Perception and Color

Introduction

- Understanding of Mechanism of Human Vision
  - To construct the measures of image fidelity & intelligibility
  - To design and evaluate image processing algorithms and imaging systems

Introduction (cont.)

- Topics:
  - Brightness (or Perceived Luminance)
  - MTF(Modulation transfer function) of Human Visual System
  - Visibility Function
  - Monochrome Vision Model
  - Image Fidelity Criteria
  - Temporal Properties of Human Visual System

  - Color Vision Models and Colorimetry : (Part 2)

Brightness (Perceived Luminance)

- Light ~ radiant energy which, by its action on the organs of visions, enables them to perform their function of sight
  - Spectral energy distribution $L(\lambda)$, $\lambda = 350\text{nm} \sim 780\text{nm}$
  - Light received from an object

$$I(\lambda) = \rho(\lambda)L(\lambda)$$

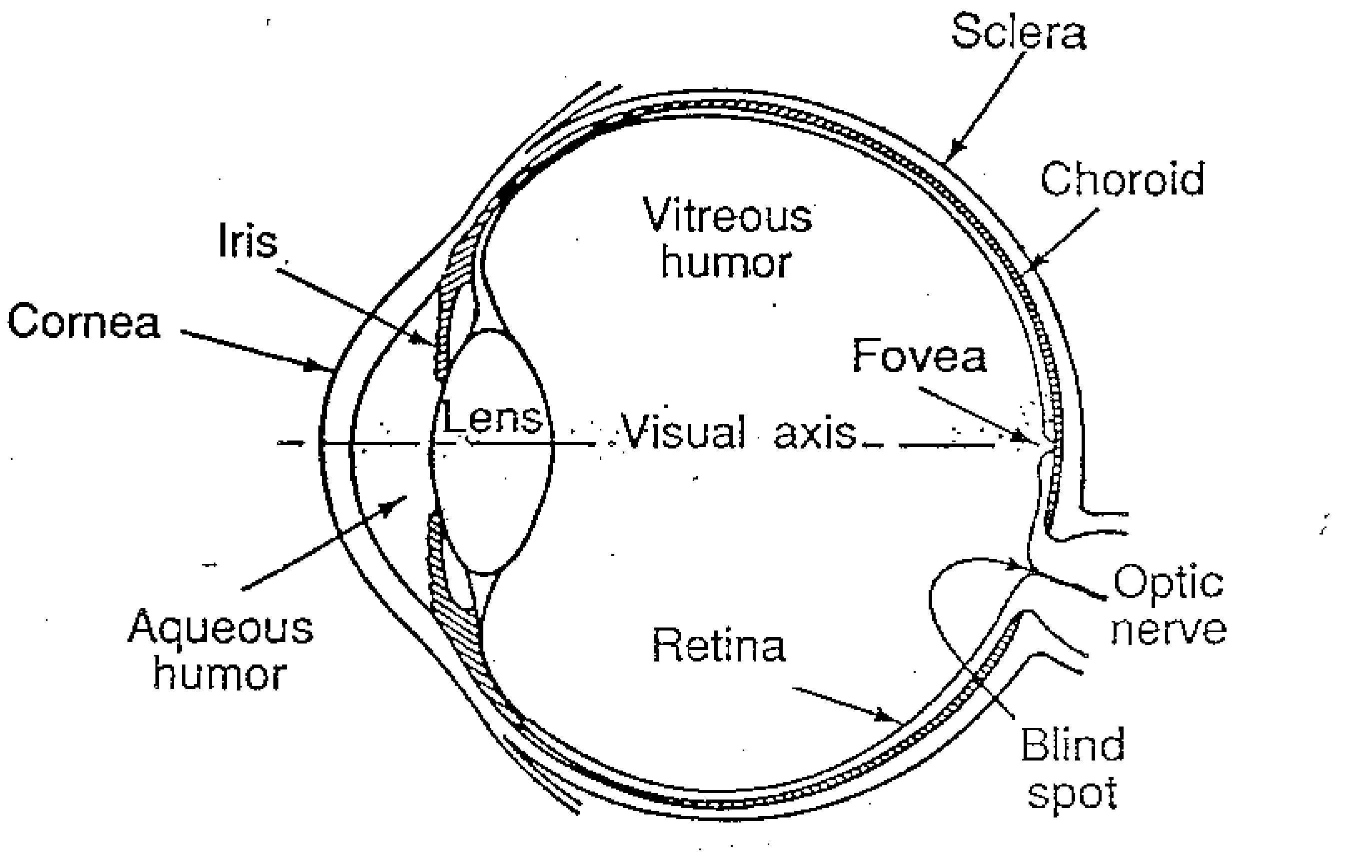
$\rho(\lambda)$: reflectivity or transmissivity of the object

Brightness(Perceived Luminance)(cont.)

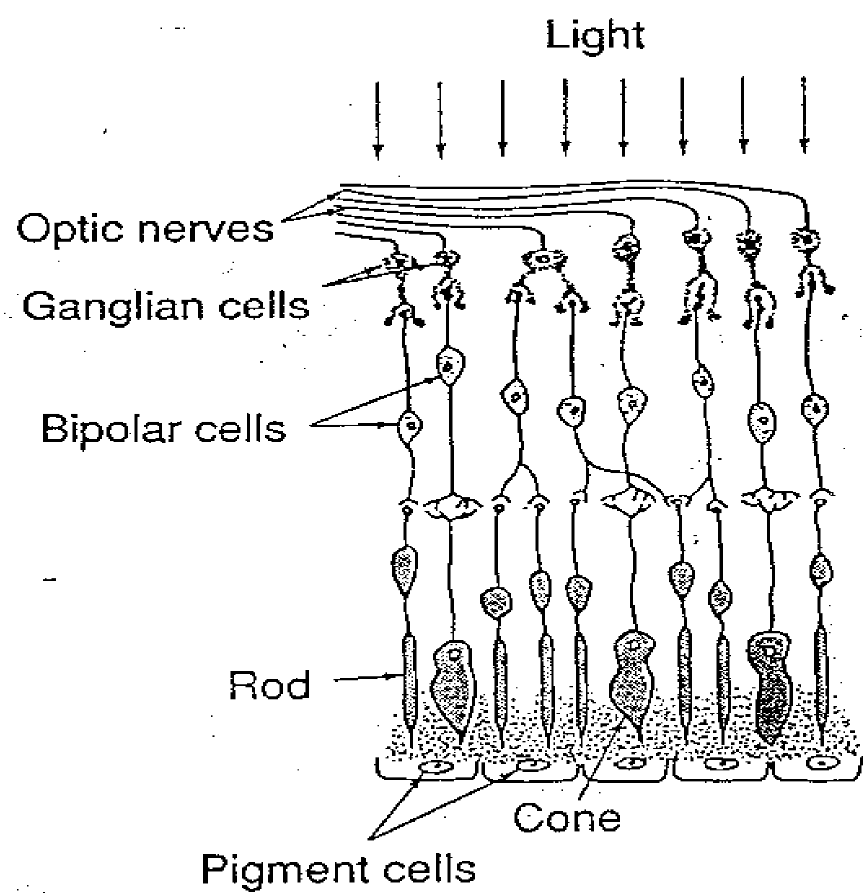
- Human Eye
  - visible range : 350 nm < wavelength < 780 nm
  - photoreceptors
    - rods : about 100 millions
    - cones : about 6.5 millions (Color Vision)

    - scotopic vision : rods (dark environment)
    - mesopic vision : rods + cones (middle range)
    - photopic vision : cones (bright environment)

The Human Visual System



The Human Visual System (cont.)



Brightness(cont.)

- Luminance (or Intensity)

  : independent of luminance of the surrounding object

$$f(x,y)=\int I(x,y,\lambda)V(\lambda)d\lambda$$

  - Luminosity Function (Relative Luminous Efficiency Function)

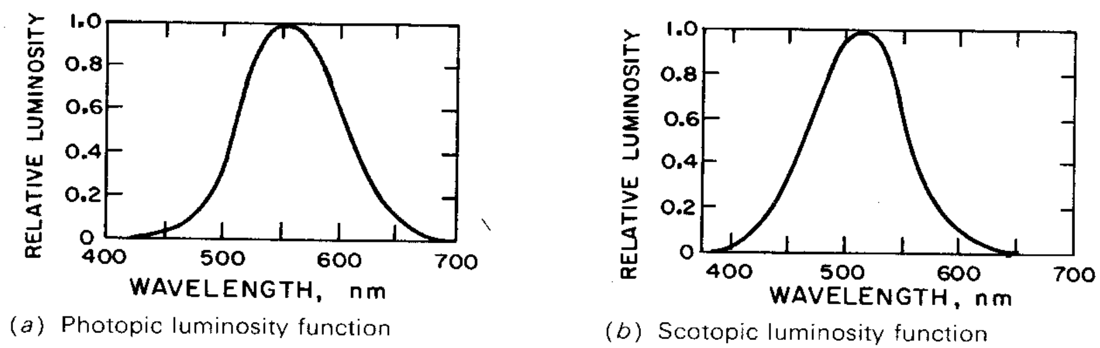


FIGURE 3.1-4. Relative luminous efficiency functions (9).

