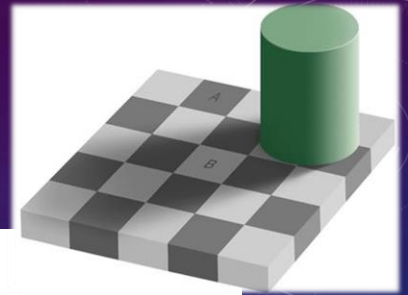
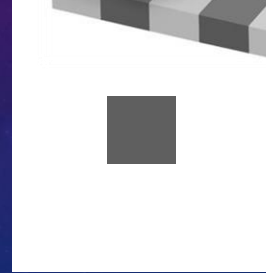
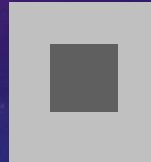
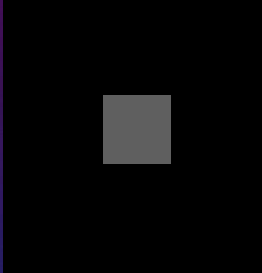


VISION PROPERTIES

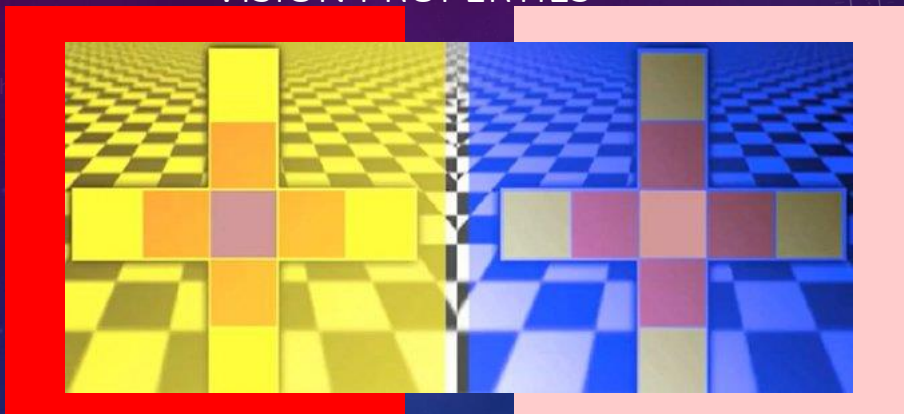


- **Simultaneous Contrast**

- The perceived **brightness** is dependent on the intensity of the surrounds

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VISION PROPERTIES



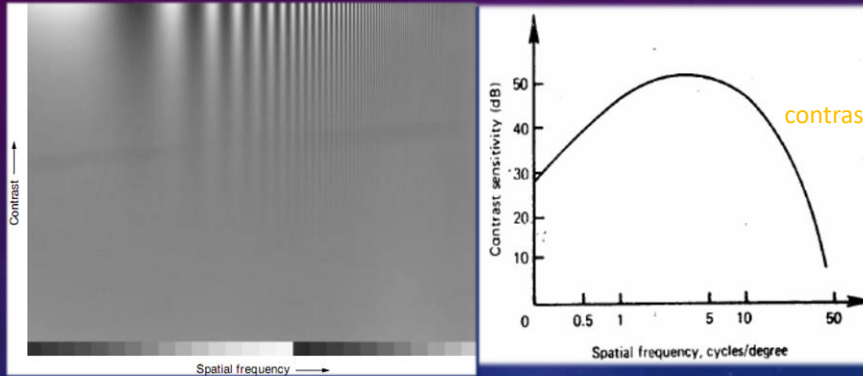
X chromosome

- **Chromatic Adaption**

- The hue of a perceived **color** is dependent on the wavelength composition of surrounding light

