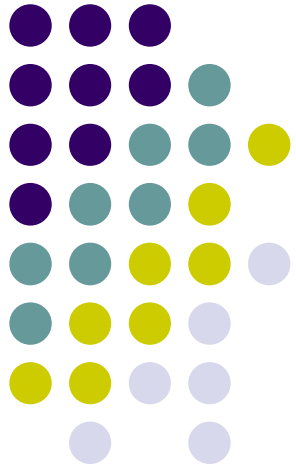
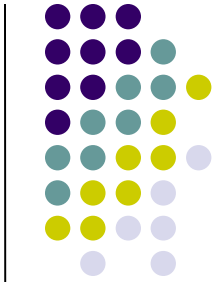
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Sampling (extensions to general lattice), Video, and Color

Shahram Ebadollahi



Lecture Outline



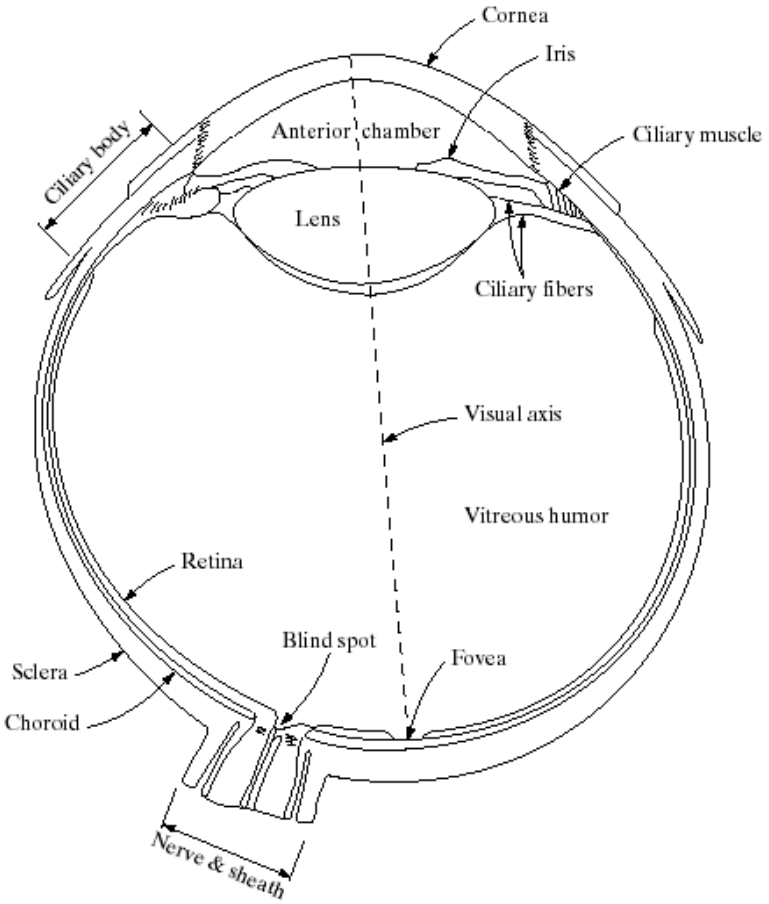
- Review of Lecture 2
- Sampling on general lattice
- Video
  - Fundamentals of Analog and Digital Video
- Color
  - Visual Perception
  - Color Representation
  - Color Models and Transformations
  - Color Sampling and Interpolation

Progressive:

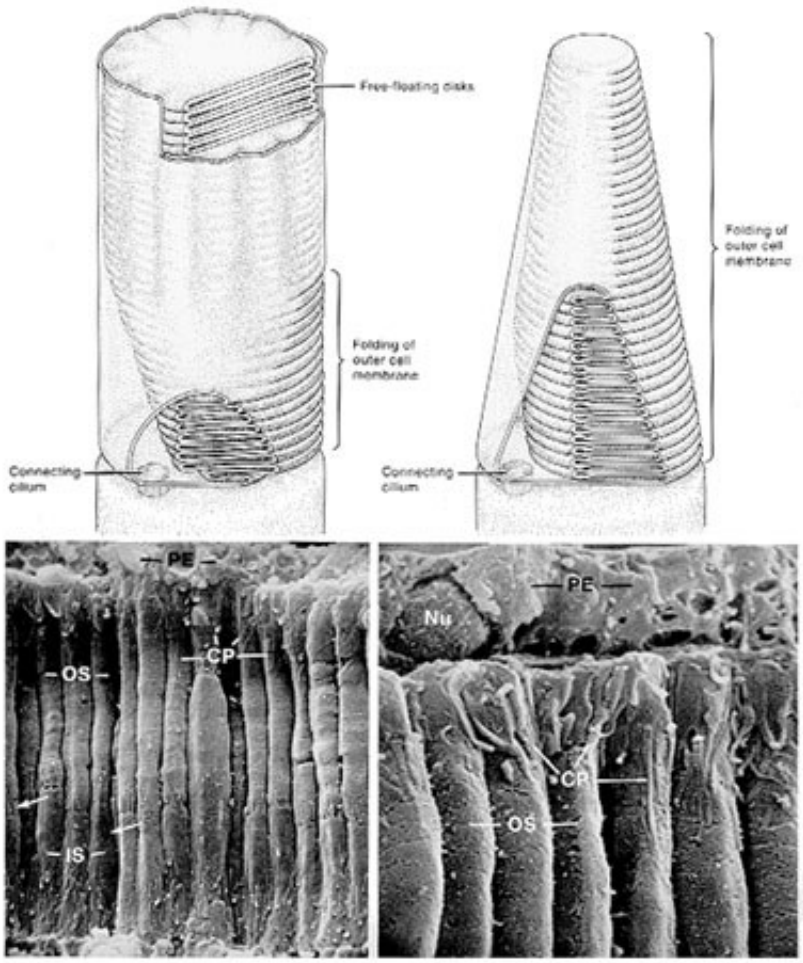
Interlaced:

