Digital Image Processing
Lecture 12

- Color
- Numbers according to Gonzales & Woods, Global Edition, 4th edition. (Numbers in other editions may vary).
- Gonzales & Woods:
  - Chapter 6

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Color spectrum
Color wavelength

Which wavelength has magenta?

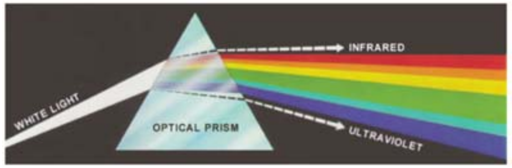


Fig. 6.1

In 1666, Newton discovered that sunlight (white light) passing through a glass prism split up into a color spectrum of wave lengths in the interval 400-700nm.

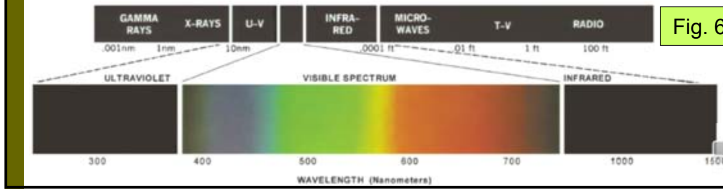


Fig. 6.2

Color of objects

An object that reflects light in all wave lengths appears white.

An object that reflects blue light and absorbs green-yellow-red light appears blue.

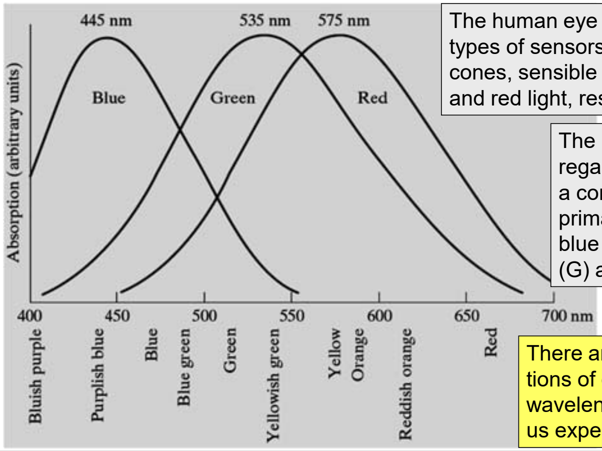
An object that reflects red light and absorbs blue-green-yellow light appears red.

Characteristics of a light source

- 1) Radiance
  - Total amount of energy that flows from the light source.
  - Measured in watts (W).
- 2) Luminance
  - A measure of the amount of energy the observer *perceives* from a light source.
  - Measured in lumens (lm).
  - Ex 1) Normally high Radiance corresponds to high Luminance.
  - Ex 2) High Radiance of infrared light correspond to low Luminance
- 3) Brightness
  - Embodies the achromatic notion of intensity
  - Impossible to measure
  - Ex) Which color is most intense - blue or red?

Absorption of light by the cones in the human eye

Fig. 6.3



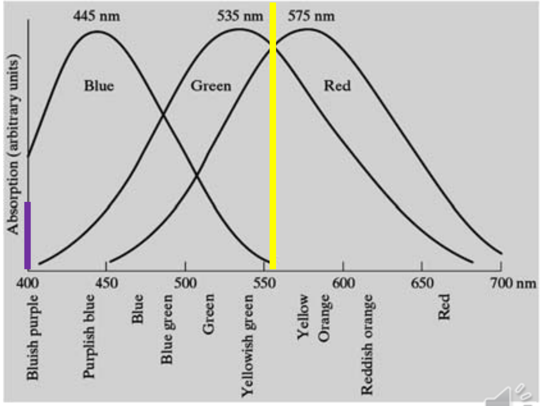
The human eye contains 3 types of sensors named cones, sensible to blue, green and red light, respectively.

The human eye regards a color as a combination of 3 primary colors blue (B), green (G) and red (R).

There are ∞ combinations of discrete wavelengths that let us experience yellow.

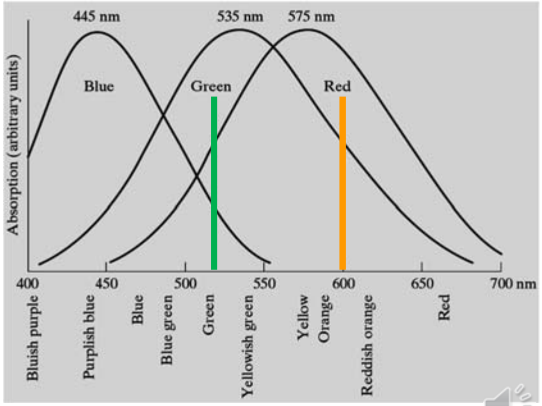
Absorption of light by the cones in the human eye. Example 1)

- 100% yellow light at 555nm stimulates cone G and cone R equally.
- (A little bit of bluish purple stimulates the cone B.)
- We experience yellow!