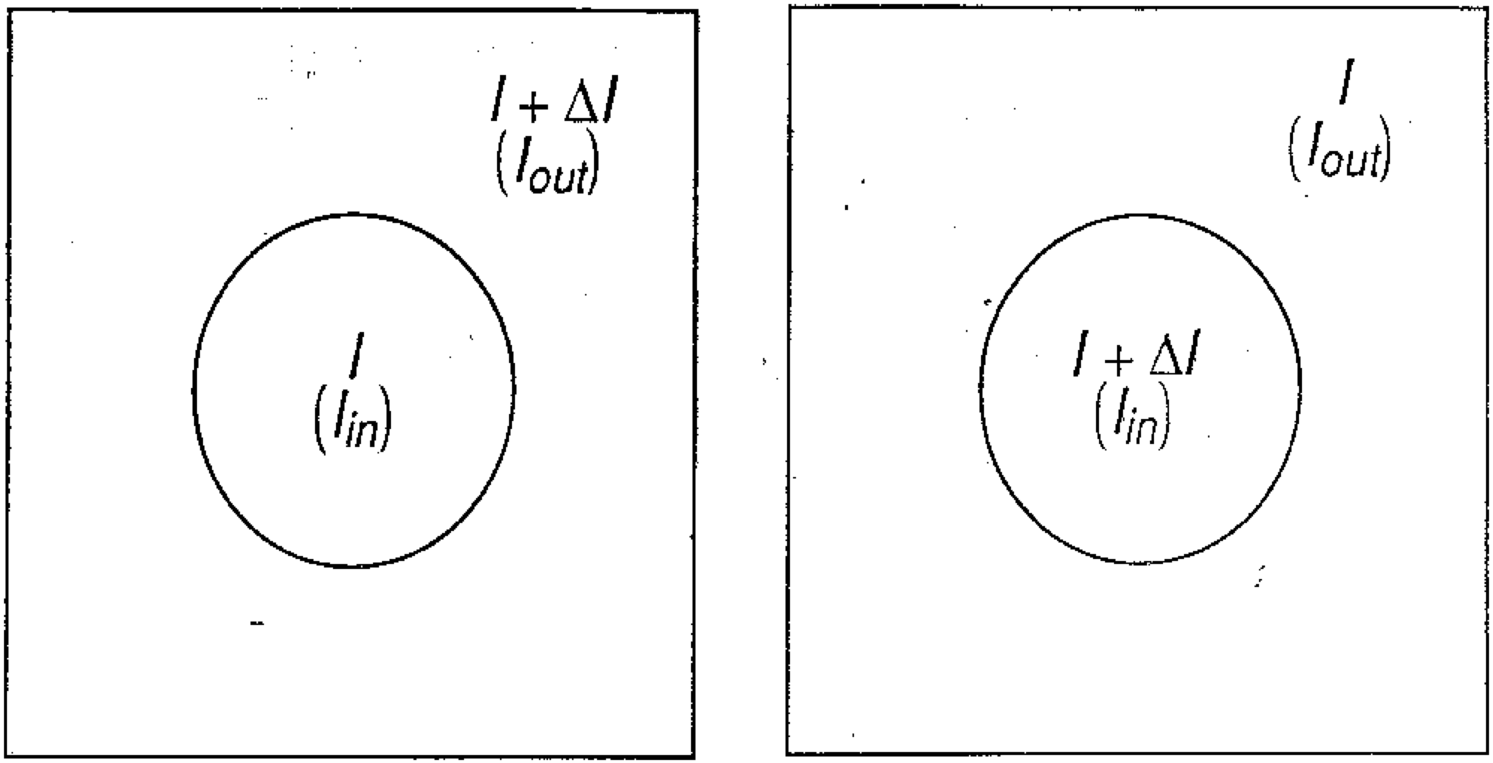
Brightness(cont.)

- Contrast
  - Brightness : dependent upon the surroundings

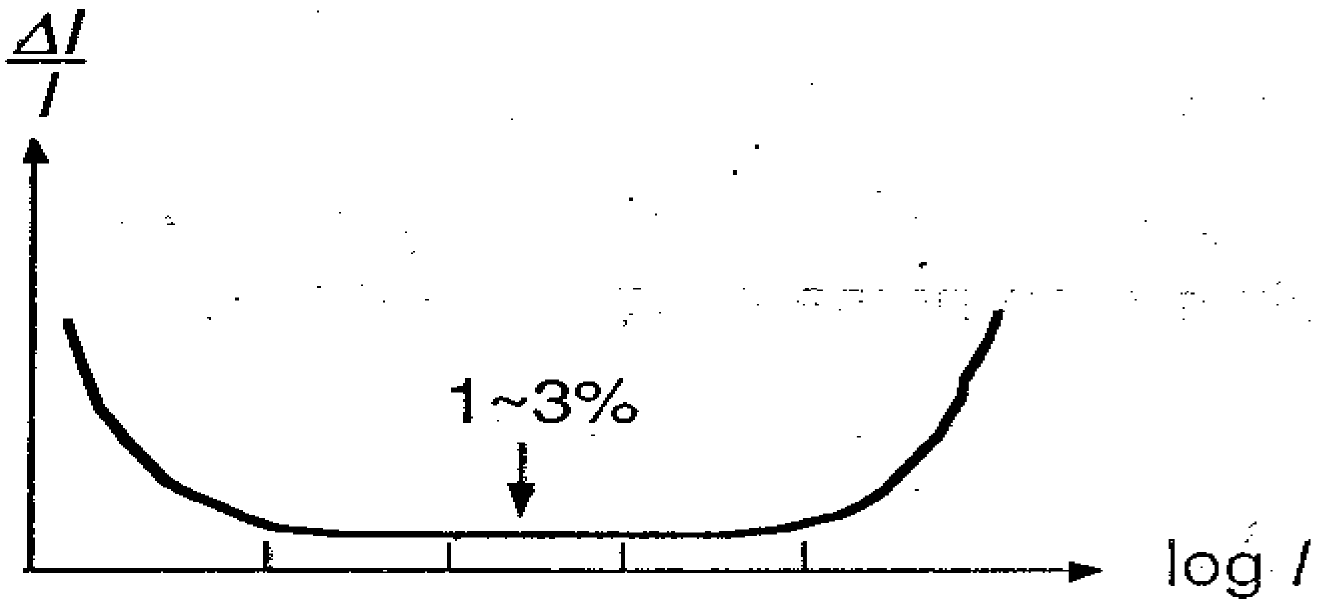
  - Weber's Law :

$$\frac{\left|f_{surround} - f_{object}\right|}{f_{object}} = \frac{\left|\Delta f\right|}{f} = \Delta c \cong 0.02$$

Intensity Discrimination Experiment



Weber's Law



$$\frac{\Delta I}{I} \approx \text{constant}$$

$$\frac{dI}{I} = d(\log I) \approx \text{constant}$$

Brightness(cont.)

- Contrast (cont.)
  - Luminance-to-Contrast Models
    - Logarithmic Law :

      $$c = 50\log_{10} f, 1 \le f \le 100$$

    - Power Law :

      $$c = \alpha_n f^{1/n}, n = 2,3,....$$
      $$\alpha_2 = 10, \alpha_3 = 21.9$$

    - Background ratio :

      $$c = \frac{f(f_B + 100)}{f_B + f}$$
      $$f_B = background\ luminance$$

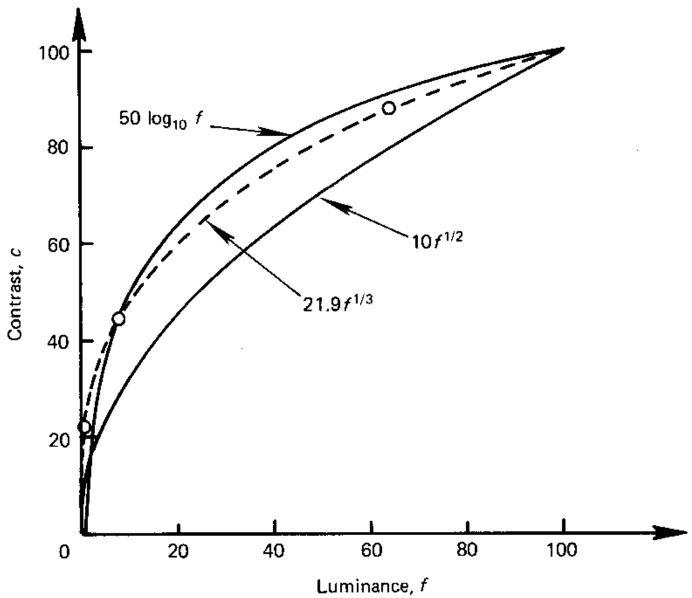
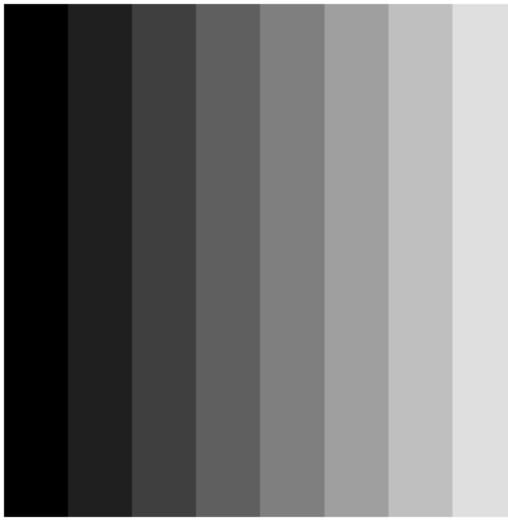
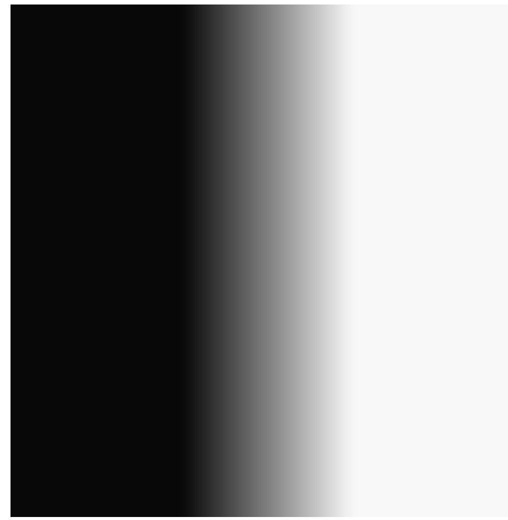


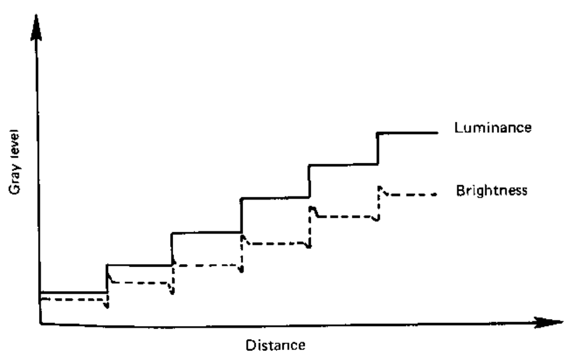
Figure 3.4 Contrast models.

Brightness(cont.)

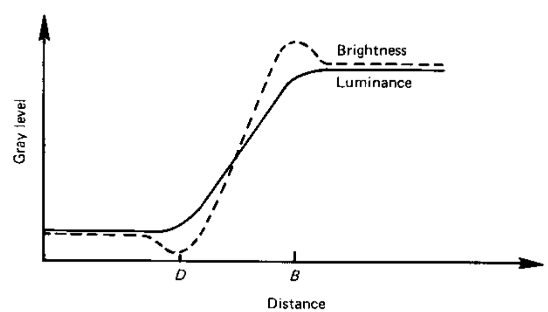
- Mach Bands







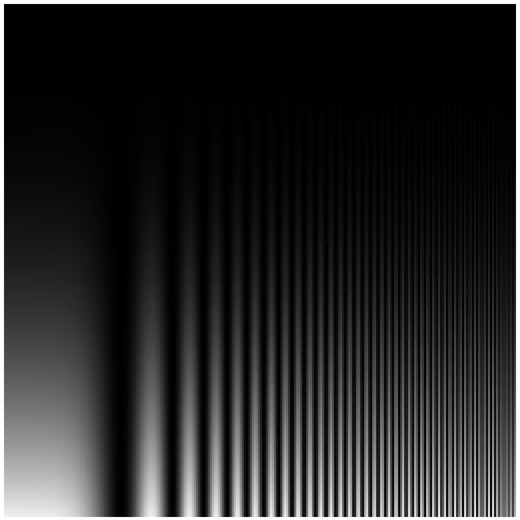
Luminance versus brightness.