Eye Physiology & Visual Perception

$$I(x,y,\lambda) = r(x,y,\lambda)\,L(x,y,\lambda)$$



Eye Physiology & Visual Perception

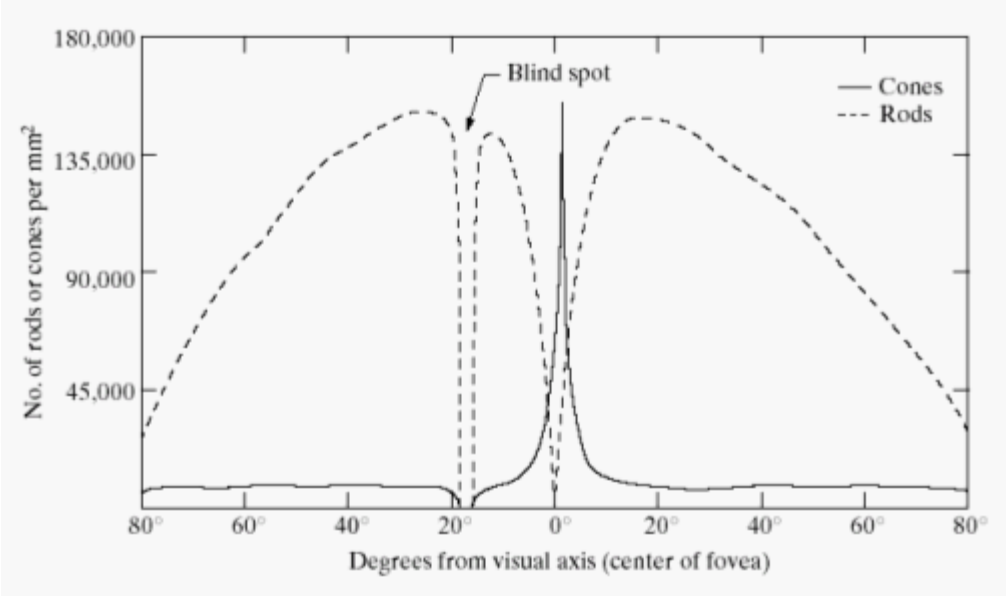


Photoreceptor Cells

- 75~150 Million
- Sensitive to low illumination
- Distributed over Retina
- Scotopic (dim light) vision

- 6~7 Million
- Highly sensitive to color
- Concentrated in Fovea
- Photopic (day light) vision

