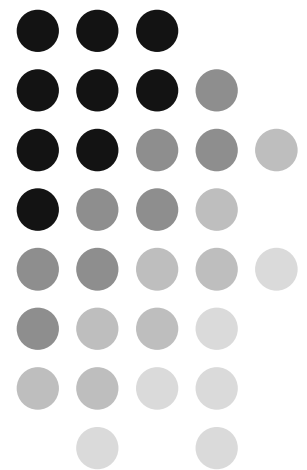


**Lecture 3** (2.11.08)

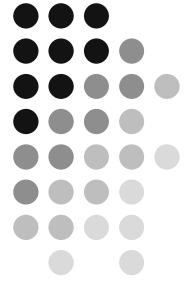
# Color and Video

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Shahram Ebadollahi

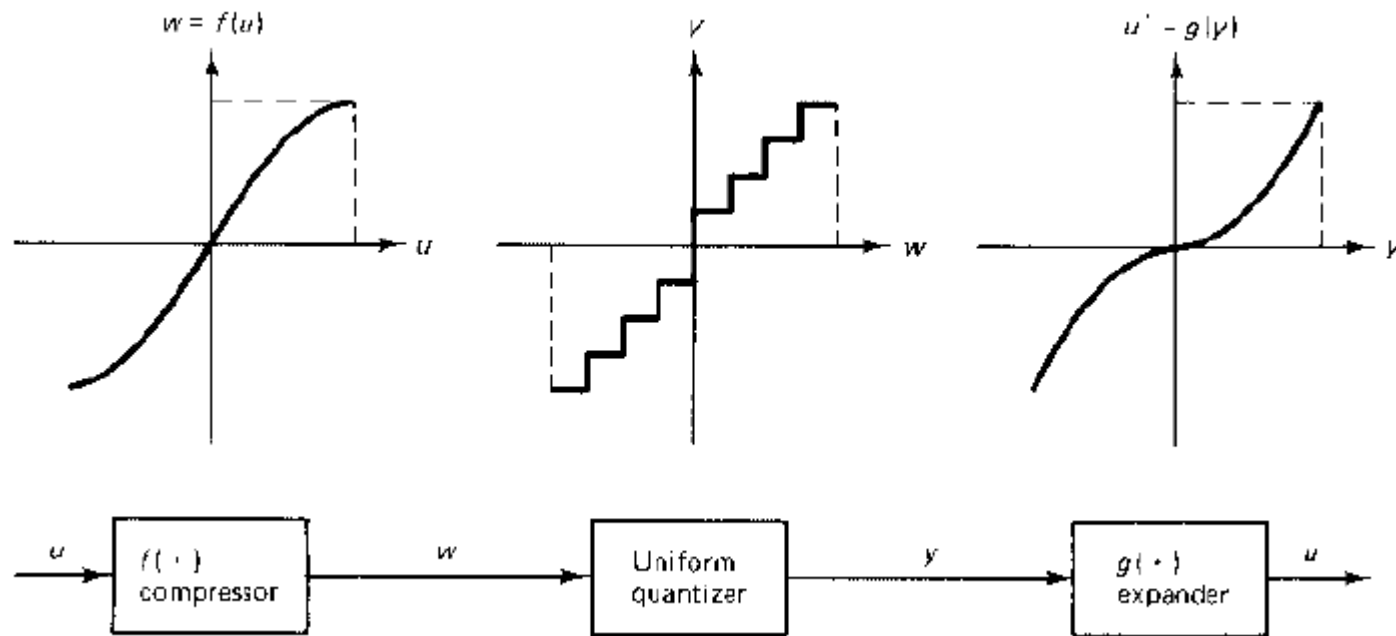
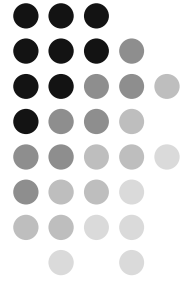


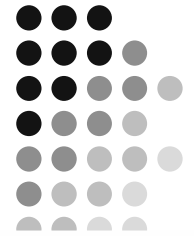
# Lecture Outline



- Review of Lecture 2
  - Finishing Combandor and Dither
- Color
  - Visual Perception
  - Color Representation
  - Color Models and Transformations
  - Color Sampling and Interpolation
- Video
  - Fundamentals of Analog and Digital Video
  - Video Sampling
  - Video Processing
- Multivariate Imaging (time permitting)
  - Introduction and Examples
  - Principal Component Analysis

# Compendor



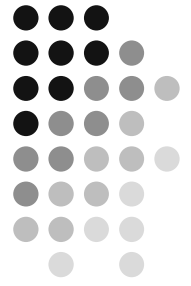


**TABLE 6.1-2.** Companding quantization transformations

|           | Probability Density  | Forward Transformation  | Inverse Transformation   |
|-----------|--|---|--|
| Gaussian  | $p(f) = (2\pi\sigma^2)^{-1/2} \exp\left\{-\frac{f^2}{2\sigma^2}\right\}$ | $g = \frac{1}{2} \operatorname{erf}\left\{\frac{f}{\sqrt{2}\sigma}\right\}$ | $\hat{f} = \sqrt{2}\sigma \operatorname{erf}^{-1}\{2\hat{g}\}$         |
| Rayleigh  | $p(f) = \frac{f}{\sigma^2} \exp\left\{-\frac{f^2}{2\sigma^2}\right\}$    | $g = \frac{1}{2} - \exp\left\{-\frac{f^2}{2\sigma^2}\right\}$               | $\hat{f} = [\sqrt{2}\sigma^2 \ln\{1/(\frac{1}{2} - \hat{g})\}]^{1/2}$  |
| Laplacian | $p(f) = \frac{\alpha}{2} \exp\{-\alpha f \}$                             | $g = \frac{1}{2}[1 - \exp\{-\alpha f\}] \quad f \geq 0$                     | $\hat{f} = -\frac{1}{\alpha} \ln\{1 - 2\hat{g}\} \quad \hat{g} \geq 0$ |
|           | $\alpha = \frac{\sqrt{2}}{\sigma}$                                       | $g = -\frac{1}{2}[1 - \exp\{\alpha f\}] \quad f < 0$                        | $\hat{f} = \frac{1}{\alpha} \ln\{1 + 2\hat{g}\} \quad \hat{g} < 0$     |

where  $\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp\{-y^2\} dy$

# Quantization: Contouring Problem



1-bit



2-bit



3-bit



4-bit



5-bit



6-bit

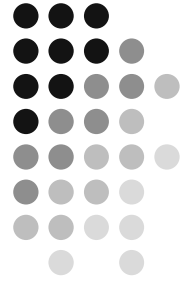


7-bit



8-bit

# Dithering



Original  
(8 bits)

