Digital Image Processing

Chapter 6:

Color Image Processing

Spectrum of White Light

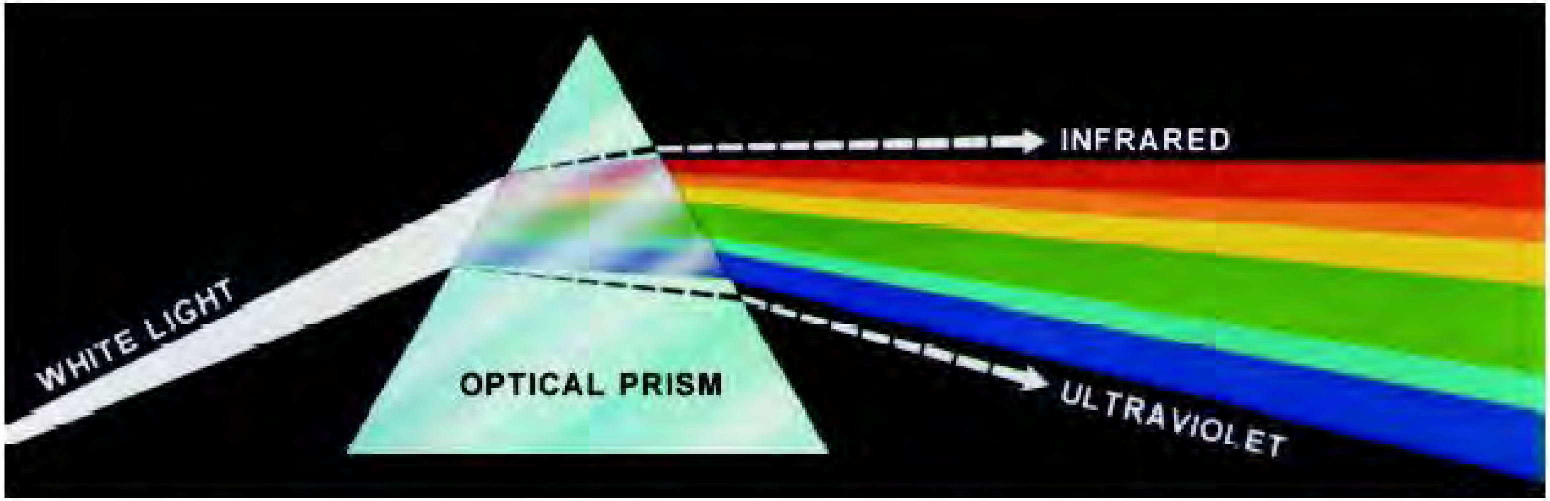
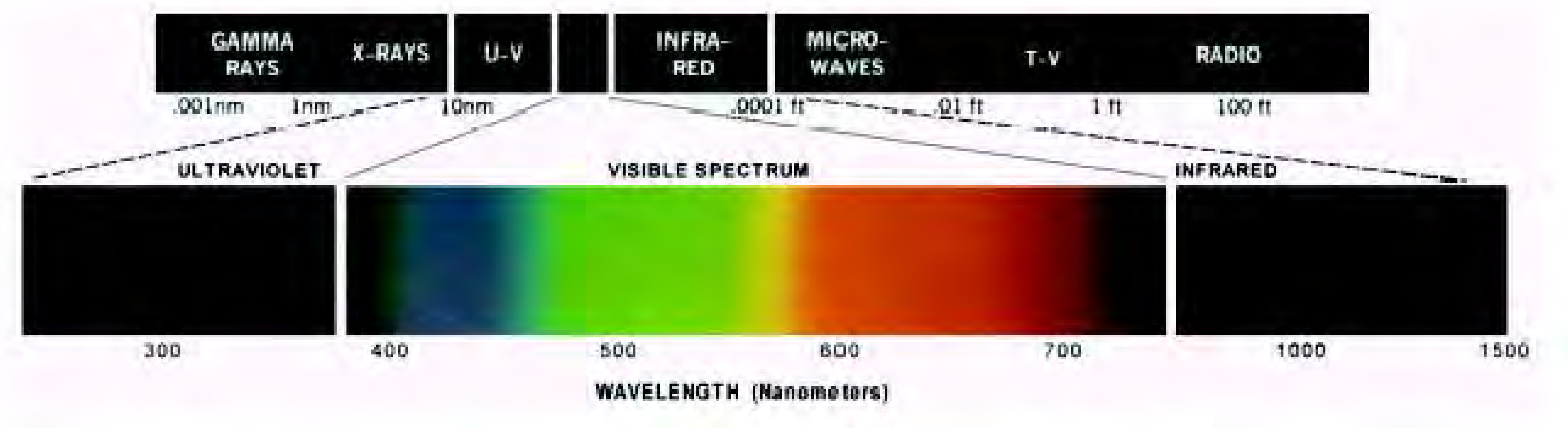


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

1666 Sir Isaac Newton, 24 year old, discovered white light spectrum.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Electromagnetic Spectrum



Visible light wavelength: from around 400 to 700 nm

1. For an achromatic (monochrome) light source, there is only 1 attribute to describe the quality: intensity

2. For a chromatic light source, there are 3 attributes to describe the quality:
   - Radiance = total amount of energy flow from a light source (Watts)
   - Luminance = amount of energy received by an observer (lumens)
   - Brightness = intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Two Types of Photoreceptors at Retina

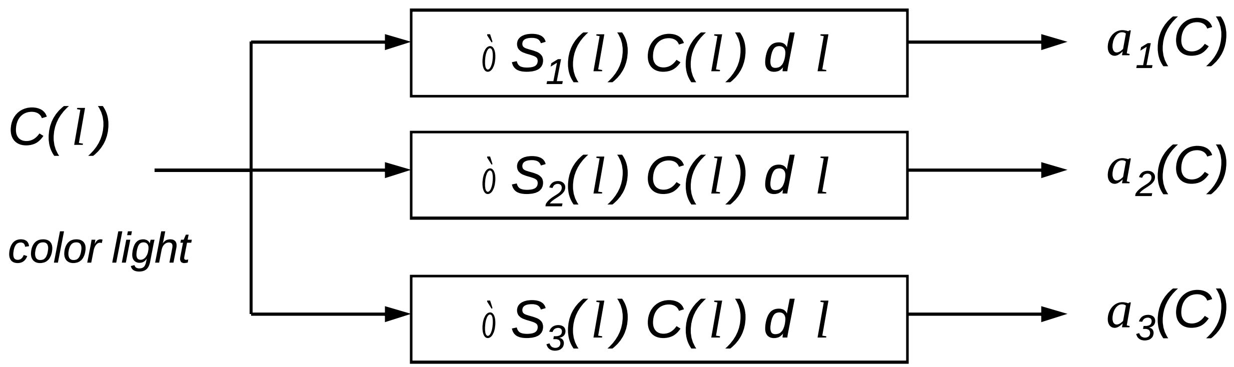
- Rods
  - Long and thin
  - Large quantity (~ 100 million)
  - Provide ***scotopic*** vision (i.e., dim light vision or at low illumination)
  - Only extract luminance information and provide a general overall picture
- Cones
  - Short and thick, densely packed in fovea (center of retina)
  - Much fewer (~ 6.5 million) and less sensitive to light than rods
  - Provide ***photopic*** vision (i.e., bright light vision or at high illumination)
  - Help resolve fine details as each cone is connected to its own nerve end
  - Responsible for color vision

    our interest
    (well-lighted display)

  - Mesopic vision
    - provided at intermediate illumination by both rod and cones

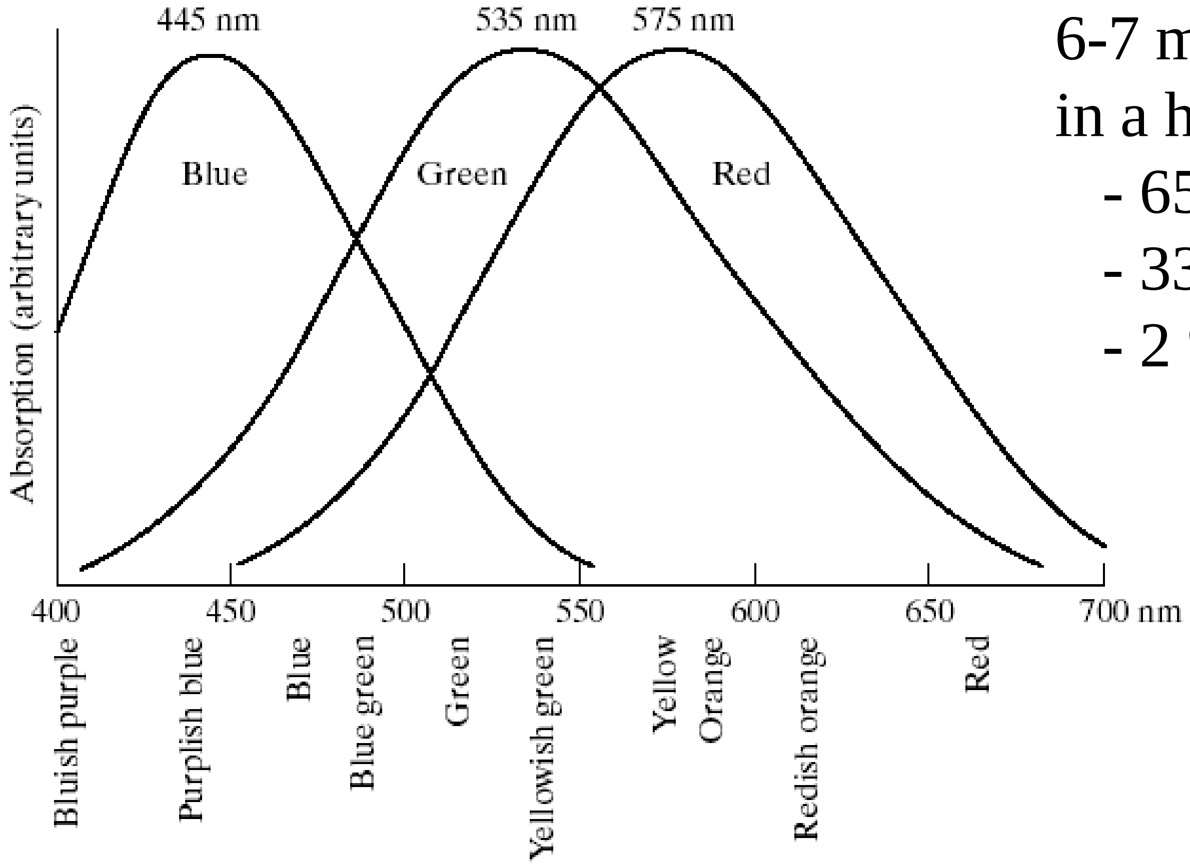
Representation by Three Primary Colors

- Any color can be reproduced by mixing an appropriate set of three primary colors (Thomas Young, 1802)
- Three types of cones in human retina
  - Absorption response $S_i(\lambda)$ has peaks around 450nm (blue), 550nm (green), 620nm (yellow-green)
  - Color sensation depends on the spectral response $\{\alpha_1(C), \alpha_2(C), \alpha_3(C)\}$ rather than the complete light spectrum $C(\lambda)$



Identically perceived colors if $\alpha_i(C_1) = \alpha_i(C_2)$

Sensitivity of Cones in the Human Eye



6-7 millions cones
in a human eye

- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

Primary colors:
Defined CIE in 1931

Red = 700 nm
Green = 546.1nm
Blue = 435.8 nm

CIE = Commission Internationale de l'Eclairage
(The International Commission on Illumination)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: Seeing Yellow Without Yellow