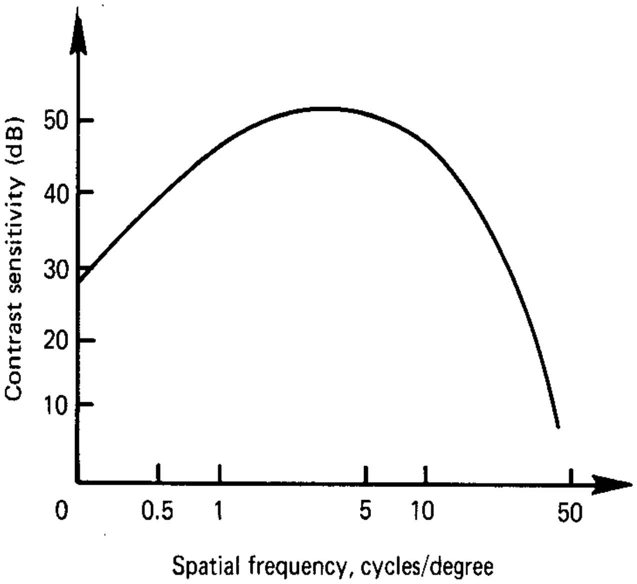


Mach band effect.

MTF of the Visual System

- Measurement of visual system in frequency domain





$$H(\xi_1,\xi_2) = H_\rho(\rho) = A\left[\alpha + \left(\frac{\rho}{\rho_0}\right)\right]\exp\left[-\left(\frac{\rho}{\rho_0}\right)^\beta\right]$$

$$\rho = \sqrt{\xi_1^2 + \xi_2^2} \text{ cycles/degree}$$

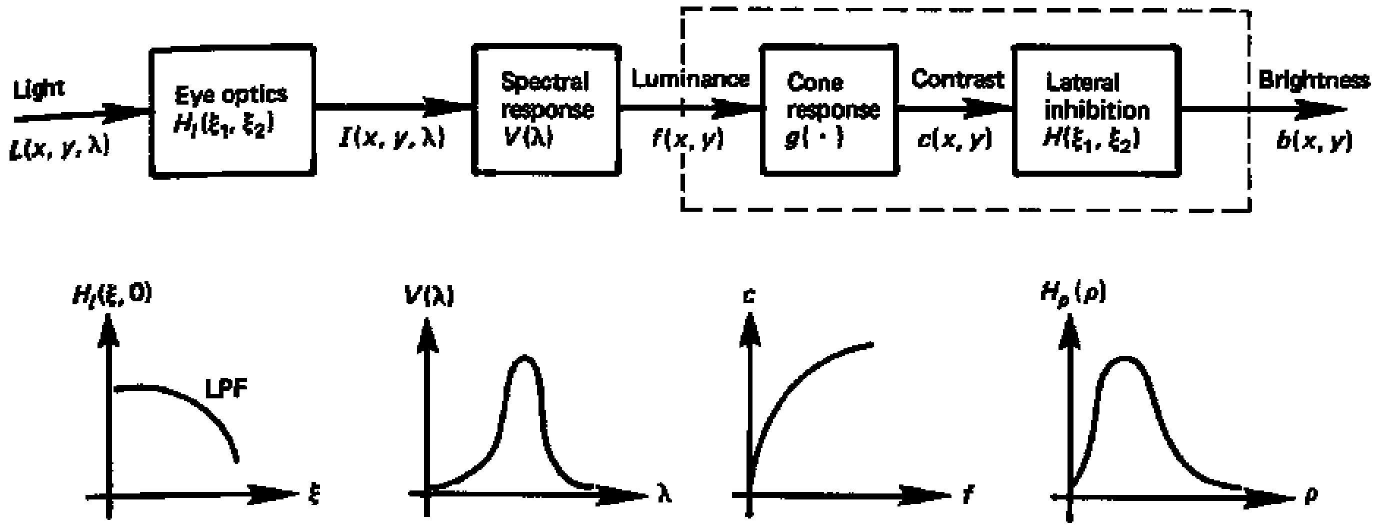
< Useful Values for Image Coding Applications >

$A = 2.6,\quad \alpha = 0.0192,\quad \beta = 1.1$

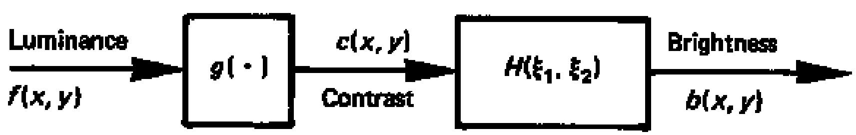
$\rho_0 = (0.114)^{-1} = 8.772,.$

peak frequency : 8 cycles/degree

Monochrome Vision Model

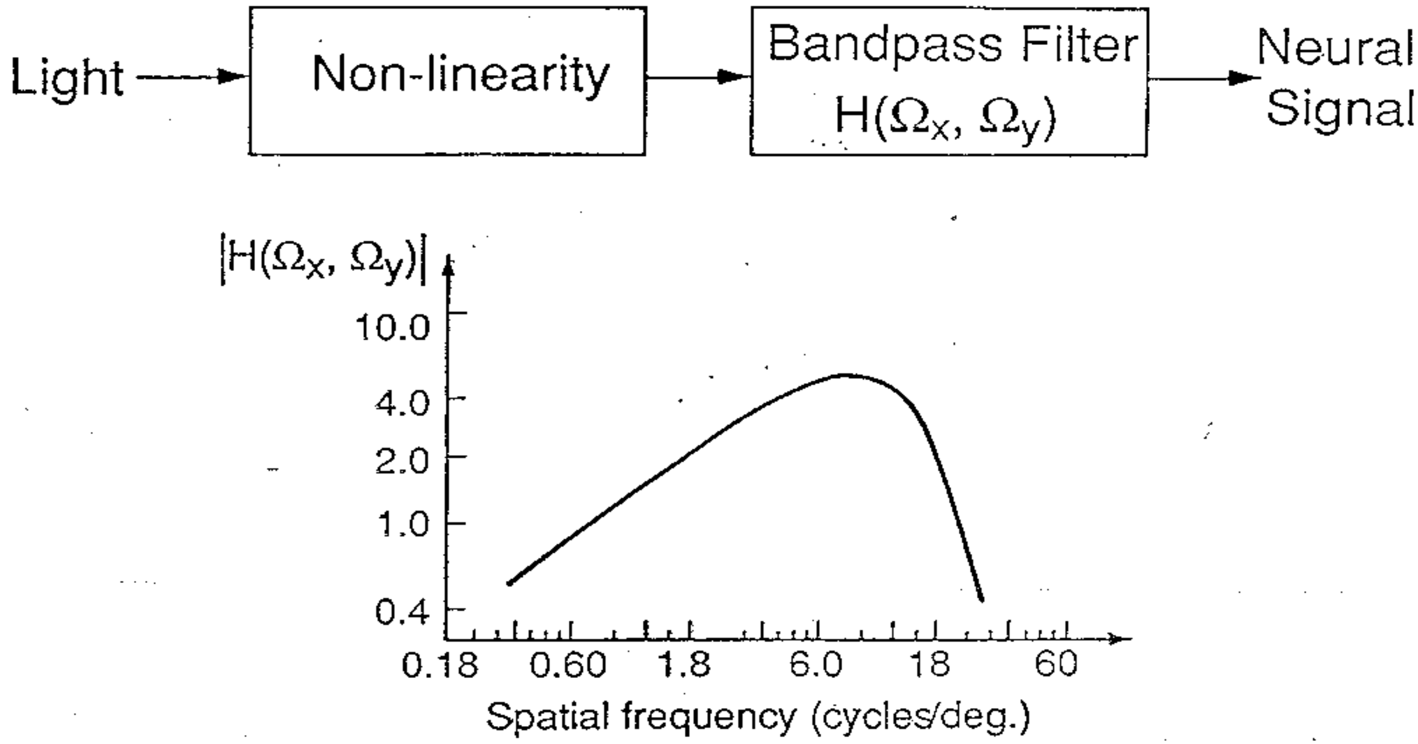


(a) Overall monochrome vision model.



(b) Simplified monochrome vision model.

One Simple Model of the Visual System



$$I_0(x, y) = k_1 \log[k_2 + k_3 I_i(x, y)]$$

$$I_0(x, y) = [I_i(x, y)]^{\alpha}$$

Image Fidelity Criteria

- Goal :
  - Image quality measurement
  - Performance evaluation of image processing techniques or systems

- Quantitative Criteria
  - Mean square criterion : $\sigma_{ms}^2 = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\left|u(m,n)-u'(m,n)\right|^2$
  - SNR(signal-to-noise ratio) : $SNR = 10\log_{10}\frac{\sigma^2}{\sigma_{ms}^2}$
  - PSNR(peak-to-peak SNR) :

$$PSNR = 10\log_{10}\frac{(\text{peak-to-peak value})^2}{\sigma_{ms}^2}$$

Image Fidelity Criteria (cont.)

- Subjective Criteria

TABLE 3.2 Image Goodness Scales

Overall goodness scale		Group goodness scale	
Excellent	(5)	Best	(7)
Good	(4)	Well above average	(6)
Fair	(3)	Slightly above average	(5)
Poor	(2)	Average	(4)
Unsatisfactory	(1)	Slightly below average	(3)
		Well below average	(2)
		Worst	(1)

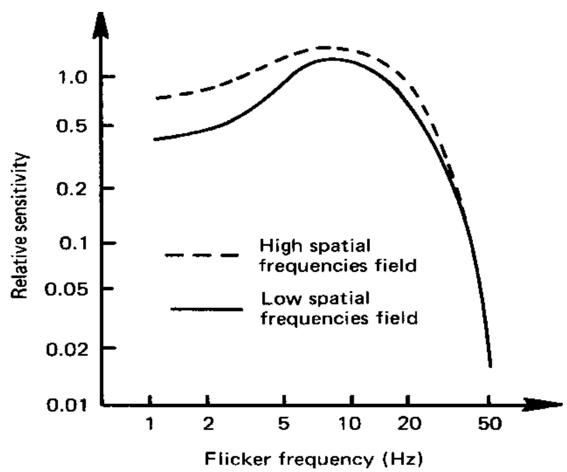
The numbers in parenthesis indicate a numerical weight attached to the rating.