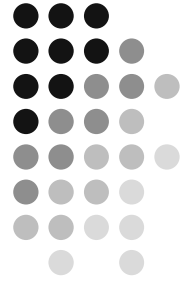


Uniform  
Quantization  
(1 bit)



Random  
Dither  
(1 bit)

# Dithering: Ordered vs. Random



Original  
(8 bits)

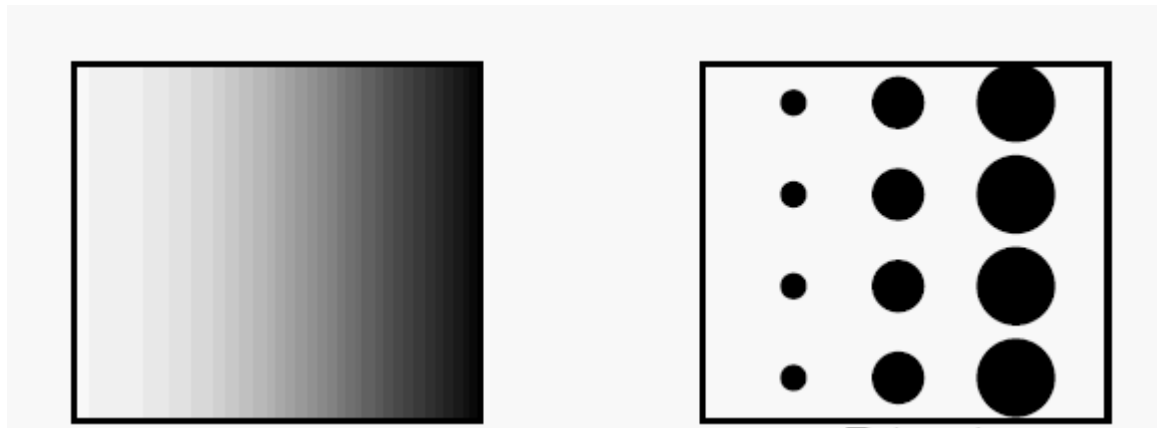
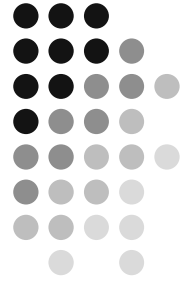


Random  
Dither  
(1 bit)

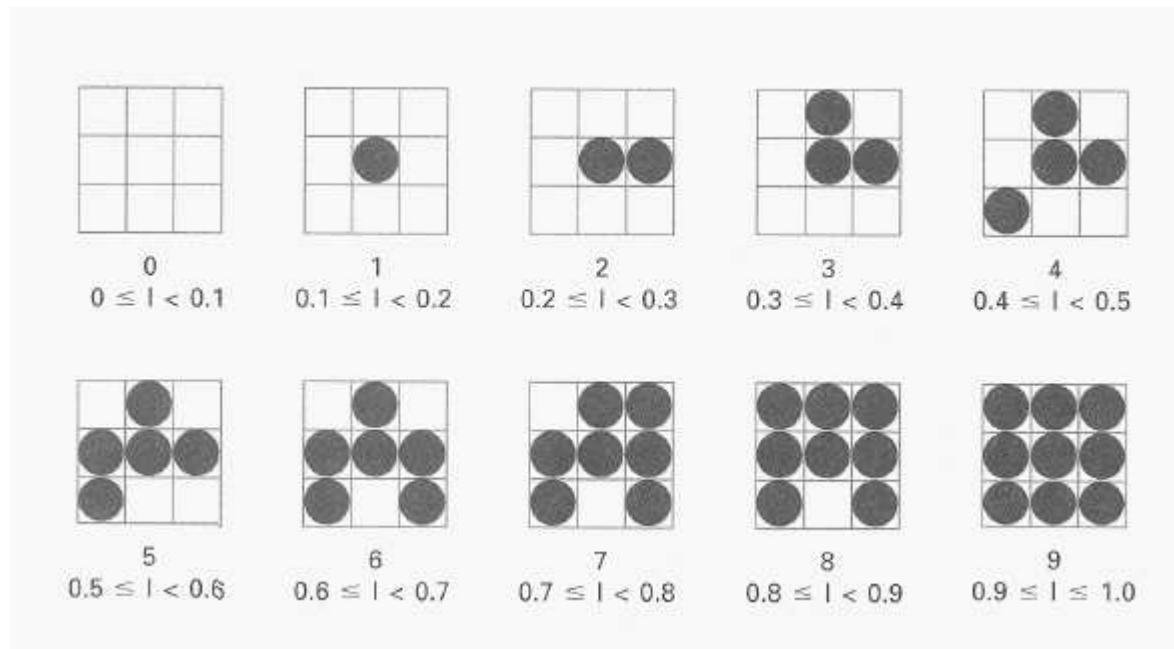
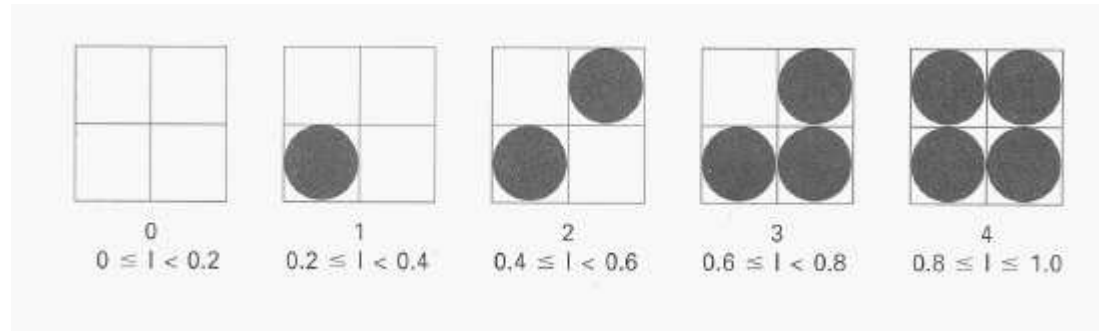
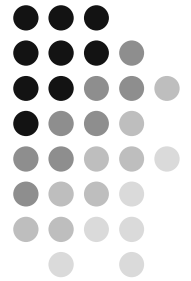