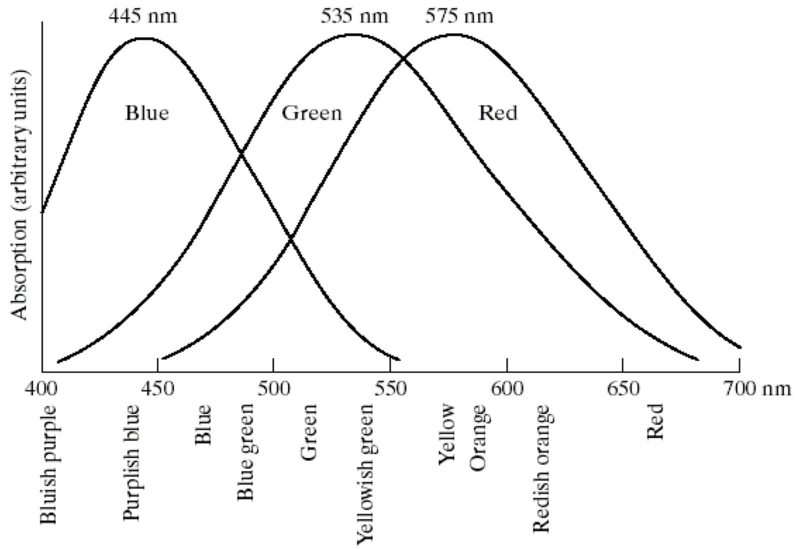
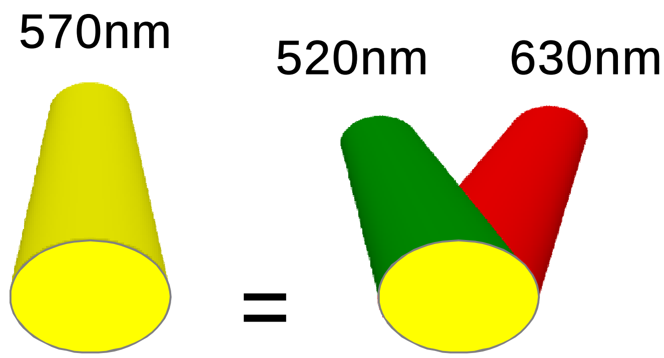


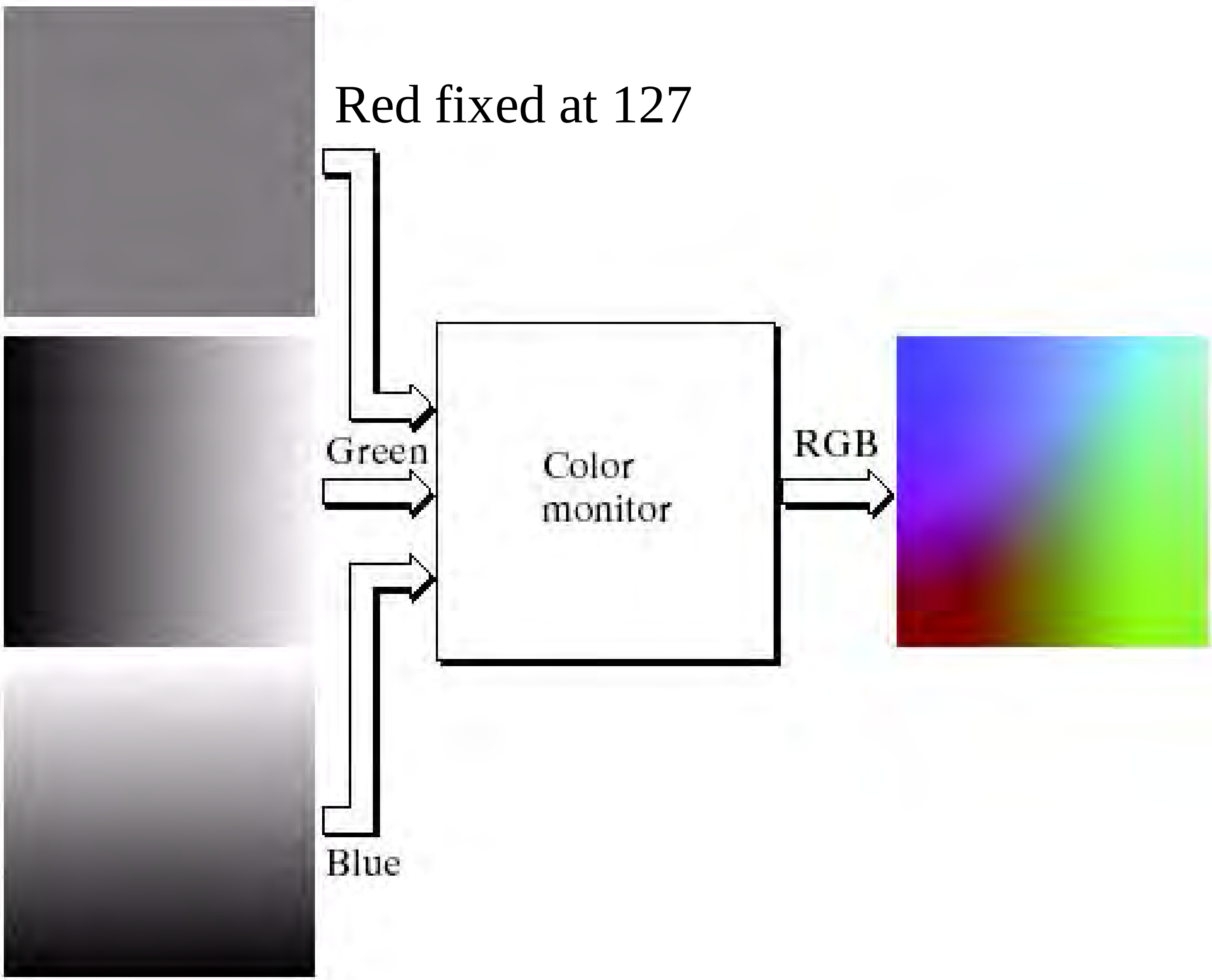
FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



mix green and red light to obtain perception of yellow, without shining a single yellow photon

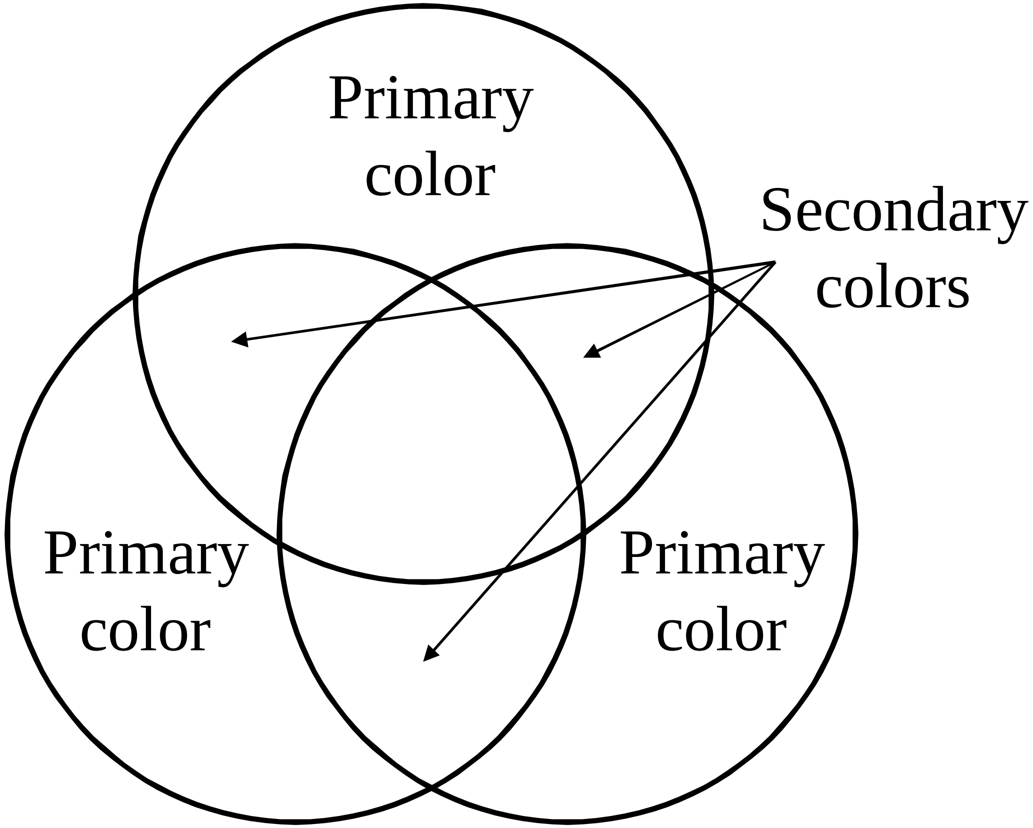
"Seeing Yellow" figure is from B.Liu ELE330 S'01 lecture notes @ Princeton; R/G/B cone response is from slides at Gonzalez/ Woods DIP book website

RGB Color Model (cont.)

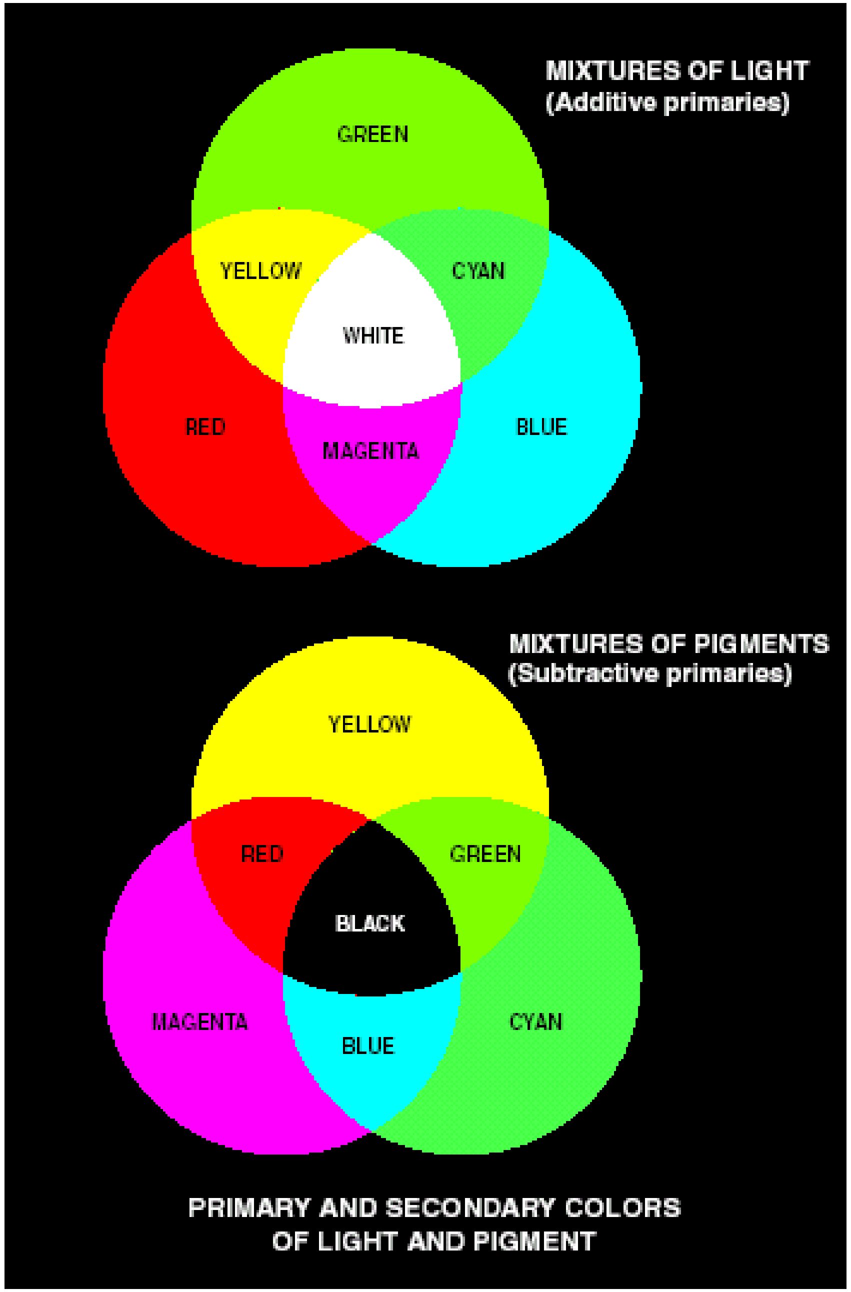


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Primary and Secondary Colors



Primary and Secondary Colors (cont.)