TABLE 3.3 Impairment Scale

Not noticeable	(1)
Just noticeable	(2)
Definitely noticeable but only slight impairment	(3)
Impairment not objectionable	(4)
Somewhat objectionable	(5)
Definitely objectionable	(6)
Extremely objectionable	(7)

Temporal Properties of Vision

- Bloch's law
  - Critical duration of light flashes : about 30 ms.
- Critical fusion frequency(CFF)
  - CFF : about 50 to 60 Hz
  - Applications : TV camera, CRT, Computer Monitor.



- Spatial versus temporal effects

Perception of Intermittent Light

- Perception depends on its frequency (N cycles/sec)
  - Small N : Flashes appear separated in time
  - Increase N : unsteady flicker, unpleasant
  - Increase N further : Continuous light perception

- Fusion frequency
  : Frequency at which an observer begins perceiving light flashes as continuous light

Perception of Intermittent Light (cont.)

- Higher fusion frequency for larger size and larger intensity of the flickering object
  - Very dim, small light : A few cycles/sec
  - Very bright, large light : Over 100 cycles/sec

- Examples of intermittent light
  - Fluorescent light : Over 100 times/sec
  - Motion picture : 24 frames/sec
  - TV monitor : 30 frames/sec, 2fields/frame
    60 fields/sec (NTSC system)

Motion Rendition

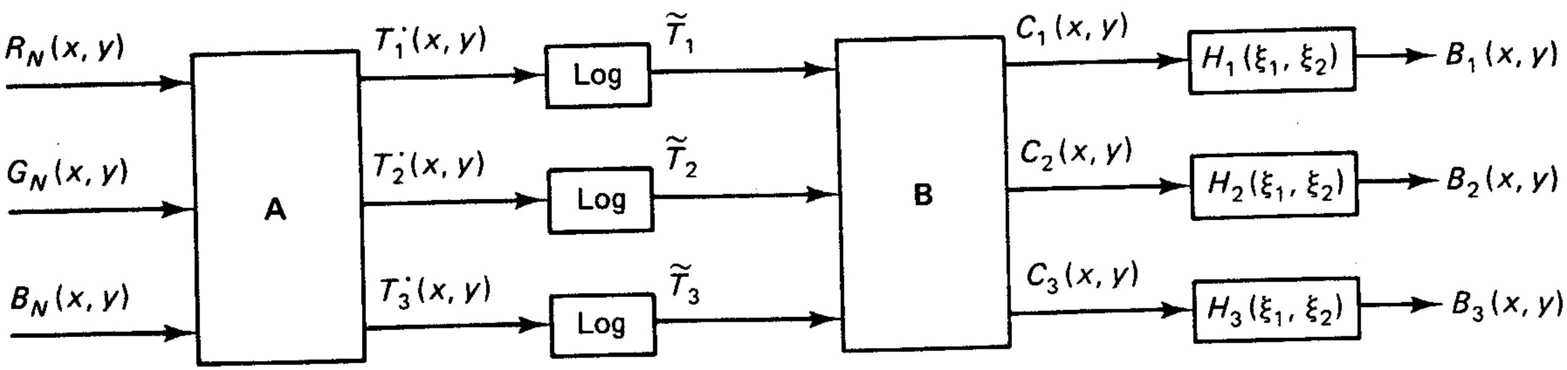
- Motion pictures, television broadcasting
  - A finite number of frames/sec. Each still frame.
  - Perception of continuous motion at a sufficiently high rate.
- A frame rate sufficient to avoid flickering is high enough for motion rendition

Empirical Observation Exploited in Image Processing

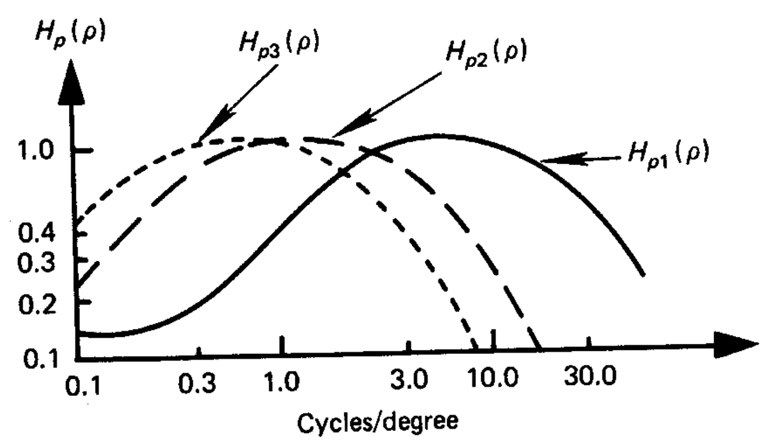
- Sharper images look better
- Same noise in uniform background region : more visible than noise in edge areas
- Same noise in dark areas : move visible than noise in bright areas
- Same amount of artificial noise : appear worse than natural looking noise

Color Vision Model

- Color image : represented by (RN,GN,BN)
- Color vision model



- Frequency responses of three color channels



Photometry

- A source of radiative energy

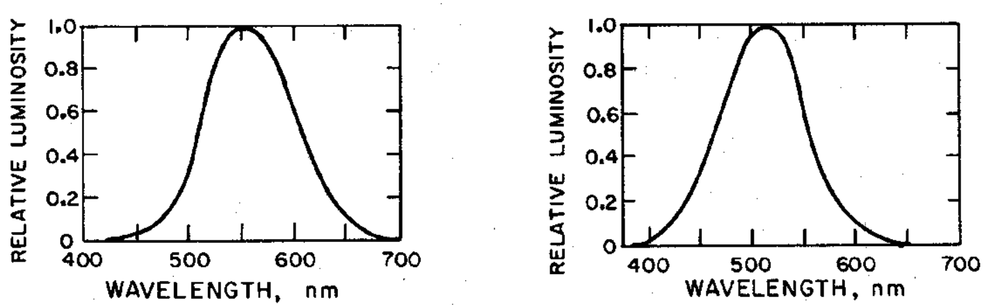
$$\Rightarrow C(\lambda): \text{Spectral energy distribution}$$

- Perceptual brightness sensation evoked by a light source

$$F = K_m \int_0^\infty C(\lambda) V(\lambda) d\lambda \Rightarrow \text{luminous flux (unit : lumen)}$$

where $V(\lambda) = \text{relative luminous efficiency}$

$$K_m = 685\, lm/W$$



(a) Photopic luminosity function (b) Scotopic luminosity function

FIGURE 3.1-4. Relative luminous efficiency functions (9).

Colorimetry

- Science for quantitatively measuring color
- The perceptual attributes of color
  - brightness : perceived luminance
  - hue : red,green,
  - saturation : the vividness of color (whiteness of a light source)

Color representation

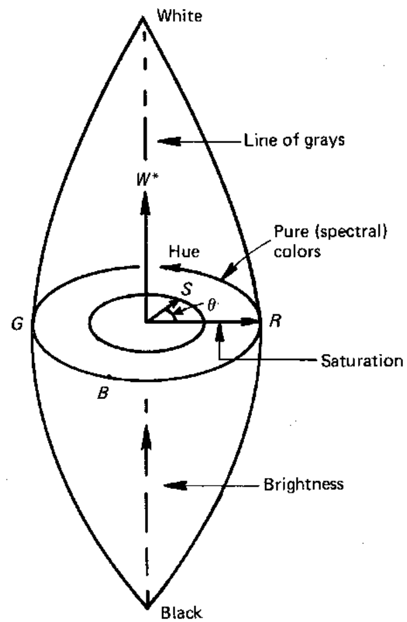


Figure 3.10 Perceptual representation of the color space. The brightness W^* varies along the vertical axis, hue θ varies along the circumference, and saturation S varies along the radius.

- Hue varies along the circumference
- Saturation varies along the radial distance

} Chromaticity

Human Visual System

- Tri-chromatic Model

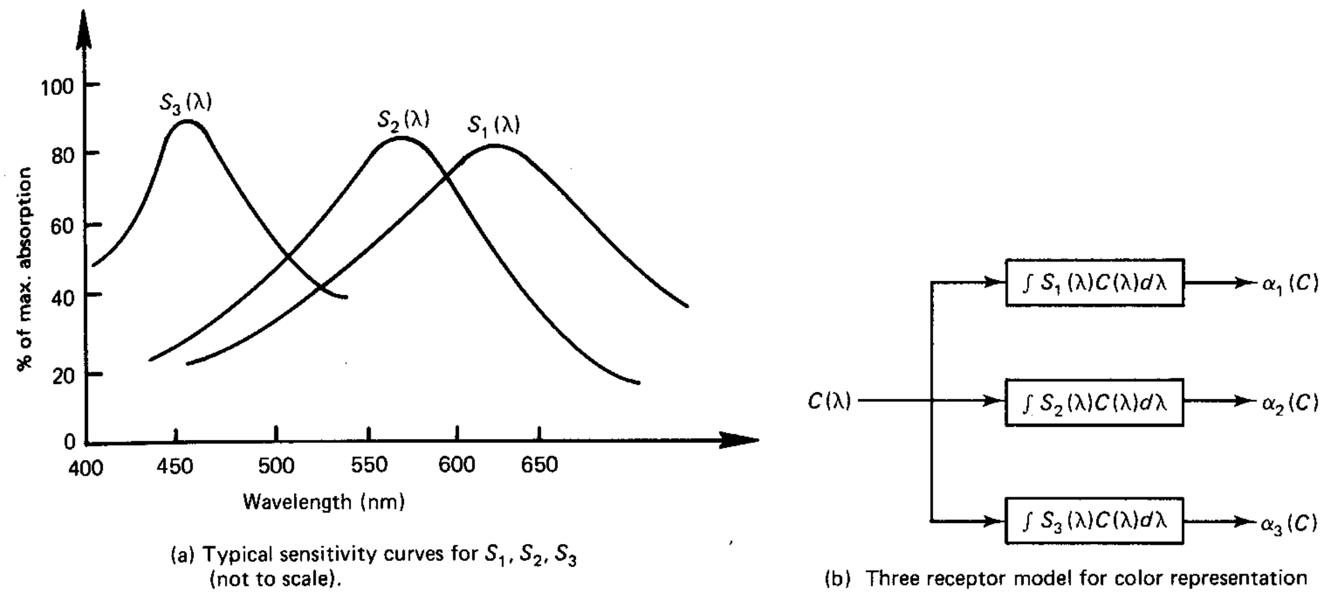
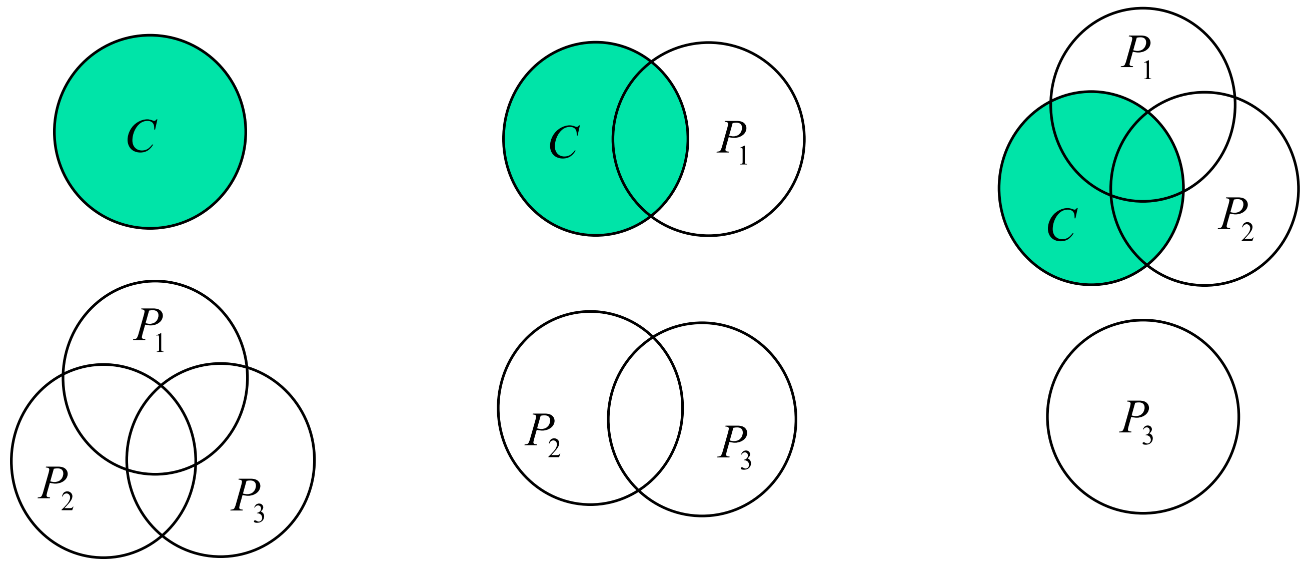


