Image Processing

Restoration and Reconstruction

Mylène Christine Queiroz de Farias

Departamento de Engenharia Elétrica
Universidade de Brasília (UnB)
Brasília, DF 70910-900

mylene@unb.br

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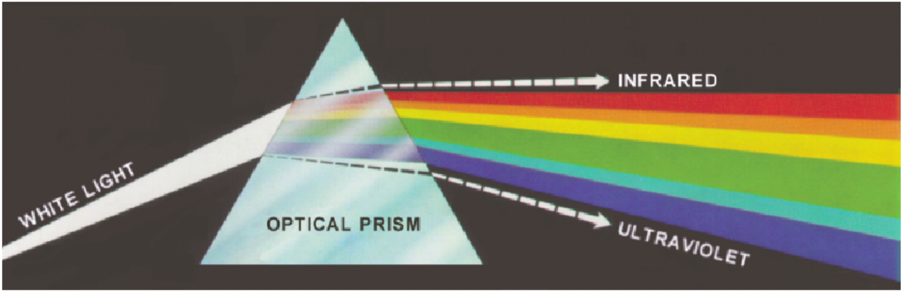
Class 07: Colors

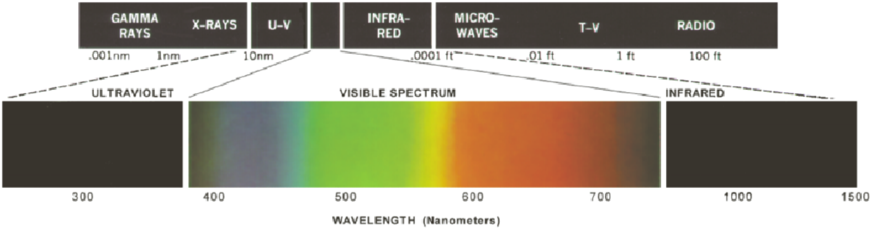
Definitions

- Colors or pseudo-colors
- Human beings are quite sensitive to colors
- The image processing algorithms are the same, but they need to be adapted

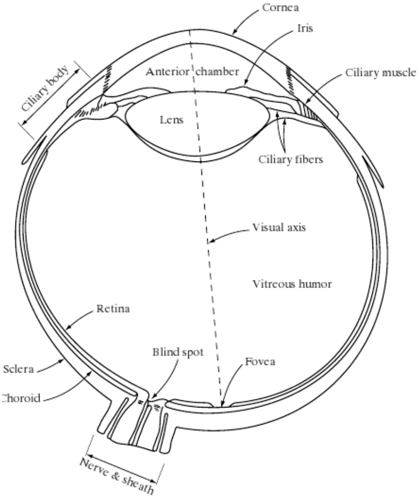
Color Spectrum

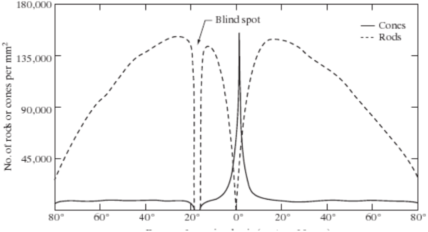


Color Spectrum

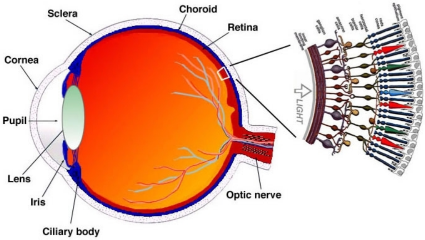


The retina:

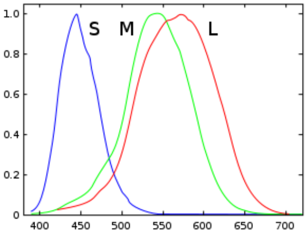

Cornea
Iris
Ciliary muscle
Ciliary body
Anterior chamber
Lens
Ciliary fibers
Visual axis
Vitreous humor
Retina
Blind spot
Fovea
Sclera
Choroid
Nerve & sheath

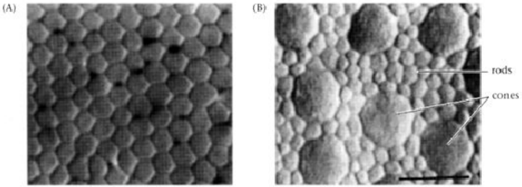

180,000
135,000
90,000
45,000
No. of rods or cones per mm²
Blind spot
Cones
Rods
80°
60°
40°
20°
0°
20°
40°
60°
80°

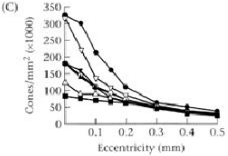
Cones and Rods



- Cones: (S, M, L) 5 milhões
  - normal levels of light,
  - allow the perception of light
  - localized in the center of the retina (details)
- Rods – 100 millions
  - perifery
  - low levels of light

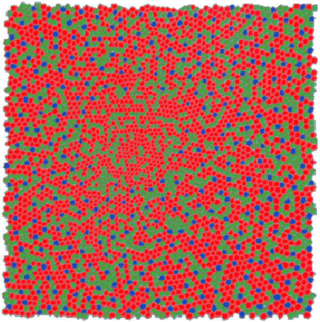


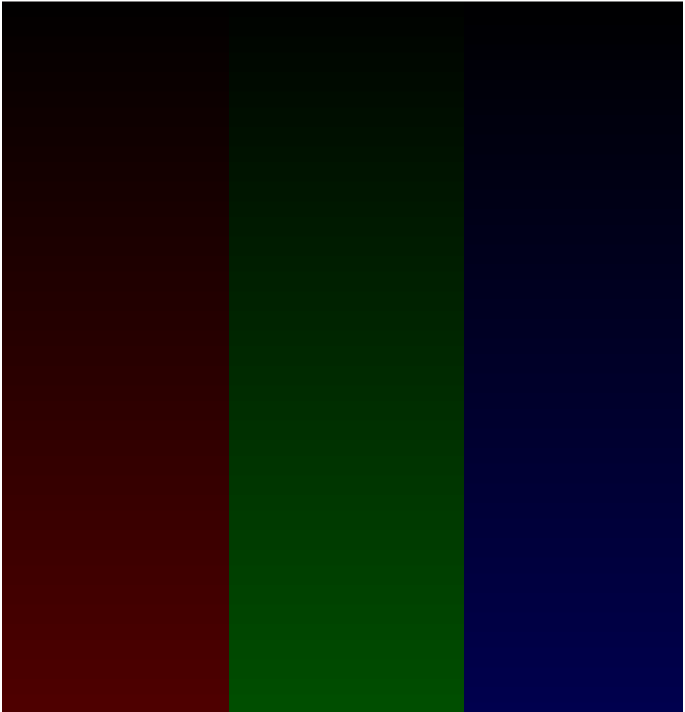


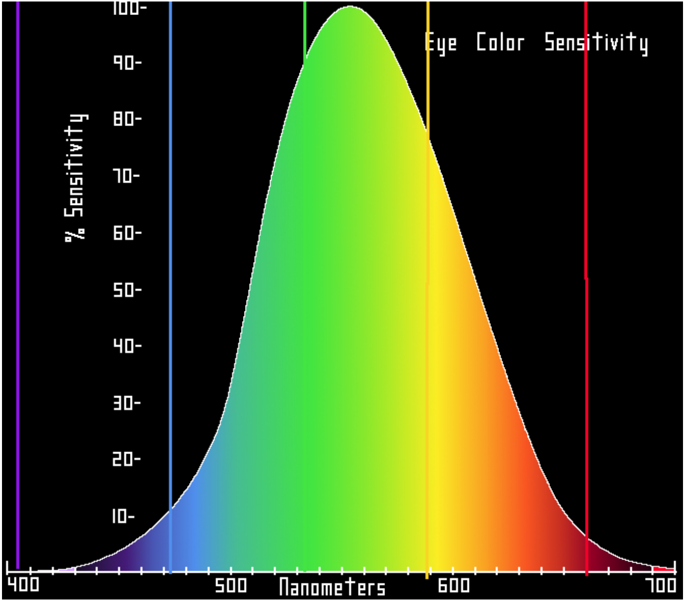


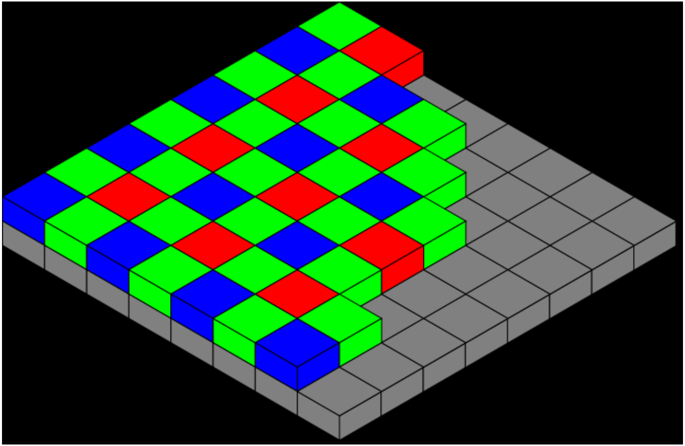
3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.