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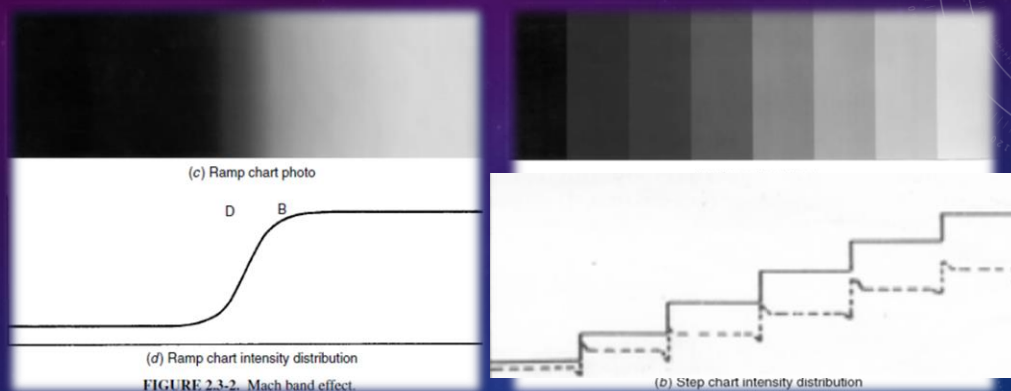
VISION PROPERTIES



- **Modulation Transfer Function**

- The human vision system is nonlinear and anisotropic (rotationally variant)
- The eye possesses a lower sensitivity to high and low spatial frequencies than to mid-estc.edu.cn frequencies

VISION PROPERTIES

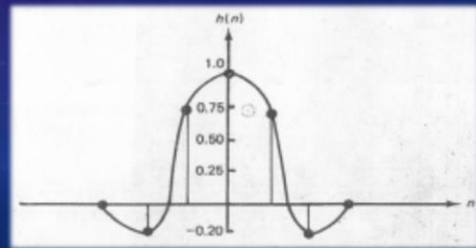
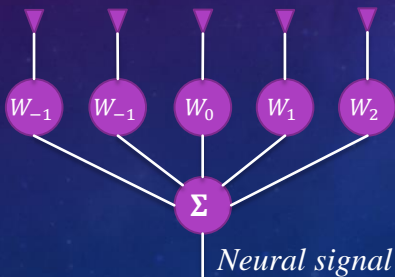


- **Mach Band**

- The perceived **brightness** is not a monotonic function of luminancehangshu@uestc.edu.cn

VISION PROPERTIES

- **Mach Band** uestc.edu.cn
 - the eye has imperfect response to high-spatial-frequency brightness transitions
 - Lateral inhibition process
 - Impulse response of human vision system

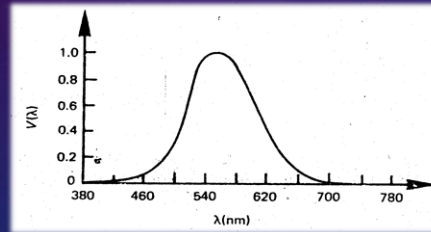


VISION PROPERTIES

- **Critical Fusion Frequency**
 - Fast flickers can not be distinguished
 - Persistence of vision (0.1~0.4s)
 - CFF is dependent on surrounding light

VISION PROPERTIES

- **Relative luminous efficiency function** $V(\lambda)$
 - The spectral response of human vision