Figure 3.11 (a) Typical absorption spectra of the three types of cones in the human retina; (b) three-receptor model for color representation.

$$\alpha_i(C) = \int_{\lambda_{\min}}^{\lambda_{\max}} S_i(\lambda)C(\lambda)d\lambda\,, \qquad i = 1,2,3$$

Color Matching

- Law of Color matching
  - Any color can be matched by mixing 3 primary light sources.



(case 1)

$$C = \alpha P_1 + \beta P_2 + \gamma P_3$$
$$(\alpha > 0, \beta > 0, \gamma > 0)$$

(case 2)

$$C = \alpha P_1 + \beta P_2 + \gamma P_3$$
$$(\alpha < 0, \beta > 0, \gamma > 0)$$

(case 3)

$$C = \alpha P_1 + \beta P_2 + \gamma P_3$$
$$(\alpha < 0, \beta < 0, \gamma > 0)$$

Additive color matching

1. Given color $[C]$ and a reference white light source $[W]$
2. Three primaries are first overlapped until perceptually matching to $[W] \Rightarrow A_1(W), A_2(W), A_3(W)$
3. Three primaries are then overlapped until perceptually matching to $[C] \Rightarrow A_1(C), A_2(C), A_3(C)$
4. Tristimulus value :

$$T_1(C) = \frac{A_1(C)}{A_1(W)}, \qquad T_2(C) = \frac{A_2(C)}{A_2(W)}, \qquad T_3(C) = \frac{A_3(C)}{A_3(W)}$$

Normalized tristimulus value :

$$t_1 = \frac{T_1}{T_1 + T_2 + T_3}, \qquad t_2 = \frac{T_2}{T_1 + T_2 + T_3}, \qquad t_3 = \frac{T_3}{T_1 + T_2 + T_3}$$

$$t_1 + t_2 + t_3 = 1$$

- Chromaticity Diagram

$$\text{Normalized tristimulus values } t_k \equiv \frac{T_k}{T_1 + T_2 + T_3}, \quad k = 1,2,3$$

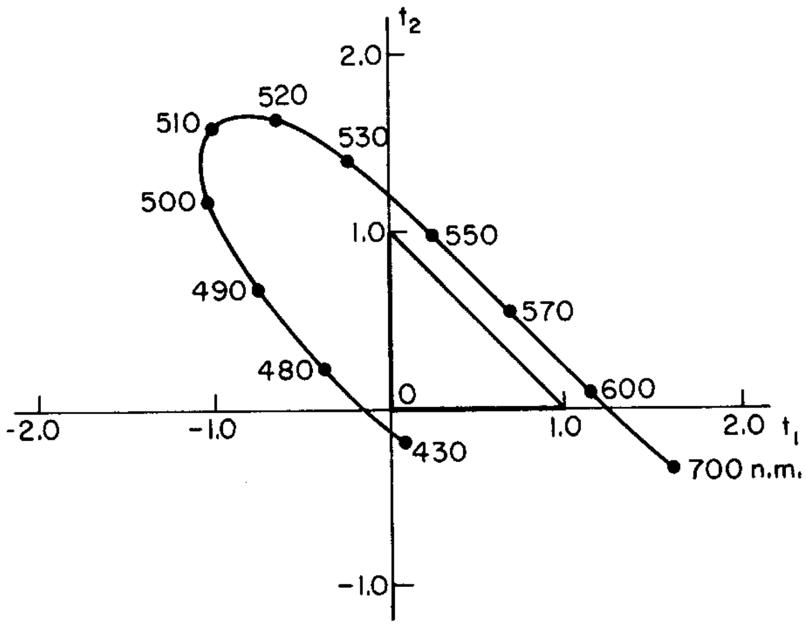


FIGURE 3.3-3. Chromaticity diagram for typical red, green, and blue primaries.

Color Matching

- Law of Color matching (cont.)
  - Luminance of a color mixture : equal to the sum of the luminance of its components

$$Y = L(C) = \alpha L(P_1) + \beta L(P_2) + \gamma L(P_3)$$

  - The human eye cannot resolve the component
  - A color match at one luminance level holds over a wide range of luminance

If $C = \alpha P_1 + \beta P_2 + \gamma P_3$,
then $\rho C = \rho\alpha P_1 + \rho\beta P_2 + \rho\gamma P_3$

Color Matching

- Law of Color matching (cont.)
  - Color addition

$$\text{If } [C_1]=[C_1'] \text{ and } [C_2]=[C_2']$$
$$\text{then } \alpha_1[C_1]+\alpha_2[C_2]=\alpha_1[C_1']+\alpha_2[C_2']$$

  - Color subtraction

$$\text{If } [C_1]+[C_2]=[C_1']+[C_2'] \text{ and } [C_2]=[C_2'],$$
$$\text{then } [C_1]=[C_1']$$

  - Transitive law

$$\text{If } [C_1]=[C_2] \text{ and } [C_2]=[C_3] \text{ then } [C_1]=[C_3]$$

Colorimetry concept

$$C(\lambda) \triangleq A_1(C)P_1(\lambda) + A_2(C)P_2(\lambda) + A_3(C)P_3(\lambda) = \sum_{j=1}^{3} A_j(C)P_j(\lambda)$$

$\triangleq$: evoke the same color sensation

since $T_j(C) = \dfrac{A_j(C)}{A_j(W)}$; tristimulus value

$$C(\lambda) \triangleq \sum_{j=1}^{3} T_j(C)A_j(W)P_j(\lambda)$$

the luminance of color mixture $Y(C)$ *is*

$$Y(C) = \int C(\lambda)V(\lambda)d\lambda = \sum_{j=1}^{3}\int A_j(C)P_j(\lambda)V(\lambda)d\lambda = \sum_{j=1}^{3}\int T_j(C)A_j(W)P_j(\lambda)V(\lambda)d\lambda$$

$\Rightarrow$ equal to the luminance of its primary component

Luminance calculation

$$Y(C) = \sum_{i=1}^{3} T_i(C) Y(P_i)$$

where $Y(P_i) = \int A_i(W) P_i(\lambda) V(\lambda) d\lambda$: luminosity coefficient

$$\Rightarrow \quad Y(C) = T_1(C)Y(P_1) + T_2(C)Y(P_2) + T_3(C)Y(P_3)$$

$$\Rightarrow \quad T_1(C) = \frac{t_1(C)Y(C)}{t_1(C)Y(P_1) + t_2(C)Y(P_2) + t_3(C)Y(P_3)}$$

$$T_2(C) = \frac{t_2(C)Y(C)}{t_1(C)Y(P_1) + t_2(C)Y(P_2) + t_3(C)Y(P_3)}$$

$$T_3(C) = \frac{t_3(C)Y(C)}{t_1(C)Y(P_1) + t_2(C)Y(P_2) + t_3(C)Y(P_3)}$$

$\Rightarrow$ the tristimulus value can be expressed in terms of the luminance and chromaticity coordinate of the color

Color coordinate systems

1. C.I.E. Primary color coordinate (RGB) 1931

$$R(\lambda) = 700nm, \quad G(\lambda) = 546.1nm, \quad B(\lambda) = 435.8nm$$

reference white has flat spectrum and R=G=B=1.0

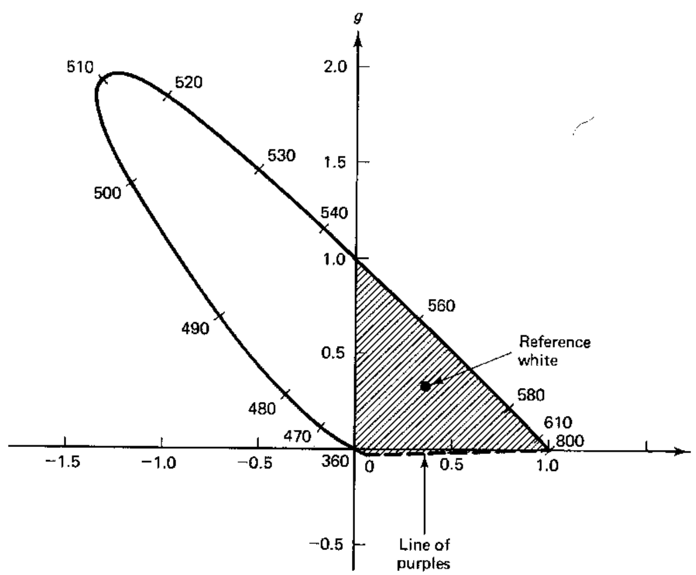


Figure 3.14 Chromaticity diagram for the CIE spectral primary system. Shaded area is the color gamut of this system.