Additive primary colors: RGB use in the case of light sources such as color monitors

RGB add together to get white

Subtractive primary colors: CMY use in the case of pigments in printing devices

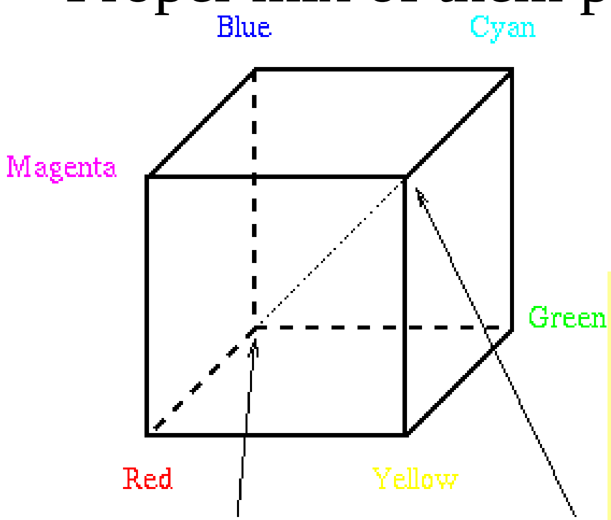
White subtracted by CMY to get Black

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

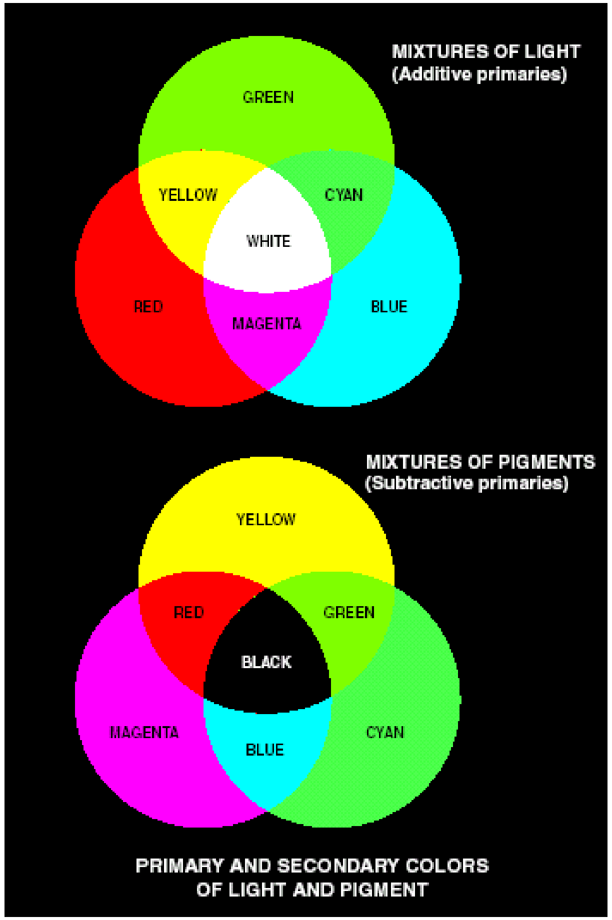
CMY and CMYK Color Models

C = Cyan
M = Magenta
Y = Yellow
K = Black

- Primary colors for pigment
  - Defined as one that subtracts/absorbs a primary color of light & reflects the other two
- CMY – Cyan, Magenta, Yellow
  - Complementary to RGB
  - Proper mix of them produces black

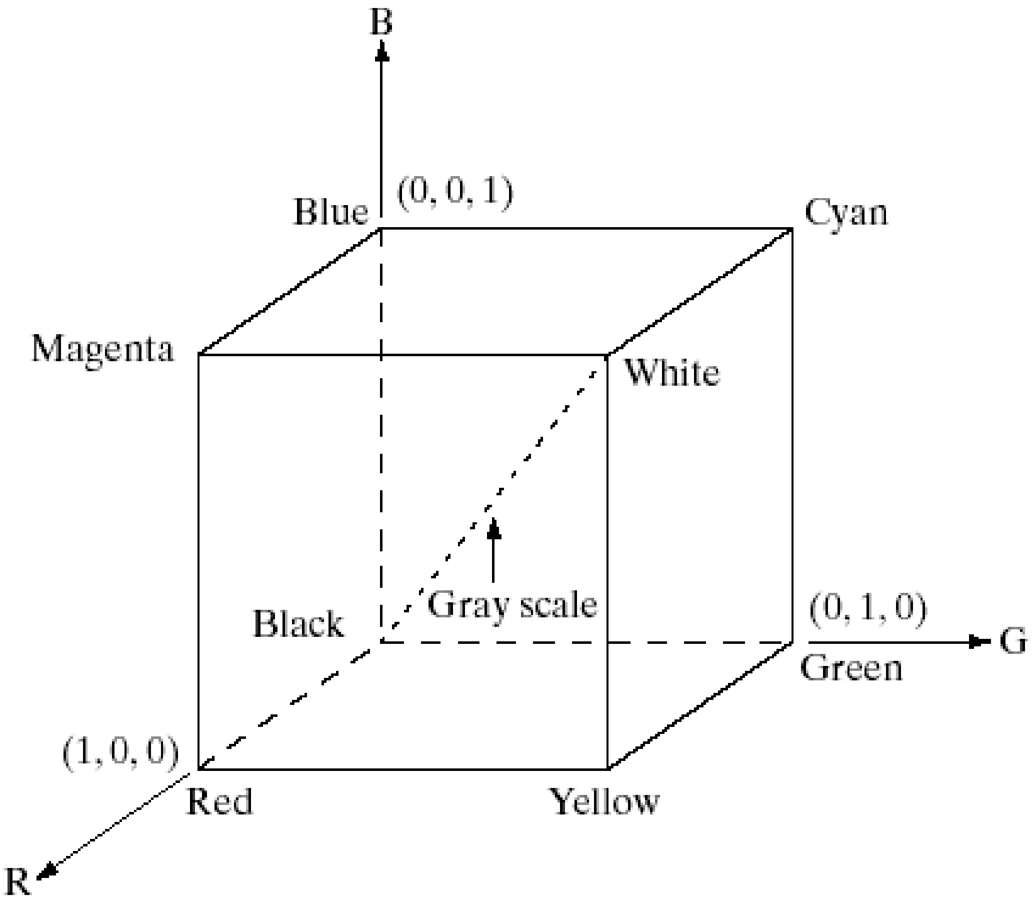


$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



RGB Color Model

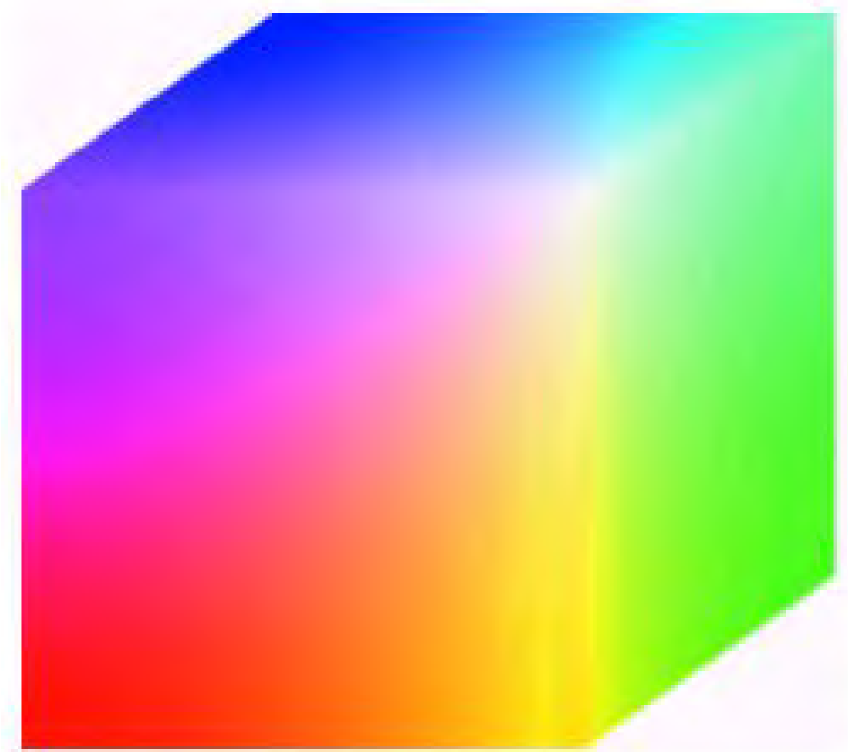
Purpose of color models: to facilitate the specification of colors in some standard



RGB color models:
- based on cartesian coordinate system

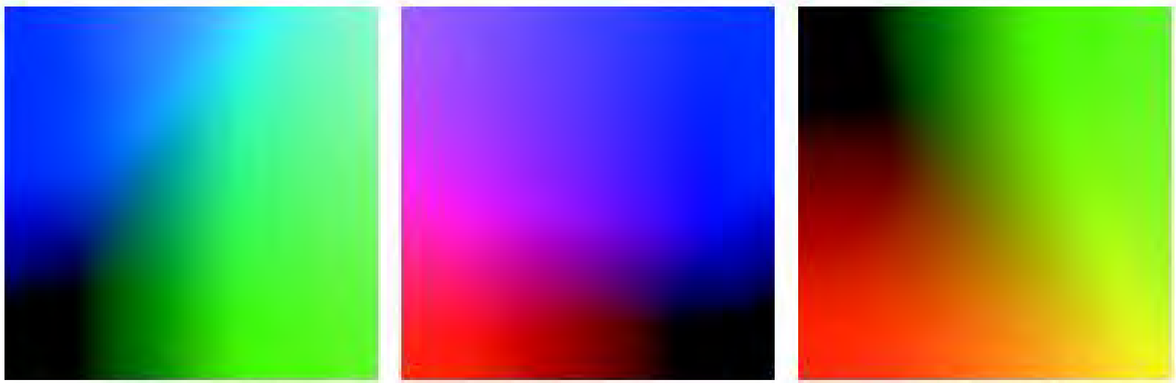
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Cube