Cone mosaic






Eye Color Sensitivity
% Sensitivity
100-
90-
80-
70-
60-
50-
40-
30-
20-
10-
400
500
Nanometers
600
700



Color Perception

- As cores dos objetos estão relacionadas às características dos corpos
- Corpos “verdes” refletem apenas luz com comprimento de onda entre 500-570 nm
- Se a luz for acromática, o seu único atributo é a intensidade (TVs preto e branco)

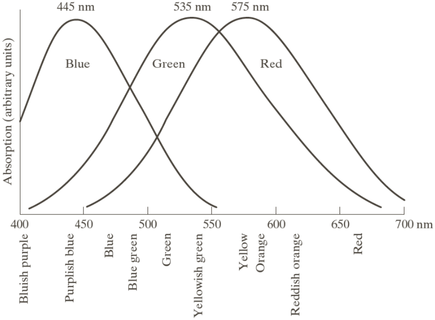
Color Perception

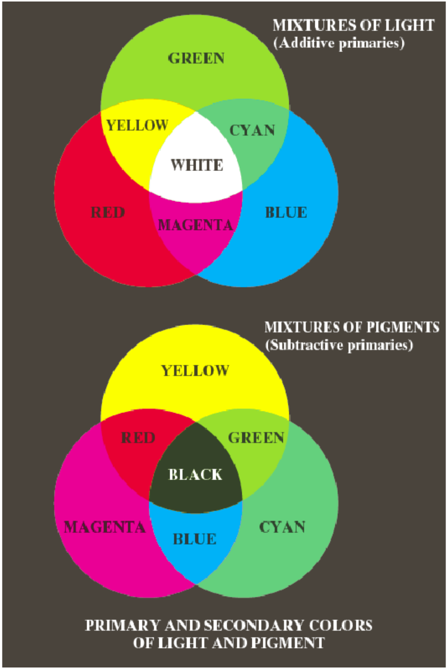
Achromatic light:

- Radiance – total energy emmited by the light source (Watts - W)
- Luminance – quantity of energy perceived by the observer (lumens lm)
- Brightness – subjective descriptor related to the intensity. It is one of the key factors used to decribe color

Color Perception

- Cones e Rods:
  - 65% red
  - 33% green
  - 2% blue
- Primary colors (RGB)
- CIE (Comission Internationale de l'Eclairage)
  - Blue: 435,8 nm
  - Red: 700 nm
  - Green: 546,1
  - Low levels of light

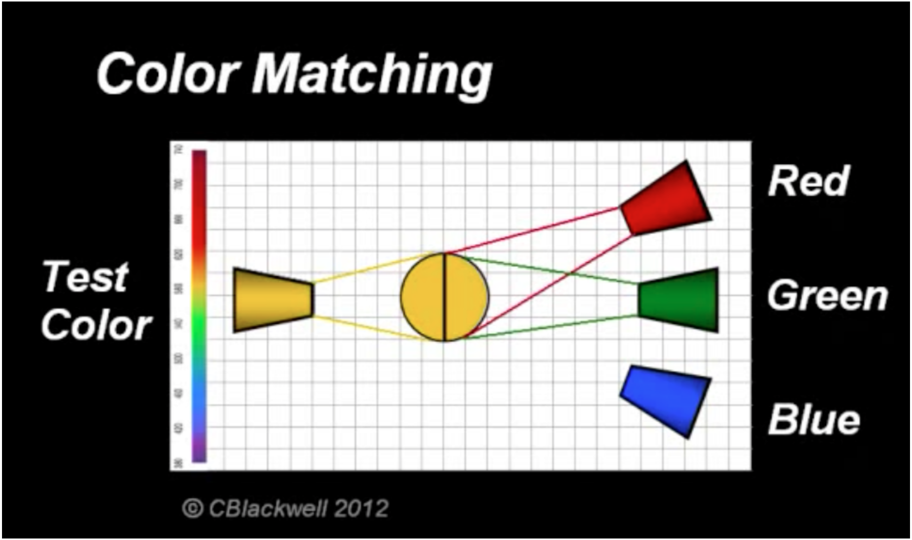



MIXTURES OF LIGHT
(Additive primaries)
GREEN
YELLOW
CYAN
WHITE
RED
MAGENTA
BLUE
MIXTURES OF PIGMENTS
(Subtractive primaries)
YELLOW
RED
GREEN
BLACK
MAGENTA
BLUE
CYAN
PRIMARY AND SECONDARY COLORS
OF LIGHT AND PIGMENT

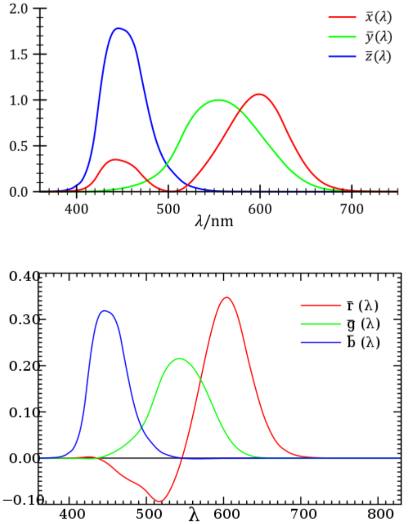
Color Perception

Distinction between colors:

- **Brightness** – cromatic intensity
- **Hue**
  - main wavelength
  - color perceived
- **Saturation**
  - light purity
  - quantity of white light
- Saturation + Hue = Cromaticity



Color Matching
Test Color
Red
Green
Blue
© CBlackwell 2012

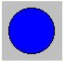


http://www.biyee.net/v/cie_diagrams/index.htm

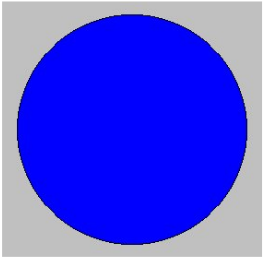
3 color matching functions, which can be extended as being spectral sensitivity curves of the 3 light detectors that generate the X, Y, and Z values of the tri-stimulus CIE XYZ.

"The 1964 (ten-degree field) observer had about 50 observers but the 1931 (two-degree field) only had about a dozen. The 1964 work included a few foreign post-doctoral fellows but the early work included only Englishmen from the region near to London."
Danny Rich

CIE 1931 2-Degree Field of View



CIE 1964 10-Degree Field of View



- Tri-stimulus:

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

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

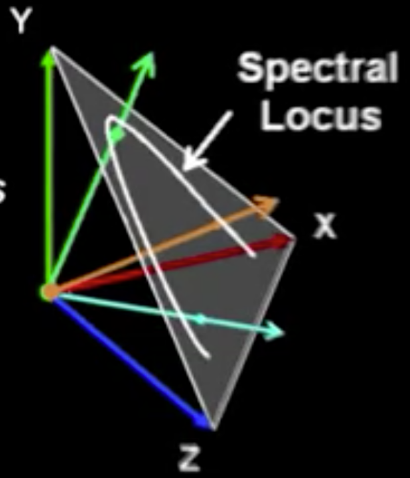
$$z = \frac{Z}{X+Y+Z}$$

onde:

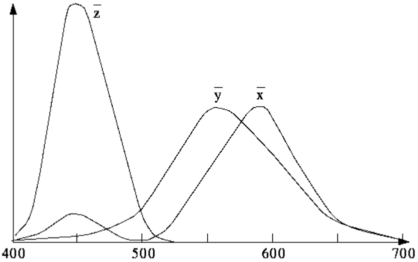
$$x + y + z = 1$$

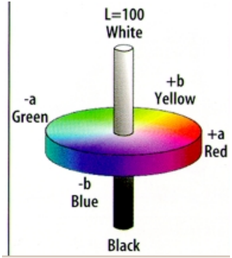
Color Space
X-Y-Z

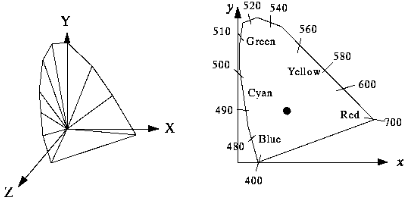
Series of Tristimulus Vectors Map Out the Chromaticity Diagram



- 1931: CIE defined 3 primary colors (X,Y,Z)
  - derivated from red, green, and blue





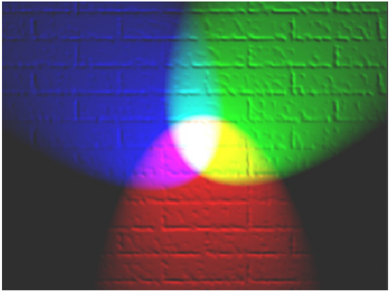


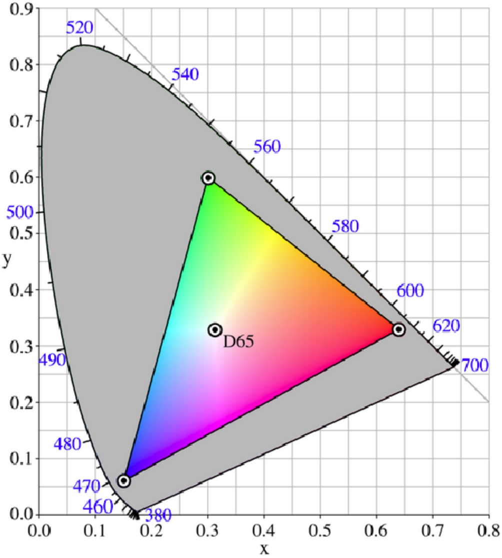
CIE Chromaticity Diagram

$$X = \int E(\lambda)\bar{x}(\lambda)d\lambda$$

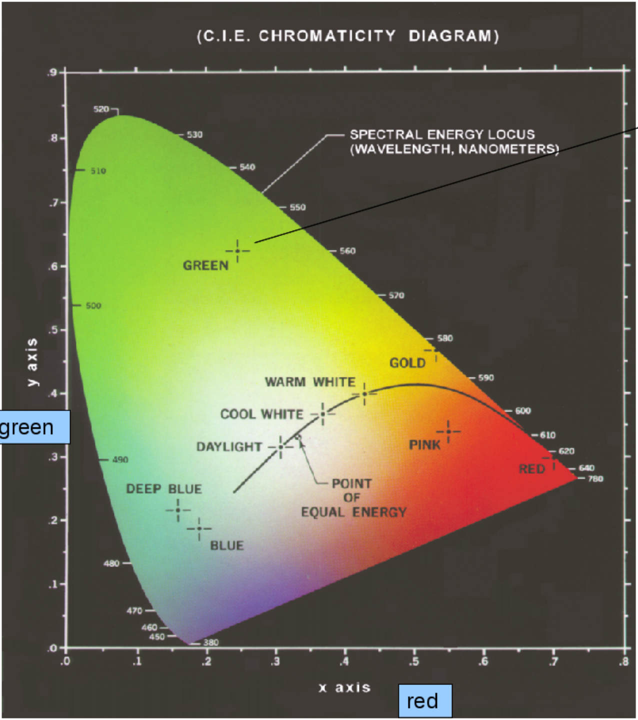
$$Y = \int E(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int E(\lambda)\bar{z}(\lambda)d\lambda$$





0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
y
520
540
560
580
600
620
700
500
490
480
470
460
380
D65
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x