Ordered  
Dither  
(1 bit)

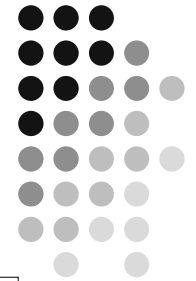
# Half-tone



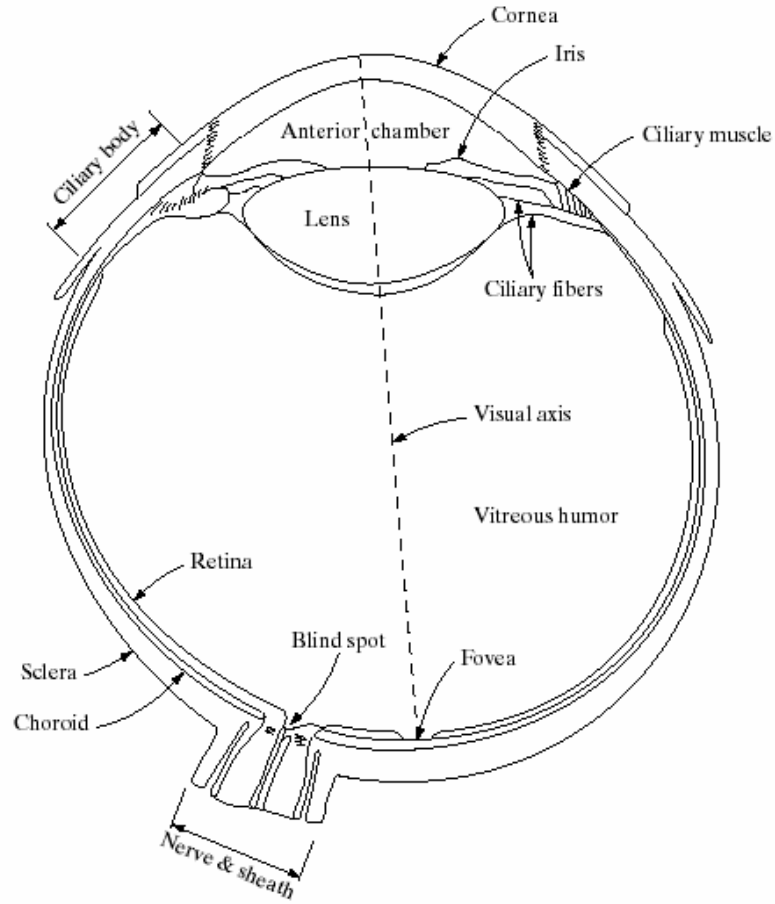
# Half-tone: how many gray-levels per block?



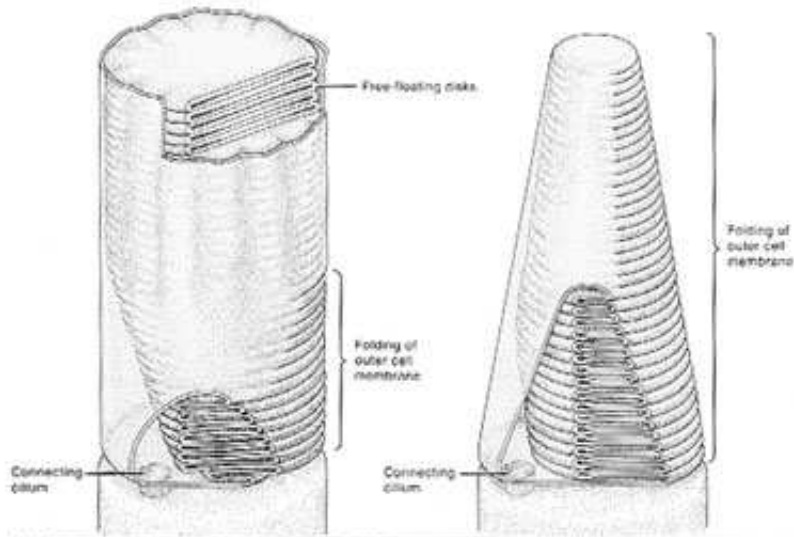
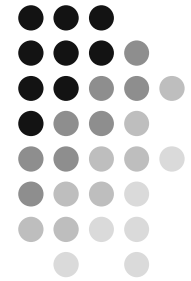
# Eye Physiology & Visual Perception