Rods: 505nm
Cones: 555nm

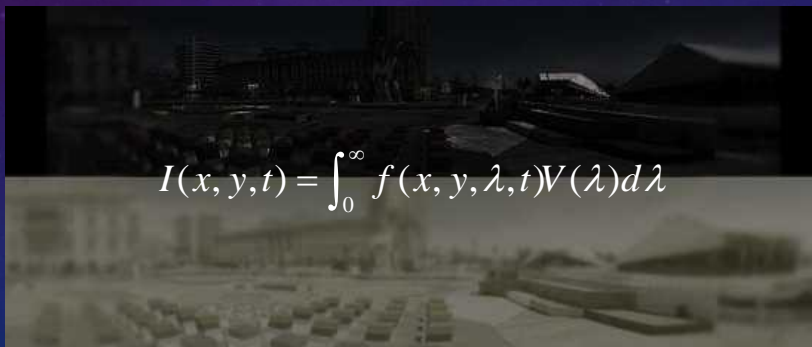
- The instantaneous luminance

$$I(x, y, t) = \int_0^\infty f(x, y, \lambda, t) V(\lambda) d\lambda$$

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VISION PROPERTIES

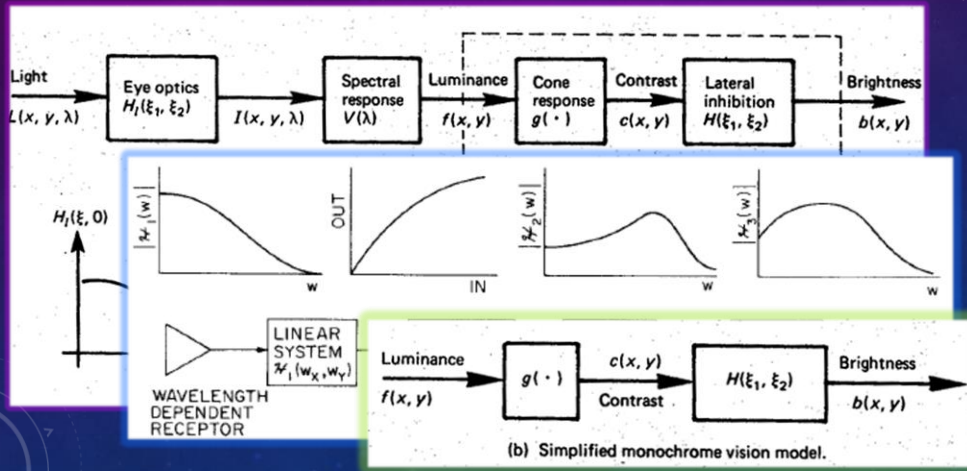
- **Relative luminous efficiency function**
 - The same scene viewed by human v.s. by cat



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VISION PROPERTIES

- Monochrome vision model



PHOTOMETRY & COLORIMETRY

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- Basic concepts of colorimetry
 - Color = brightness + chromaticity



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PHOTOMETRY & COLORIMETRY

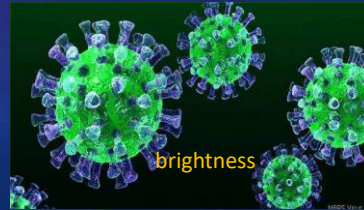
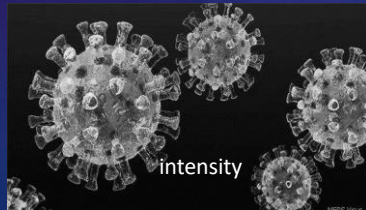
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- Basic concepts of colorimetry
 - Color = brightness + chromaticity

watts

candela/m²

- Radiance, luminance, brightness, -> energy, perceived energy, a subjective descriptor



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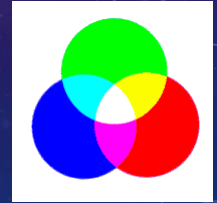
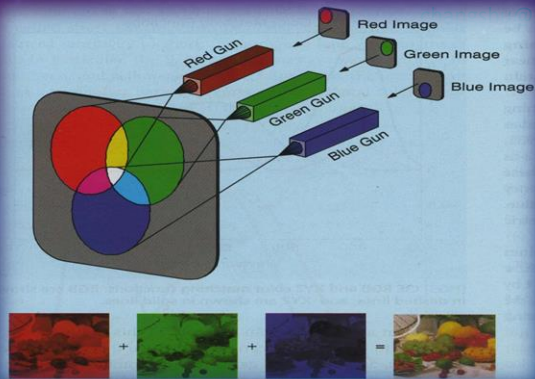
PHOTOMETRY & COLORIMETRY

- Basic concepts of colorimetry
 - Color = brightness + chromaticity
 - chromaticity = hue + saturation
 - Color = brightness + hue + saturation
 - Radiance, luminance, brightness, -> energy, perceived energy, a subjective descriptor
 - Hue is the attribute of light.
 - saturation refers to the relative purity or the amount of white light mixed with a hue.