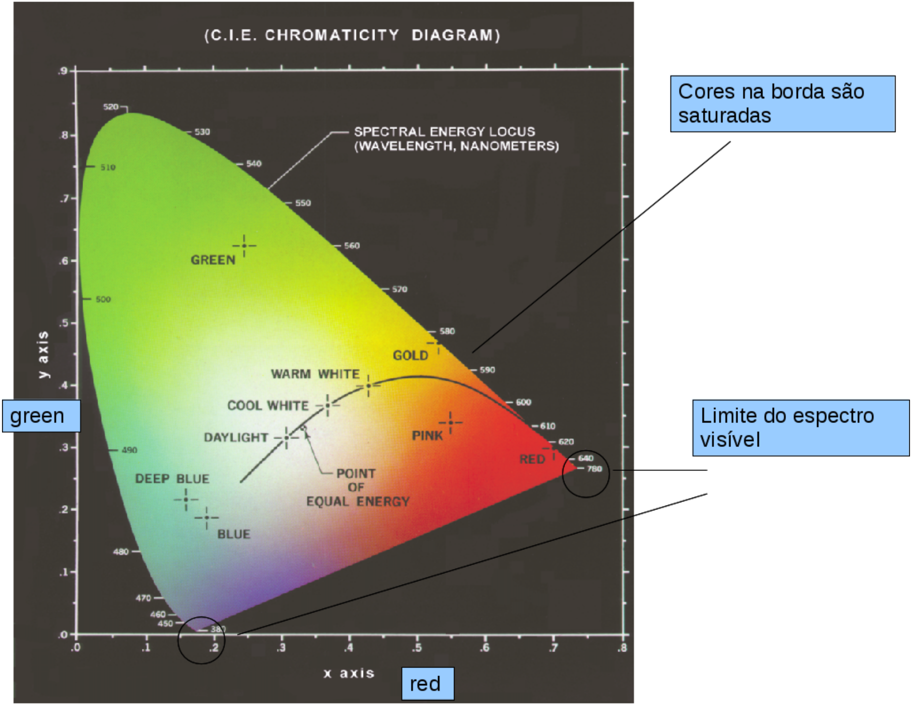
62% green
25% red
13% blue

green

red

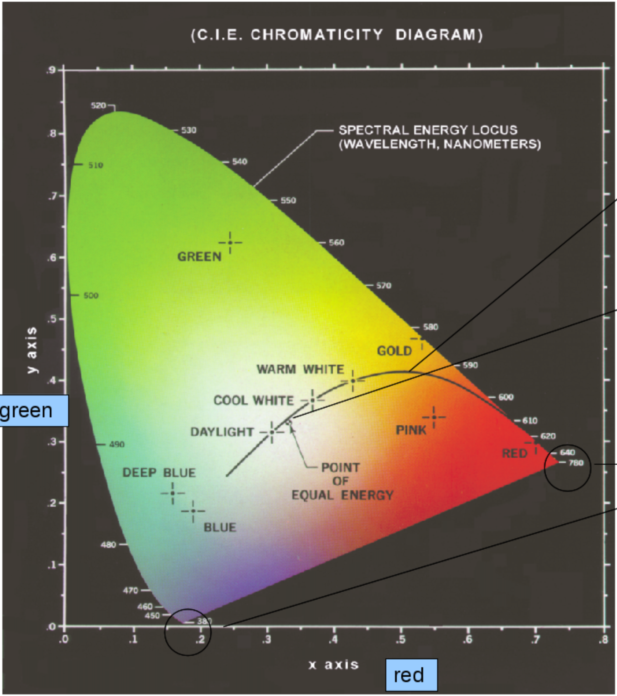
blue

$$z = 1 - (x + y)$$


(C.I.E. CHROMATICITY DIAGRAM)
SPECTRAL ENERGY LOCUS
(WAVELENGTH, NANOMETERS)
520
530
510
540
550
560
500
570
580
590
600
610
620
640
780
490
480
470
460
450
380
GREEN
GOLD
WARM WHITE
COOL WHITE
DAYLIGHT
PINK
RED
POINT
OF
EQUAL ENERGY
DEEP BLUE
BLUE
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
.1
.2
.3
.4
.5
.6
.7
.8
y axis
x axis
Cores na borda são saturadas
green
Limite do espectro visível
red

A reta de uma cor a outra mostra todas as cores que podem ser obtidas adiconando as duas cores.

Ponto de equi-energia
Proporção igual
Saturação = 0!



green

red

Limite do espectro visível

White

Tungsten

Warm White

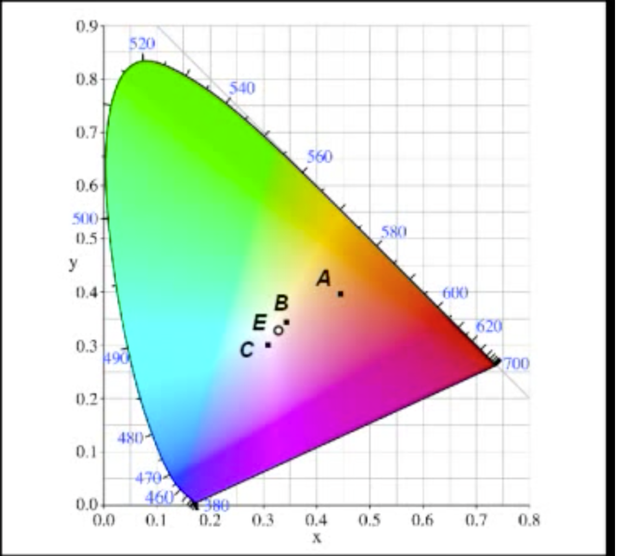
Cool White

CBlackwell 2012

CIE Chromaticity Diagram

CIE Standard Illuminants

A: Tungsten
B: Direct Sun
C: Av. Daylight



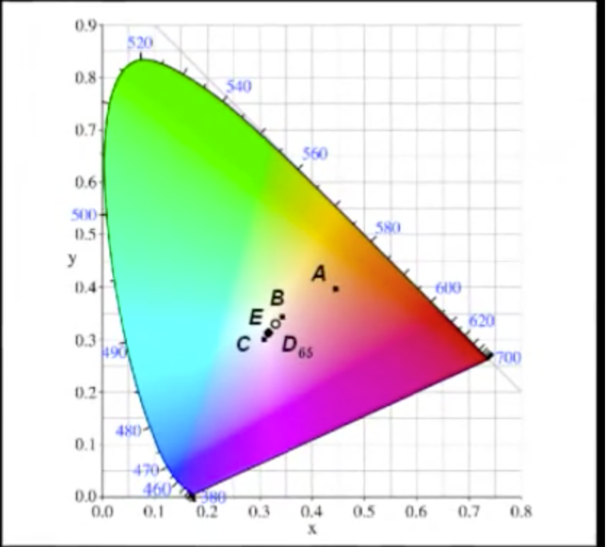
Science of Color p294
Judd, chapter 2

CBlackwell 2012

CIE Chromaticity Diagram

CIE Standard Illuminants

A: Tungsten
B: Direct Sun
C: Av. Daylight
D65: Av. Day



Science of Color p294
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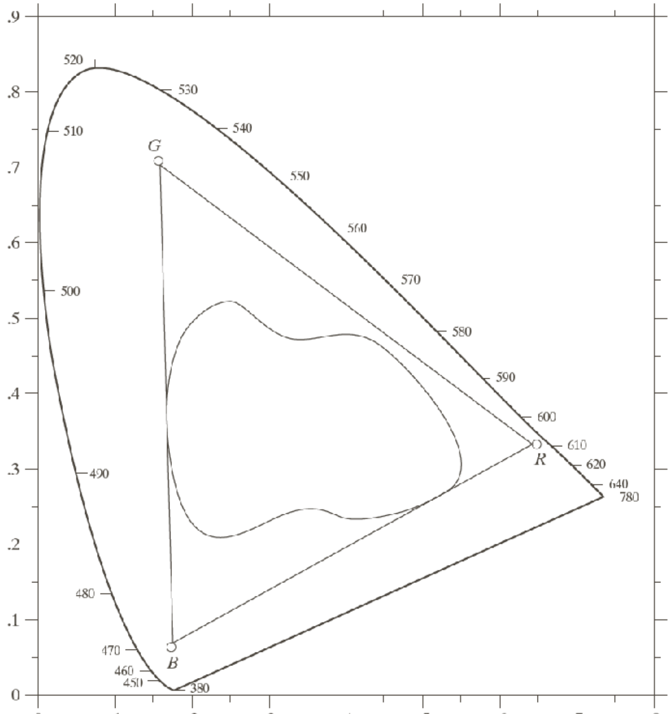
Color Temperature

Std A
Tungsten
2856 K

Std B
Direct Sun
4874 K

Std D_{65}
Daylight
6500 K

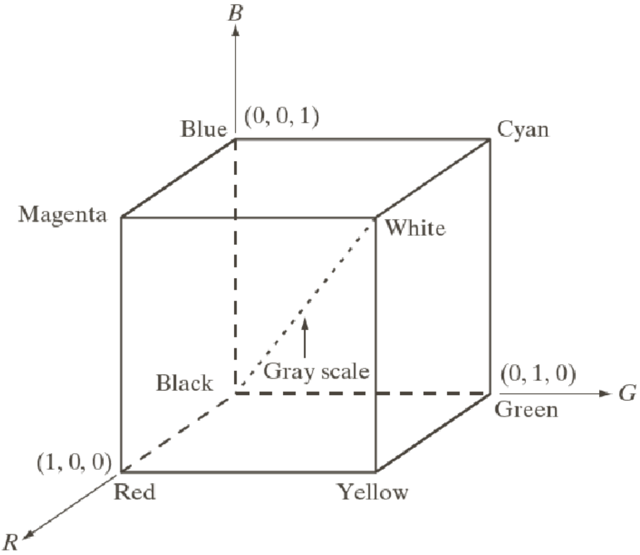


.9
.8
.7
.6
.5
.4
.3
.2
.1
0
520
530
540
550
560
570
580
590
600
610
620
640
780
510
500
490
480
470
460
450
380
G
R
B

Color Space

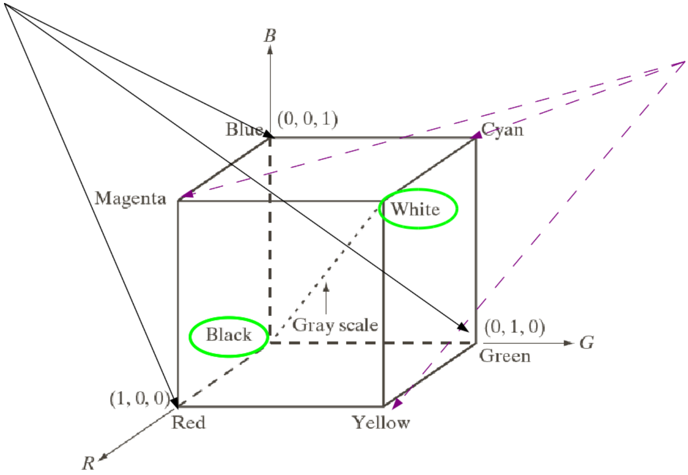
- RGB (red, green, blue)
  - cameras and monitors
- CMY (cyan, magenta, yellow)
  - printers
- CMYK (cyan, magenta, yellow, black)
  - printers
- HSO (hue, saturation, intensity)
  - perceptive model
  - decouples the intensity – used by black-and-white dispositives (grayscale intensities)