Rods & Cones Distribution in Retina



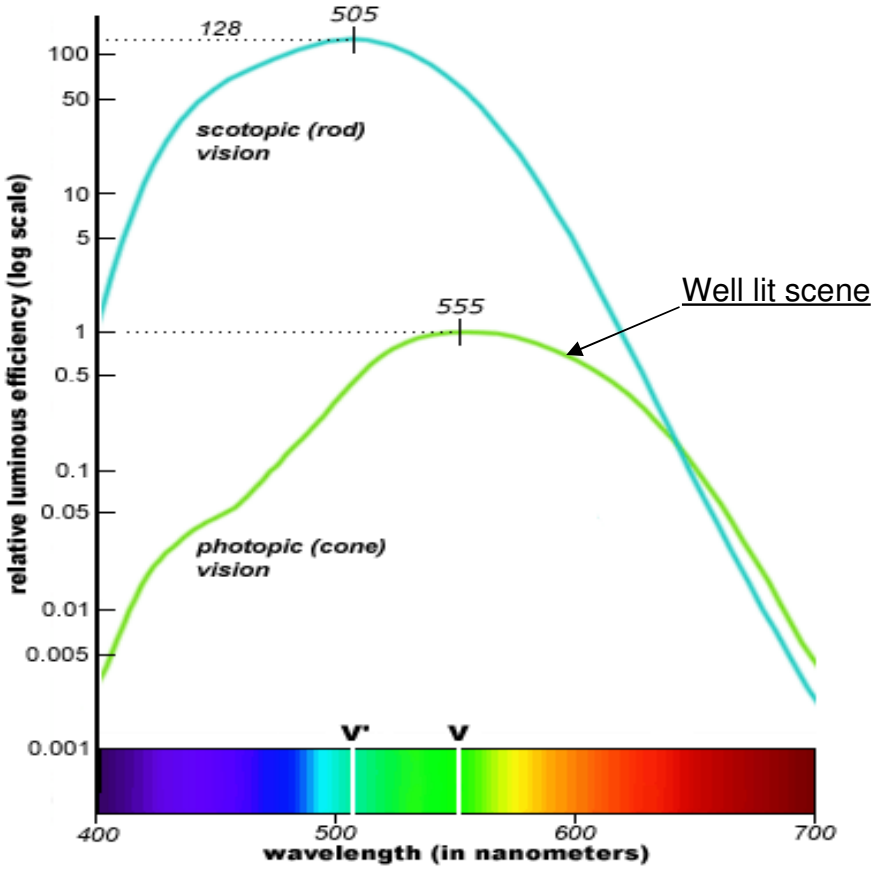
Visual Perception: Luminence

Spectral Power Distribution of the Stimulus

$$I(x,y,\lambda) = r(x,y,\lambda)\,L(x,y,\lambda)$$

$$F(x,y) = \int_0^{\infty} I(x,y,\lambda)\,V(\lambda)\,d\lambda$$

Luminance (intensity)



Visual Perception: Color

- Humans perceive only a few dozen gray levels but thousands of colors
- Color perceptual attributes:
  - Brightness (perceived Luminence)
  - Hue ("redness", "greenness", …)
  - Saturation

3 types of Cone Photoreceptors

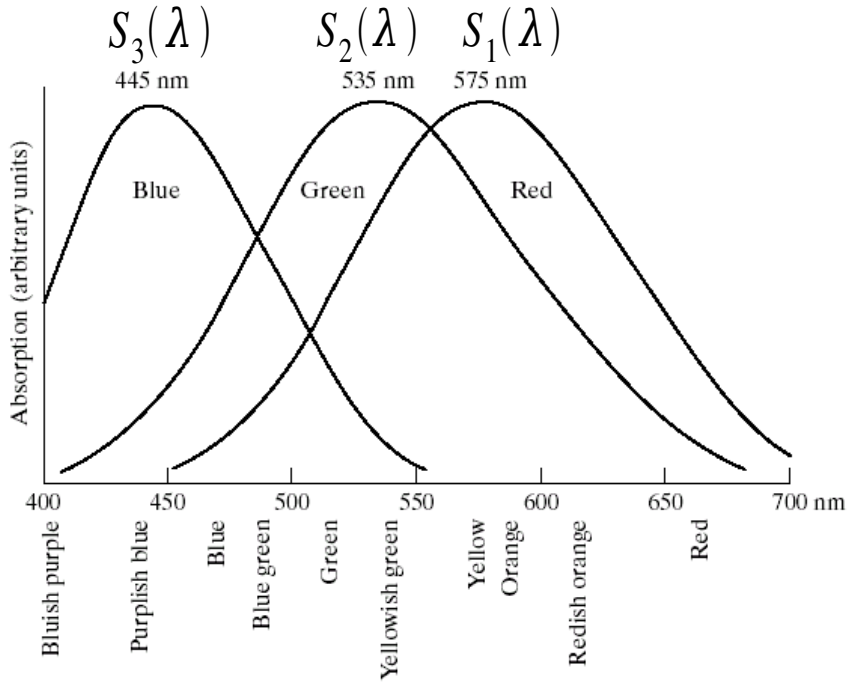
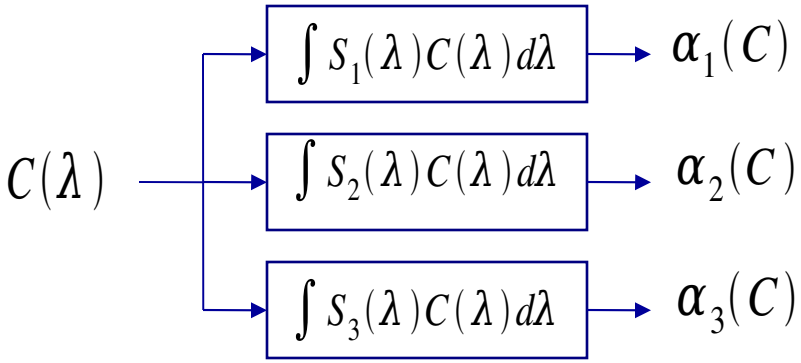


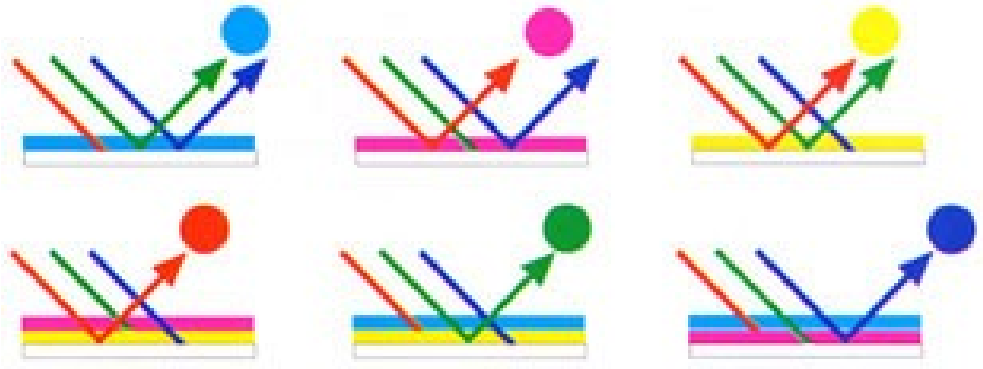
FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Cones: 65% (R), 33% (G), 2% (B)