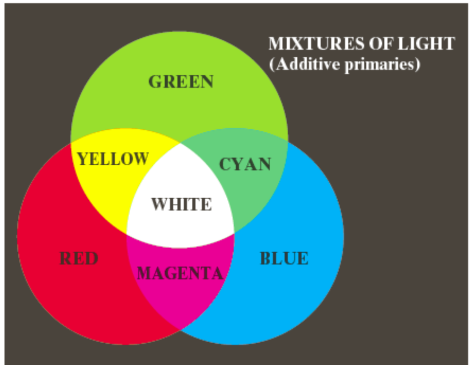


Absorption of light by the cones in the human eye. Example 2)

- 65% green light at 520nm and 65% orange light at 600nm stimulates cone G and cone R equally.
- (Cone B is slightly stimulated too.)
- We experience yellow!



Primary and secondary colors of light. Additive color mixing.



Answer to which wavelength magenta has.

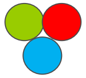
Here, secondary colors are mixtures of two primary colors.

yellow = red + green
cyan = green + blue
magenta = red + blue

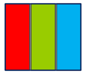
CRT
LCD
plasma

Fig. 6.4

CRT, LCD, plasma

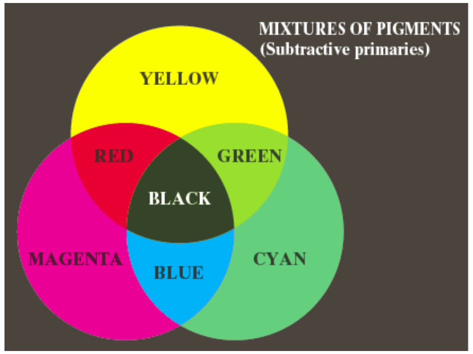


- CRT = Cathode ray tube. Old color TV screens are composed of triangular dot patterns of electron-sensitive phosphor.



- LCD = Liquid crystal display. Three sub-pixels, 1 red, 1 green, 1 blue generates a single color pixel. The principle is based on polarized light to block or pass light through screen. Light filters are used to produce the 3 primary colors.
- Plasma. Three sub-pixels, 1 red, 1 green, 1 blue generates a single color pixel. A tiny gas cell coated with phosphor produce one primary color.

Primary and secondary colors of pigments. Subtractive color mixing.



A primary color of pigment absorbs 1 primary color of light and reflects the others.

red = yellow + magenta
green = cyan + yellow
blue = magenta + cyan

Painting colors
Clay

Fig. 6.4

Characteristics of a color

- 1) Brightness
  - Embodies the achromatic notion of intensity
  - Impossible to measure
- 2) Hue
  - Associated with the dominant wavelength in a mixture of light waves
  - Dominant color as perceived by an observer
- 3) Saturation
  - Refers to the relative purity or the amount of white light mixed with a hue
  - The pure spectrum colors are fully saturated
- Chromaticity
  - Hue and saturation taken together
  - A color may be characterized by its brightness and chromaticity
- Tristimulus
  - The amount of X (“red”), Y (“green”) and Z (“blue”) needed to form a particular color.
  - Does not exist in reality. Compiled from extensive experimental results with humans.
  - Imagine that we “could individually stimulate each cone”

CIE Chromaticity diagram

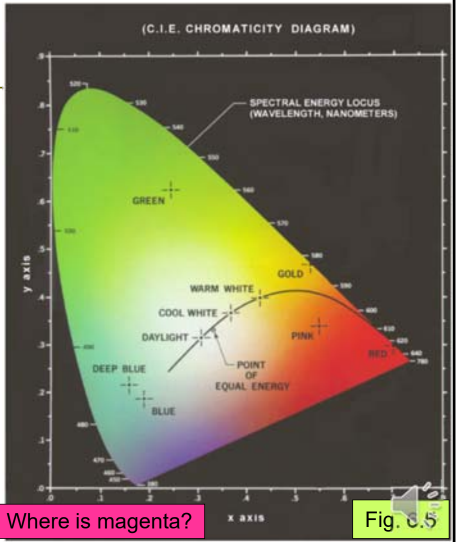
Trichomatic coefficients:

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

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

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

$$x + y + z = 1$$



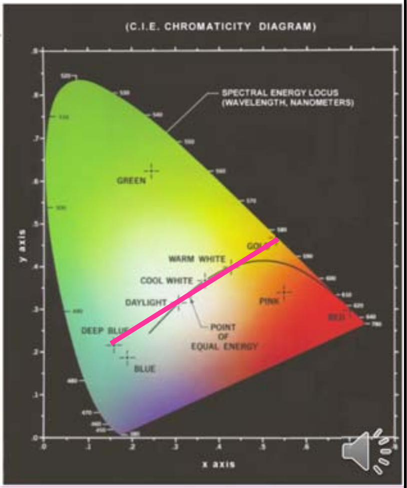
Useful for mixing colors because a straight line between two colors gives the additive mixing result color.

Where is magenta?

Fig. 6.5

Measured values in the CIE Chromaticity diagram

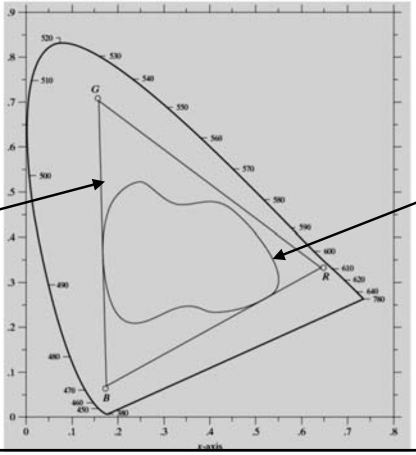
- The point marked GREEN has:
  - x=0.25 "red"
  - y=0.62 "green"
  - z=1-(x+y) =0.13 "blue"
- DAYLIGHT = 0.40·GOLD + 0.60·DEEPBLUE
- WARMWHITE = 0.70·GOLD + 0.30·DEEPBLUE



Typical color gamut of color monitors and color printing devices

Color gamut is defined as the range of colors which a device can produce.

Not all colors can be obtained with three single fixed primaries.

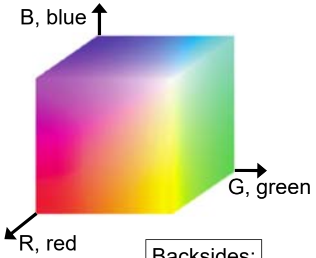


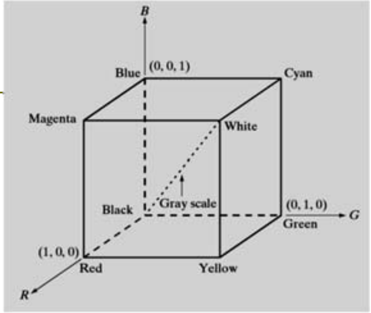
The colors inside this triangle can be composed by a typical RGB color monitor.

The colors inside this area can be composed by a high quality printing device.

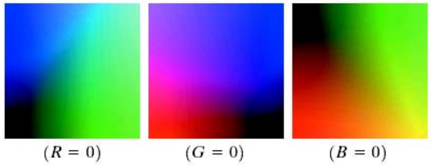
Fig. 6.6

The RGB color model





Backsides:


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

The purpose is to specify the colors in some standard, generally accepted way.

The colors have been normalized.

Fig. 6.7 Fig. 6.8 Fig. 6.9

Generating the cross-sectional color plane (127,G,B) of the RGB color model

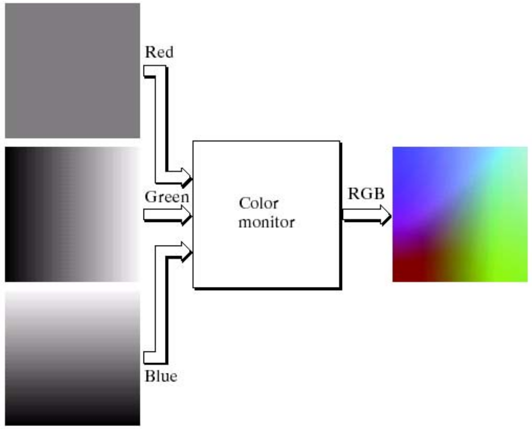
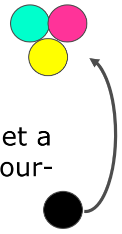


Fig. 6.9

The CMY and CMYK color models

- For pigments. Subtractive color mixing.
- The RGB color model transforms into the CMY (Cyan, Magenta, Yellow) model according to:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{(6-5)}$$



- CMYK: A fourth color (black) is added to get a better black color. Publishers talk about "four-color printing".