R = 8 bits
G = 8 bits
B = 8 bits

Color depth 24 bits
= 16777216 colors



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

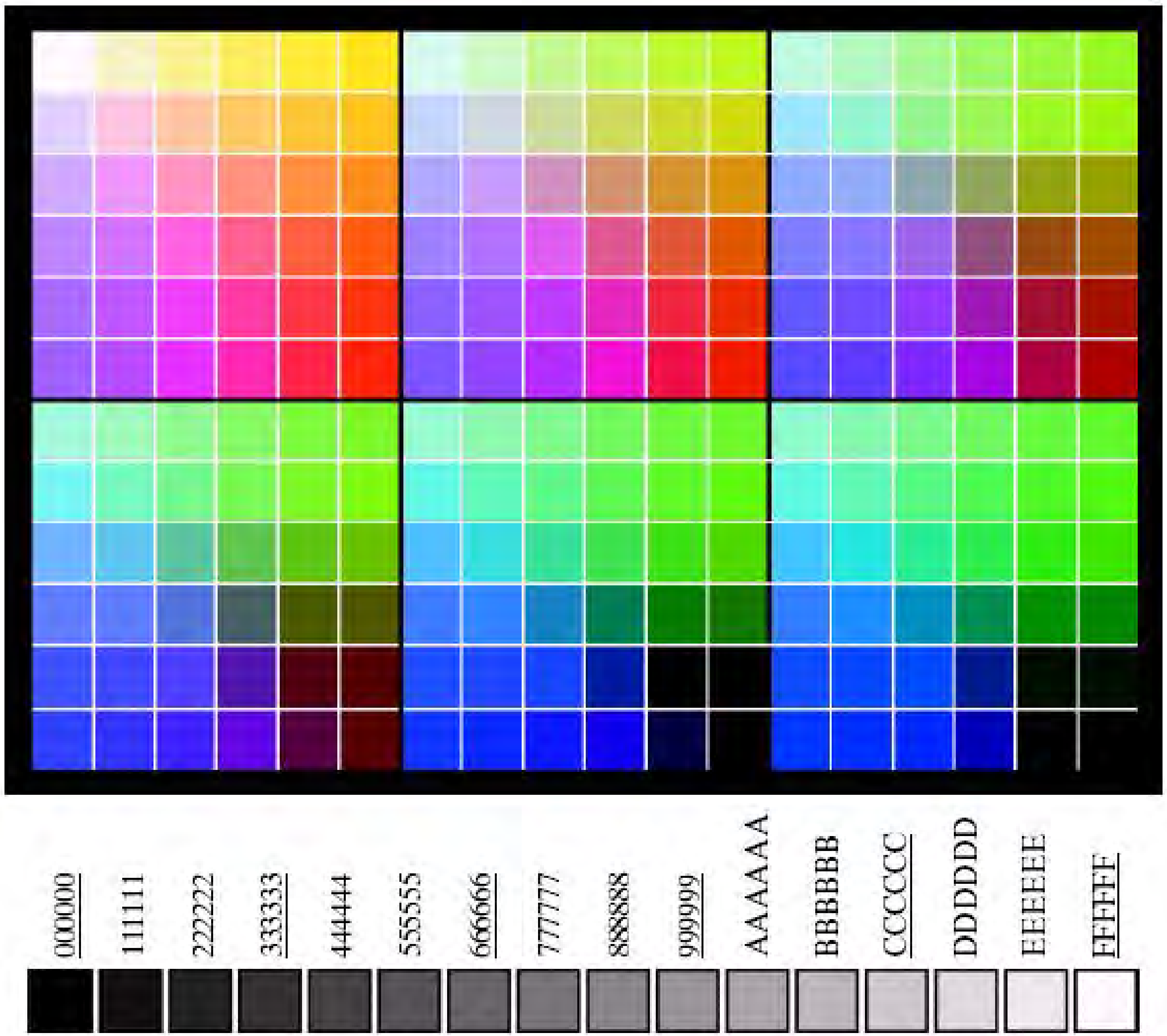
Hidden faces
of the cube

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



a
b

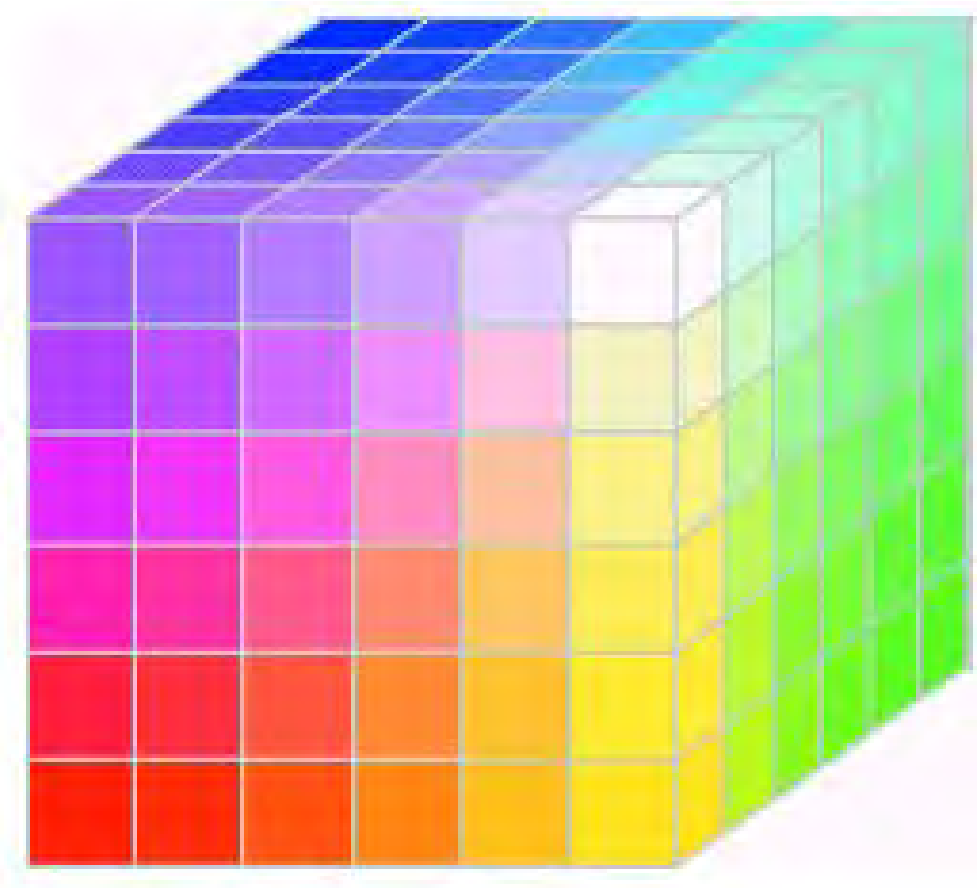
FIGURE 6.10
(a) The 216 safe RGB colors.
(b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Safe-color Cube

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.



The RGB Cube is divided into 6 intervals on each axis to achieve the total $6^3 = 216$ common colors.

However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

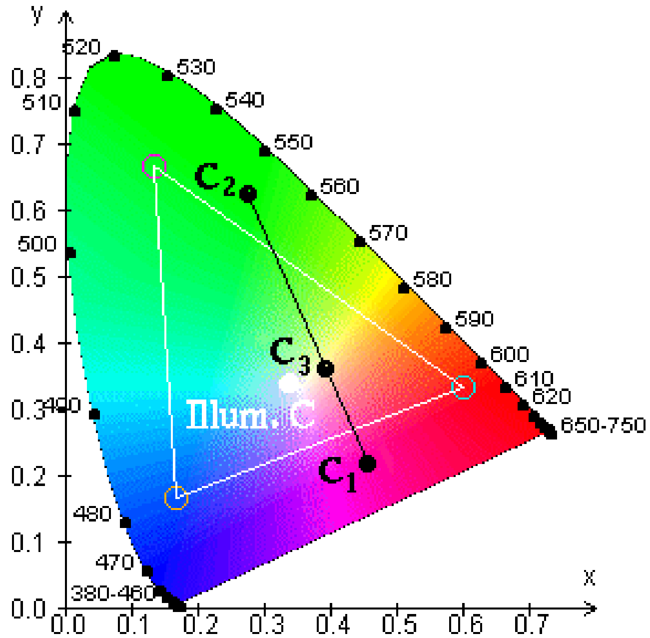
CIE Color Coordinates (cont'd)

- CIE XYZ system

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

  - hypothetical primary sources to yield all-positive spectral tristimulus values

- Color gamut of 3 primaries
  - Colors on line C1 and C2 can be produced by linear mixture of the two
  - Colors inside the triangle gamut can be reproduced by three primaries

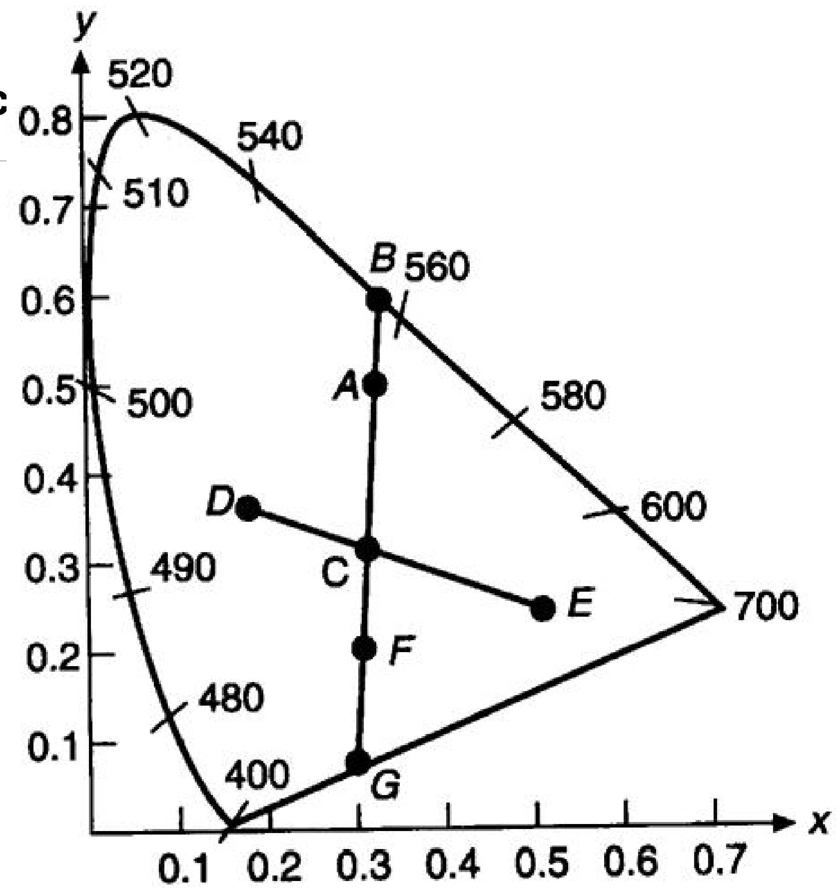


From http://www.cs.rit.edu/~ncs/color/t_chroma.html

Standard Color Model

e a ale e l la a e e e ee a a

a e alle e la e e ee lue.



When two color A and B are added together new color C lies on the line connects both colors.

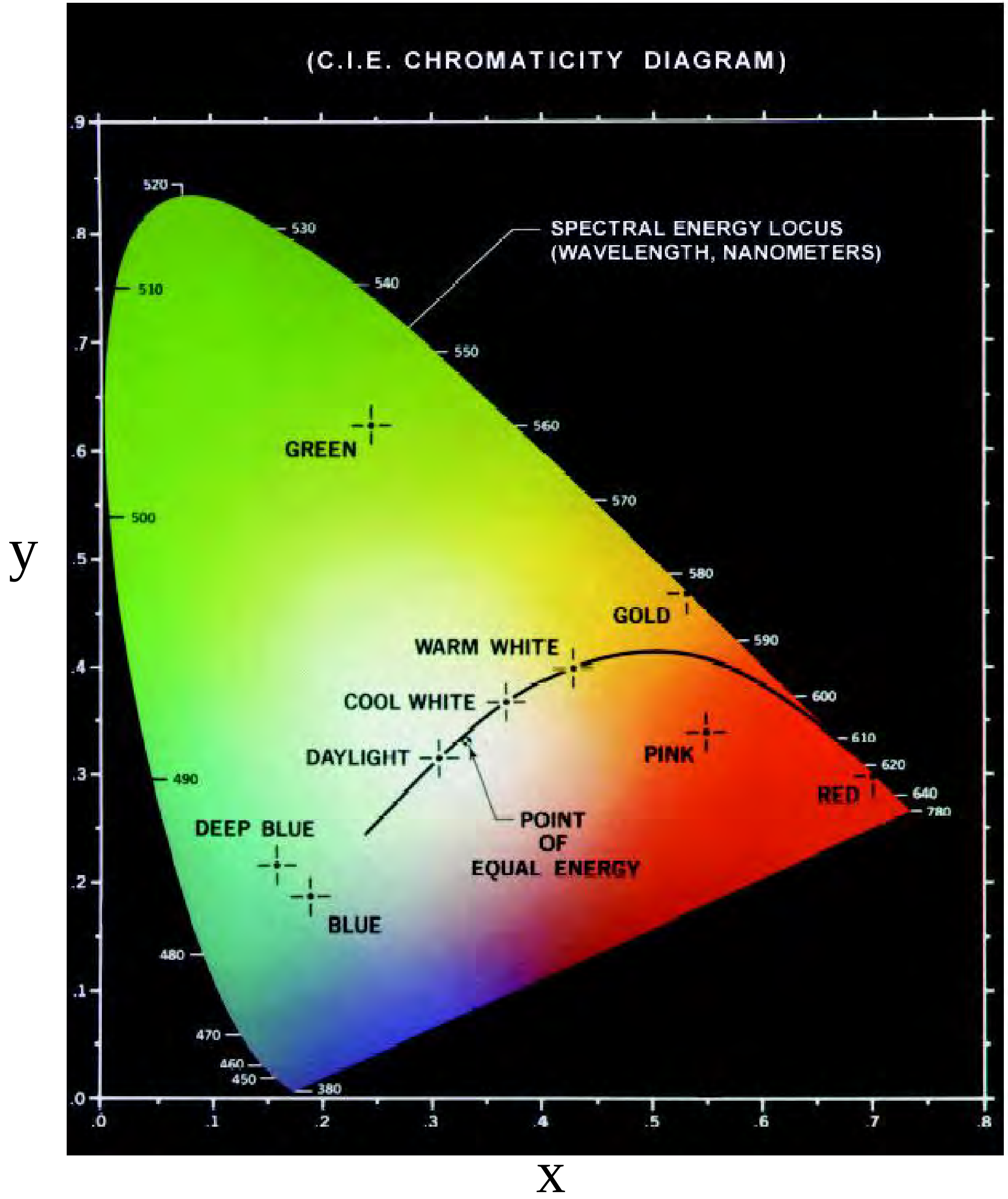
In the side Figure, B defines the dominant wavelength, and the ratio AC to BC expressed as a percent of the excitation purity of A. The closer A to C the more light A includes.