Color Representation

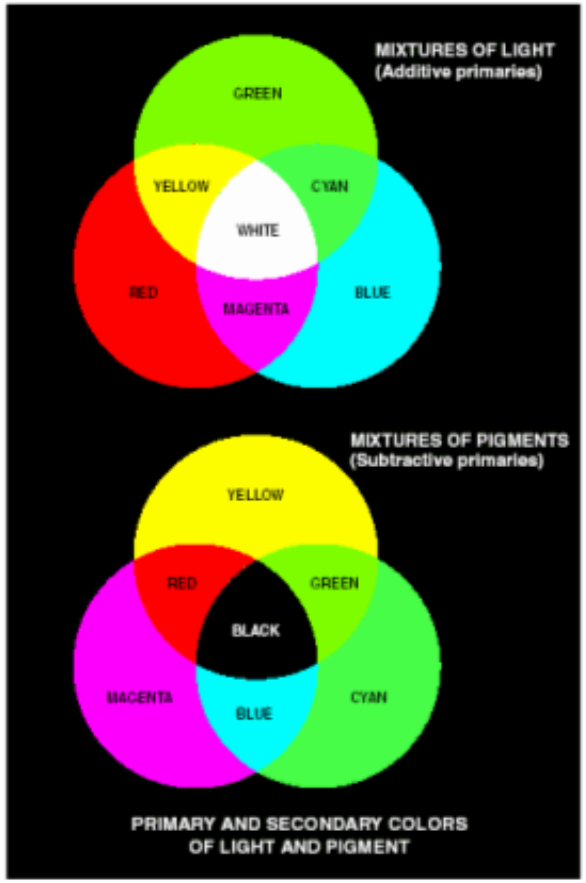


Primary & Secondary Colors



Ink Color	Absorbs	Reflects	Appears
C	Red light	Green and Blue light	Cyan
M	Green light	Red and Blue light	Magenta
Y	Blue light	Red and Green light	Yellow
M + Y	Green & Blue light	Red light	Red
C + Y	Red and Blue light	Green light	Green
C + M	Red and Green light	Blue light	Blue

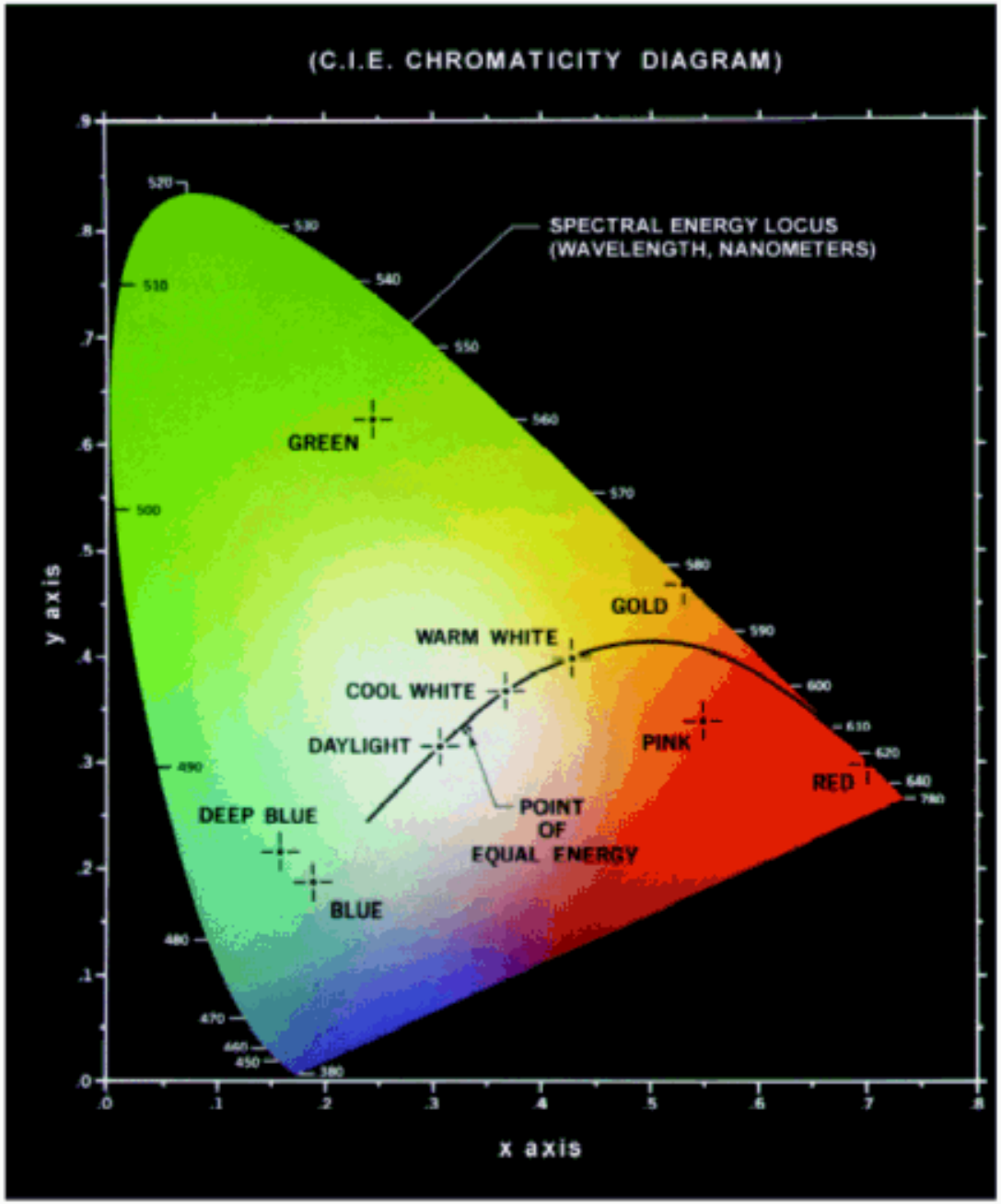
Images above from: http://www.rgbworld.com/color.html



