← just intensity

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

strawberries are highly saturated

color transformations

$$s_i = T_i(r_1, r_2, \ldots, r_n) \quad i = 1, \ldots, n = \# \text{ of color components}$$

s_i: new color components

$r_1, r_2, \ldots, r_n$: color components, i.e., R, G, B

T_i = set of color transformations.

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

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

in HSI color space $\quad s_3 = k r_3$

$\quad s_1 = r_1, \; s_2 = r_2$

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

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

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

RGB space:

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

to modify intensity

$$I' = \frac{1}{3}(kR+kG+kB)$$

$$= \frac{k}{3}(R+G+B) = kI$$

CMY space

$$I = \frac{1}{3}(1-C+1-m+1-Y)$$

$$I = \frac{1}{3}(3-C-m-Y) = 1-\frac{1}{3}(C+m+Y)$$

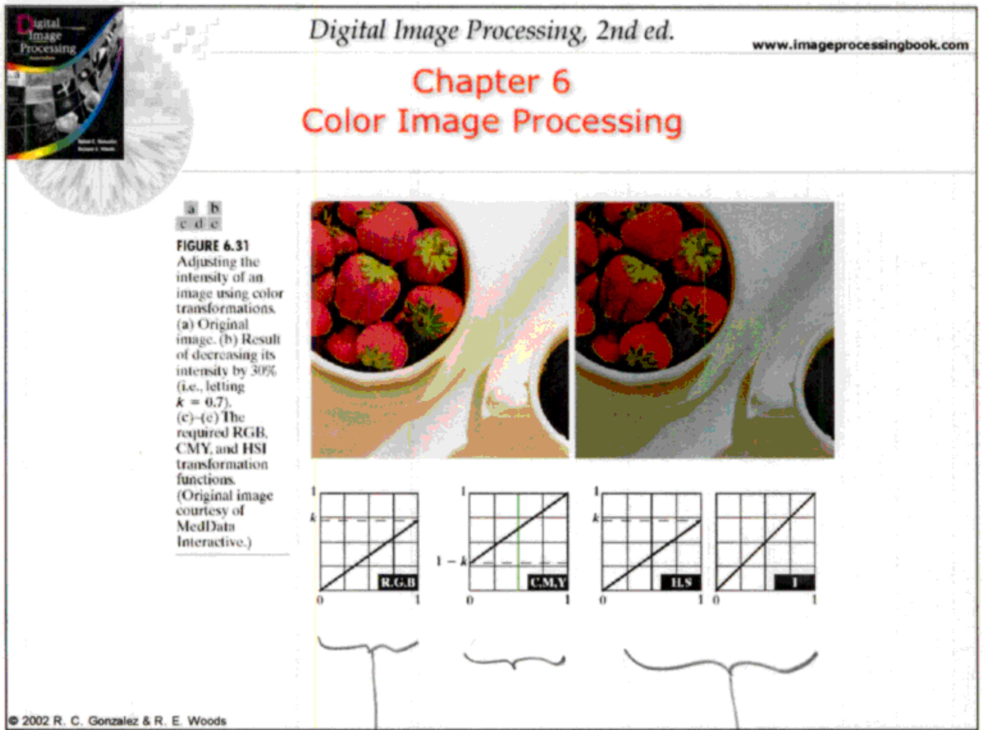
let $C' = kC+(1-k)$

$$I' = 1-\frac{1}{3}\left[kC+(1-k)+km+(1-k)+kY+(1-k)\right]$$

$$= 1-\frac{1}{3}\left[k(C+m+Y)+3(1-k)\right]$$

$$= 1-\frac{k}{3}(C+m+Y)-(1-k)]$$

$$= k\left[1-\frac{1}{3}(C+m+Y)\right] = kI$$

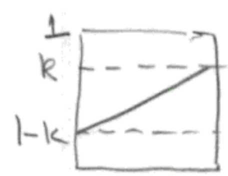


Scale each component in RGB

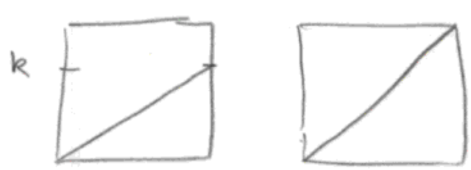
Since $C = 1 - R$, etc. This is simply a linear transformation.

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

lots of errors in figure

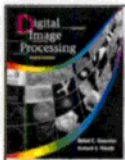


CMY



I

H, S.



Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

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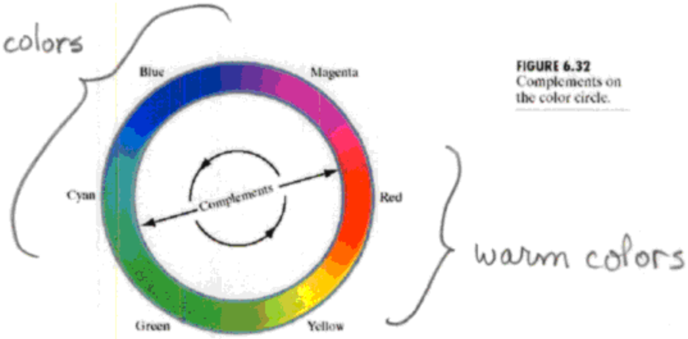
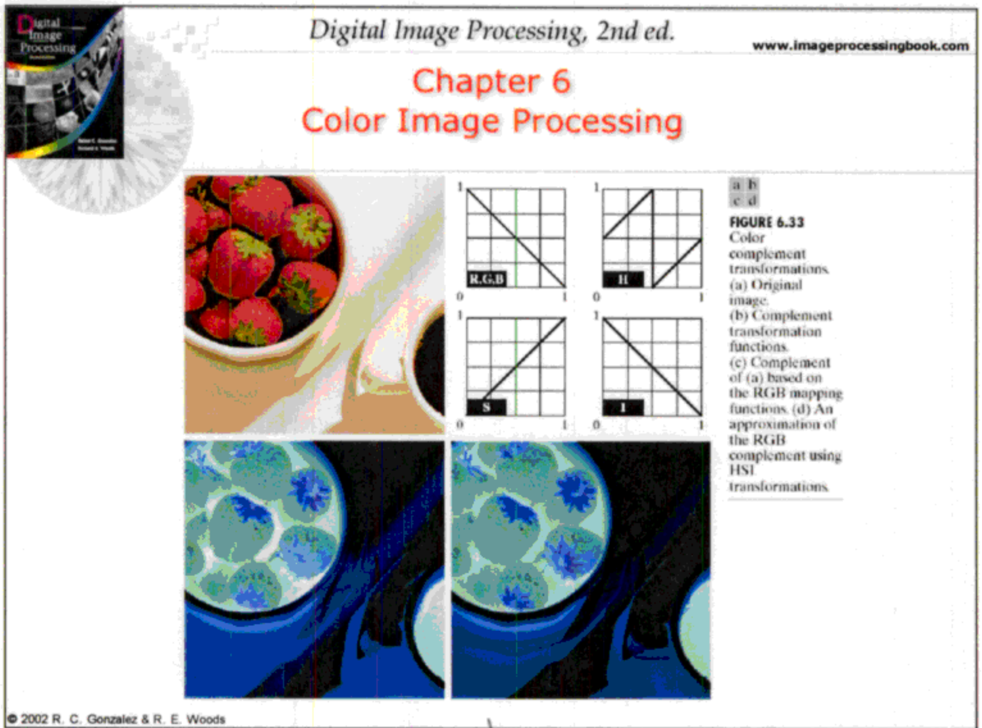


FIGURE 6.32 Complements on the color circle.

Newton's color circle summarizes the additive properties of colors



RGB complement

HSI complement.

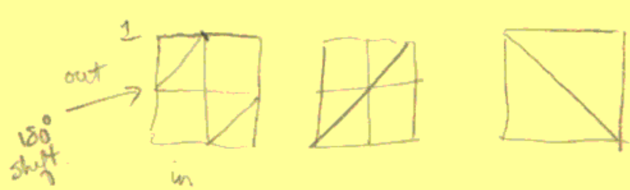
As you decrease each color (R,G,B) its complement becomes evident.

R ⟷ cyan

G ⟷ magenta

B ⟷ yellow

complement not straight forward
See problem 6.18



H

S
no change

$I = \frac{1}{3}(R+G+B)$
decreasing since
$C=1-R$, etc.

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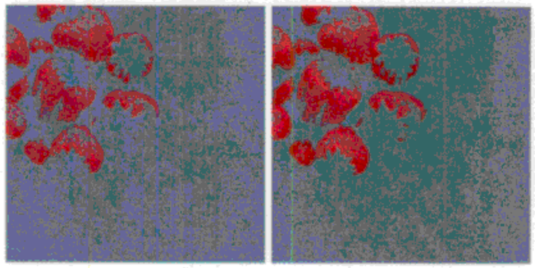


a b

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).

