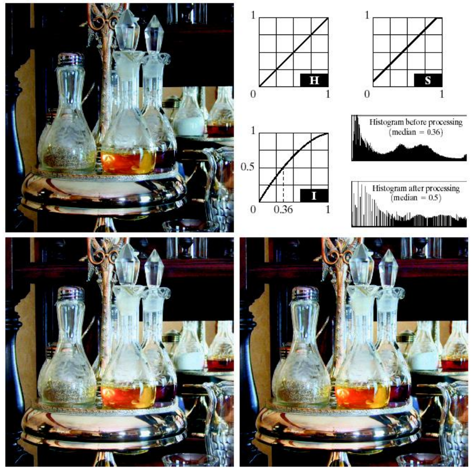


FIGURE 6.32 Complements on the color circle.

Histogram Processing



a b
c d

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

- It results in the **erroneous color** by equalizing the components of a color image **independently**.
- Correct way: We should **spread the color intensities (I) uniformly** and **leave the colors (H) unchanged**.

Color Image Smoothing

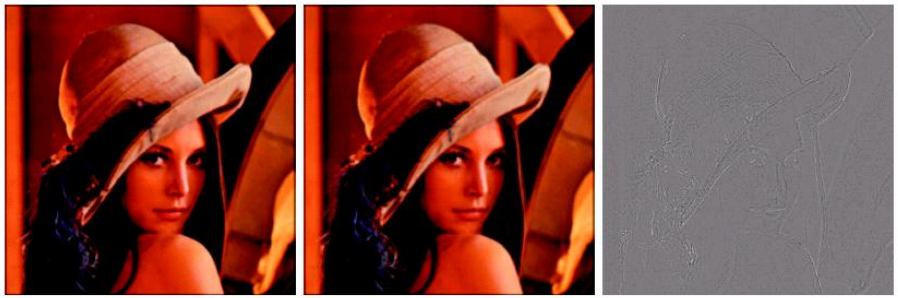
RGB color space

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

HSI color space

Smooth **only on I** using **gray-level smoothing technique**.

Color Imag Smoothing
Example



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.

- RGB averaging mix two colors, **not** either the original image
- HSI approach is **better**: Decouple intensity and color
- This is why two results are diff. Diff increases when **mask size** ↑

Color Image Sharpening

RGB color space

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

HSI color space

Sharpening **only on I** using **gray-level sharpening technique**.

Color Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations

Color Imag Sharpening

Example

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.

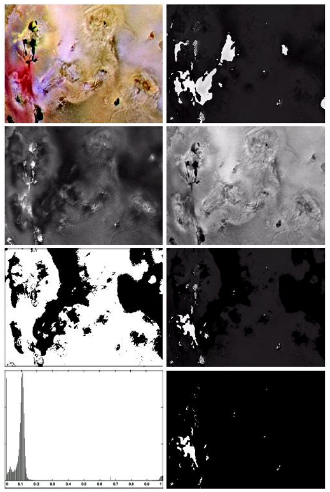
Color Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations Smoothing and Sharpen

Segmentation in HSI

____________ is **intuitive**

Method

- H is used to **segment image**
- S is used as **a masking image** to isolate further ROI in H.
- I is **seldeom** used



Color Fundamental Color Model Pseudocolor Image Processing Basics of Full-color Image Processing Color Transformations Smoothing a

Segmentation in RGB

____________ provides **better** results than HSI's

Method

Segmenting object by **a specified color range**:

1. Specifiy a set of **sample color points of interest**
2. Obtain an estimate of **the "average" color** to segment.
3. Let the average color be denoted by RGB vector $\mathbf{a}$, and seg is **a binary image** $\begin{cases} \text{object (white)} & \text{if } D(\mathbf{z},\mathbf{a}) \le D_0 \\ \text{background (black)} & \text{if } D(\mathbf{z},\mathbf{a}) > D_0 \end{cases}$

   where

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

Segmentation in RGB

Variation (Generalized)

________ : Let $\mathbf{C}$ be the covariance matrix of the sample represntative of the color we wish to segment

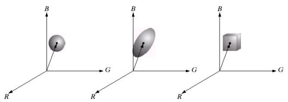
$$D(\mathbf{z},\mathbf{a}) = [(\mathbf{z}-\mathbf{a})^T\mathbf{C}^{-1}(\mathbf{z}-\mathbf{a})]^{1/2}$$

- The principle axes of Elliptic are oriented in the direction of **max data spread**

Variation (Complexity Reduced)