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



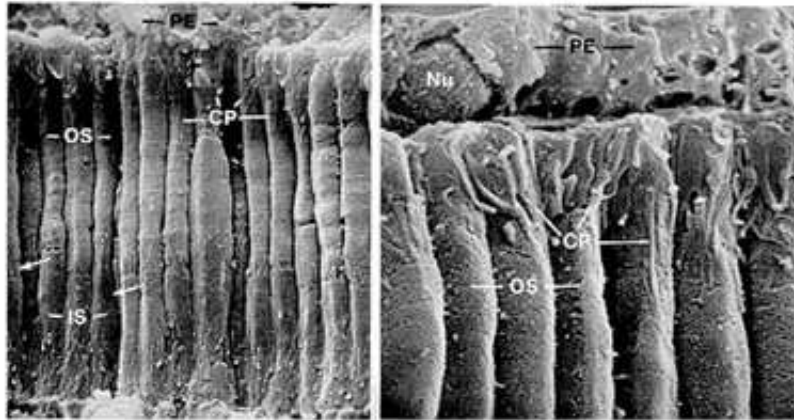
# Eye Physiology & Visual Perception



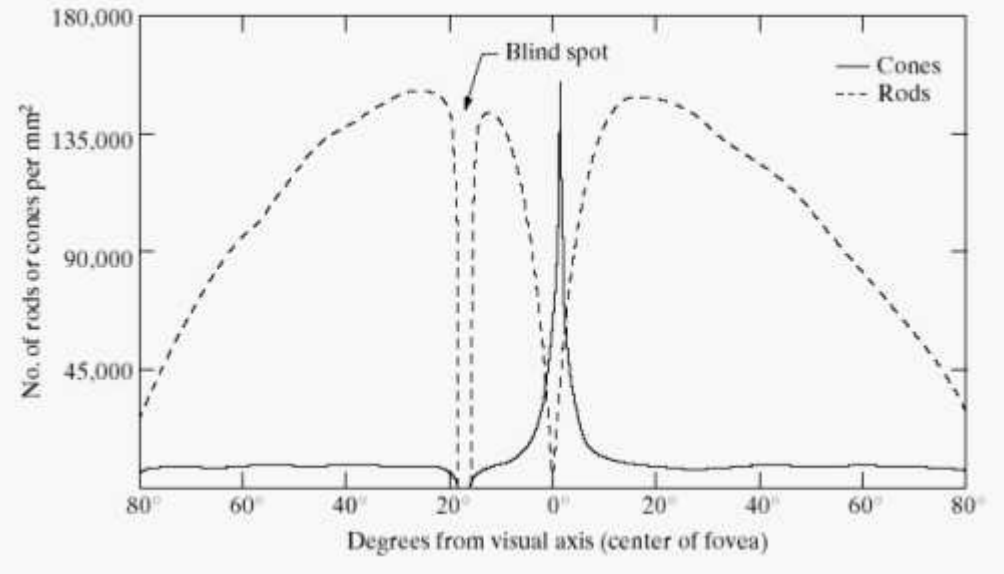
- 75~150 Million
- Sensitive to low illumination
- Distributed over Retina
- Scotopic (dim light) vision

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

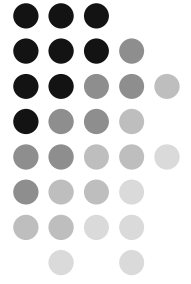
## Rods & Cones Distribution in Retina



Photoreceptor Cells



# Visual Perception: Luminance



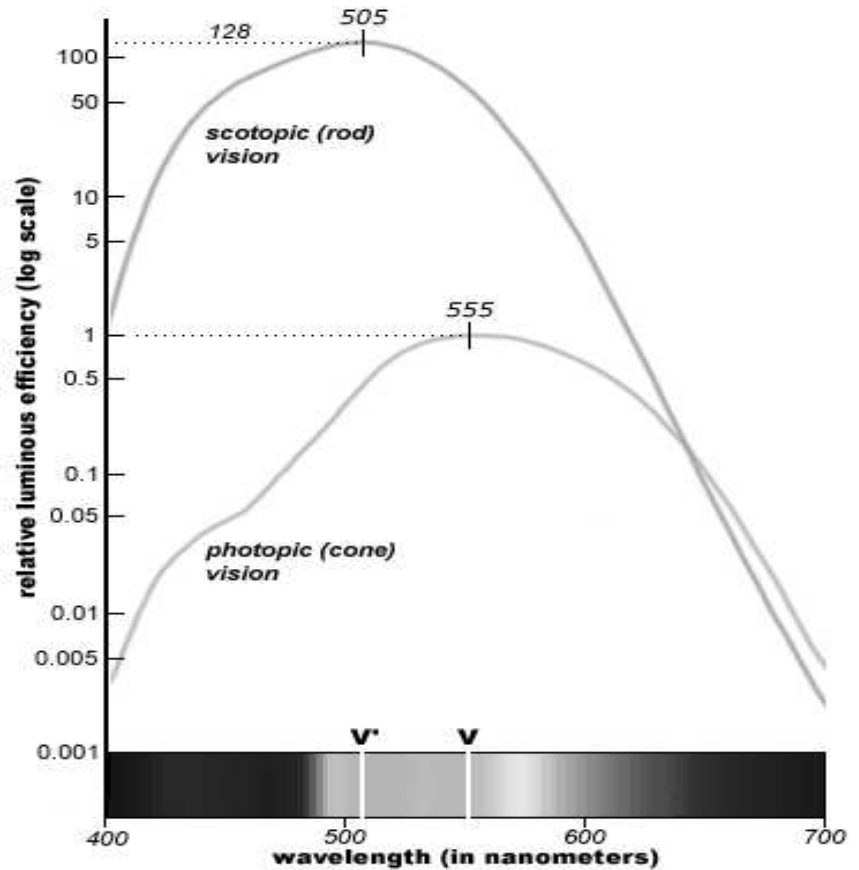
Spectral Power  
Distribution of the  
Stimulus



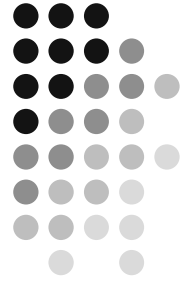
$$I(x, y, \lambda) = r(x, y, \lambda)L(x, y, \lambda)$$

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

Luminance (intensity)