sphere might be slightly better

RGB cube   RGB sphere

overlap in color space

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

cube, hypercube

neutral color

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

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

sphere

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

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

RGB

color measured when illuminated with a CIE D65 source and diffuser

6.5.4. Tone/Color correction

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

color management systems

Pantone (used by Adobe)

similar to HSI by separating color from intensity

CIE L*a*b

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

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

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

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

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

X, Y, Z – R, G, B tristimulus values

$L^* a^* b^*$ is

colorimetric – colors perceived as identical have identical values

perceptually uniform – color differences are perceived uniformly

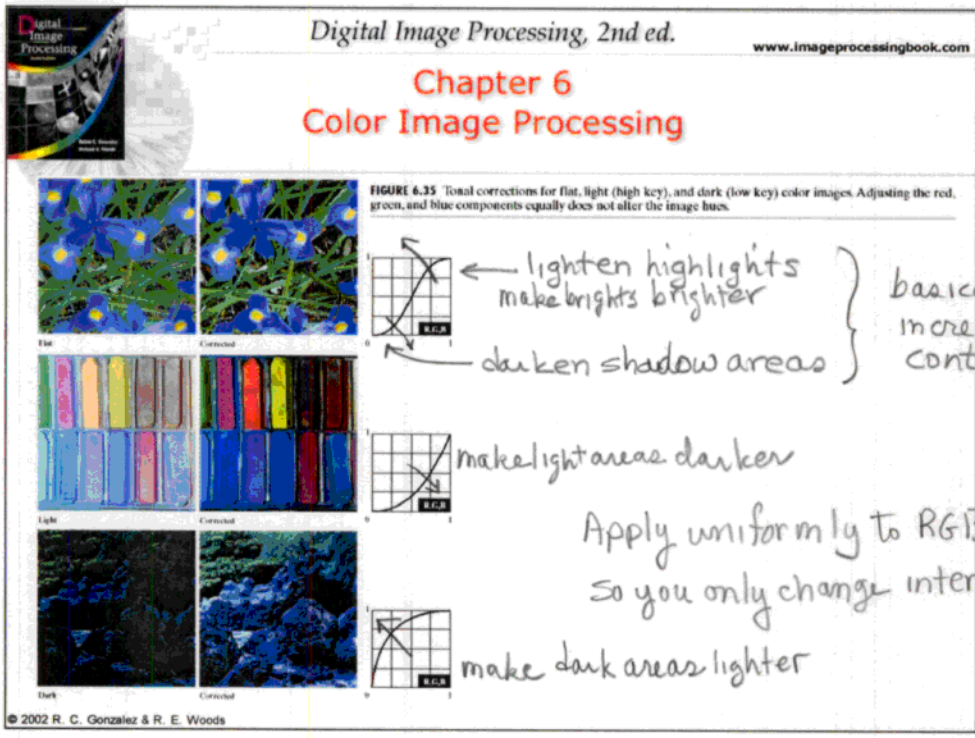
device independent

correction

flat

light

dark



← lighten highlights
make brights brighter

darken shadow areas

} basically increases contrast

make light areas darker

Apply uniformly to RGB
so you only change intensity.

make dark areas lighter

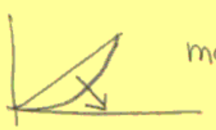
tonal range – key type

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

low-key – " " at low intensities

middle-key – " " at intermediate intensities

make dark areas brighter



make dark areas lighter
→ light areas darker.

make brights brighter (lights)

make darks darker.

CMYK images.

Apply these transforms to correct

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

Simple transformations to either boost or lighten a CMYK image.