Color coordinate systems

2. C.I.E. XYZ coordinate

hypothetical primary source such that all $t_i (i = 1,2,3)$ values are positive $\Rightarrow$ physically unrealizable

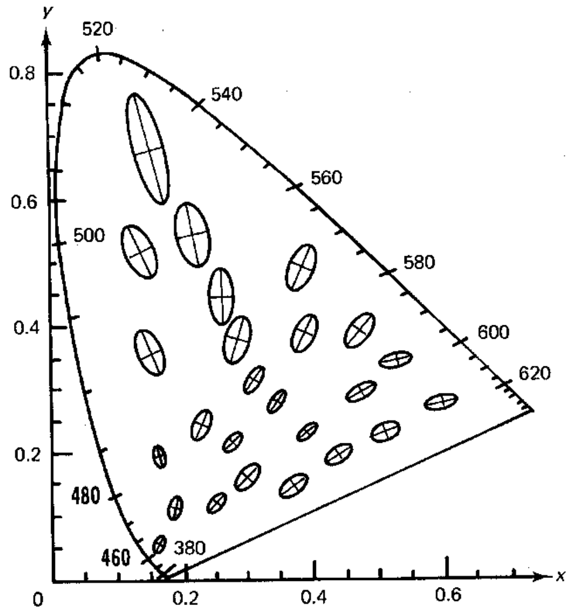


Figure 3.15 Chromaticity diagram for the CIE XYZ color coordinate system. The (MacAdam) ellipses are the just noticeable color difference ellipses.

- Characteristics
  - $(R_c, G_c, B_c) \to (X, Y, Z)$

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

  - $Y = L(C)$
  - $X \geq 0, Y \geq 0, Z \geq 0 \quad \text{for} \quad \forall C$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 2.365 & -0.897 & -0.468 \\ -0.515 & 1.426 & 0.089 \\ 0.005 & -0.014 & -1.009 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

- Chromaticity diagram for CIE x-y-z system

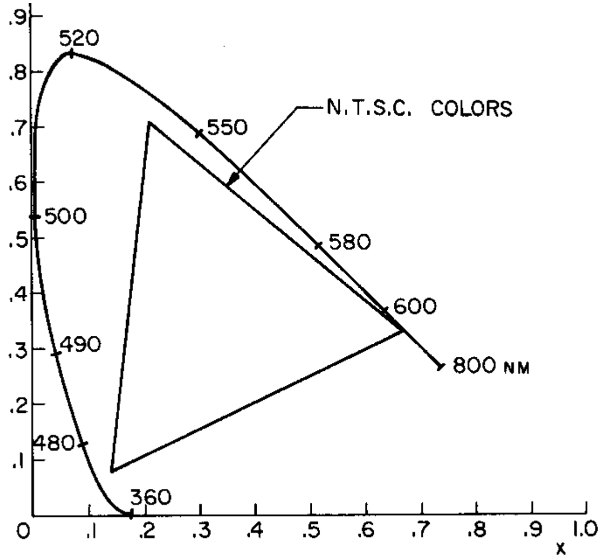
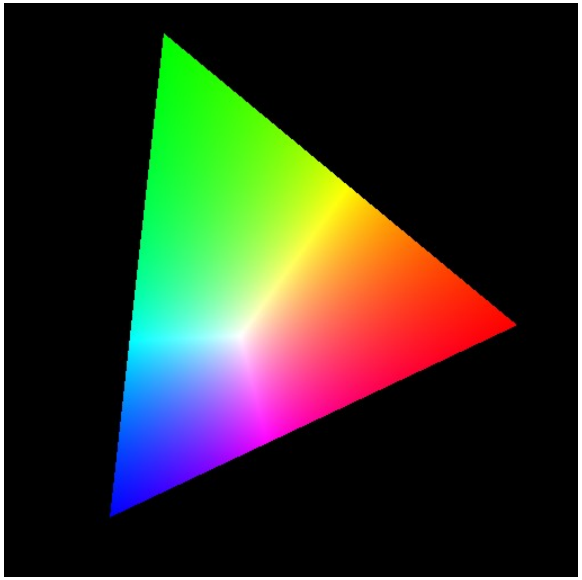


FIGURE 3.5-4. Chromaticity diagram for C.I.E. *XYZ* primary system (4).



Color coordinate systems

3. C.I.E uniform chromaticity scale (USC) system : UVW

: u, v, Y

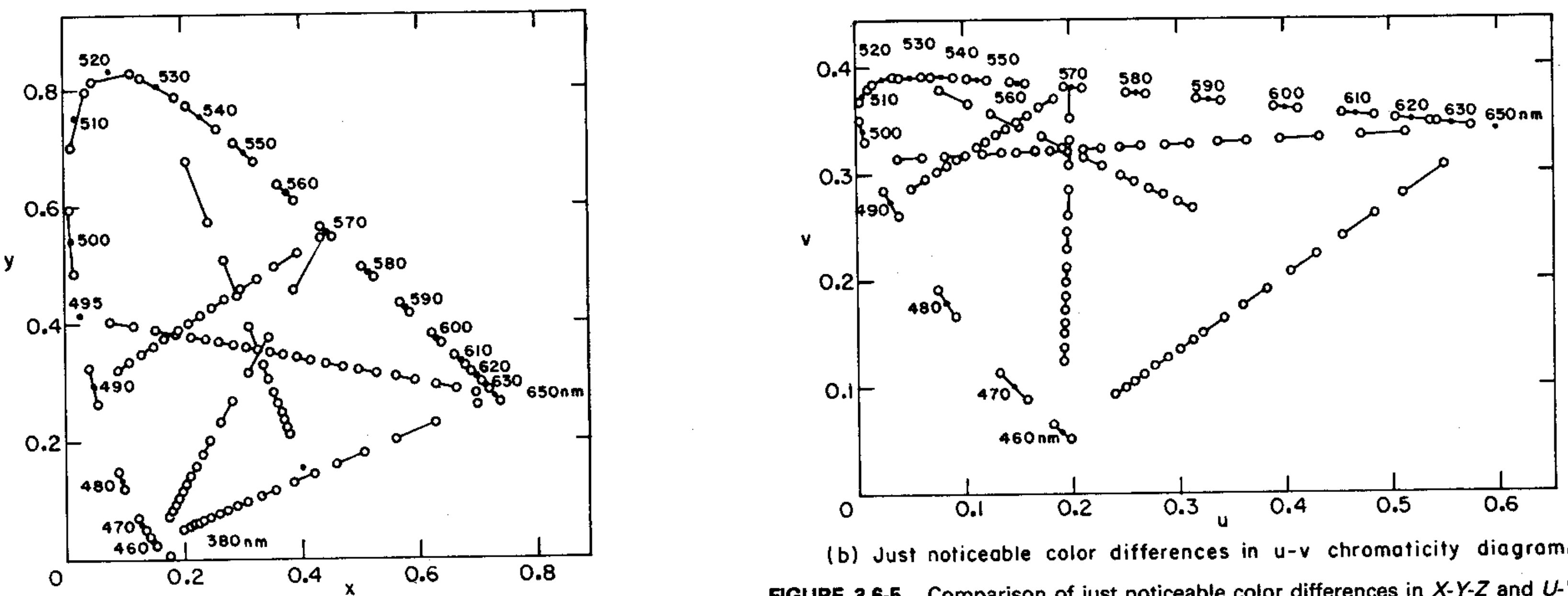
- u, v = chromaticities
- Y = luminance
- U, V, W = tristimulus values corresponding to u, v, w

$$u = \frac{4X}{X + 15Y + 3Z} \equiv \frac{4x}{-2x + 12y + 3}$$

$$v = \frac{6Y}{X + 15Y + 3Z} \equiv \frac{6y}{-2x + 12y + 3}$$

$$U = \frac{2X}{3}, \quad V = Y, \quad W = \frac{-X + 3Y + Z}{2}$$

CIE UCS (uniform chromaticity scale) system (UVW Color System)



(a) Just noticeable color differences in x-y chromaticity diagram.

(b) Just noticeable color differences in u-v chromaticity diagram.

FIGURE 3.6-5. Comparison of just noticeable color differences in *X-Y-Z* and *U-V-W* coordinate systems. Lines are 10 times one just noticeable color difference (12).

Color coordinate systems

4.

U^*, V^*, W^* system(modified UCS system)

$Y = \text{luminance } [\,0.01, 1\,]$

$$U^* = 13W^*(u - u_0)$$
$$V^* = 13W^*(v - v_0)$$
$$W^* = 25(100Y)^{1/3} - 17, \; 1 \le 100Y \le 100$$
$$u_0, v_0 = \text{chromaticities of reference white}$$
$$W^* = \text{contrast or brightness}$$

Color coordinate systems

5.

S, θ, W^* system

$S = \text{saturation}$

$\theta = \text{hue}$

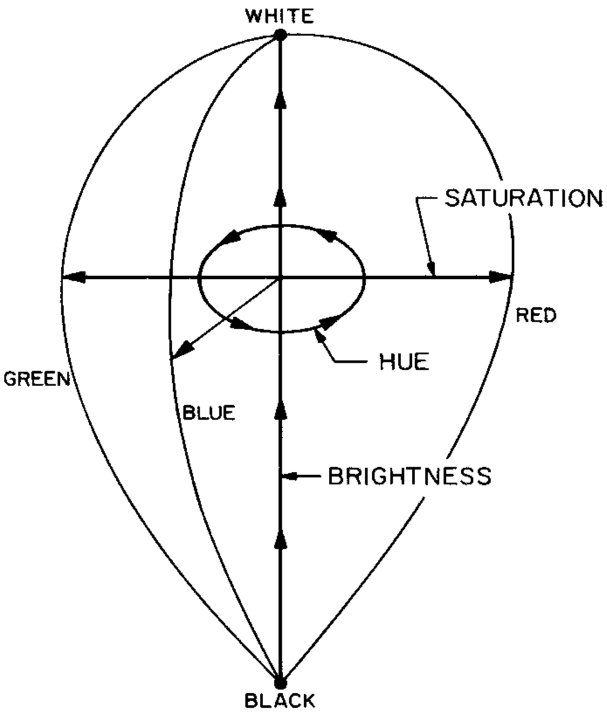
$W^* = \text{brightness}$

$$S = [(U^*)^2 + (V^*)^2]^{1/2} = 13W^*[(u - u_0)^2 + (v - v_0)^2]^{1/2}$$

$$\theta = \tan^{-1}\left(\frac{V^*}{U^*}\right) = \tan^{-1}[(v - v_0)/(u - u_0)],\ 0 \le \theta \le 2\pi$$

Intensity, Saturation, & Hue

- Perceptual representation



IHS system

$$\begin{bmatrix} I \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ \frac{-1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & \frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} & 0 \end{bmatrix} \begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix}$$