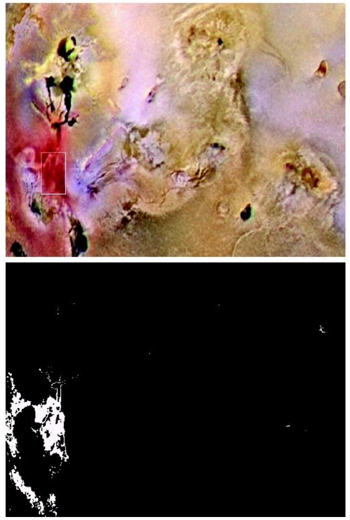
________ :

- Avoid **square root** computations
- Use bounding box which dimentions is proportional to the **standard deviation** of the samples along each of the axis.



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

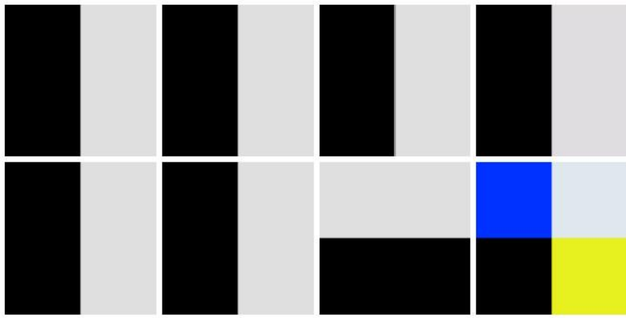
Segmentation in RGB
Example



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

Can we perform grdient operation to detect color edge on per-color-component?
☹ **Not good!!** Ex: Below, all edges should have same strength



a b c d
e f g h
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.

Color Edge Detection

Q&A

Can we perform **gradient operation** to detect color edge on vector-based processing?

NO?! Gradient only works on **scalar**.

Solution

Di Zenzo [1986]: New defintion of the gradient applicable to vector quantities. (Recall that the gradient is a vector poining in the direction of **maximum rate of change** of f at coordinates (x,y))

$$\begin{aligned}\mathbf{u} &= \frac{\partial R}{\partial x}\mathbf{r} + \frac{\partial G}{\partial x}\mathbf{g} + \frac{\partial B}{\partial x}\mathbf{b}\\ \mathbf{v} &= \frac{\partial R}{\partial y}\mathbf{r} + \frac{\partial G}{\partial y}\mathbf{g} + \frac{\partial B}{\partial y}\mathbf{b}\end{aligned}$$

$$\begin{aligned}g_{xx} &= \mathbf{u}\cdot\mathbf{u} = \mathbf{u}^{\mathbf{T}}\mathbf{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2\\ g_{yy} &= \mathbf{u}\cdot\mathbf{u} = \mathbf{u}^{\mathbf{T}}\mathbf{u} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2\\ g_{xy} &= \mathbf{u}\cdot\mathbf{v} = \mathbf{u}^{\mathbf{T}}\mathbf{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}\end{aligned}$$

Color Edge Detection

The **direction** of maximum rate of change of $\mathbf{c}(x, y)$ is given by the angle

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

The **value** of the rate of change at (x, y) in the direction of θ is

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

- $F(\theta)$, where θ is max rate change angle, is the **edge map**
- $F(\theta) = F(\theta + \pi)$, so F needs to be computed **only for** θ **in** $[0, \pi)$
- Because of $\tan^{-1}$, if θ_0 is a sloution, so is $\theta_0 \pm \pi/2$. (orthogonal directions). Along one of those directions F is maximum, and it is **minimum along the other(orthogonal).**
- **Sobel** can be used to compute the g_{xx}, g_{yy}, g_{xy} in previous slide.

Color Edge Detection
Example

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).

Both provide resaonable results, but extra detail (right eye) is provided in gradient on RGB vector with higher complexity.

Color Edge Detection
Example

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 Image

- Can have **same** characteristics in each color channel
- Can affect **differently** in color channel (CCD camera's red filter)

- Can carry out on per-compoent (scalar) basis.
- Can directly process in color (vector) space.
- Two processes may have **same effect**.
  Ex: **Averaging**
- Some filters may have **no definition** in color space.
  Ex: **Order statistics filter**. The median filter in color space may find a scheme for **ordering vectors** in a way that the median makes sense. (more complex)

Noise in Color Image

RGB Example

a b
c d

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).]

Noise in Color Image

HSI Example

a b c

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

Noise in Color Image

Example

a b
c d

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.

One RGB channel noise spreads to all channels of HSI

Color Image Compression

a b
c d

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