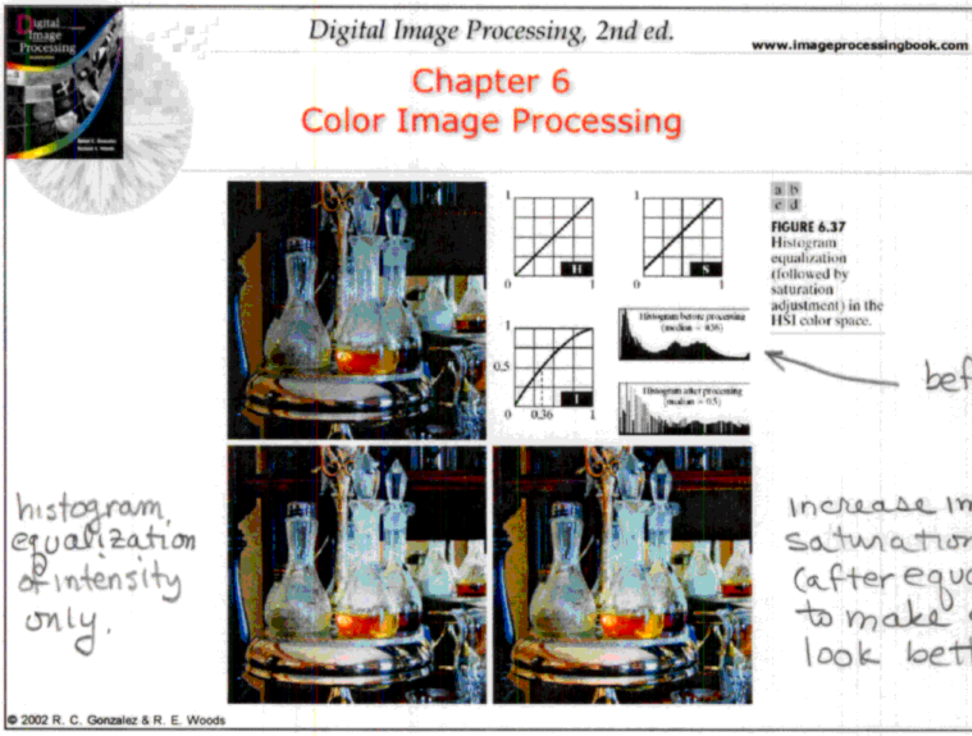
The simple transformations are shown

white
black
skin
} best references

don't use bright saturated colors

(boost) ADD

(lighten) SUBTRACT



before equalization

histogram equalization of intensity only.

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

How can you apply histogram equalization to a color image?

Don't equalize colors independently, spread color intensities such as in HSI space.

RGB components

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

Consider averaging

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

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

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a b c

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

HSI components of previous picture.

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a b c

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

Image smoothing using a 5x5 mask.

(a) smoothing each color plane independently

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

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

Reason for differences: image smoothing
average of two pixels of different color is a different color.

average of two pixels in I image doesn't change color.

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a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.

processing each RGB color plane | processing only HSI intensity plane | difference (?) image

Color image sharpening using Laplacian

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

$$g(x,y) = f(x,y) \pm \nabla^2 f$$

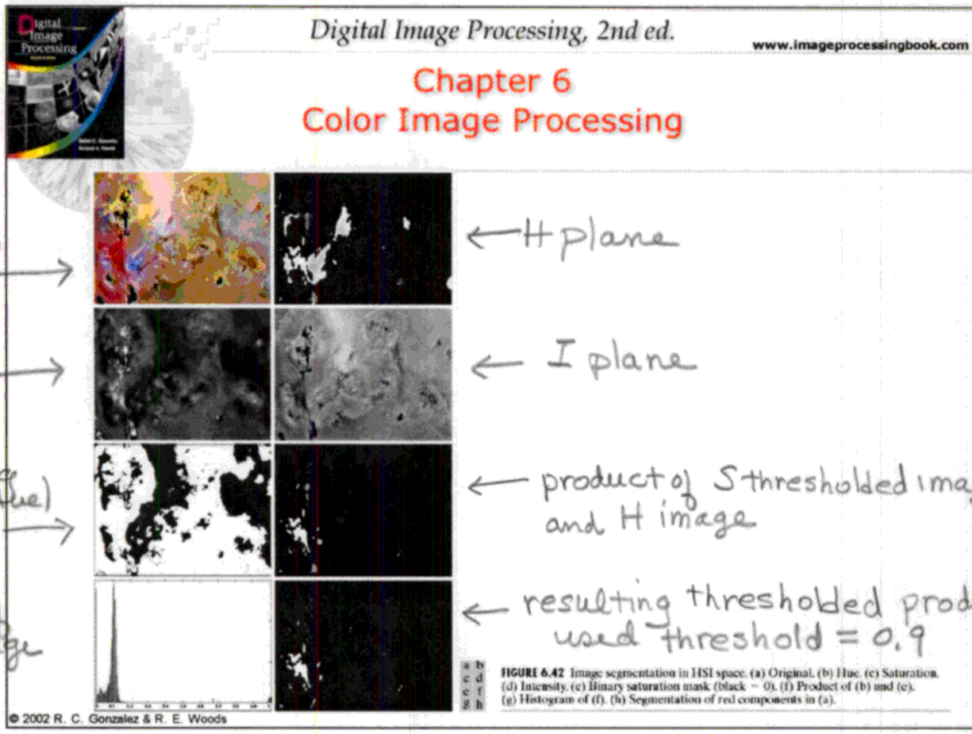

FIGURE 6.42 Image segmentation in HSI space. (a) Original. (b) Hue. (c) Saturation. (d) Intensity. (e) Binary saturation mask (black = 0). (f) Product of (b) and (e). (g) Histogram of (f). (h) Segmentation of red components in (a).

Segmentation (Chap. 10 topic)

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

1st thresholding — identify saturated colors 1 - white saturated, 0 - blk - unsaturated

products — regions of significant color

color distribution

histogram of regions of significant color

2nd thresholding will identify colors.

Colors > 0.9 are colors of interest.

colors near red