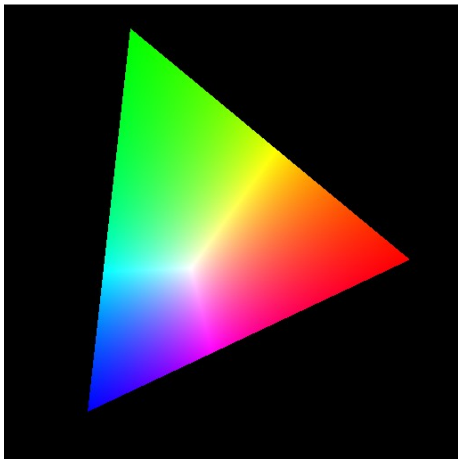
$$H = \tan^{-1}\left[\frac{V_2}{V_1}\right], \qquad S = [(V_1)^2 + (V_2)^2]^{\frac{1}{2}}$$

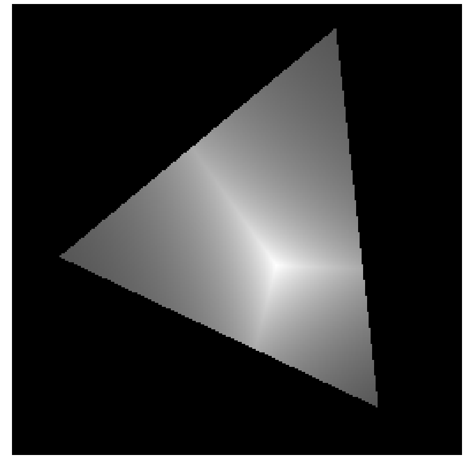
$$\begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix} = \begin{bmatrix} \frac{4}{3} & \frac{-2\sqrt{6}}{9} & \frac{\sqrt{6}}{3} \\ \frac{2}{3} & \frac{\sqrt{6}}{9} & \frac{-\sqrt{6}}{3} \\ 1 & \frac{\sqrt{6}}{3} & 0 \end{bmatrix} \begin{bmatrix} I \\ V_1 \\ V_2 \end{bmatrix}$$

$$V_1 = S\cos(H)$$

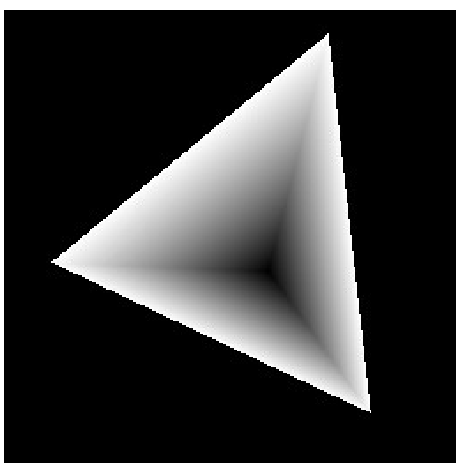
$$V_2 = S\sin(H)$$

Intensity, Saturation, & Hue(cont.)

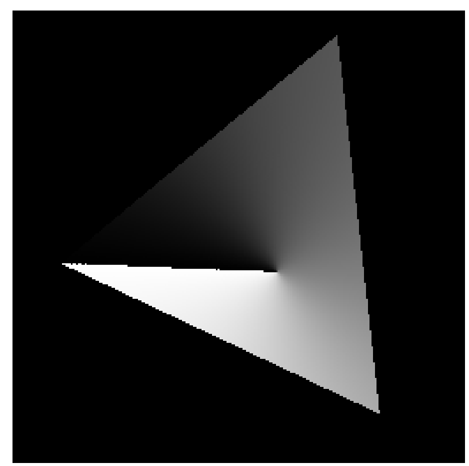




(a) I



(b) S



(c) H

Color coordinate systems

6.

NTSC receiver primary system R_N, G_N, B_N

Linear transfomation of X, Y, Z. Based on television phosphor primaries. Reference white is illuminant C for which $R_N = G_N = B_N = 1$.

$$\begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix} = \begin{bmatrix} 1.910 & -0.533 & -0.288 \\ -0.985 & 2.000 & -0.028 \\ 0.058 & -0.118 & 0.896 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

NTSC receiver primary system

- Primaries

$$\bullet \text{Red} \quad : (X, Y, Z) = (0.607, 0.299, 0.000)$$
$$\bullet \text{Green} : (X, Y, Z) = (0.174, 0.584, 0.066)$$
$$\bullet \text{Blue} \quad : (X, Y, Z) = (0.201, 0.114, 1.117)$$

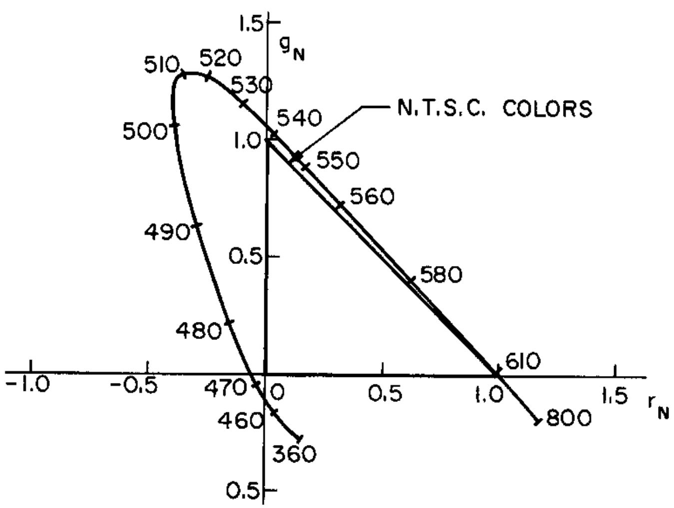


FIGURE 3.5-3. Chromaticity diagram for N.T.S.C. receiver phosphor primary system.

Color coordinate systems

TABLE 3.6 Transformations from NTSC Receiver Primary to Different Coordinate Systems. Input Vector is $[R_N\ G_N\ B_N]^T$.

Output vector	Transformation matrix	Comments
$\begin{bmatrix} R \\ G \\ B \end{bmatrix}$	$\begin{pmatrix} 1.167 & -0.146 & -0.151 \\ 0.114 & 0.753 & 0.159 \\ -0.001 & 0.059 & 1.128 \end{pmatrix}$	CIE spectral primary system
$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$	$\begin{pmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.117 \end{pmatrix}$	CIE $X,\ Y,\ Z$ system
$\begin{bmatrix} U \\ V \\ W \end{bmatrix}$	$\begin{pmatrix} 0.405 & 0.116 & 0.133 \\ 0.299 & 0.587 & 0.114 \\ 0.145 & 0.827 & 0.627 \end{pmatrix}$	CIE UCS tristimulus system
$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$	$\begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix}$	NTSC transmission system

Color coordinate systems

7.

NTSC transmission system:

$Y =$ luminance

$I, Q =$ chrominances

$$Y = 0.299R_N + 0.587G_N + 0.114B_N$$

$$I = 0.596R_N - 0.274G_N - 0.322B_N$$

$$Q = 0.211R_N - 0.523G_N + 0.312B_N$$

NTSC transmission system (YIQ Color System)

- YIQ conversion

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix} \begin{pmatrix} R_N \\ G_N \\ B_N \end{pmatrix}$$

or

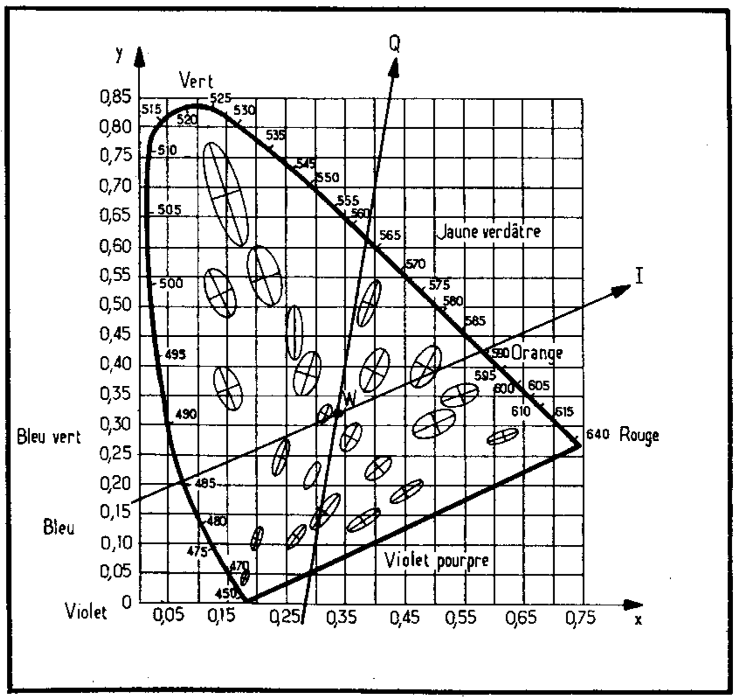
$$\begin{cases} I = D_R \cos 33^\circ - D_B \sin 33^\circ \\ Q = D_R \sin 33^\circ - D_B \cos 33^\circ \end{cases}$$

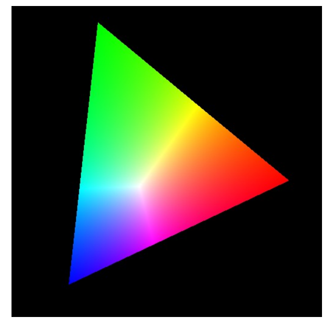
where

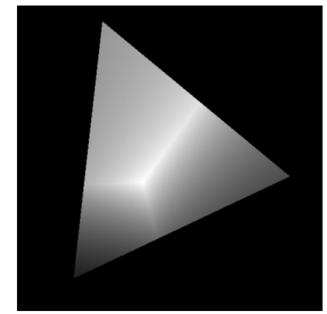
$$D_R = (R - Y)/1.14$$

$$D_B = (B - Y)/2.03$$

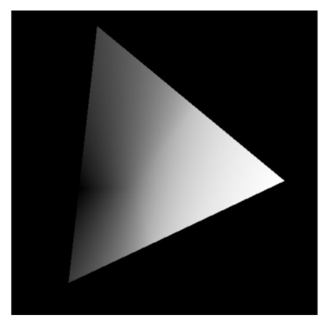
NTSC transmission system (cont.) (YIQ Color System)