Complementary colors are those that can be mixed to produce white light. D and E on the side Figure are complementary colors.

Nonspectral color are those that can not be defined by dominant wavelength such as F.

Color gamuts or color ranges is the effect of adding colors together

CIE Chromaticity Diagram



Trichromatic coefficients:

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

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

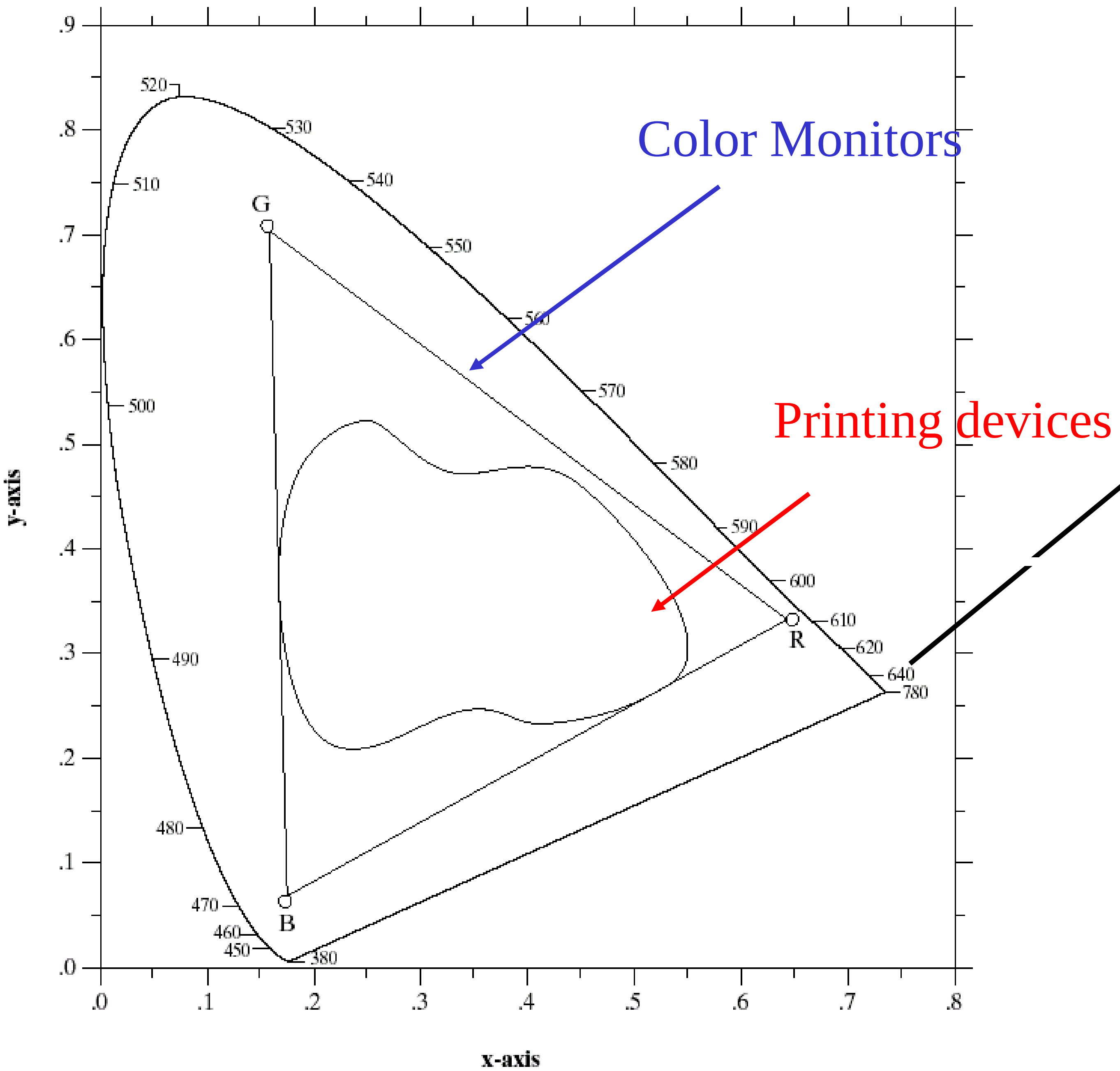
$$z = \frac{Z}{X+Y+Z}$$

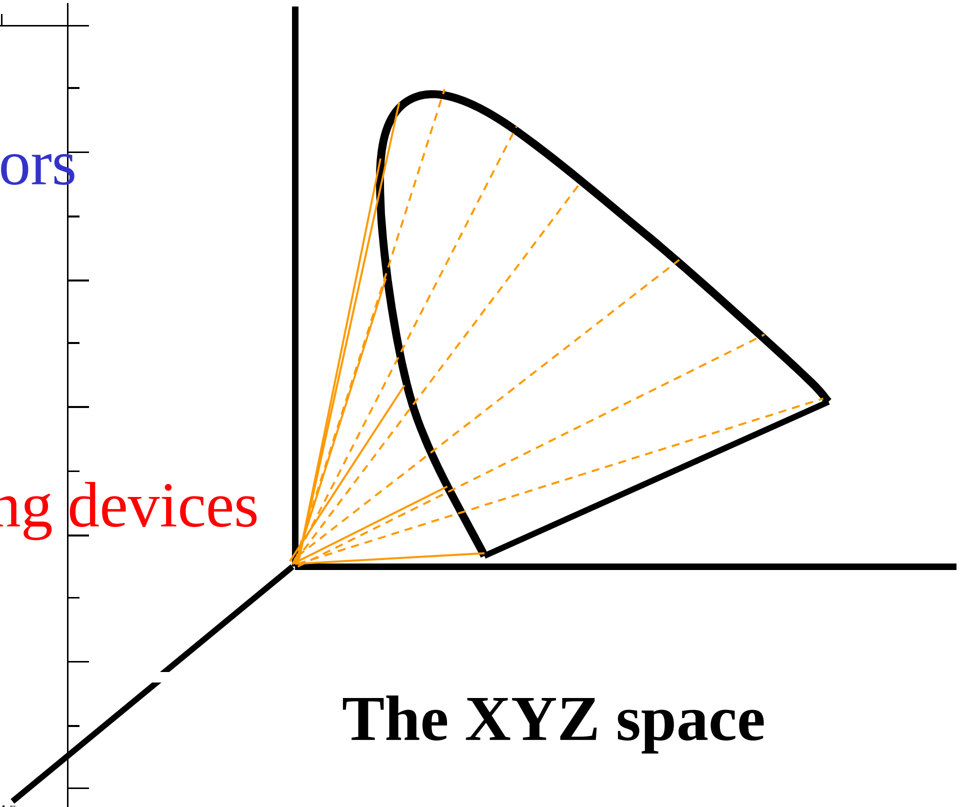
$$x + y + z = 1$$

Points on the boundary are fully saturated colors

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Gamut of Color Monitors and Printing Devices





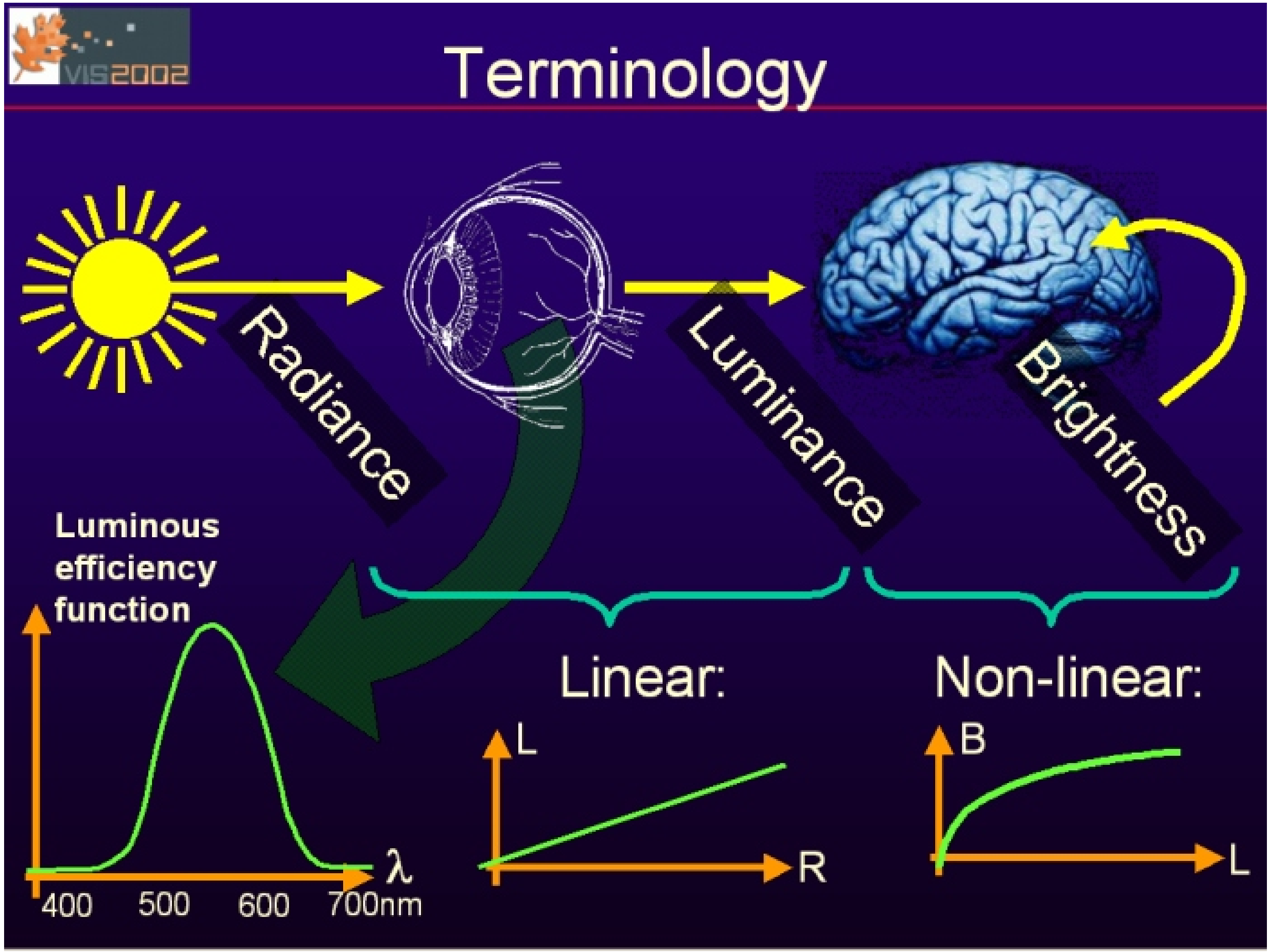
The XYZ space

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Coordinates

- RGB
- u
- XYZ
- HS
- HSV u HS
- HS
- HSV
- YUV (YCbCr)
- a
- uv

Luminance vs. Brightness



- Brightness
  - Perceived luminance
  - Depends on surrounding luminance
- Luminance (or intensity)
  - Independent of the luminance of surroundings

HSI Color Model

RGB and CMY models: straightforward + ideally suited for hardware implementations
+ RGB system matches nicely the human eye perceptive abilities
But, RGB and CMY not well suited for *describing* colours in terms practical for human interpretation

Human view of a colour object described by Hue, Saturation and Brightness (or Intensity)

HSI Color model:

Hue: Dominant color

Saturation: Relative purity (inversely proportional to amount of white light added)