Note however that color printing is rather a mixture of additive and subtractive color mixing.

The HSI color model

- The HSI (Hue, Saturation, Intensity) model is good for describing colors. It decouples the intensity information from the color-carrying information.
- Let the RGB-cube stand on its black (0,0,0) vertex with the white vertex (1,1,1) pointing upwards.
- Intensity (gray level) is good for describing monochromatic images. Intensity is used instead of the previously mentioned brightness, which is subjective and impossible to measure.

A plane through a color point perpendicular to the intensity axis gives the intensity value.

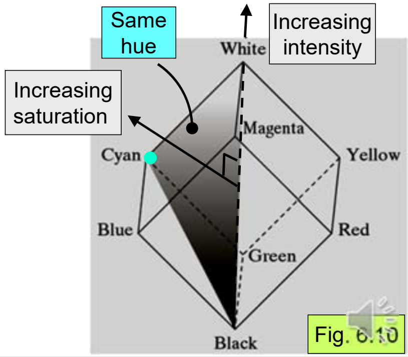


Fig. 6.10

Hue (H) and saturation (S) in the HSI model

The shape does not matter because anyone of these shapes can be warped into one of the other by a geometric transformation in S.

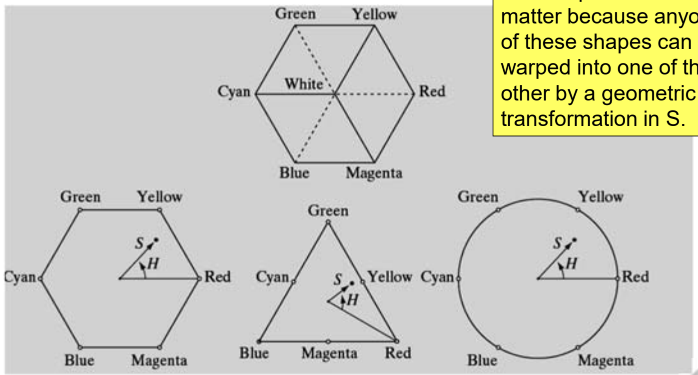


Fig. 6.11

The HSI model based on…

… triangular color planes:

… circular color planes:

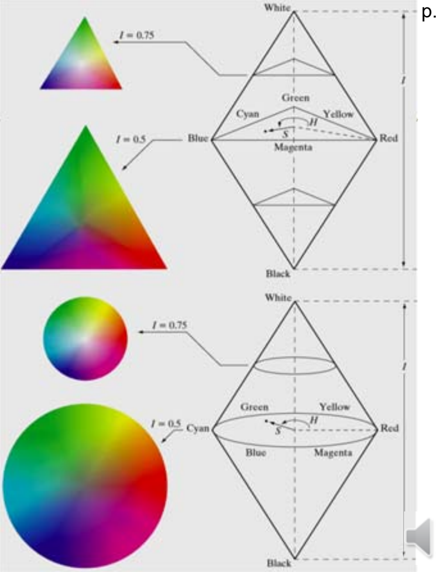


Fig. 6.12

Converting colors from RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases} \qquad \text{(6-16)}$$

Hue can then be normalized to the range [0,1].

$$\theta = \cos^{-1}\left\{ \frac{0.5[(R-G)+(R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{0.5}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)] \qquad \text{(6-17)}$$

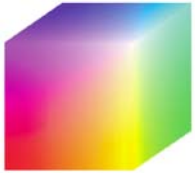
Saturation has max=1 on the backsides of the original RGB-cube.

$$I = \frac{1}{3}(R+G+B) \qquad \text{(6-18)}$$

Intensity has max=1 for white color.

Questions on the HSI components

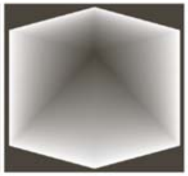
Fig. 6.8 Fig. 6.13 Fig. 6.14



RGB color cube

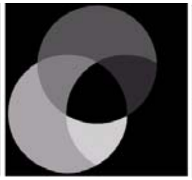
H, S, I ??

H, S, I ??



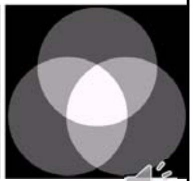
H, S, I ??

RGB image



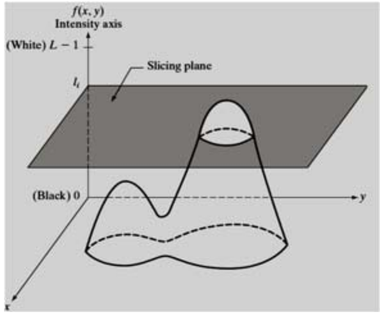
H, S, I ??