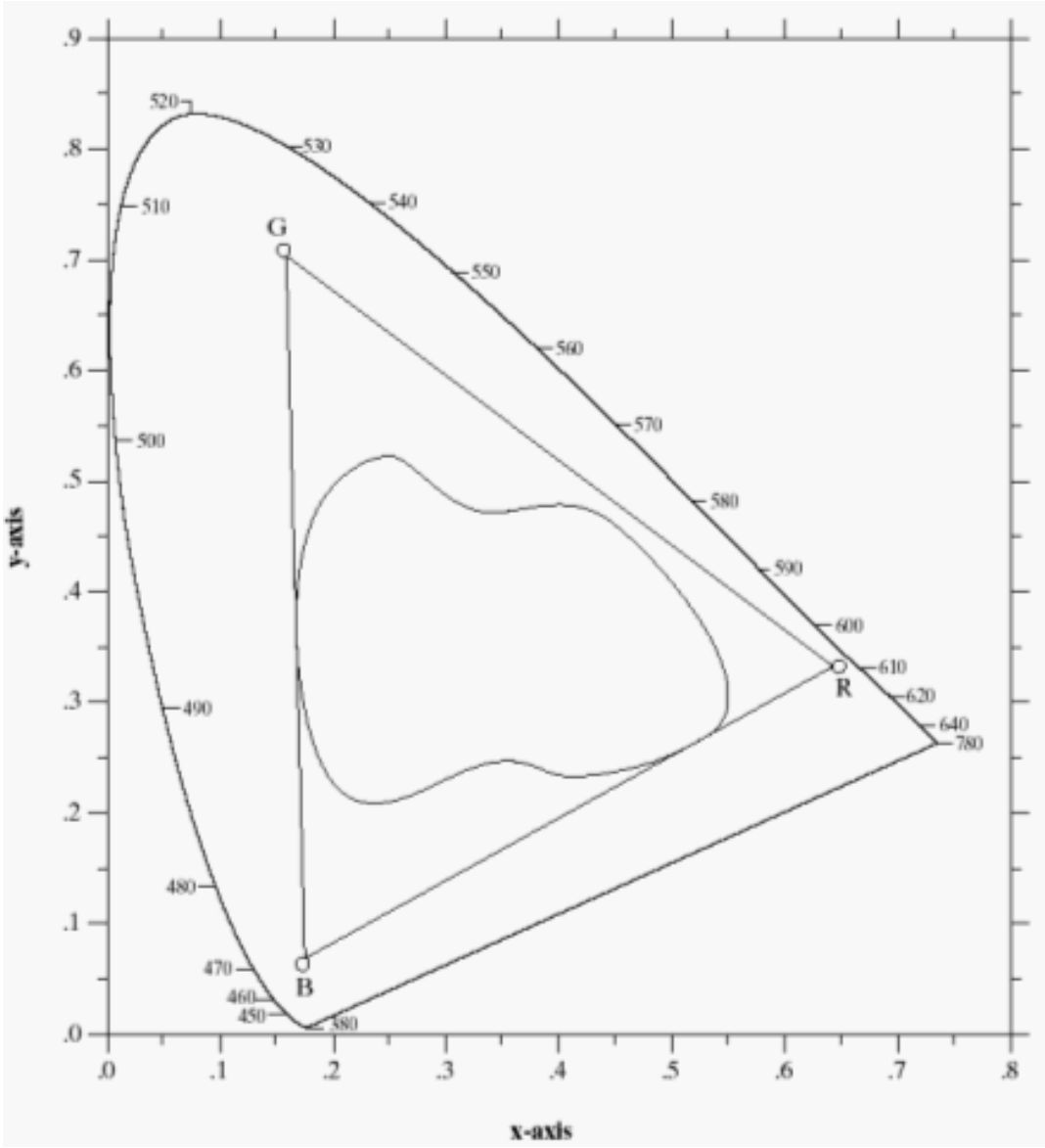
Monitors, projectors, digital camera, scanner