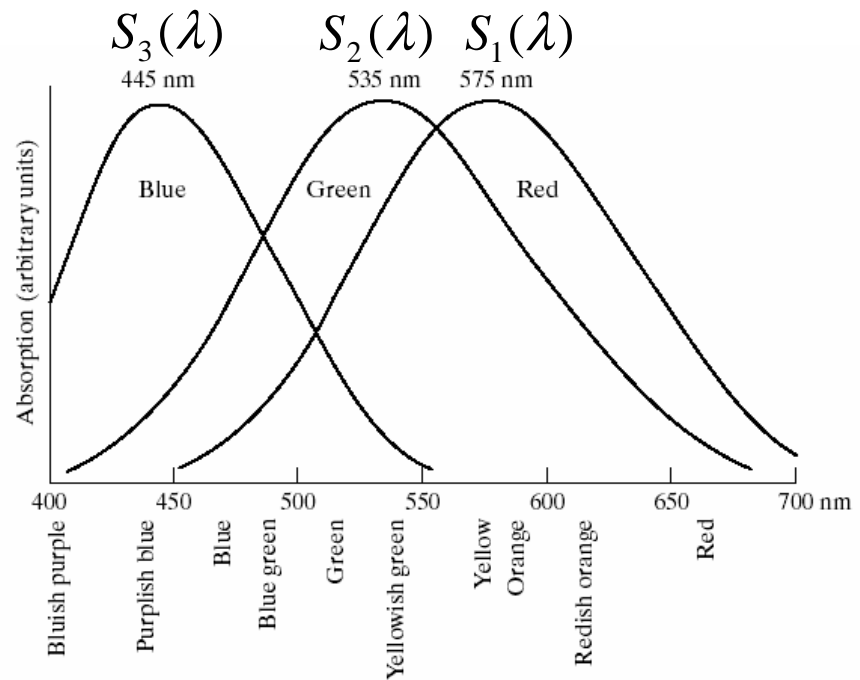


# Visual Perception: Color

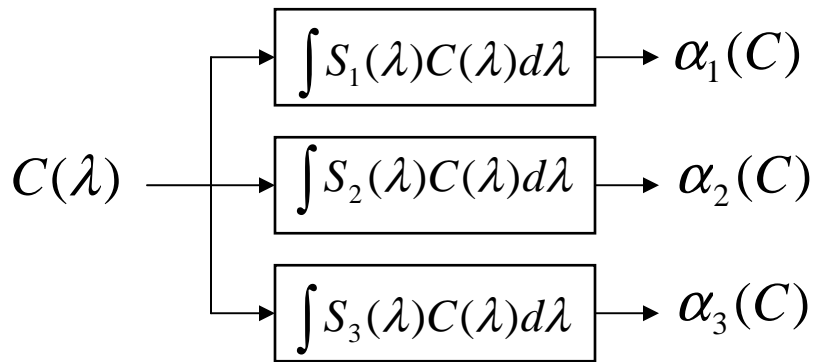


- Humans perceive only a few dozen gray levels but thousands of colors
- Color perceptual attributes:
  - Brightness (perceived Luminance)
  - Hue (“redness”, “greenness”, ...)
  - Saturation

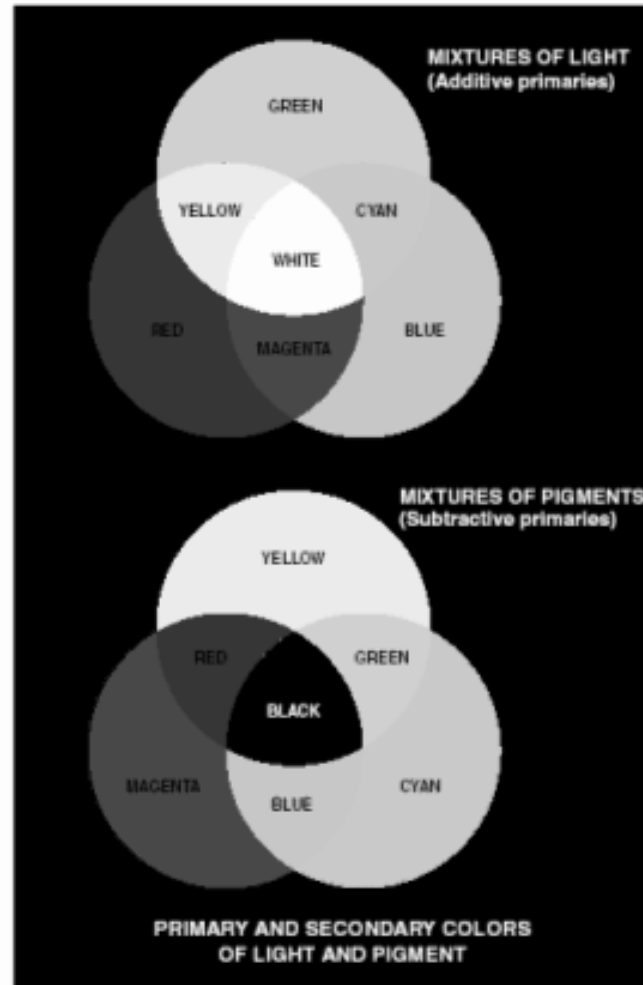
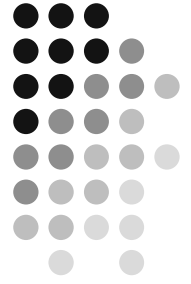
3 types of Cone Photoreceptors



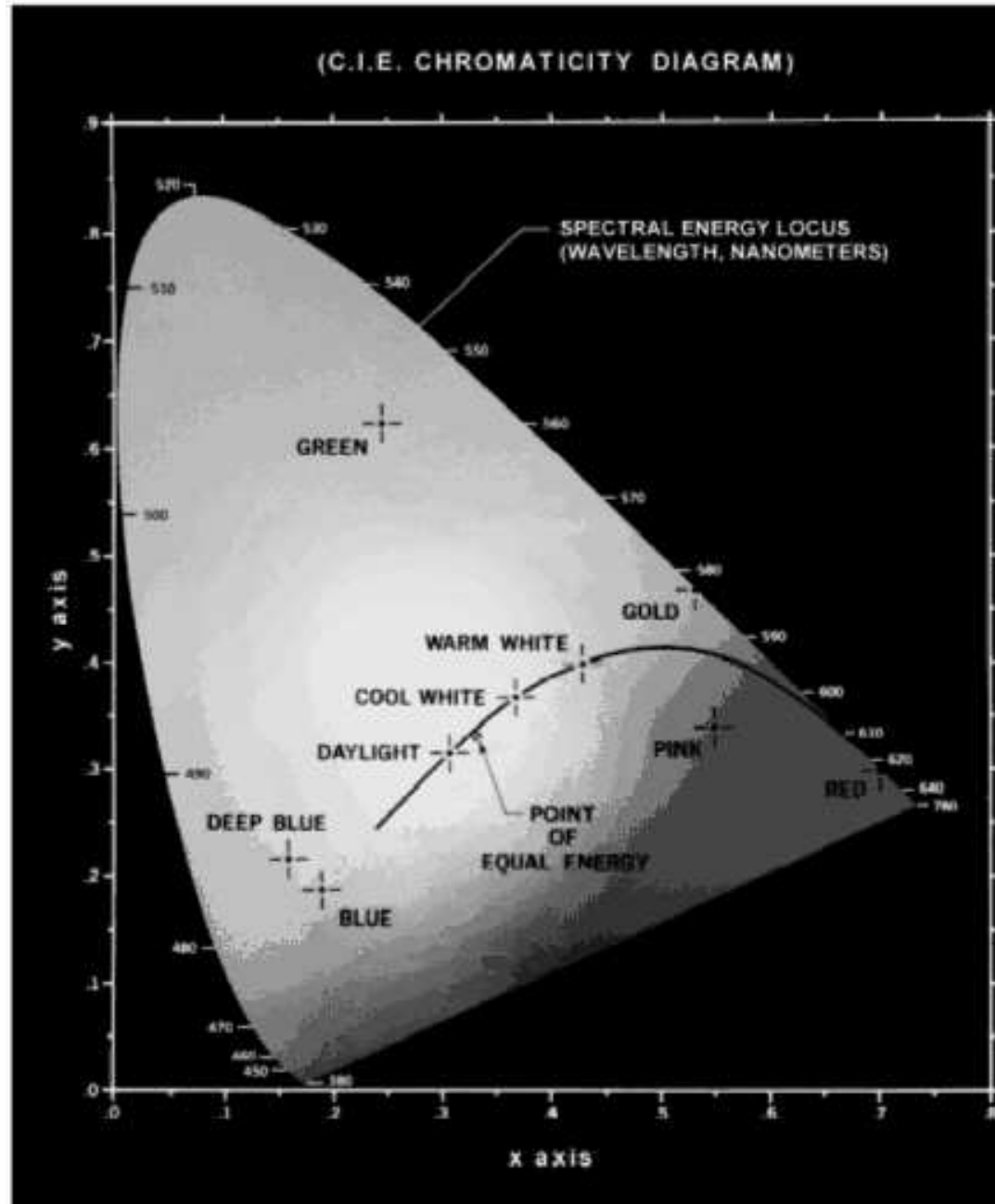
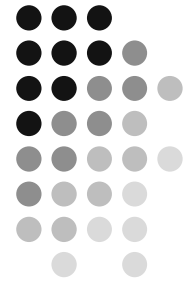
**FIGURE 6.3** Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