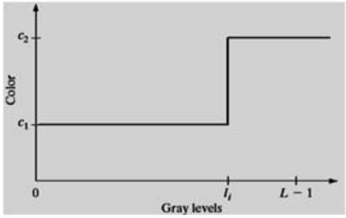
H, S, I ??



H, S, I ??

Pseudocolor Image Processing: Intensity slicing





$$f(x,y) = c_k \quad \text{if } f(x,y) \in V_k \qquad \text{(6-35)}$$

Fig. 6.16 Fig. 6.17

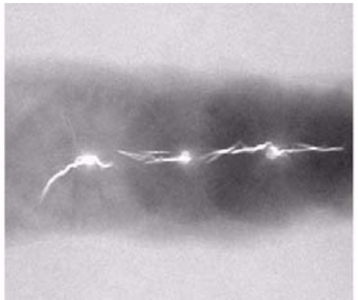
Intensity slicing, Ex1

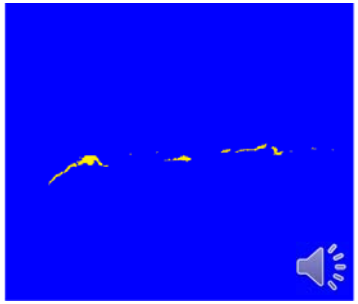
A crack in the weld => saturation of the imaging sensor.

Fig. 6.19

“a powerful aid in visualization”
“helps a human to judge the image”

$$f(x,y) = blue \quad \text{if } f(x,y) < 255$$
$$f(x,y) = yellow \quad \text{if } f(x,y) = 255$$





Intensity slicing, Ex2

Intensity slicing of the image into 8 color regions.

Regions that appear of constant intensity in the monochrome image are actually quite variable.

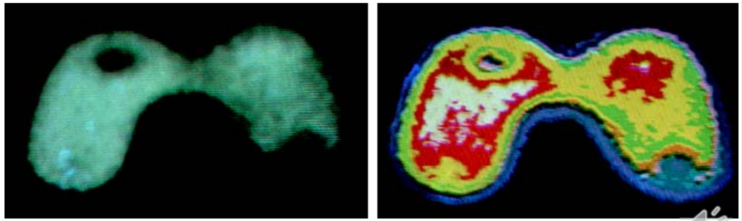


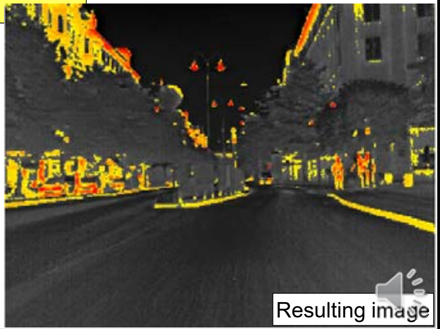
Fig. 6.18

Intensity to color transformation (here through the colortable). Ex)

Input IR-image

Construct a color transformation so that an IR-image is shown in gray scale up to 99. Then, the values are shown in a linear yellow-to-red scale from saturated yellow to saturated red.

Intensity	R	G	B
0:			
|			
98:			
99:			
100:			
|			
255:			



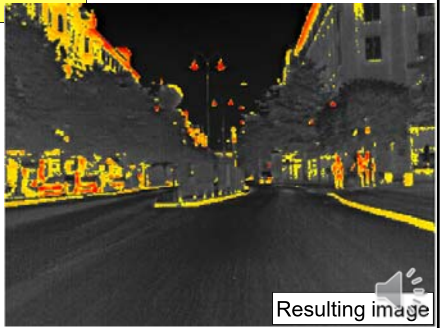
Resulting image

Answer)

Input IR-image

Construct a color transformation so that an IR-image is shown in gray scale up to 99. Then, the values are shown in a linear yellow-to-red scale from saturated yellow to saturated red.