Painting, printing

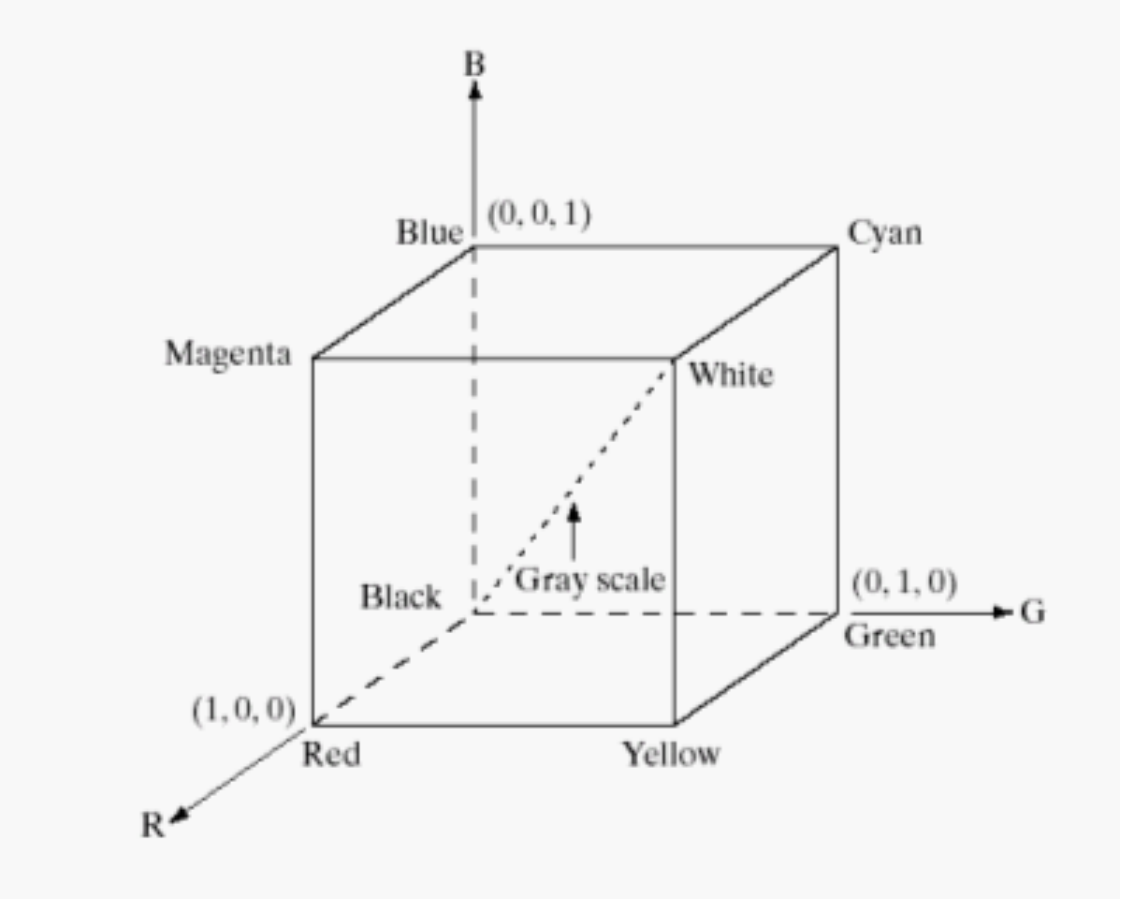
CIE Chromacity Diagram



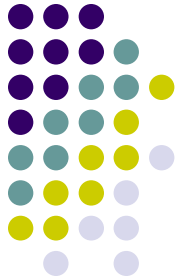
Color Monitor & Printer Color Gamut



RGB Color Cube



Color Interpolation

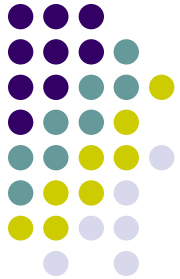


	1	2	3	4	5	6	7	8
1	G	R	G	R	G	R	G	R
2	B	G	B	G	B	G	B	G
3	G	R	G	R	G	R	G	R
4	B	G	B	G	B	G	B	G
5	G	R	G	R	G	R	G	R
6	B	G	B	G	B	G	B	G
7	G	R	G	R	G	R	G	R
8	B	G	B	G	B	G	B	G