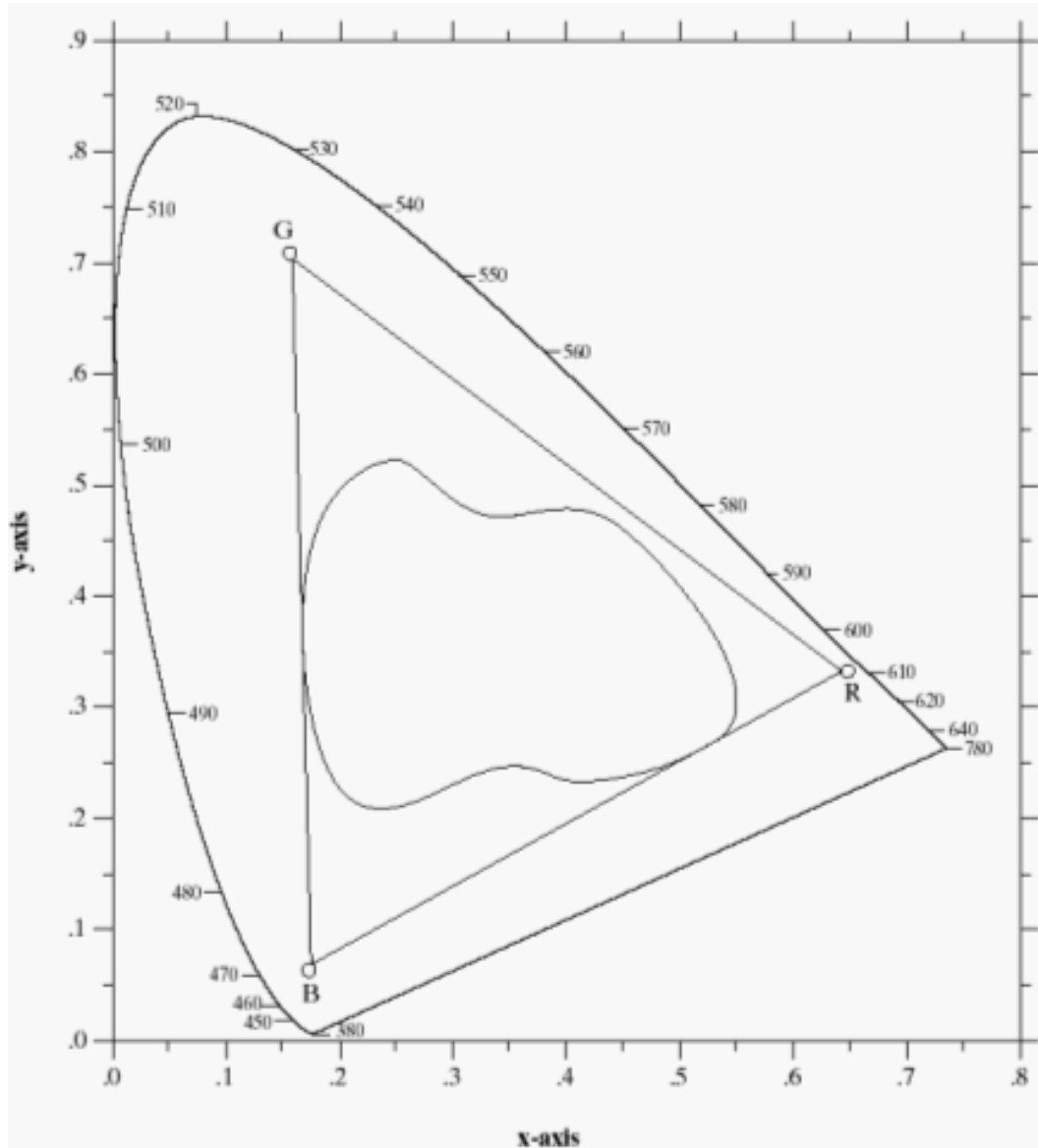
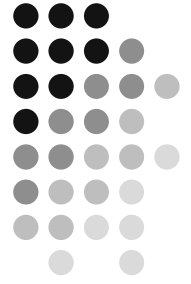
# Primary & Secondary Colors