Intensity	R	G	B
0:	0	0	0
|	|	|	|
98:	98	98	98
99:	99	99	99
100:	255	255	0
|	|	|	|
255:	255	0	0



Resulting image

Intensity to color transformation with several monochrome images

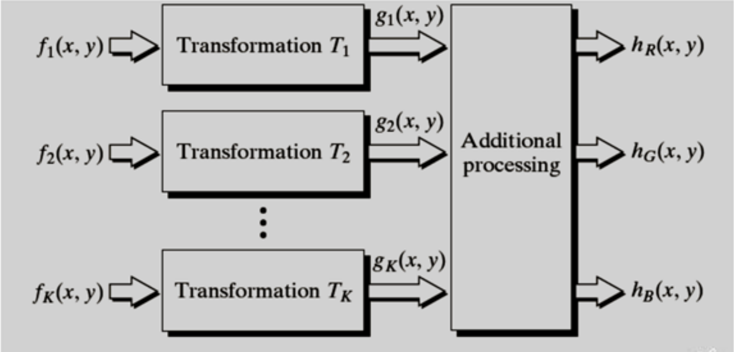


Fig. 6.24

4 images from NASA's LANDSAT satellite

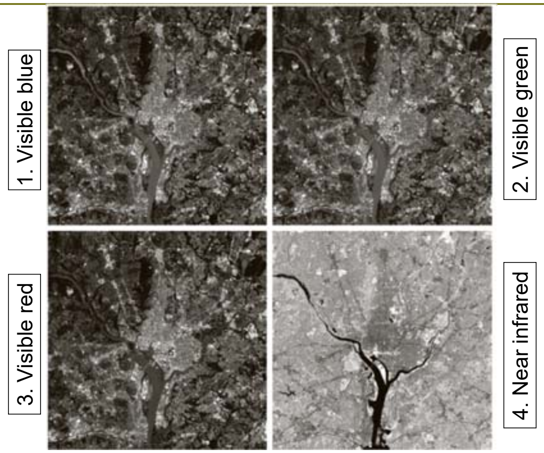


Fig. 6.25

Landsat's images combined to color images

Fig. 6.25

3, 2, 1 = R,G,B
combined to color image

4, 2, 1 = R,G,B
combined to pseudo color image

Basics of full-color image processing

- 1) We can process each color component individually and then form a composite processed color image from the individually processed components.
- 2) We can work with color pixels directly.

$$\mathbf{c}(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix} \quad (6\text{-}37)$$

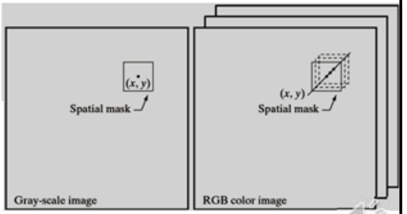
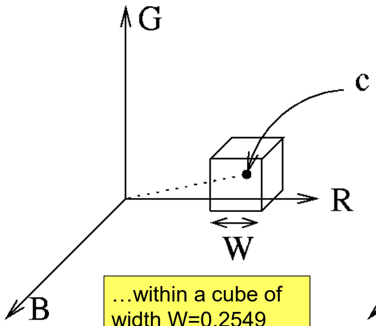
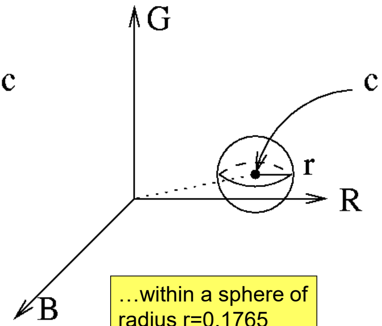


Fig. 6.27

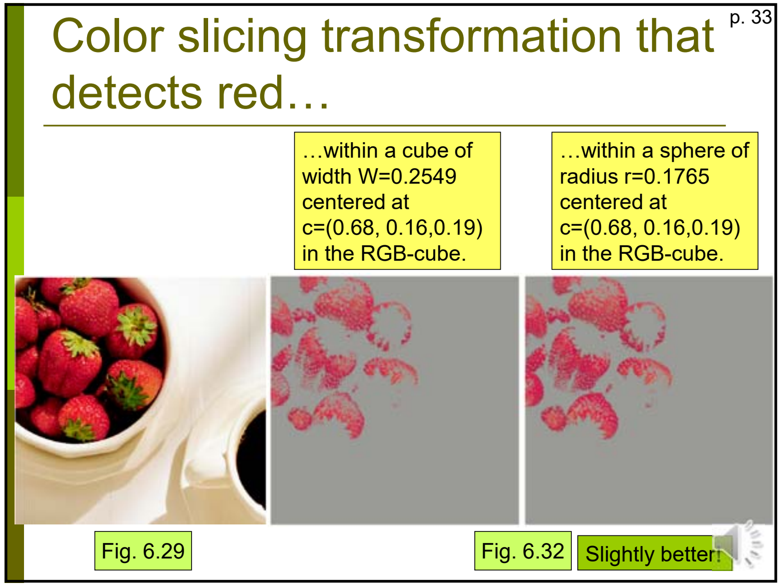
Color slicing transformation that detects red…



…within a cube of width W=0.2549 centered at c=(0.68, 0.16,0.19) in the RGB-cube.