RGB



B
Blue
(0, 0, 1)
Cyan
Magenta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

RGB



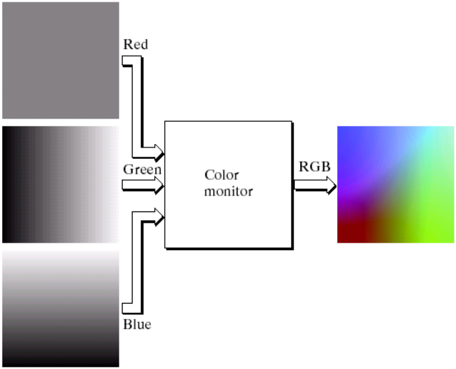
B
(0, 0, 1)
Blue
Cyan
Magenta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

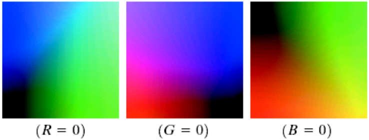
RGB

- 24 bits – 8×3 (full color) (R,G,B)
- number of colors $= (2^8)^3 = 16\ 777\ 216$

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.

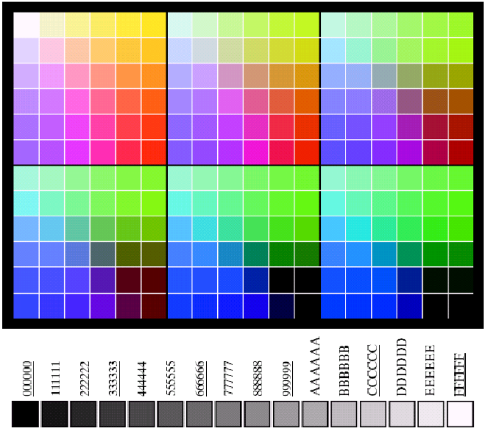




RGB

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

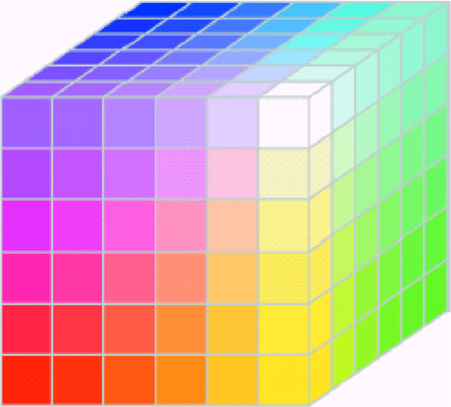
TABLE 6.1 Valid values of each RGB component in a safe color.



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).

RGB

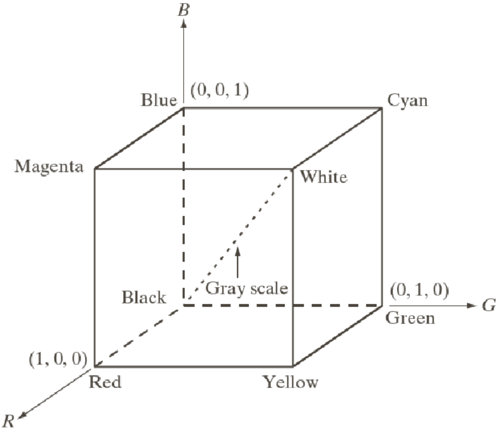


RGB safe-color cube.

- CMY: Primary colors for pigments (ink)

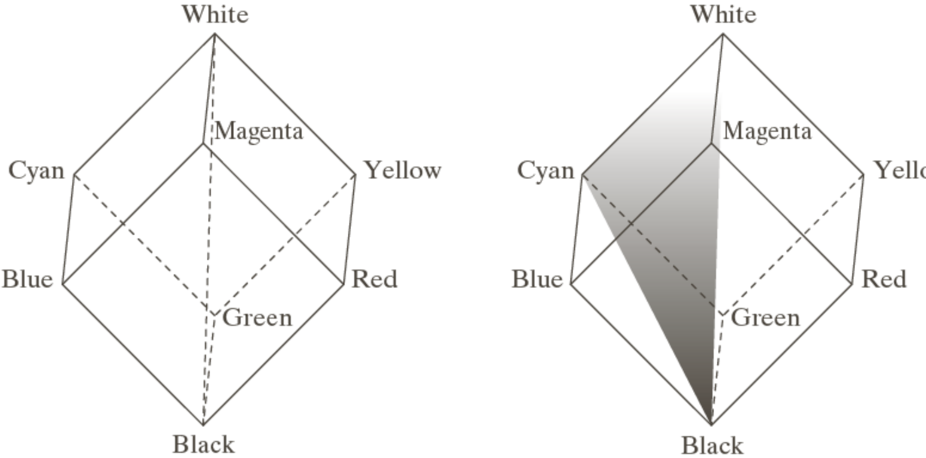
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

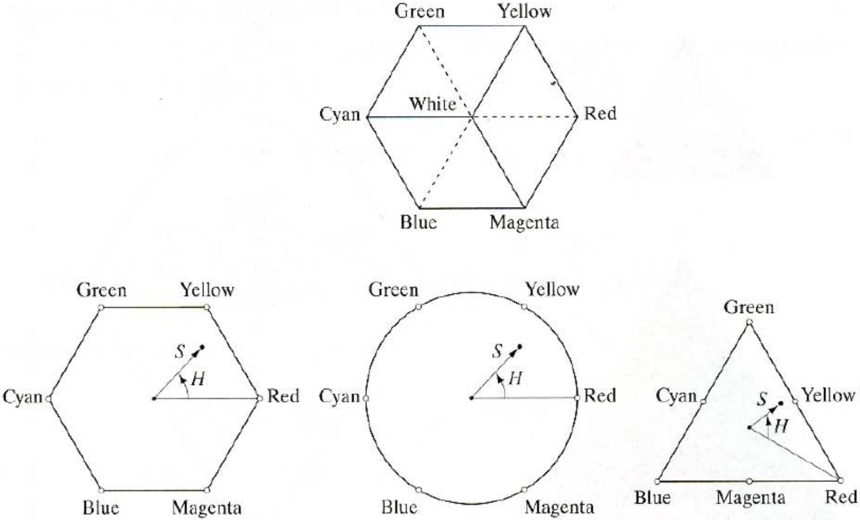
- CMYK: black is added to avoid the faded aspect of a printed black



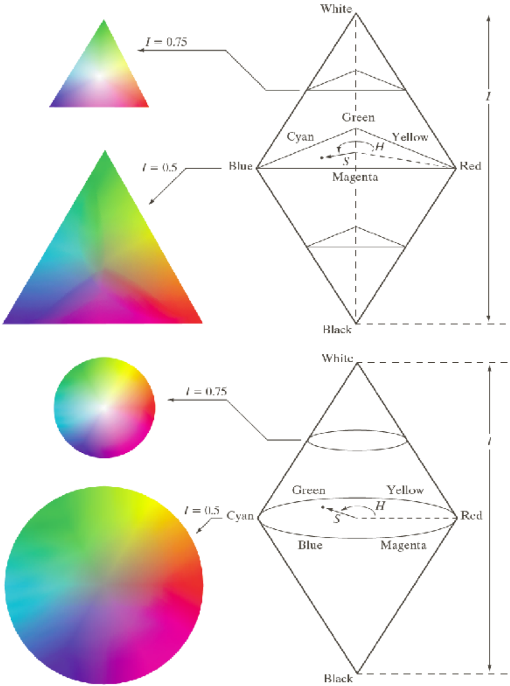
HSI Model

- Closer to how we perceive color
  - Hue, saturation, intensity
- production and reproduction of color
- Analysis – HSI and similar color spaces ...
- Decoupling the intensity component
  - grayscale intensities


White
Magenta
Cyan
Yellow
Blue
Red
Green
Black
White
Magenta
Cyan
Blue
Red
Green
Black



Green
Yellow
White
Cyan
Red
Blue
Magenta
Green
Yellow
S
H
Cyan
Red
Blue
Magenta
Green
Yellow
S
H
Cyan
Red
Blue
Magenta
Green
Cyan
Yellow
S
H
Blue
Magenta
Red



White
I = 0.75
I
Green
Cyan
Yellow
H
S
Blue
Red
I = 0.5
Magenta
Black
White
I = 0.75
I
Green
Yellow
H
S
I = 0.5
Cyan
Red
Blue
Magenta
Black

From RGB to HSI

$$H = \begin{cases} \theta, & \text{se } B \leq G \\ 360 - \theta, & \text{se } B > G \end{cases}$$

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

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

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

From HSI to RGB

RG Sector $(0^\circ \leq H \leq 120^\circ)$

$$B = I(1 - S)$$

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

$$G = 3I - (R + B)$$

BR Sector $(240^\circ \leq H \leq 360^\circ)$

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

$$G = I(1 - S)$$

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

$$R = 3I - (G + B)$$

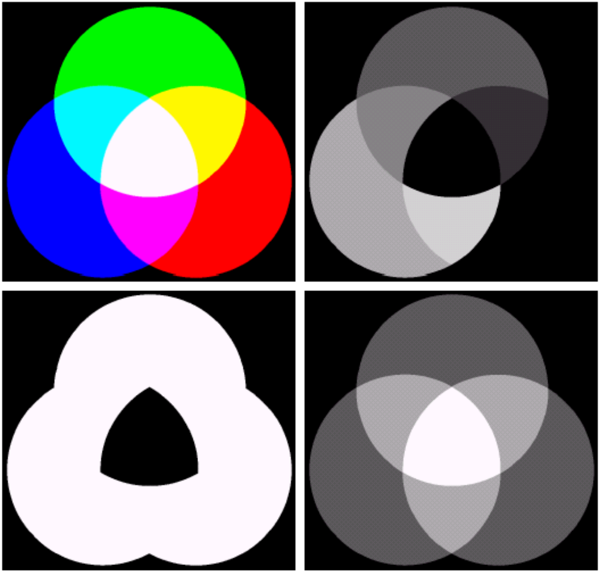
GB Sector $(120^\circ \leq H \leq 240^\circ)$