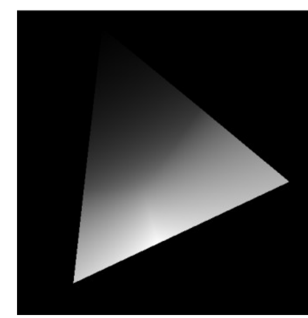




(a) Y



(b) I



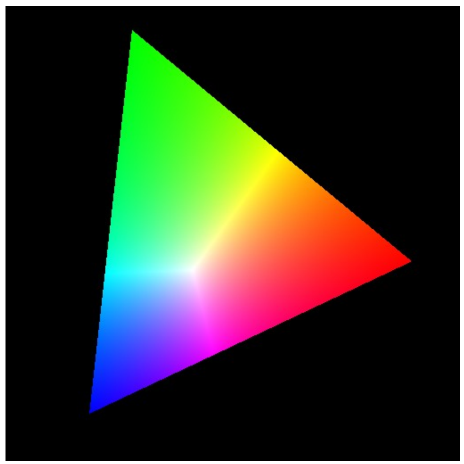
(c) Q

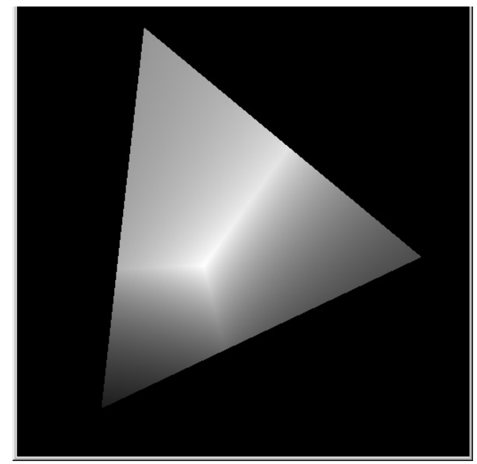
YUV Color Coordinate System

- Basic color format used by the NTSC, PAL, SECOM
- YUV conversion

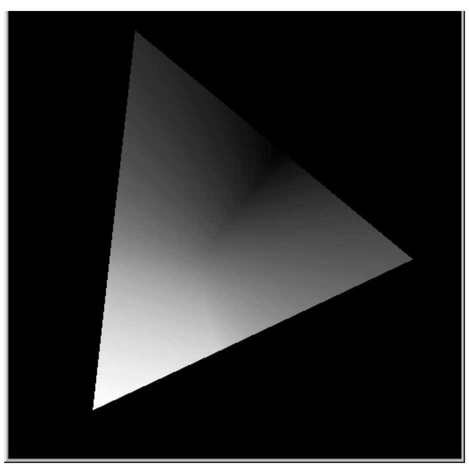
$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{pmatrix} \begin{pmatrix} R_N \\ G_N \\ B_N \end{pmatrix}$$

YUV Color Coordinate System(cont.)

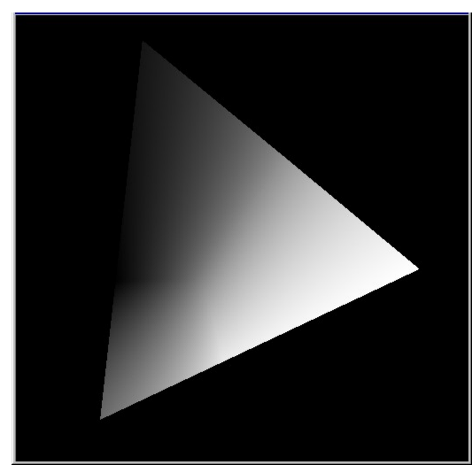




(a) Y



(b) U



(c) V

Color coordinate systems

8. L^*, a^*, b^* system:

$L^* = \text{brightness}$

$a^* = \text{red} - \text{green content}$

$b^* = \text{yellow} - \text{blue content}$

$$L^* = 25\left(\frac{100Y}{Y_0}\right)^{1/3} - 16.1 \le 100Y \le 100$$

$$a^* = 500\left[\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right]$$

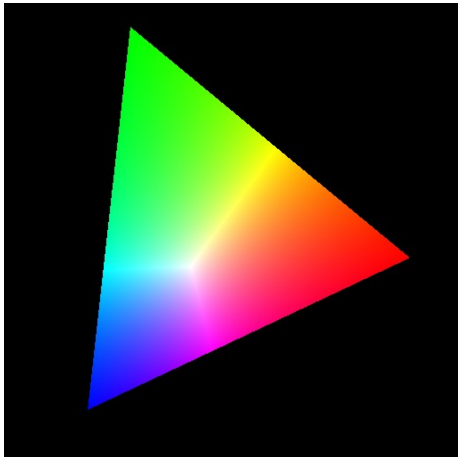
$X_0, Y_0, Z_0 = \text{tristimulus values of the reference white}$

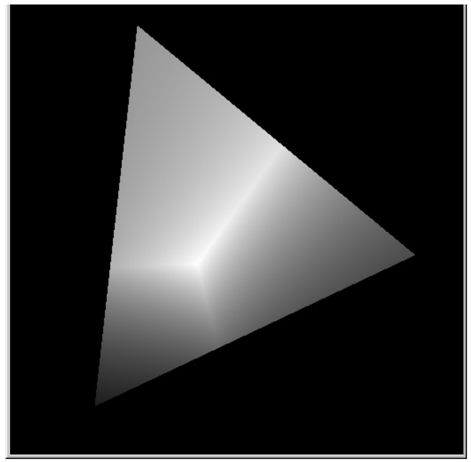
YC_bC_r Color Coordinate System

- Developed as part of ITU-R BT.601
- Widely used for digital video component standard
  - Most image compression standards adopt this format
- Scaled & offset version of YUV format
- YC_bC_r conversion

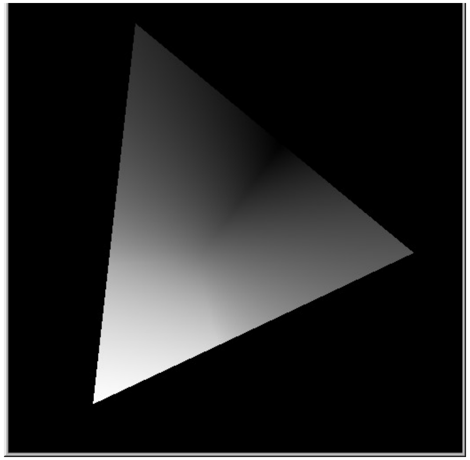
$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R_N \\ G_N \\ B_N \end{pmatrix}$$

YC_bC_r Color Coordinate System(cont.)

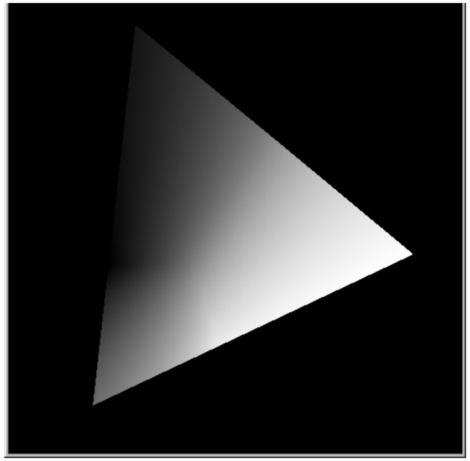




(a) Y



(b) C_b



(c) C_r

NTSC Composite Color Video Signal

- Relation between (RGB) & (YIQ)

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.000 & 0.956 & 0.621 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.106 & 1.703 \end{pmatrix} \begin{pmatrix} Y \\ I \\ Q \end{pmatrix}$$

NTSC Composite Signal (cont.)

- NTSC composite color video signal coding process

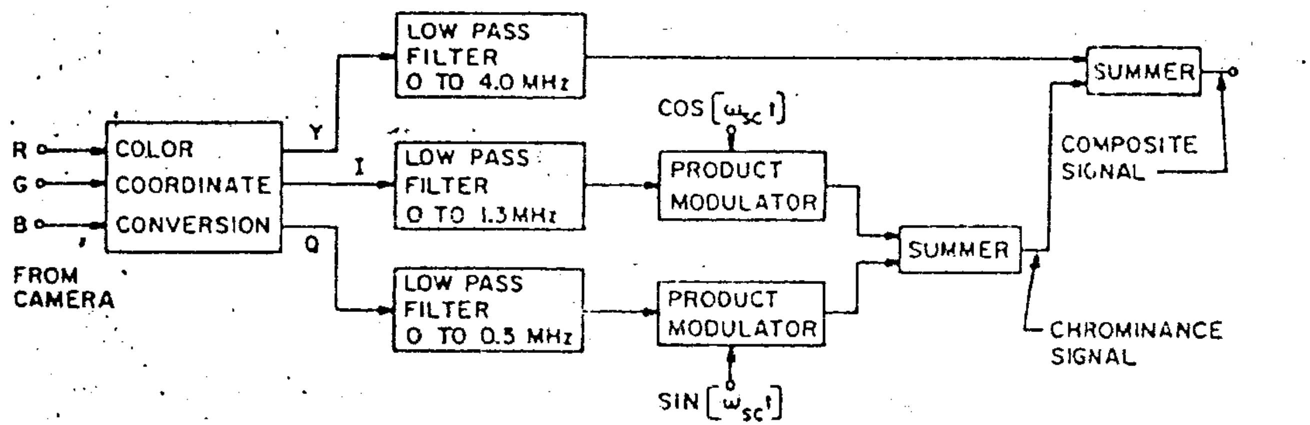


FIGURE 21.2-3. NTSC composite color video signal coding process.

$$g(t) = Y(t) + I(t)\cos\left(2\pi f_{SC} t + 33^\circ\right) + Q(t)\sin\left(2\pi f_{SC} t + 33^\circ\right)$$

$$\text{where} \quad f_{SC} = 30 \times 525 \times \frac{455}{2} = 3.583125\ \text{MHz}$$

NTSC Composite Signal (cont.)

- 1-Dim. spectrum of NTSC video signal

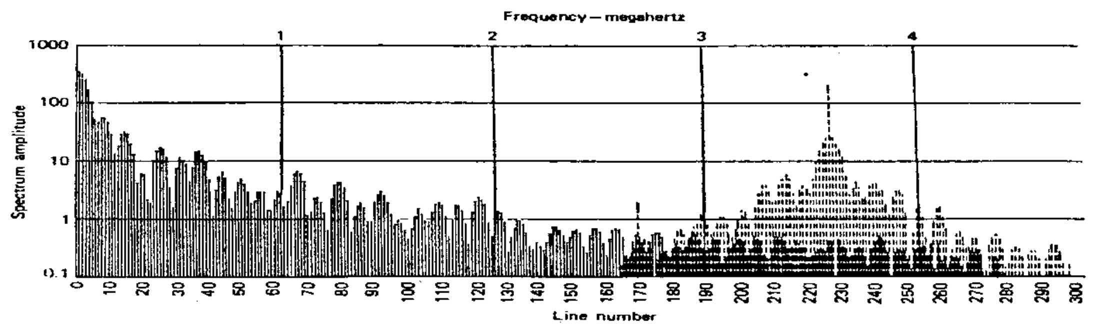


FIGURE 21.2-4. Composite luminance/chrominance spectrum (15).