Bayer Pattern

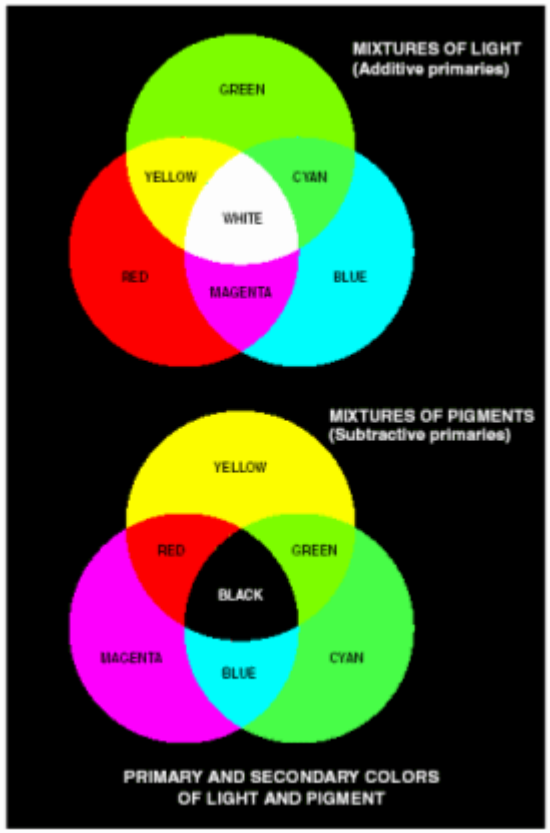
(a color filter array CFA pattern)

CMY and CMYK Color Model

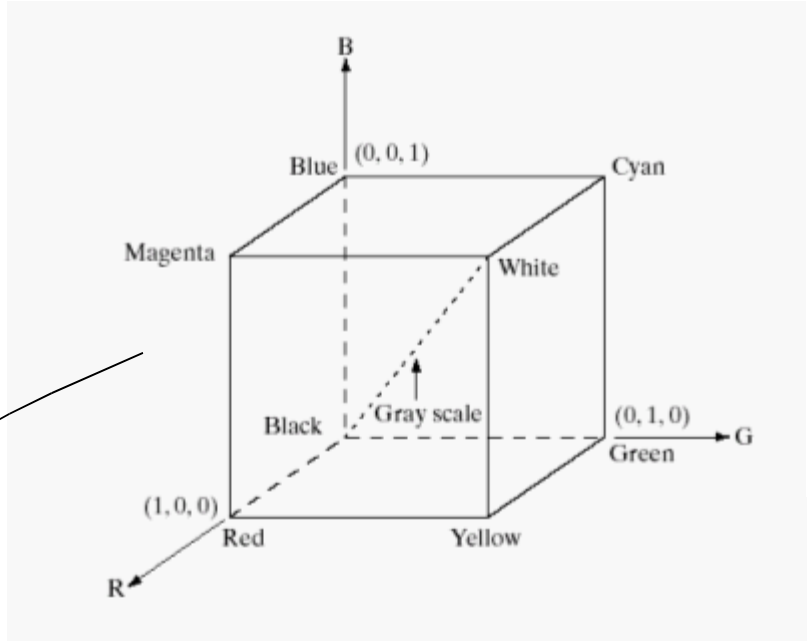


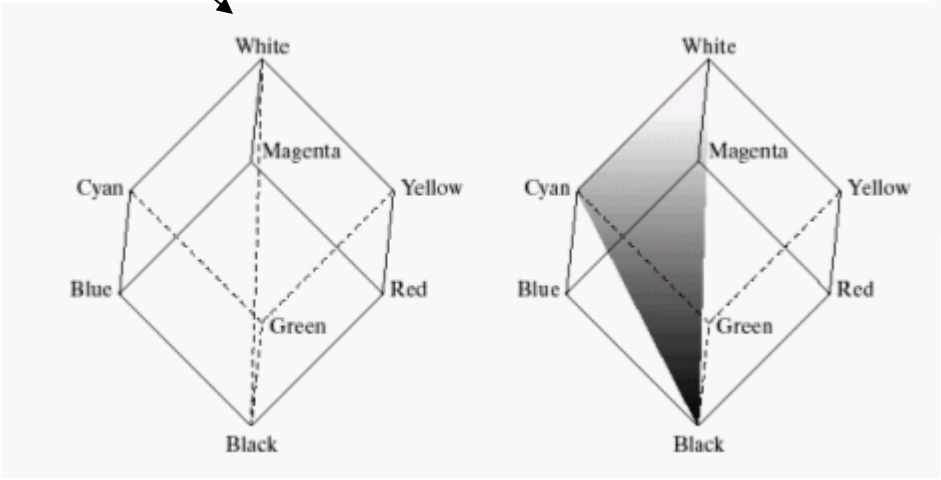
- Used in printers
- Primary pigment colors, secondary light colors
- Subtractive vs. Additive