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

$$R = I(1 - S)$$

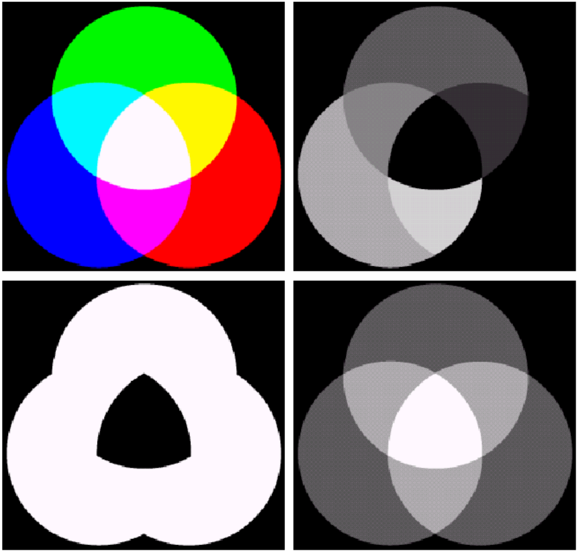
$$G = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$B = 3I - (G + B)$$



a b
c d

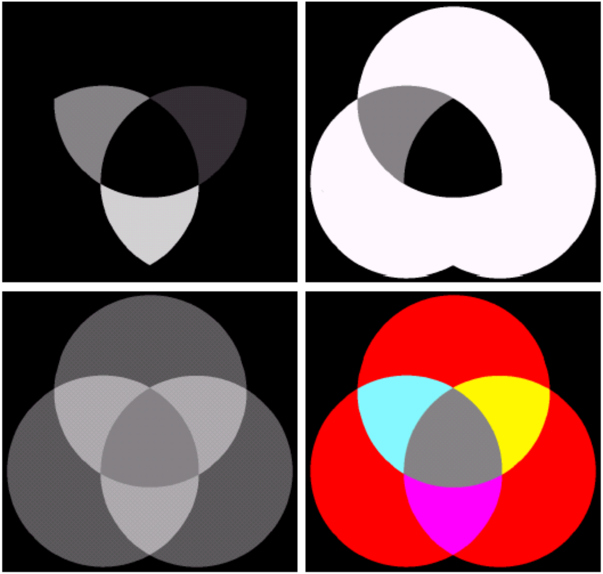
FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



Mudança:
zerar todos
os valores
de tonalidade

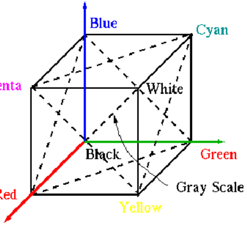
a b
c d

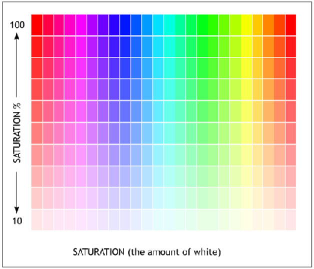
FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



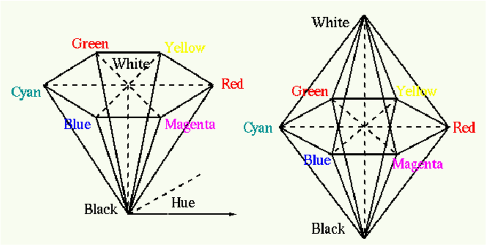
a b
c d

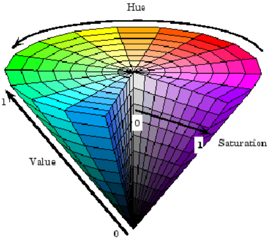
FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)


Blue
Cyan
Magenta
White
Black
Green
Red
Gray Scale
Yellow


100
SATURATION %
10
SATURATION (the amount of white)

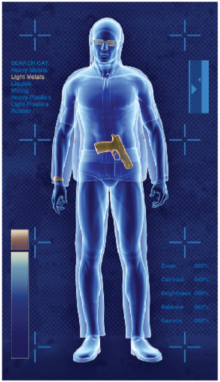
HSV


Green
Yellow
White
Cyan
Red
Blue
Magenta
Black
Hue
White
Green
Yellow
Cyan
Red
Blue
Magenta
Black


Hue
1
0
1
Saturation
Value
0

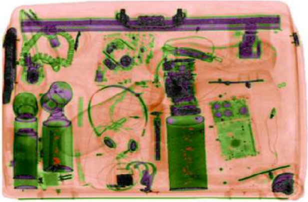
- Pseudo-colors = false colors
- Human visualization (raio x @ airport)
- Color slicing
- Transforming intensity images to color images

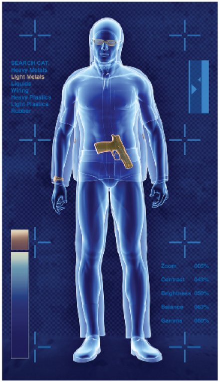
- Blue: Hard materials. Metals (blue/black), har plastic materials, alloys, etc. Ex.: guns and knives appear as a mixture of blue and black. The same for wires, batteries, etc.



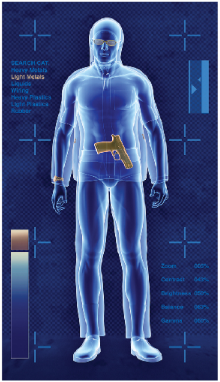
Color Processing

- Orange: Biologic material. Everything that is natural and some other things. Rubber, leather, food, dynamite and other explosives (except for plastic, liquids, gels and organic powders.

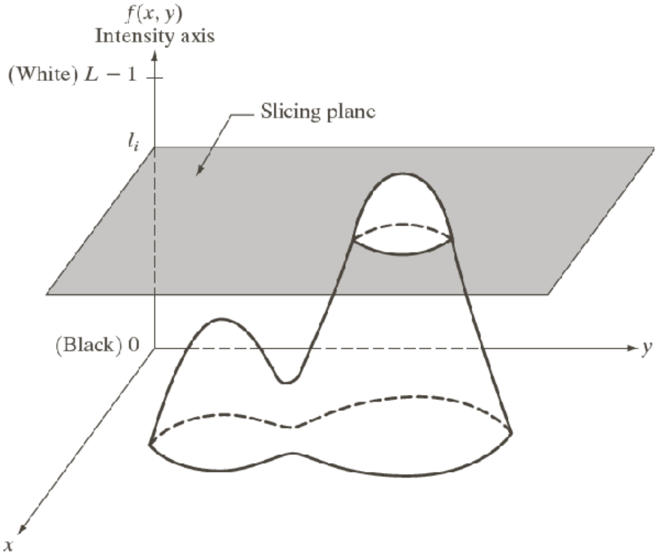




- Green: Plastic and alloys for which the density is not so high that make them appear as blue or black. Ceramic (dense) – otherwise it will appear as orange.

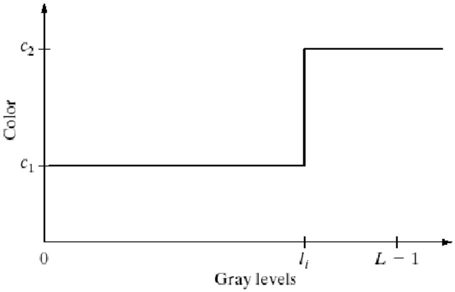


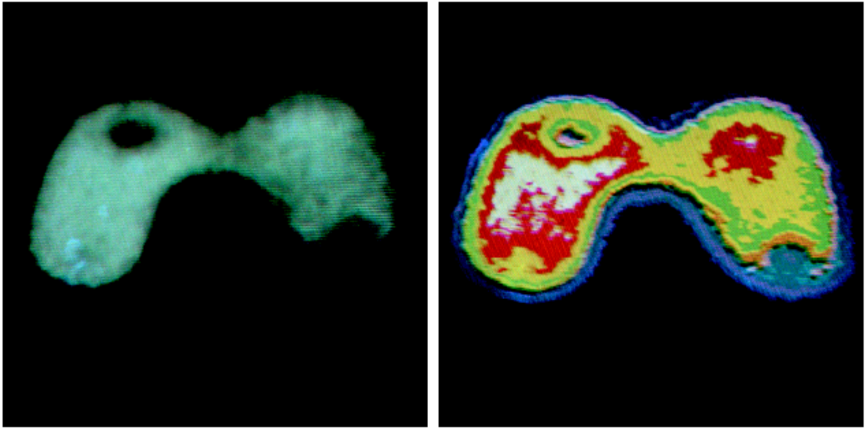
Pseudo-Colors Processing



Pseudo-Colors Processing

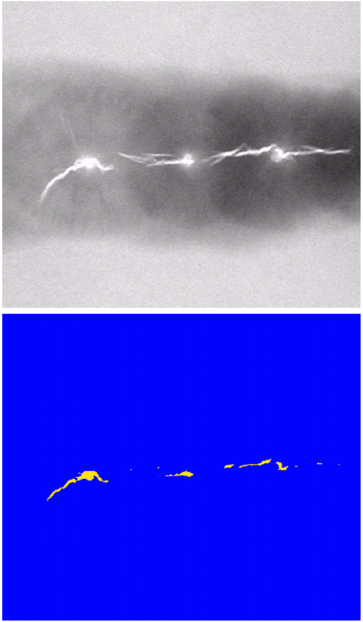
$$f(x, y) \in V_k \longrightarrow f(x, y) = c_k$$





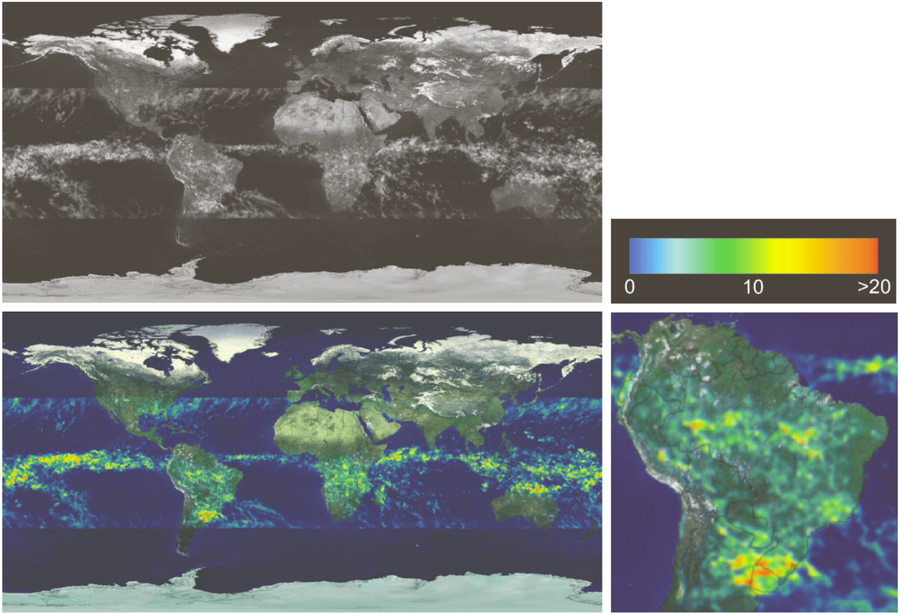
a b

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.)