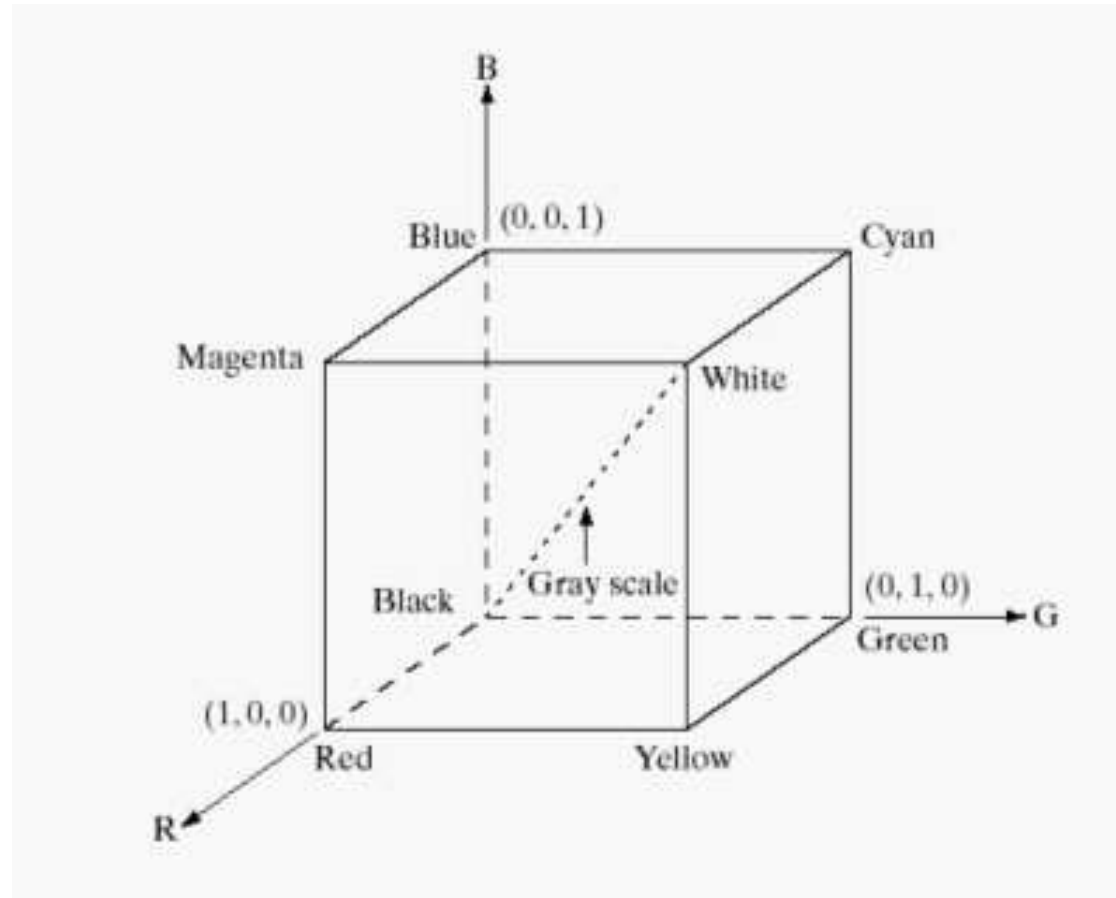
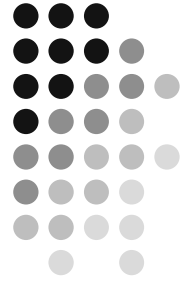
# CIE Chromacity Diagram



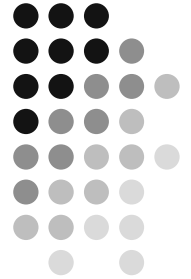
# Color Monitor & Printer Color Gamut



# RGB Color Cube



# Color Interpolation

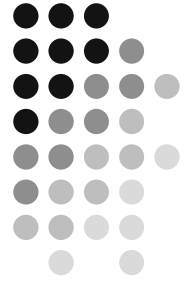


|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | G | R | G | R | G | R | G | R |
| 2 | B | G | B | G | B | G | B | G |
| 3 | G | R | G | R | G | R | G | R |
| 4 | B | G | B | G | B | G | B | G |
| 5 | G | R | G | R | G | R | G | R |
| 6 | B | G | B | G | B | G | B | G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

**Bayer Pattern**

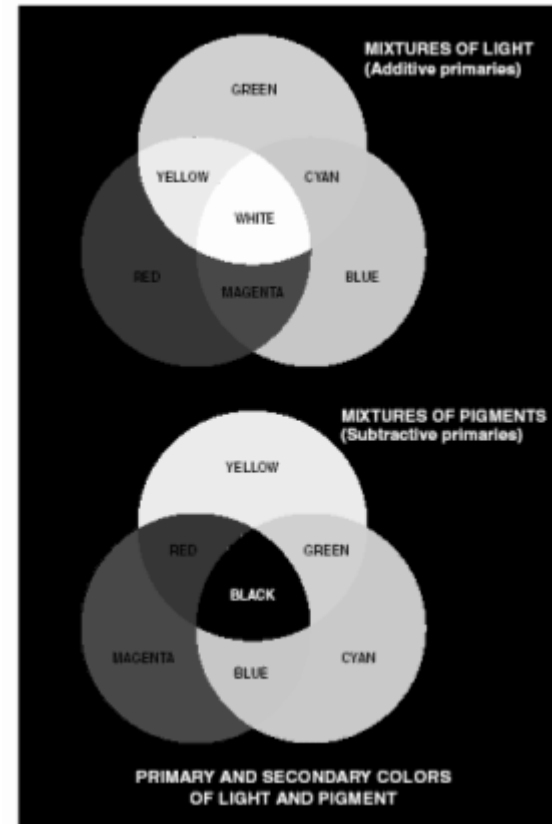
**(a color filter array CFA pattern)**

# CMY and CMYK Color Model

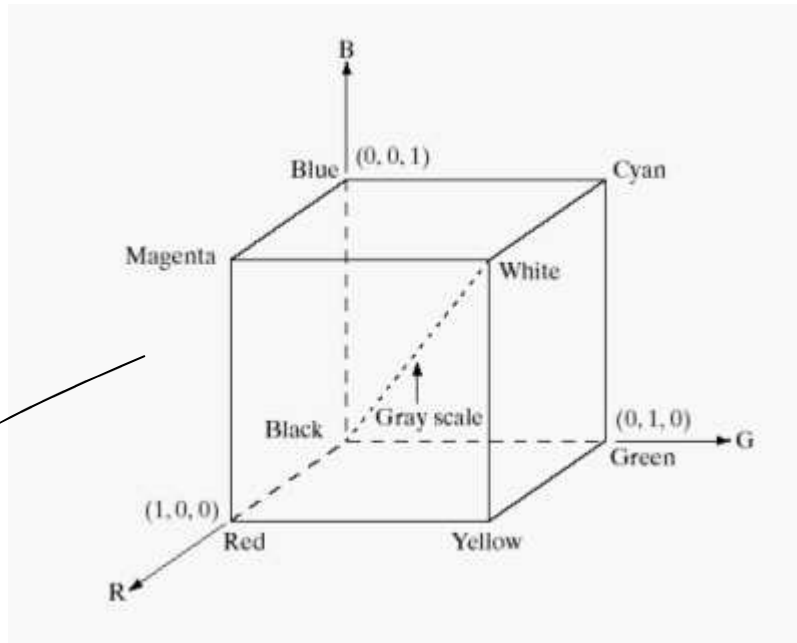
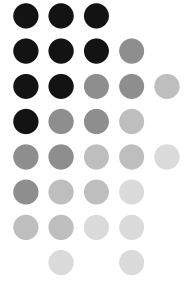