…within a sphere of radius r=0.1765 centered at c=(0.68, 0.16,0.19) in the RGB-cube.



Color slicing transformation that detects red…

…within a cube of width W=0.2549 centered at c=(0.68, 0.16,0.19) in the RGB-cube.

…within a sphere of radius r=0.1765 centered at c=(0.68, 0.16,0.19) in the RGB-cube.

Fig. 6.29

Fig. 6.32

Slightly better!

Tone and color corrections

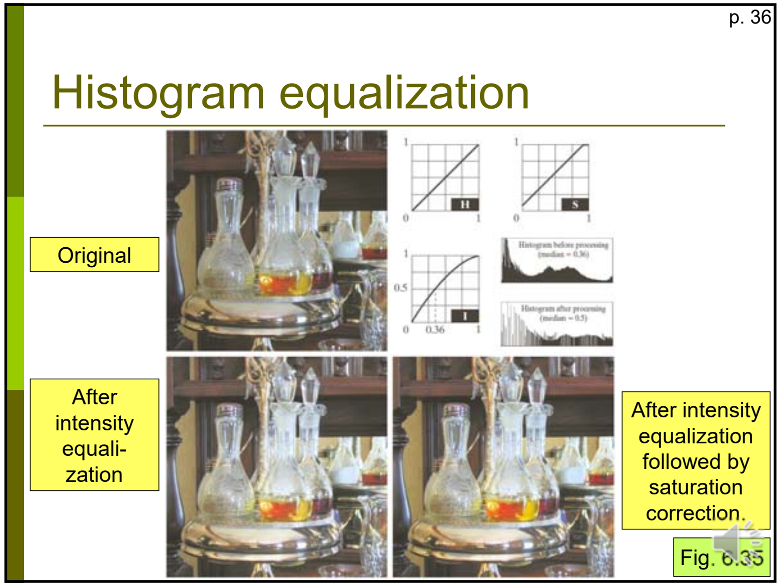
Fig. 6.33

The digital darkroom 1!

Color balancing corrections for CMYK images

The digital darkroom 2!

Fig. 6.34



Histogram equalization

Original

After intensity equalization

After intensity equalization followed by saturation correction.

Fig. 6.35

Image smoothing

$$a(x,y) = \begin{array}{|c|c|c|c|c|}\hline 1&1&1&1&1\\\hline 1&1&1&1&1\\\hline 1&1&\boxed{1}&1&1\\\hline 1&1&1&1&1\\\hline 1&1&1&1&1\\\hline\end{array} /25$$

$$g(x,y) = a(x,y) * f(x,y)$$

Original

Processing all RGB

Processing I of HSI

Only small Difference

Fig. 6.38

Image sharpening with the Laplacian

$$\nabla^2 = \begin{array}{|c|c|c|}\hline 0&1&0\\\hline 1&\boxed{-4}&1\\\hline 0&1&0\\\hline\end{array}$$

$$g(x,y) = f(x,y) + c[\nabla^2 f(x,y)]$$

where c is a weighting factor

Original

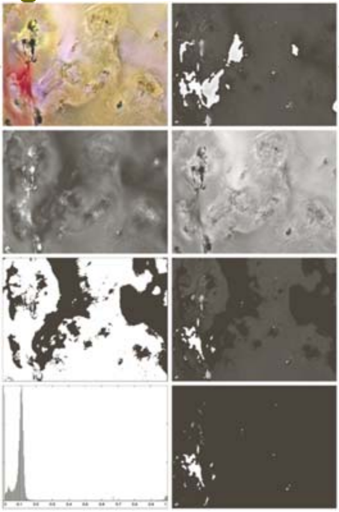
Processing all RGB

Processing I of HSI

Only small Difference

Fig. 6.39

Image segmentation in the HSI space



Original

Hue

Saturation

Intensity

Binary saturation mask

Binary saturation mask times hue

histogram

Segmentation of red components in the original

Fig. 6.40

Image segmentation in the RGB space

- Compute the color mean **a** and the standard deviation σ in the rectangle.
- A sphere (alt. ellipsoid or box) with radius ~ to σ was centered at **a**
- Pixels with colors inside the sphere => segmentation result

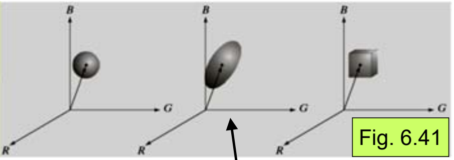


Fig. 6.41

$$D(\mathbf{z},\mathbf{a}) = [(\mathbf{z}-\mathbf{a})^T\mathbf{C}^{-1}(\mathbf{z}-\mathbf{a})]^{0.5}$$

where **z** is an arbitrary point in the RGB−space (6-49)