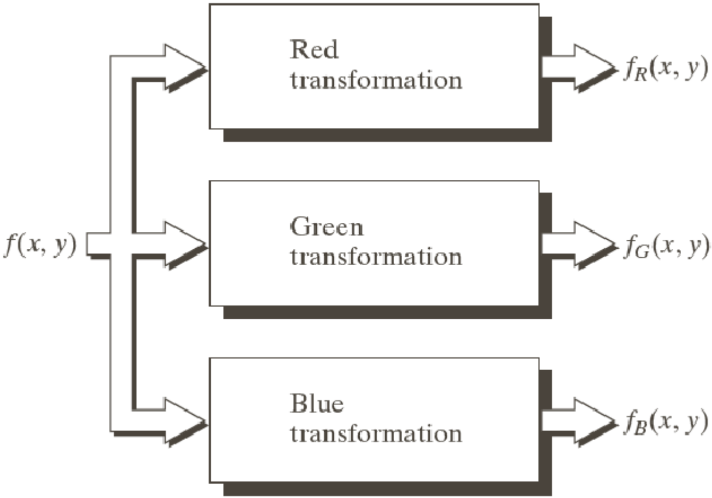


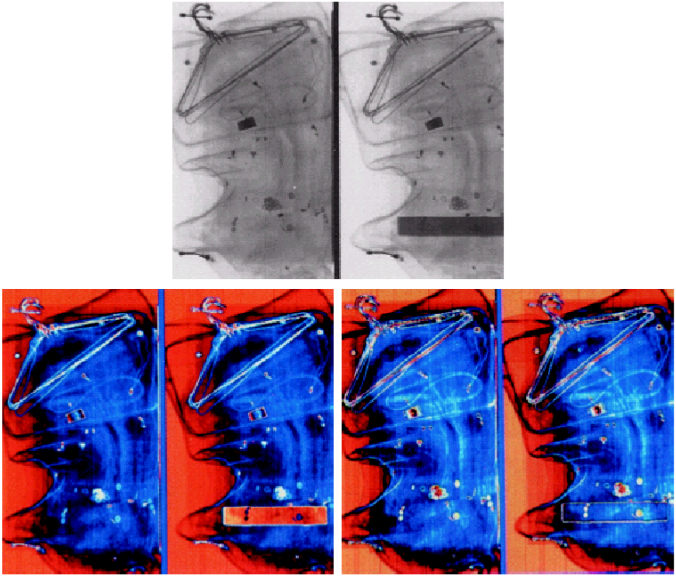
a
b

FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)


0
10
>20

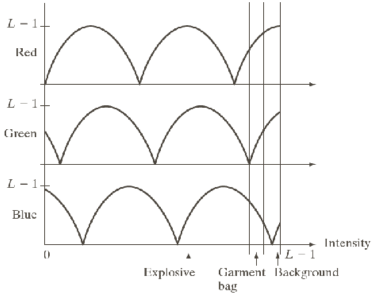
Transformations: Color Intensities

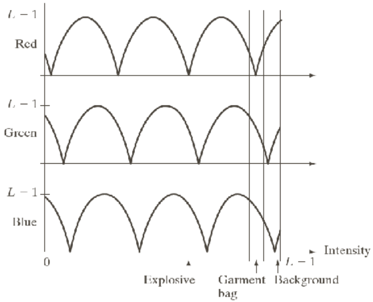


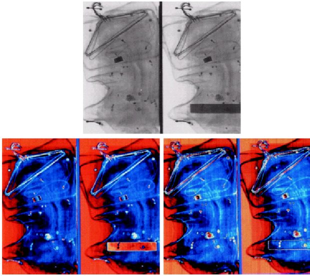


a
b c

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.)



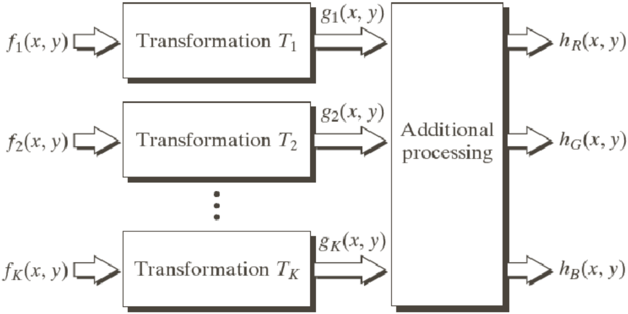




a
b c

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

Combining Images



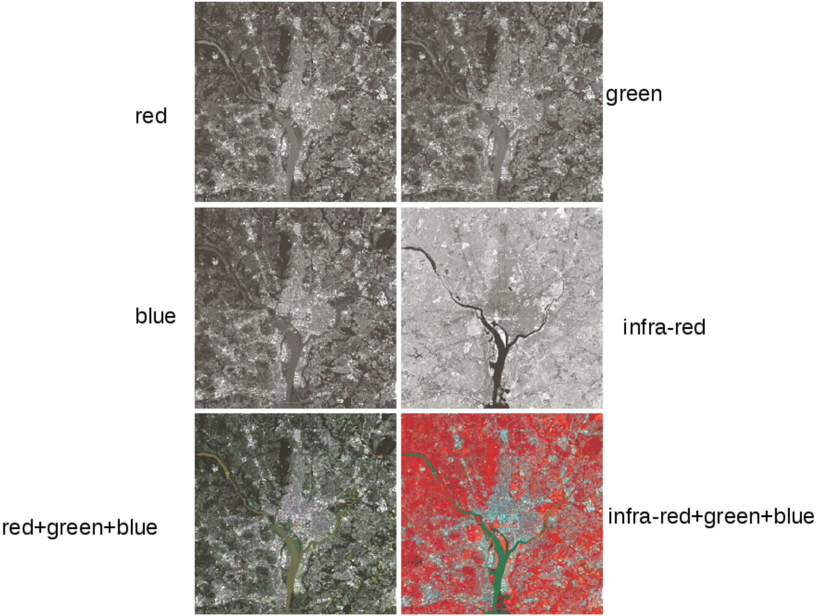
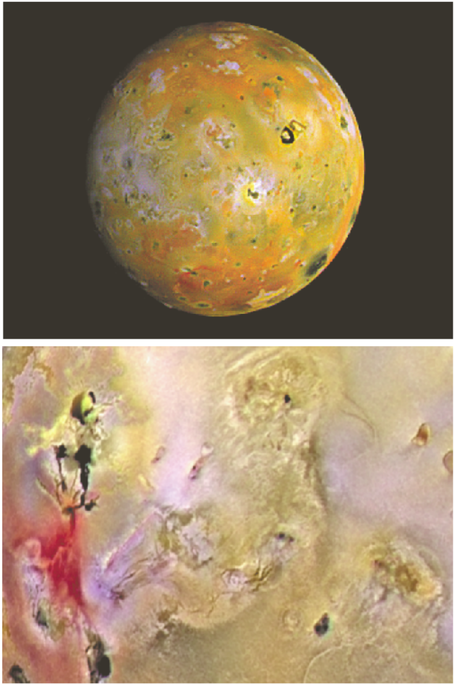


FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral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

a	b
c	d
e	f

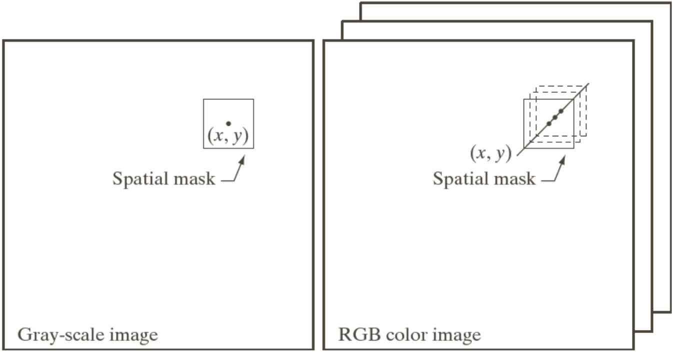


a
b

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

Imagem obtida combinando imagens de sensores com várias bandas.

Color Processing



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

Imagem colorida e suas componentes em vários espaços de cores.

Full color

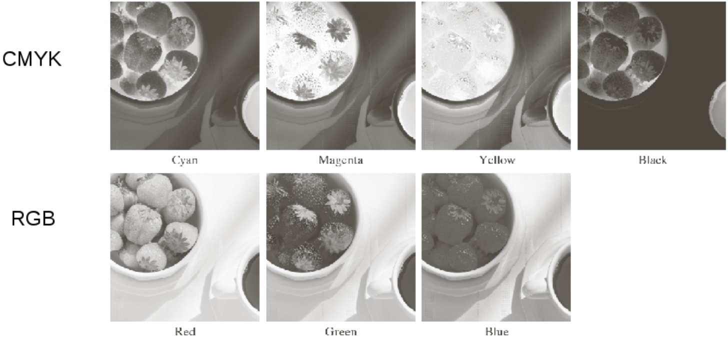
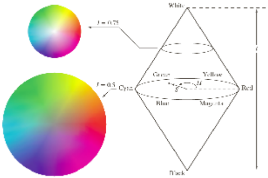


Imagem colorida e suas componentes em vários espaços de cores.