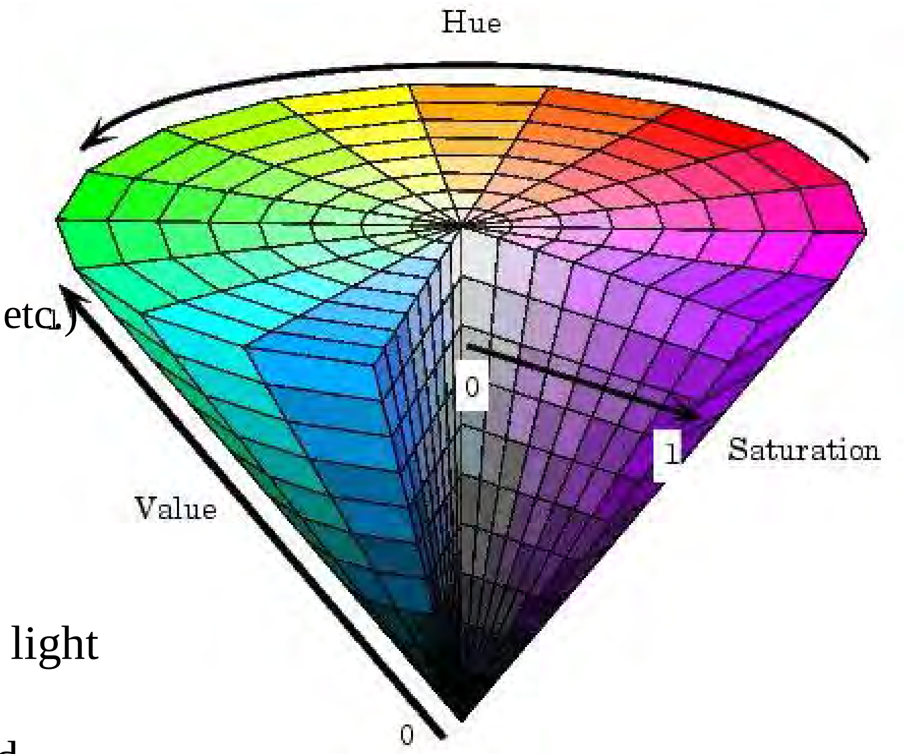
Color carrying information

Intensity: Brightness

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Perceptual Attributes of Color

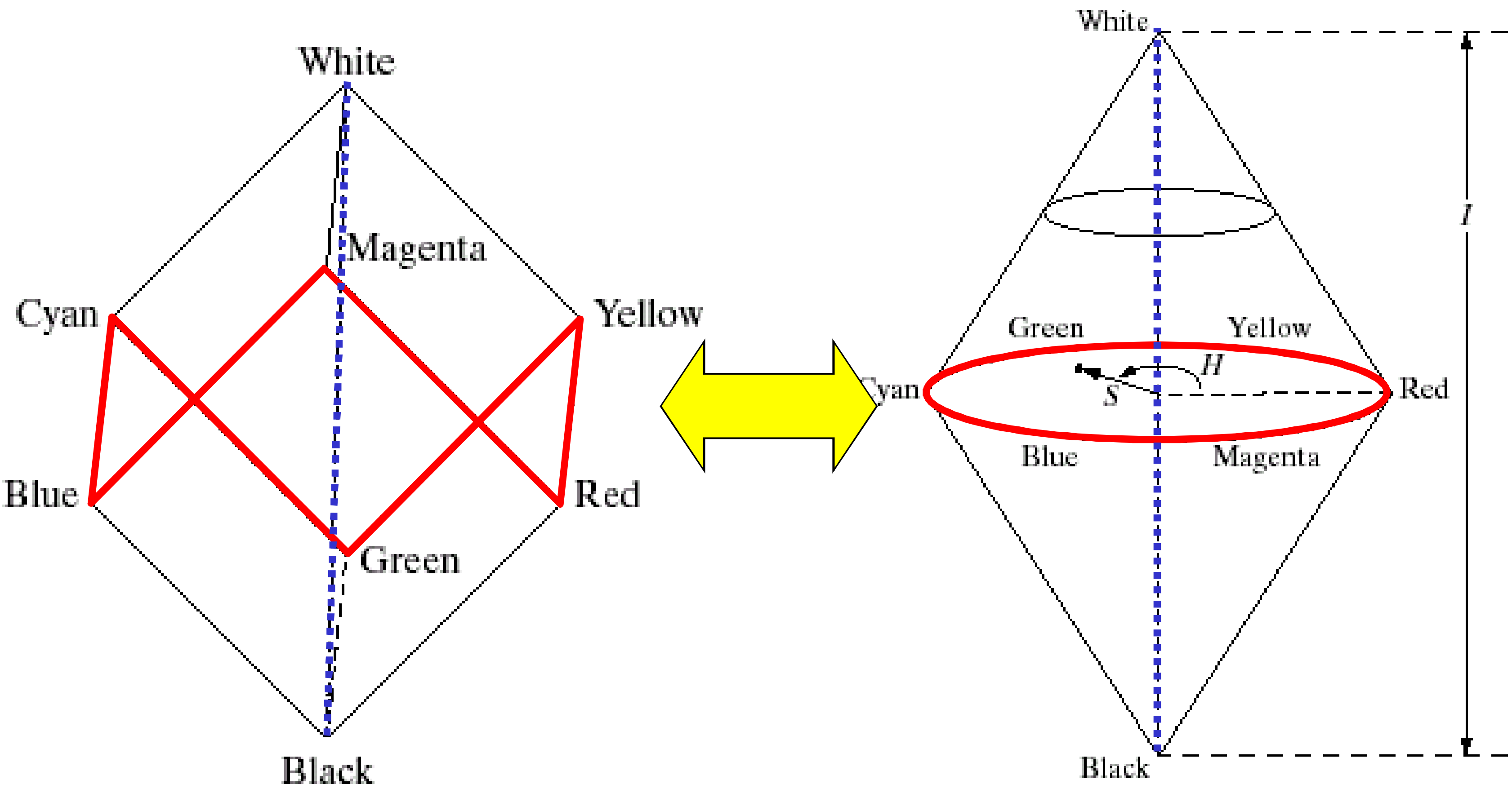
- Value of Brightness (perceived luminance)
- Chrominance
  - **Hue (Matiz em português)**
    - specify color tone (redness, greenness, etc.)
    - depend on peak wavelength
  - **Saturation**
    - describe how pure the color is
    - depend on the spread (bandwidth) of light spectrum
    - reflect how much white light is added
    - e e l a a .
-
- RGB ó HSV Conversion ~ *nonlinear*



HSV circular cone is from online documentation of Matlab image processing toolbox

http://www.mathworks.com/access/helpdesk/help/toolbox/images/color10.shtml

Relationship Between RGB and HSI Color Models

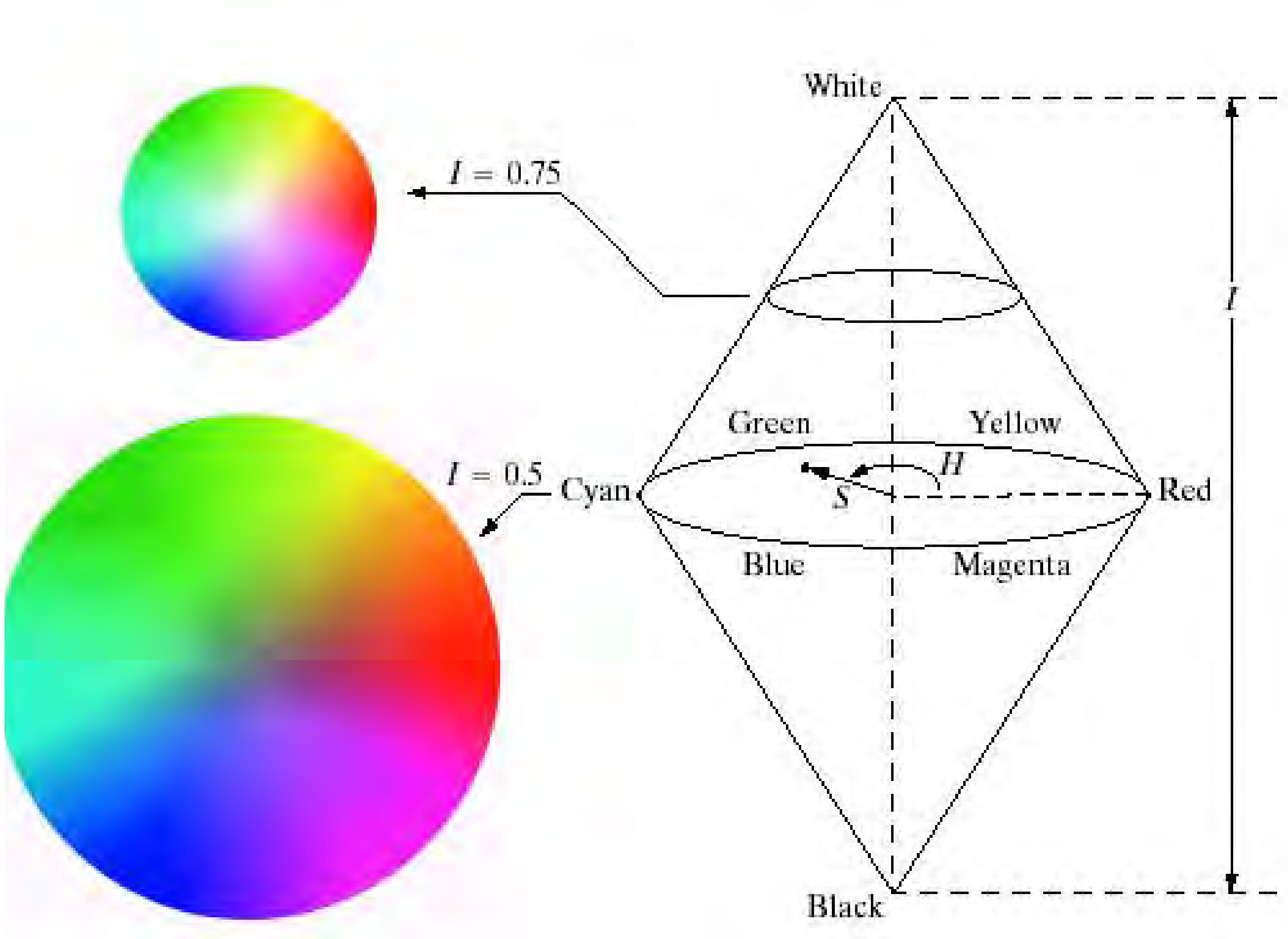


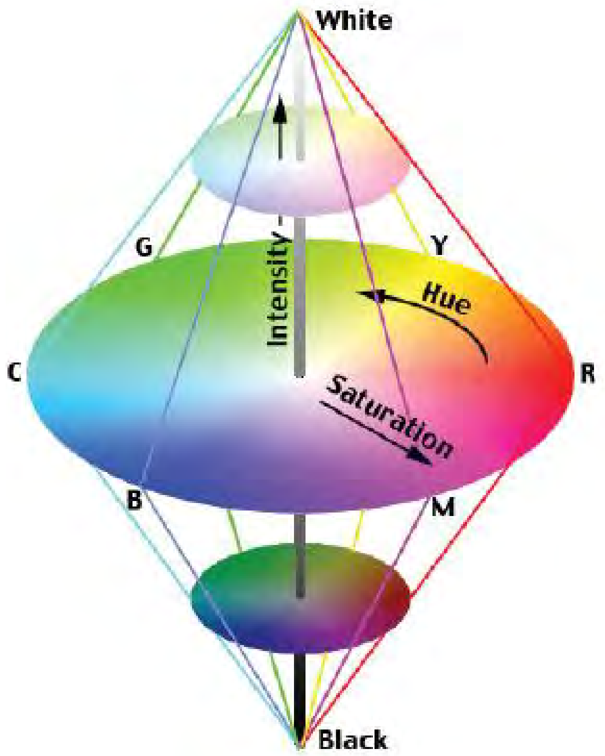
RGB

HSI

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

HSI Color Model (cont.)





Intensity is given by a position on the vertical axis.