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

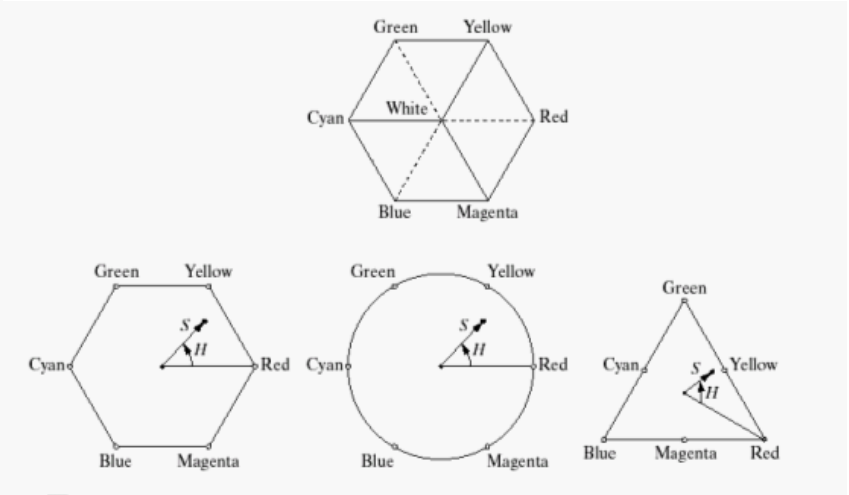


HSI Color Model





- Intensity
- Hue
- Saturation

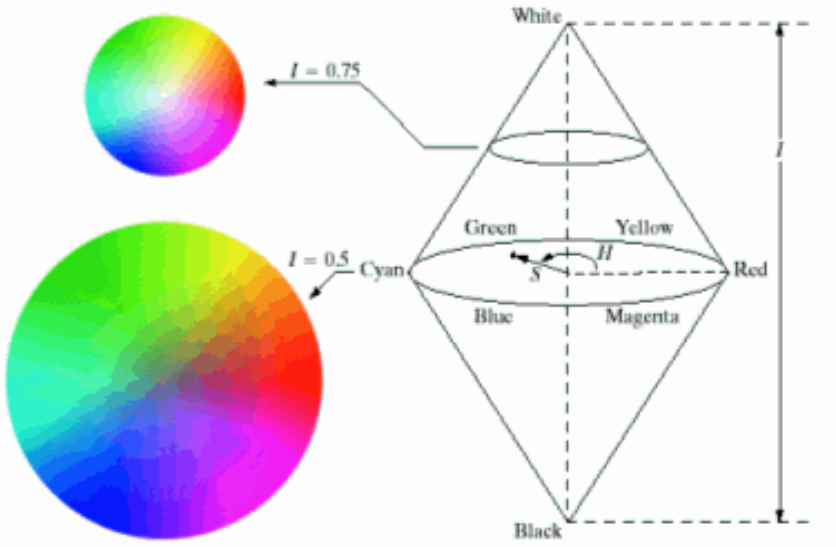


Cube at different intensity cross-sections

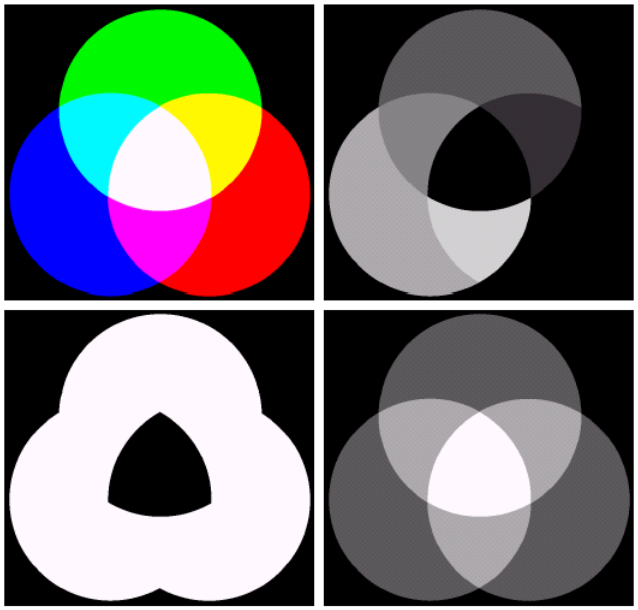
HSI Color Model

- Saturated colors on the outer points
- Max. saturation at intermediate intensity levels
- Distance between colors:

$$D(C_1, C_2) = w_1 \Delta H + w_2 \Delta S + w_3 \Delta I$$

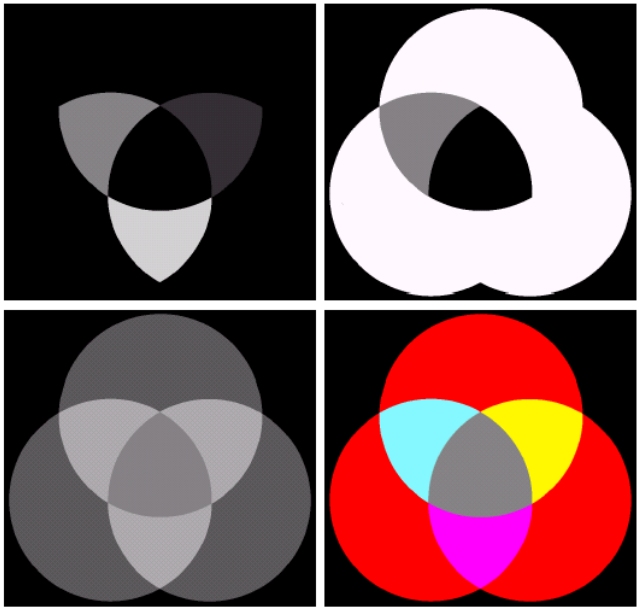


Manipulation HSI images



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.)

- HSI values of primary and secondary colors
- HSI allows for independent manipulation of colors

- Hue of Green & Blue set to Zero
- Saturation of Cyan reduced by ½
- Intensity of white reduced by ½

Color Image Processing: Point vs. Kernel Processing

$$f(x,y)=\begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$

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

a b

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