Full color



- Exampe of a transformation:

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

- HSI

$$i(x, y) = s_3(x, y) = k \cdot r_3(x, y)$$
$$h(x, y) = s_1(x, y) = r_1(x, y)$$
$$s(x, y) = s_2(x, y) = r_2(x, y)$$

- Exampe of a transformation:

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

- RGB

$$r(x, y) = s_1(x, y) = k \cdot r_1(x, y)$$
$$g(x, y) = s_2(x, y) = k \cdot r_2(x, y)$$
$$b(x, y) = s_3(x, y) = k \cdot r_3(x, y)$$

- Exampe of a transformation:

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

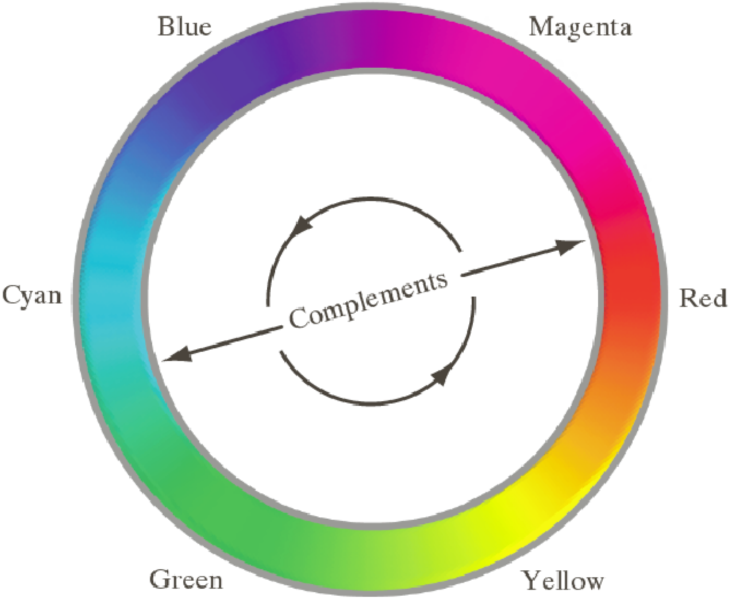
- CMY

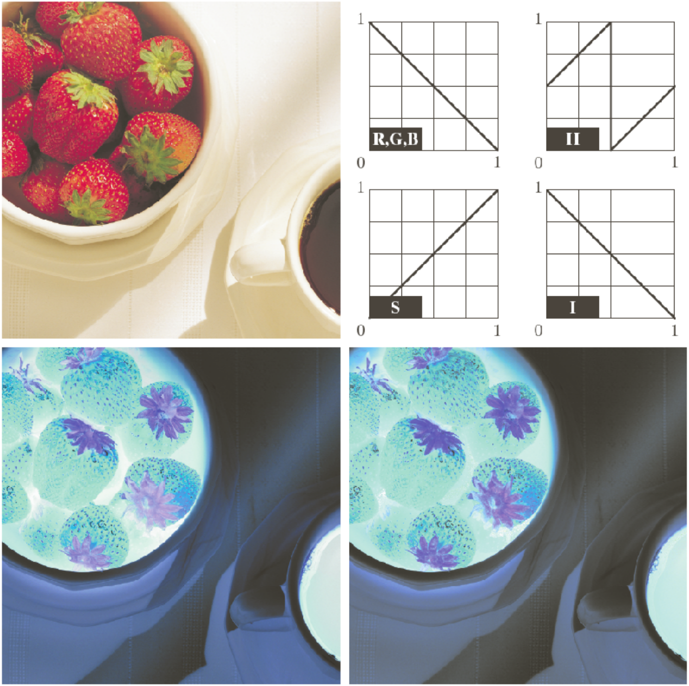
$$c(x, y) = s_1(x, y) = k \cdot r_1(x, y) + (1 - k)$$
$$m(x, y) = s_2(x, y) = k \cdot r_2(x, y) + (1 - k)$$
$$y(x, y) = s_3(x, y) = k \cdot r_3(x, y) + (1 - k)$$

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 Circle





a b
c d

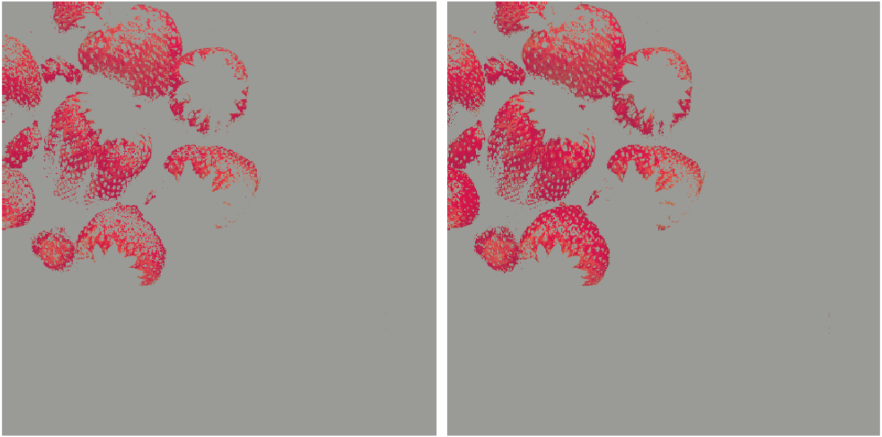
FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

- Separation of Objects in a scene
  - The colors must be clearly separated from the background
  - The color region is used as a mask

$$s_i = \begin{cases} 0,5 & \text{se } \left[|r_j - a_j| > \frac{W}{2}\right]_{1 \leq j \leq n}, \\ r_i, & \text{otherwise} \end{cases}$$

$$s_i = \begin{cases} 0,5 & \text{se } \sum_{j=1}^{n} (r_j - a_j)^2 > R_0^2, \\ r_i, & \text{otherwise} \end{cases}$$

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



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 $(0.5, 0.5, 0.5)$.

Color and Hue Correction

- Color Models that are indenpendent of the dispositives
  - Scanner, display, printer, etc.
  - Color profiles
  - Color System – CIE L*a*b* or CIELAB

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

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

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

CIELAB

- Xw, Yw and Zw the reference white values (CIE standard D65)
  - Color metrics, perceptually uniform, independent of the dispositive
  - Represents all visible spectrum

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

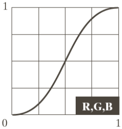
$$a^* = 500\left[h\left(\frac{X}{X_W}\right) - h\left(\frac{Y}{Y_W}\right)\right]$$

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

$$h(q) = \begin{cases} \sqrt[3]{q}, & q > 0,008856 \\ 7,787q + 16/116, & q \leq 0,008856 \end{cases}$$

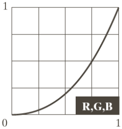

Flat


Corrected



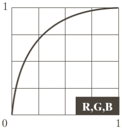

Light


Corrected




Dark


Corrected



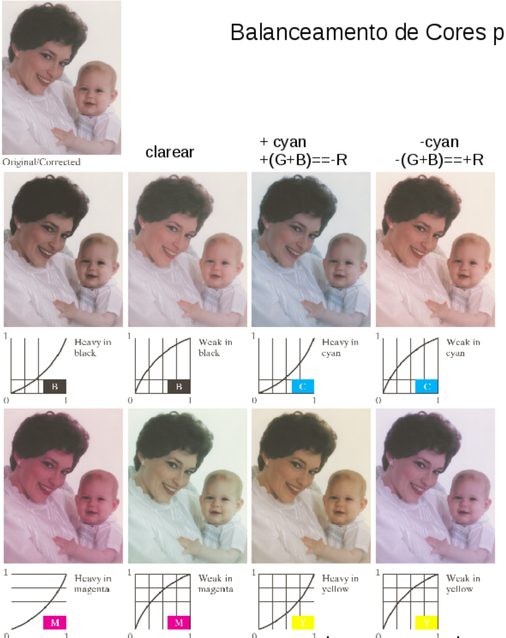
Balanceamento de Cores para imagens CMYK

escurecer

clarear

+ cyan
+(G+B)==-R

-cyan
-(G+B)==+R



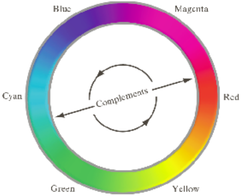
+ magenta
+(R+B)== -G

- magenta
-(R+B)== +G

+ amarelo
+(G+R)==-B

-r amarelo
-(G+R)==+B

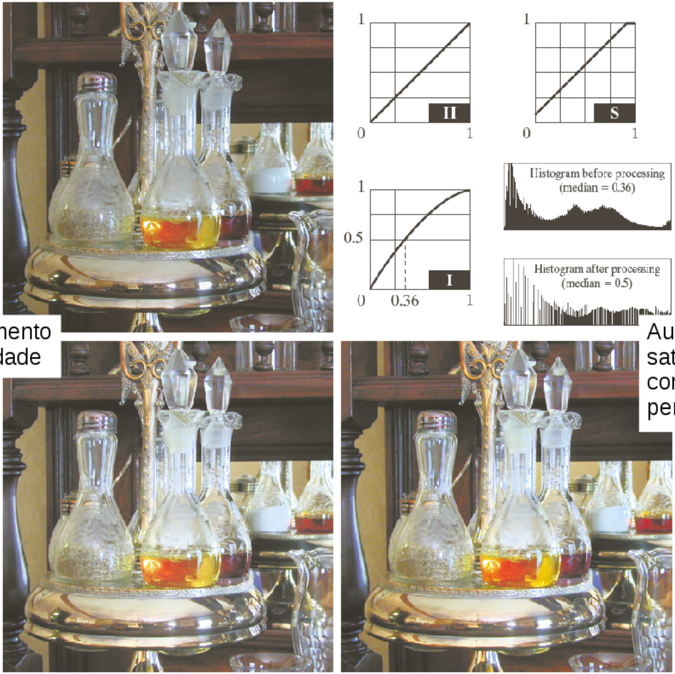
Cyan = G+B
Magenta= R+B
Yellow=R+G



Equalization of Color Histograms

- Similar to what was presented in CHapter 3
- But, the colors cannot be independently processed
  - Artifacts (defects): False colors
- Hue must be preserved

original



Processamento da intensidade

Aumento da saturação p compensar perdas de cor

Smoothing

- Consider the neighborhood S_{xy}

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

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

a	b
c	d

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

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

Smoothing with a 5 $\times$ 5 spatial mask

Sharpening

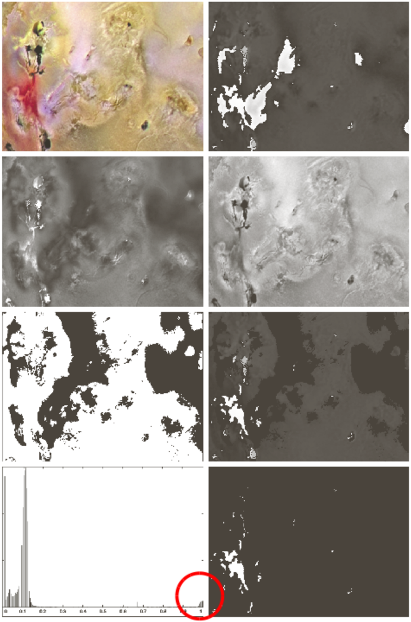
$$\nabla^2[\boldsymbol{c}(x,y)] = \begin{bmatrix} \nabla^2[R(x,y)] \\ \nabla^2[G(x,y)] \\ \nabla^2[B(x,y)] \end{bmatrix}$$