Converting Colors from RGB to HSI

$$H = \begin{cases} q & \text{if } B \le G \\ 360 - q & \text{if } B > G \end{cases}$$

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

$$S = 1 - \frac{3}{R+G+B}$$

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

Converting Colors from HSI to RGB

RG sector: $0 \le H < 120$

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

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

$$G = 1 - (R + B)$$

BR sector: $240 \le H \le 360$

$$H = H - 240$$

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

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

$$R = 1 - (G + B)$$

GB sector: $120 \le H < 240$

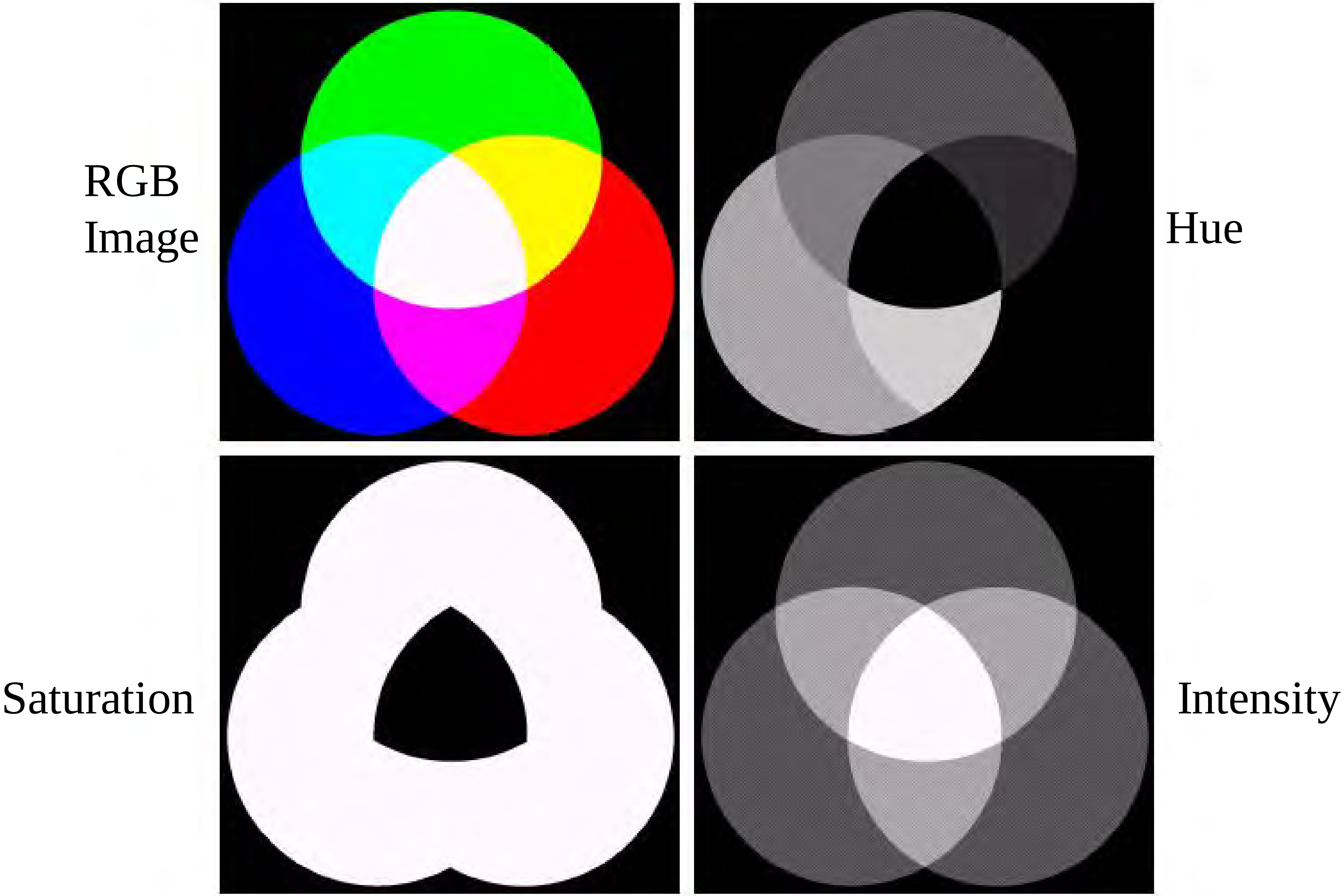
$$H = H - 120$$

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

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

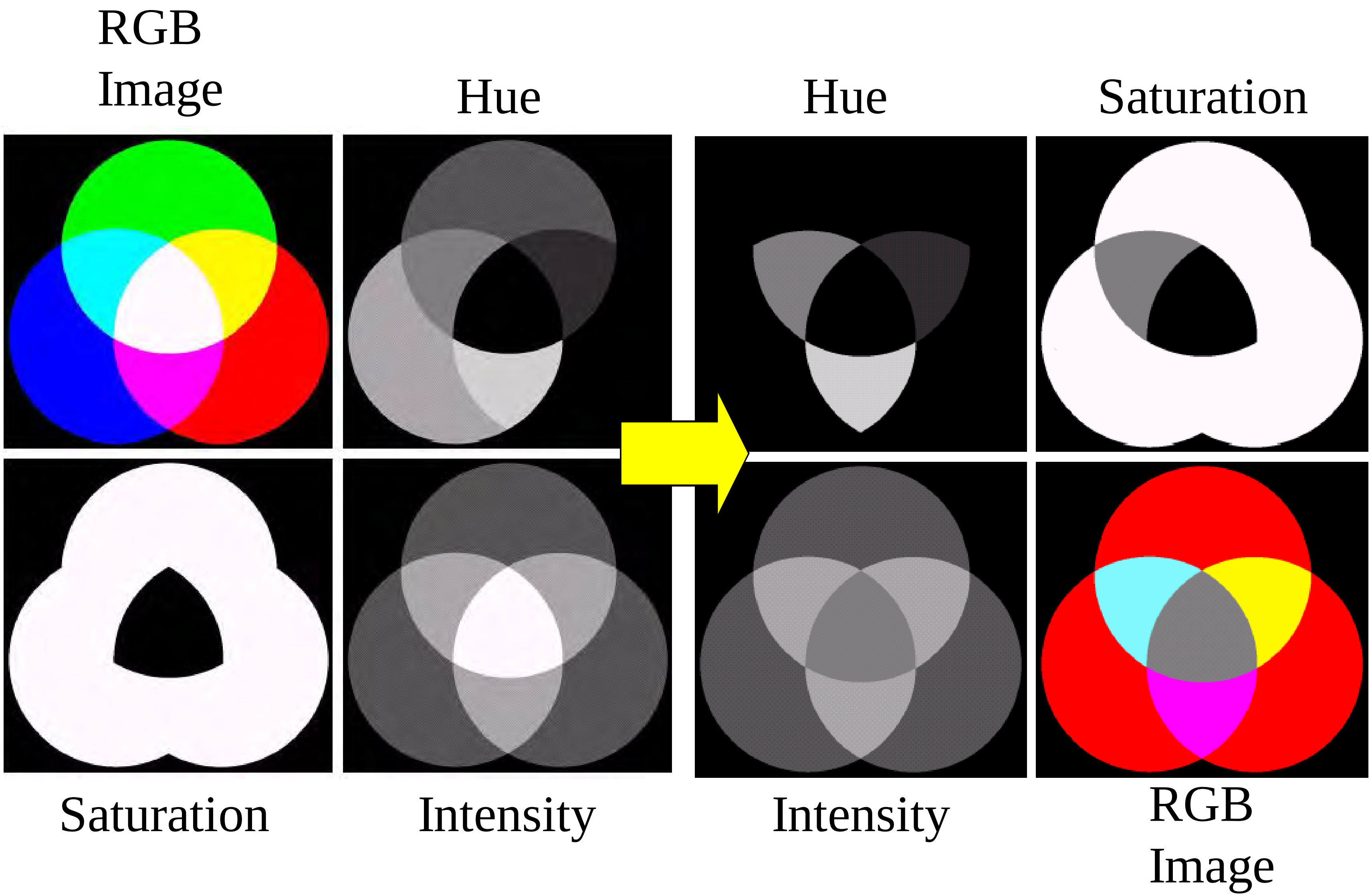
$$B = 1 - (R + G)$$

Example: HSI Components of RGB Colors

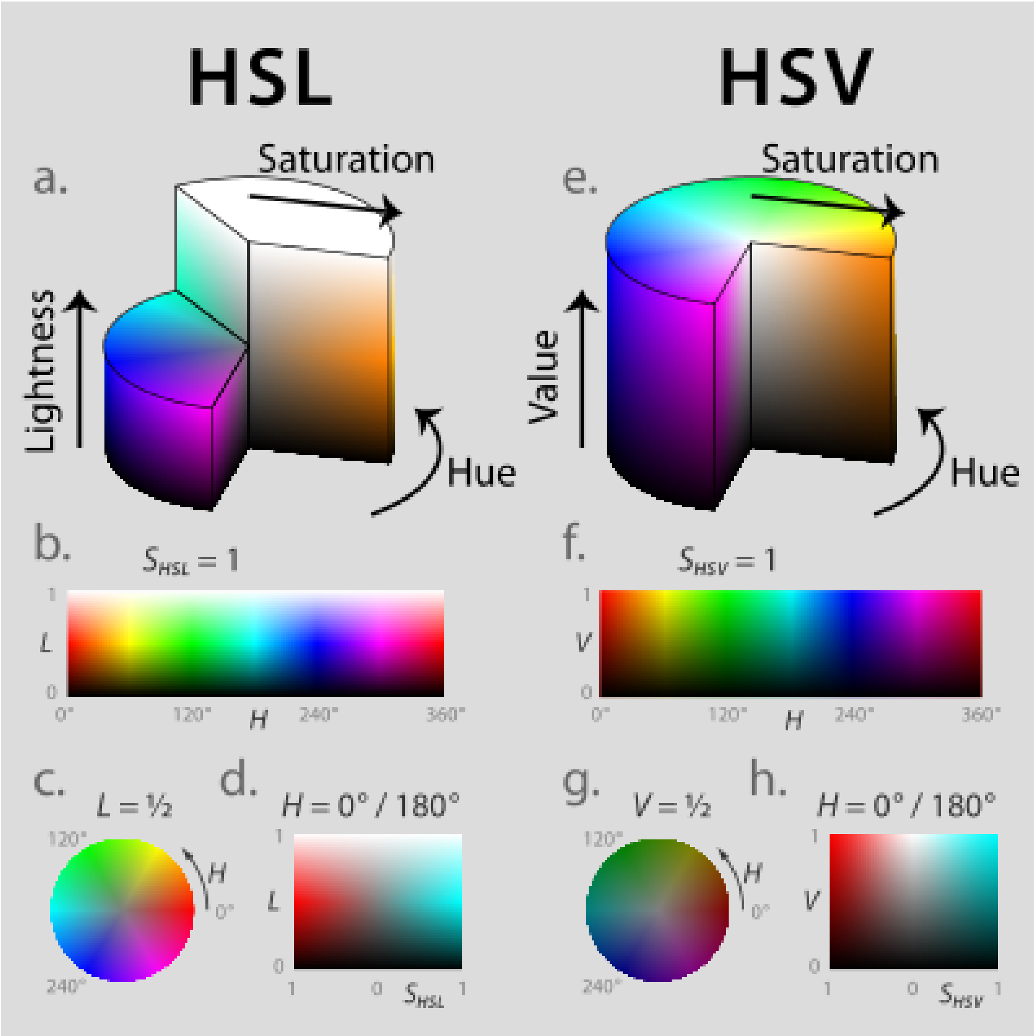


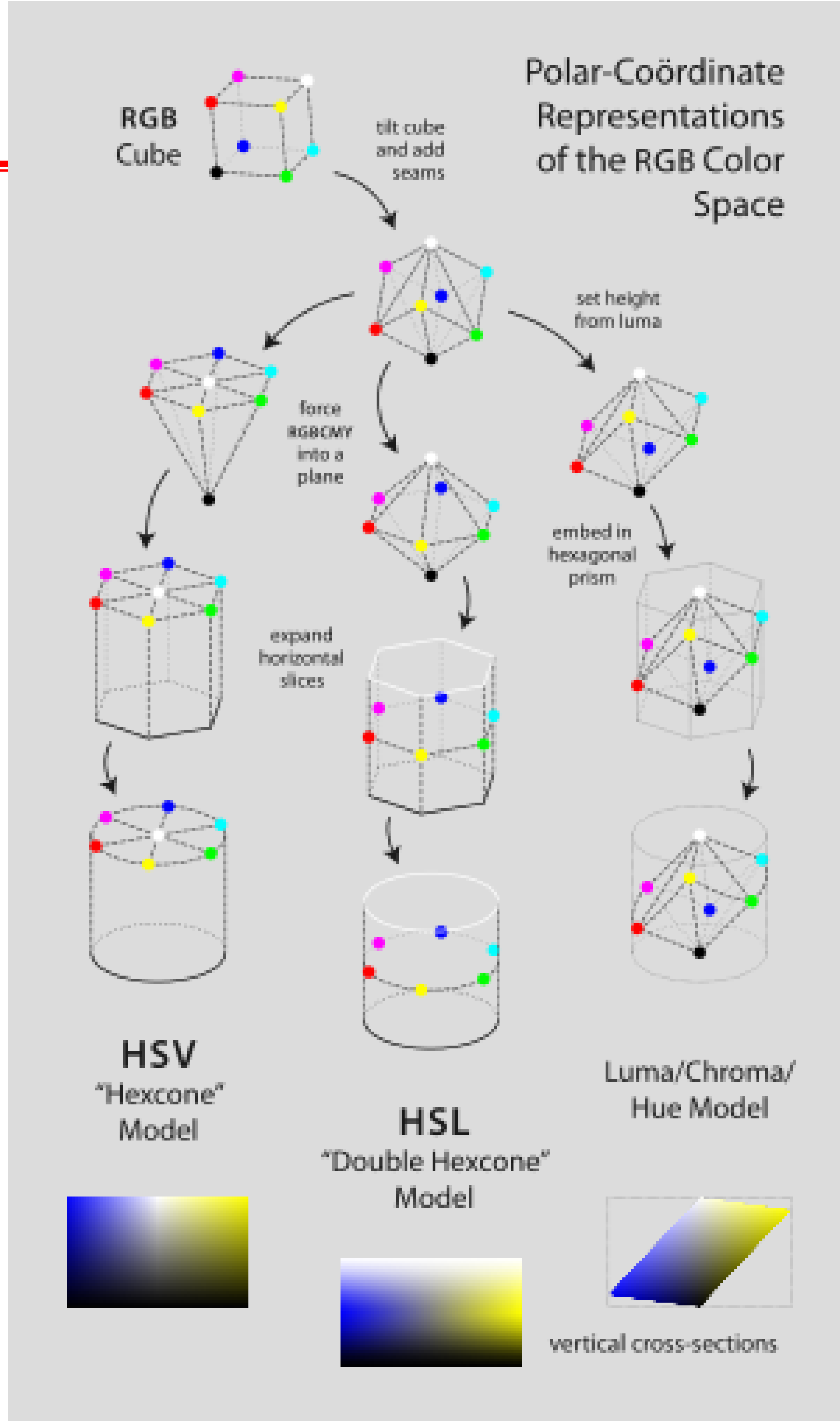
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: Manipulating HSI Components

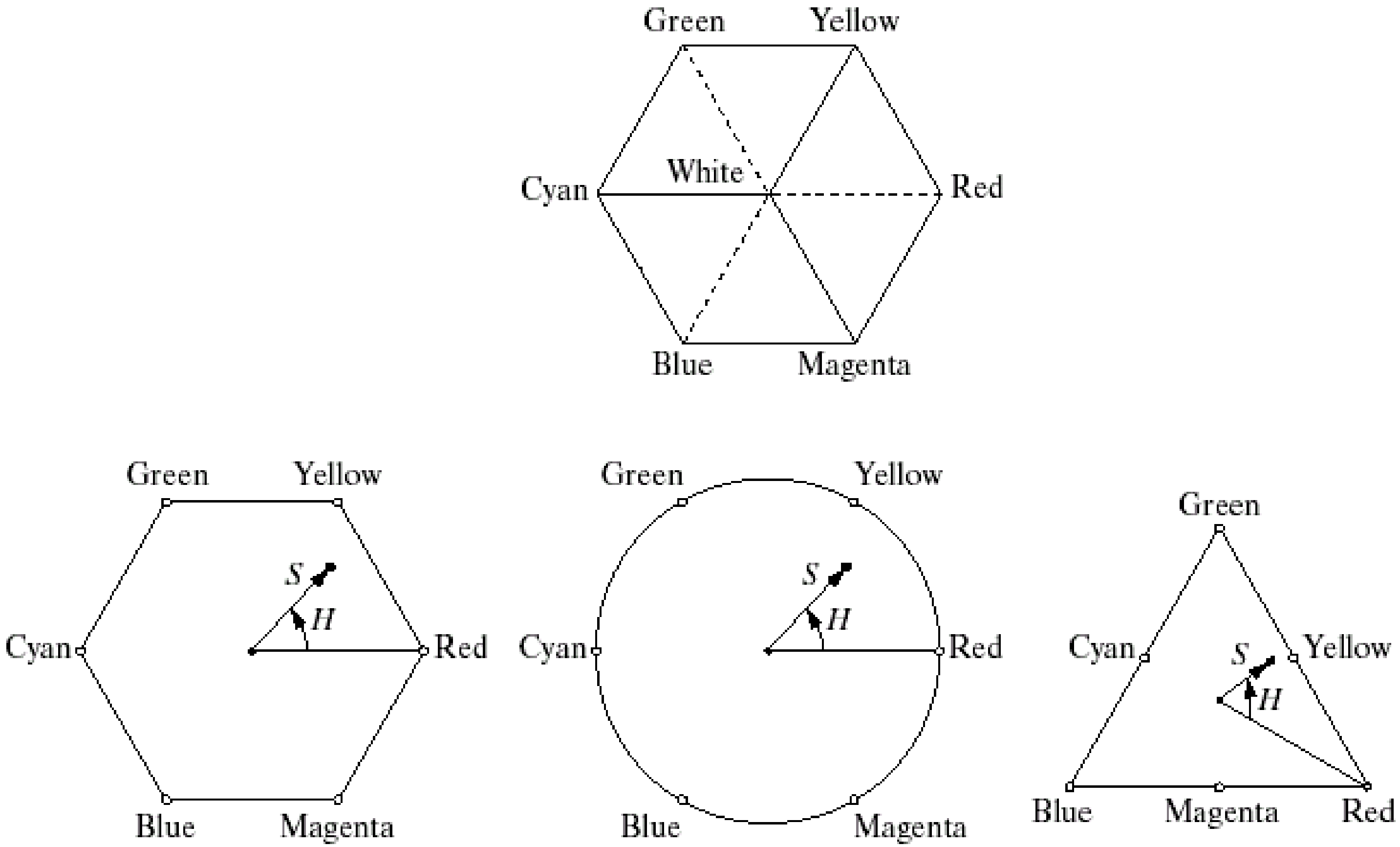


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.


HSL
HSV
a.
Saturation
Lightness
Hue
e.
Saturation
Value
Hue
b.
$S_{HSL} = 1$
1
L
0
0°
120°
H
240°
360°
f.
$S_{HSV} = 1$
1
V
0
0°
120°
H
240°
360°
c.
$L = ½$
120°
H
0°
240°
d.
$H = 0° / 180°$
1
L
0
1
0
S_{HSL}
1
g.
$V = ½$