- Used in printers
- Primary pigment colors, secondary light colors
- Subtractive vs. Additive

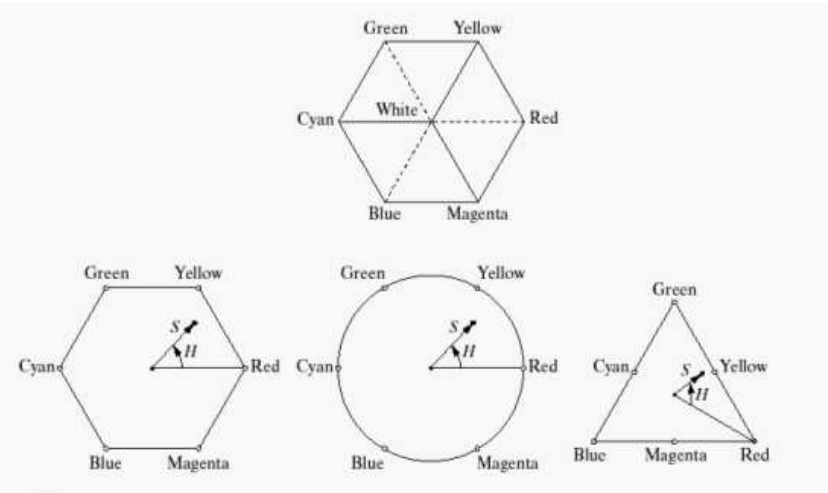
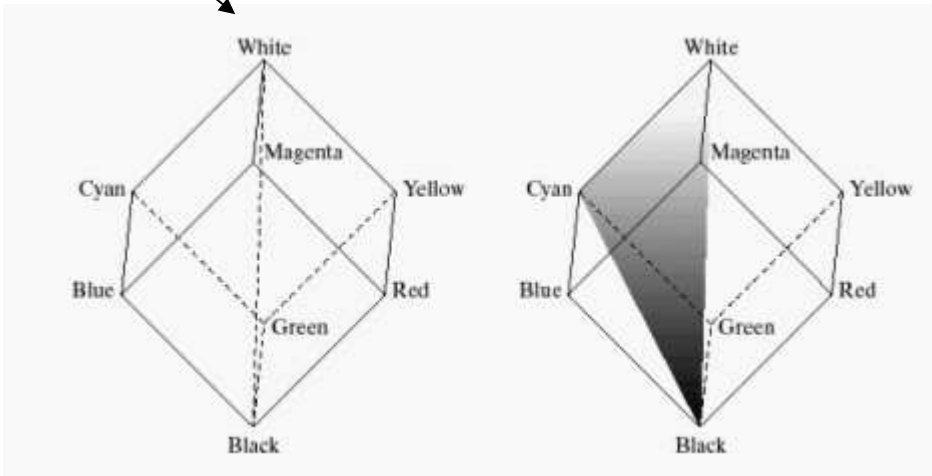
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



# HSI Color Model



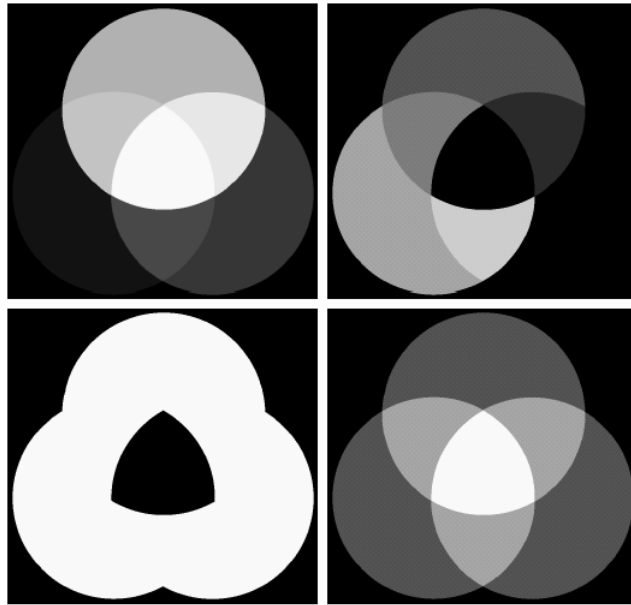
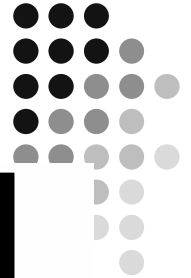
- Intensity
- Hue
- Saturation



Cube at different intensity cross-sections

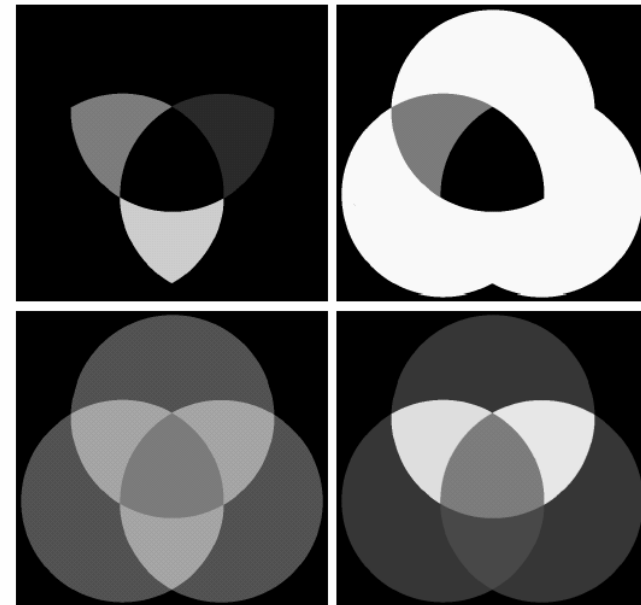


# Manipulation HSI images



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.



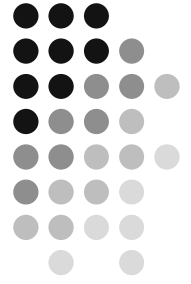
a b  
c d

**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  $\frac{1}{2}$
- Intensity of white reduced by  $\frac{1}{2}$

# Color Image Processing: Point vs. Kernel Processing



$$f(x, y) = \begin{bmatrix} f_R(x, y) \\ f_G(x, y) \\ f_B(x, y) \end{bmatrix} \quad g(x, y) = T[f(x, y)]$$

a b

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