No RGB

Apenas a componente I do HSI

Diferença absoluta

Segmentação por Cores



original

H

S

I

Máscara binária gerada de S

Produto da máscara com H

Limiar 0,9 aplicado ao produto

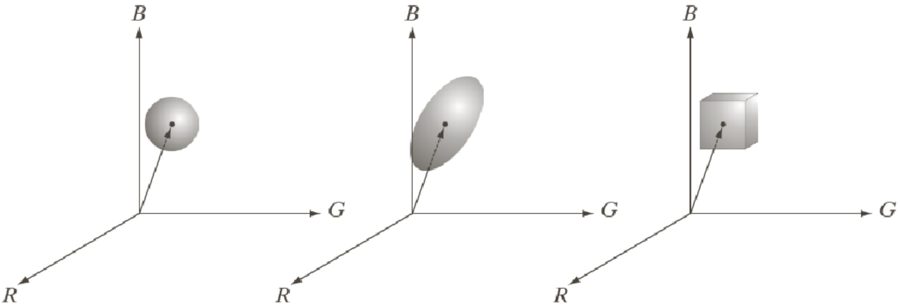
Histograma do produto.

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 (c). (g) Histogram of (f). (h) Segmentation of red components in (a).

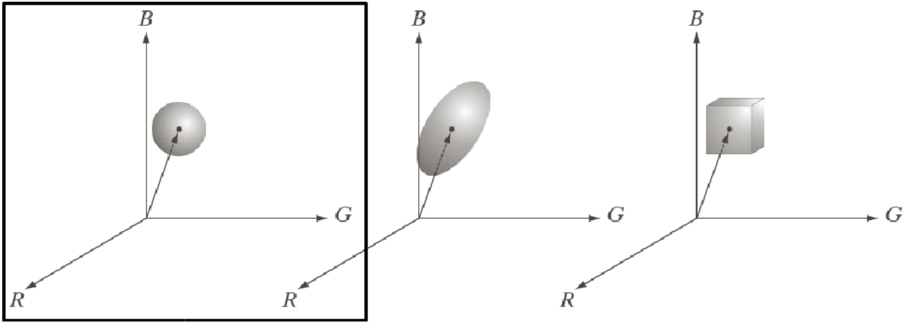
RGB Segmentation

$$D(\boldsymbol{z}, \boldsymbol{a})$$



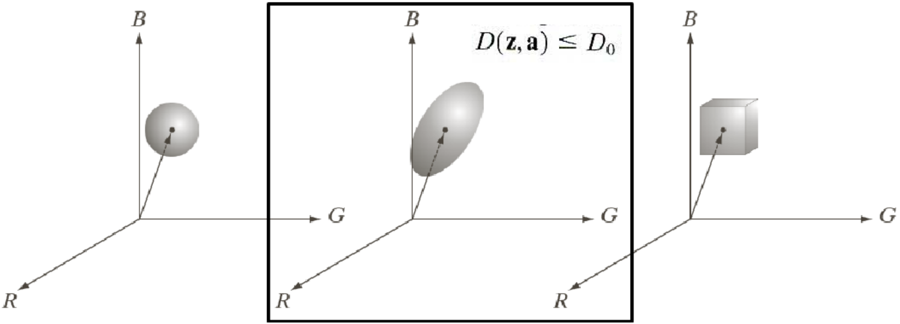
RGB Segmentation

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

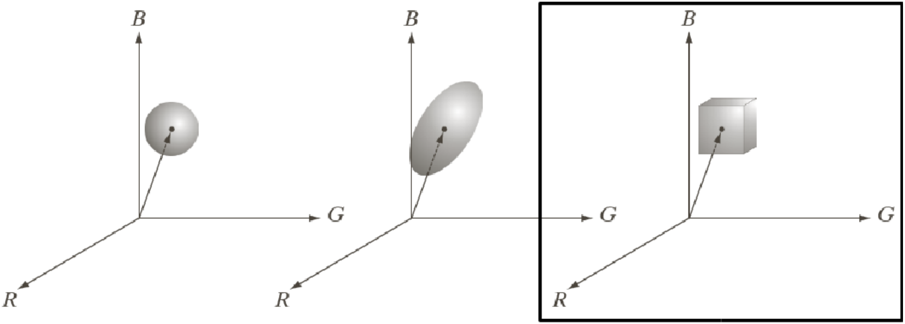


RGB Segmentation

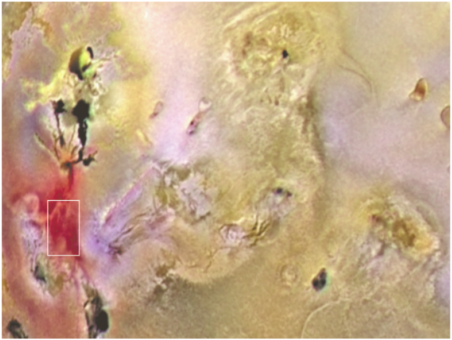
$$D(\mathbf{z}, \mathbf{a}) = \left[(\mathbf{z} - \mathbf{a})^T \mathbf{C}^{-1} (\mathbf{z} - \mathbf{a}) \right]^{\frac{1}{2}}$$



$$D(\boldsymbol{z}, \boldsymbol{a}) \leq D_0$$



Mais simples.

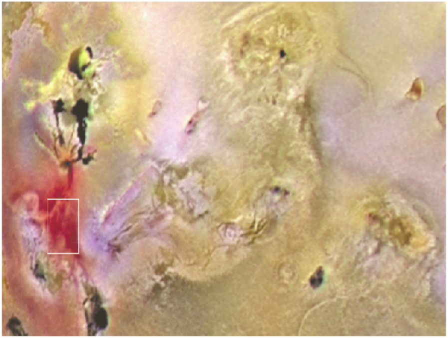


- σ_R standard deviation of the red component.
- Dimensions of the cube in the R component:

$$(a_R - 1,25\sigma_R) \text{ a } (a_R + 1,25\sigma_R)$$

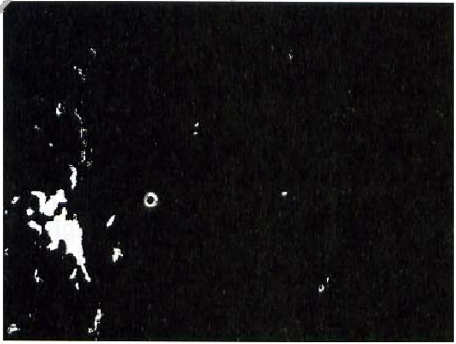
- original and segmentation mask

Comparando com o resultado anterior



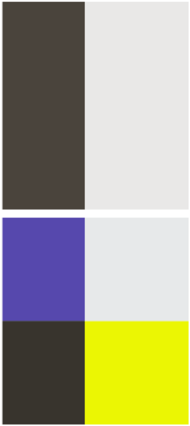
Utilizando o RGB

Utilizando o HSI

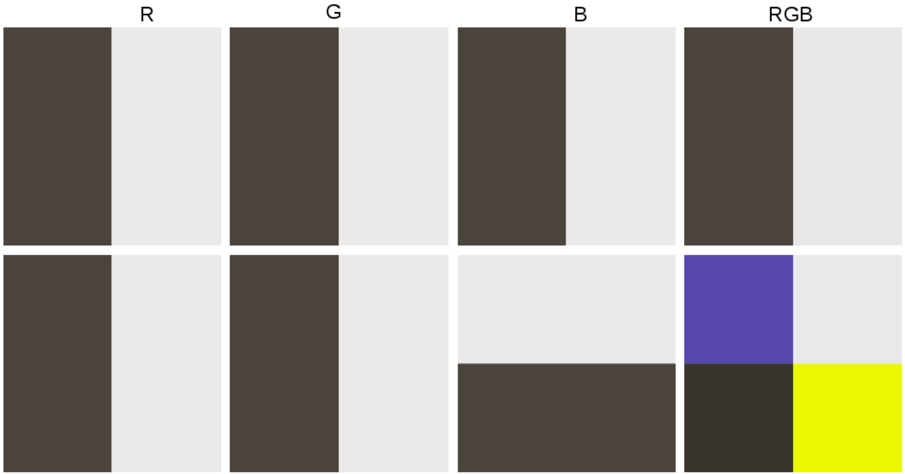


Decomposing Color Images

R G B RGB



Decomposing Color Images



Di Zenzo, 1986

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

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

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

Di Zenzo, 1986

Direction with a maximum rate of variation:

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

Velue of the maximum rate of variation in (x, y) in the direction:

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

$$F(\theta) = F(\theta + \pi)$$


Gradiente calculado Nos 3 planos
Gradiente calculado Individualmente e somado.
diferença

Gradiente calculados individualmente em R, G e B.

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 same models are valid

Noise in Color Images

- The same models are valid
- But, the different color components can be affected in a non-uniform way
- CCD sensors are sensitive to noises in low levels of light

Componentes R, G e B de uma imagem corrompida com ruído Gaussiano (média 0 e variância 800)

Componentes H, S e I da imagem anterior – ruído Gaussiano (média 0 e variância 800)

Componente G corrompida com ruído sal e pimenta.

Hue

Saturation

Intensity