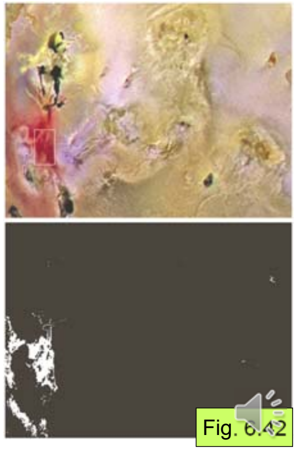


Fig. 6.42

Image segmentation in the RGB space, example

Note: $\boldsymbol{C} = \begin{pmatrix} \mathrm{var}(z_R) & \mathrm{cov}(z_R, z_G) & \mathrm{cov}(z_R, z_B) \\ \mathrm{cov}(z_R, z_G) & \mathrm{var}(z_G) & \mathrm{cov}(z_G, z_B) \\ \mathrm{cov}(z_R, z_B) & \mathrm{cov}(z_G, z_B) & \mathrm{var}(z_B) \end{pmatrix}$

Example) Suppose $\boldsymbol{C} = \boldsymbol{C}^{-1} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$

$$D(\mathbf{z}, \mathbf{a}) = [(\mathbf{z} - \mathbf{a})^T \mathbf{C}^{-1} (\mathbf{z} - \mathbf{a})]^{0.5} = [(\mathbf{z} - \mathbf{a})^T (\mathbf{z} - \mathbf{a})]^{0.5} =$$

$$= \left[(z_R - a_R, \quad z_G - a_G, \quad z_B - a_B) \begin{pmatrix} z_R - a_R \\ z_G - a_G \\ z_B - a_B \end{pmatrix} \right]^{0.5} =$$

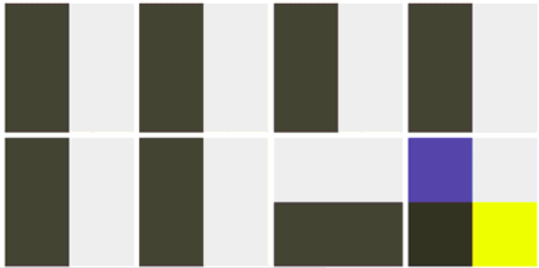
$$= [(z_R - a_R)^2 + (z_G - a_G)^2 + (z_B - a_B)^2]^{0.5} =$$

Sphere centered at (a_R, a_G, a_Z) with radius D!

Color edge detection

There is not optimal to just sum the magnitude of the gradient for the 3 components.

Extra, optional



R+G+B=RGB

R+G+B=RGB

$$g_{xx} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2 \quad (6\text{-}52)$$

$$g_{yy} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2 \quad (6\text{-}53)$$

$$g_{xy} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y} \quad (6\text{-}54)$$

A better method…

Fig. 6.43

Color edge detection

Fig. 6.44

somewhat better

Extra, optional

…a better method.

(6-55)

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

Original

After (6.56)

Σ of magn. of grad:s

Difference

(6-56)

$$F_\theta(x, y) = \left\{\frac{1}{2}\left[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\,\theta(x, y) + 2g_{xy}\sin 2\,\theta(x, y\right.\right.^{0.5}$$

Conversion from color to gray scale in MATLAB

True color image

Gray scale image

$$\mathrm{GrayV} = 0.2989 \cdot R + 0.5870 \cdot G + 0.1140 \cdot B \ \ (\mathrm{MatLab{:}}\ \ \mathrm{rgb2gray})$$

p. 45

The YCbCr Color model

Extra, optional

Not in G&W!

- Used for image compression, JPEG.
- The relation between R, G, B for the luminance component Y is similar to MATLAB:s rgb2gray.
- Decouples luminance and chromaticity.
- Uses color differences Cb, Cr instead of hue and saturation for chromaticity.
- The fact that chromaticity can be more compressed is utilized. There are higher frequencies in the luminance component.
- Note that luminance Y and intensity I are different. Probably Y describes the subjective brightness better. However, equal amount of R,G, and B in an RGB-image gives a gray-scale image.

$$\begin{pmatrix} Y \\ Cb \\ Cr \end{pmatrix} = \left(\begin{pmatrix} 16 \\ 128 \\ 128 \end{pmatrix} + \begin{pmatrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -93.786 & -18.214 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \right) /255$$