120°
H
0°
240°
h.
$H = 0° / 180°$
1
V
0
1
0
S_{HSV}
1


Polar-Coördinate Representations of the RGB Color Space
RGB Cube
tilt cube and add seams
set height from luma
force RGBCMY into a plane
embed in hexagonal prism
expand horizontal slices
HSV "Hexcone" Model
HSL "Double Hexcone" Model
Luma/Chroma/ Hue Model
vertical cross-sections

Hue and Saturation on Color Planes



1. A dot is the plane is an arbitrary color
2. Hue is an angle from a red axis.
3. Saturation is a distance to the point.

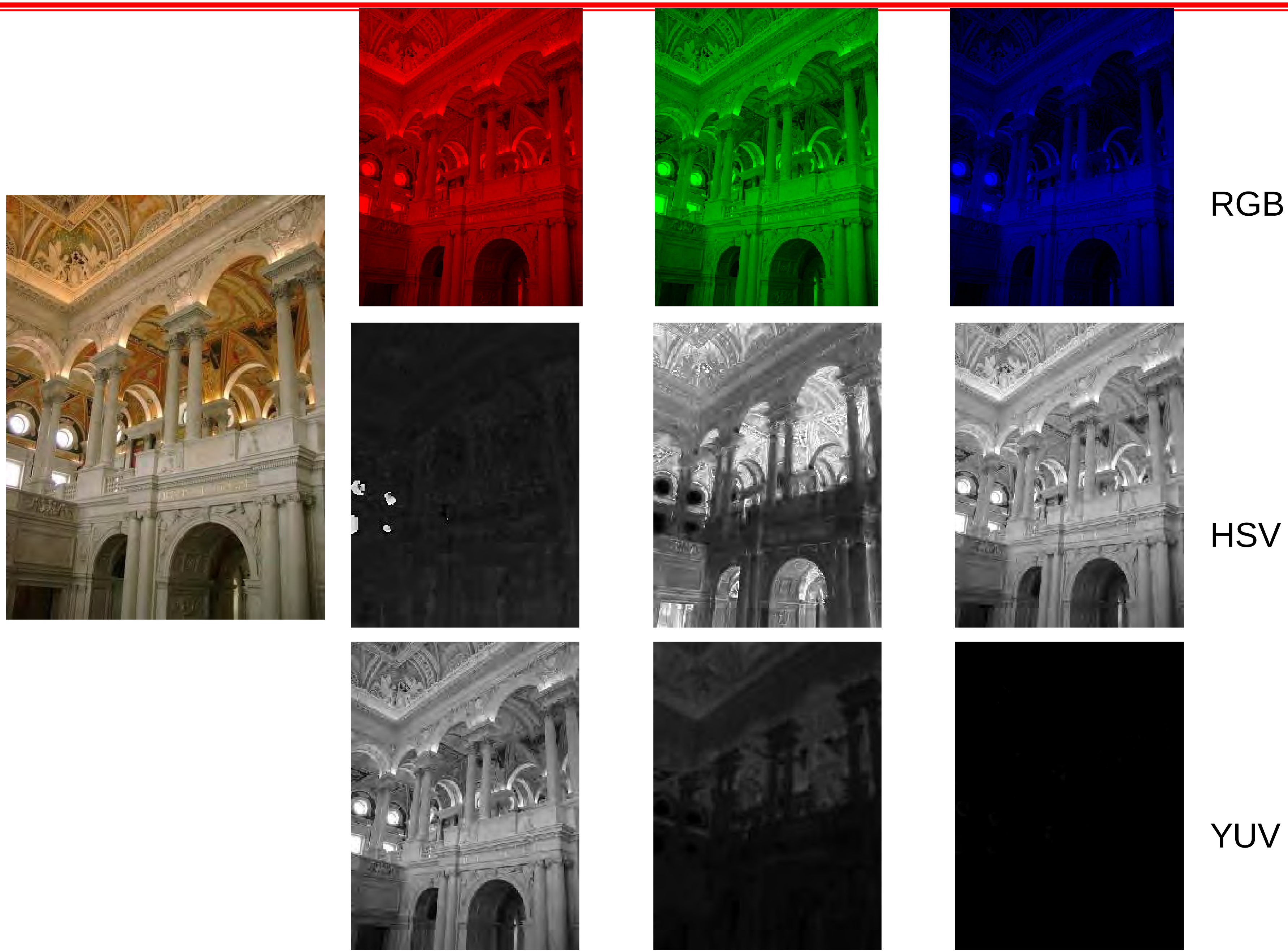
Color Coordinates Used in TV Transmission

- Facilitate sending color video via 6MHz mono TV channel
- YIQ for NTSC (National Television Systems Committee) transmission system
  - Use receiver primary system (R_N, G_N, B_N) as TV receivers standard
  - Transmission system use (Y, I, Q) color coordinate
    - Y ~ luminance, I & Q ~ chrominance
    - I & Q are transmitted in through orthogonal carriers at the same freq.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix}. \qquad \begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R_P \\ G_P \\ B_P \end{bmatrix}.$$

- YUV (YCbCr) for PAL and digital video
  - Y ~ luminance, Cb and Cr ~ chrominance

Examples



Examples

A colour image

Red component

Green component

Blue component

RGB

Hue

Saturation

Value

HSV

Y

I

Q

YIQ

Pseudocolor Coding

HS l e .

.

HSV value V.

HSL/HSV hue of each color shifted by −30°