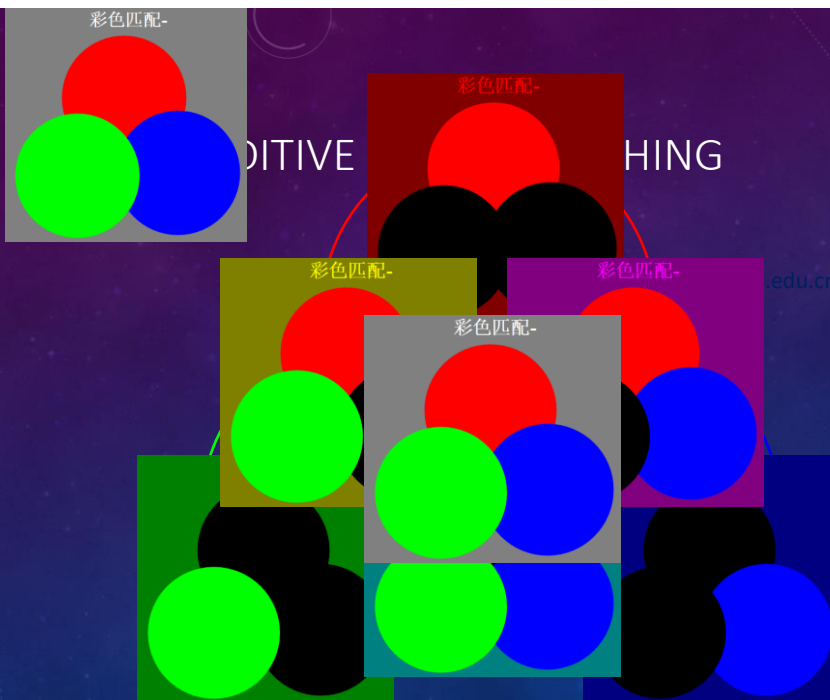


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ADDITIVE COLOR MATCHING



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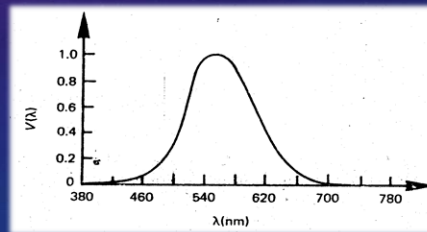
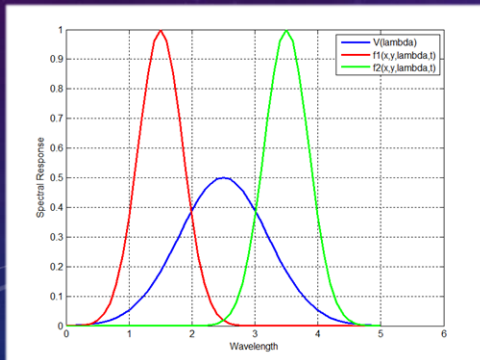
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$$I(x, y, t) = \int_0^\infty f(x, y, \lambda, t) V(\lambda) d\lambda$$

COLOR MATCHING-GRASSMAN'S AXIOMS

- Relative luminous efficiency function

$$I(x, y, t) = \int_0^\infty f(x, y, \lambda, t) V(\lambda) d\lambda$$



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COLORIMETRY –TRICHROMATIC THEORY

Metamerism
同色异谱

- Metamerism

Receptors with different spectral sensitivities $V_i(\lambda)$ (represents the absorption pigments of the retina) produce signals

$$I_i(f) = \int_{\lambda_{\min}}^{\lambda_{\max}} f(\lambda) V_i(\lambda) d\lambda, \quad i = 1, 2, 3$$

For two different incident light sources with different spectral energy distribution $f_1(\lambda)$ and $f_2(\lambda)$, if

$$I_i(f_1) = I_i(f_2), \quad i = 1, 2, 3$$

f_1 and f_2 are of the same color

COLOR MATCHING-GRASSMAN'S AXIOMS

- Any color can be matched by a mixture of no more than three colored lights
- A color match at one radiance level holds over a wide range of levels
- Components of a mixture of colored lights cannot be resolved by the human eye
- The luminance of a color mixture is equal to the sum of the luminance of its components
- Law of addition

$$(A \diamond B) \cap (C \diamond D) = (A \oplus B) \diamond (C \oplus D)$$

- Law of subtraction

$$(A \oplus B) \diamond (C \oplus D) \cap (B \diamond D) = (A \diamond C)$$

- Transitive law

$$(A \diamond B) \cap (B \diamond C) = A \diamond C$$

three primary colors

Blue(B) Red (R) Green (G)

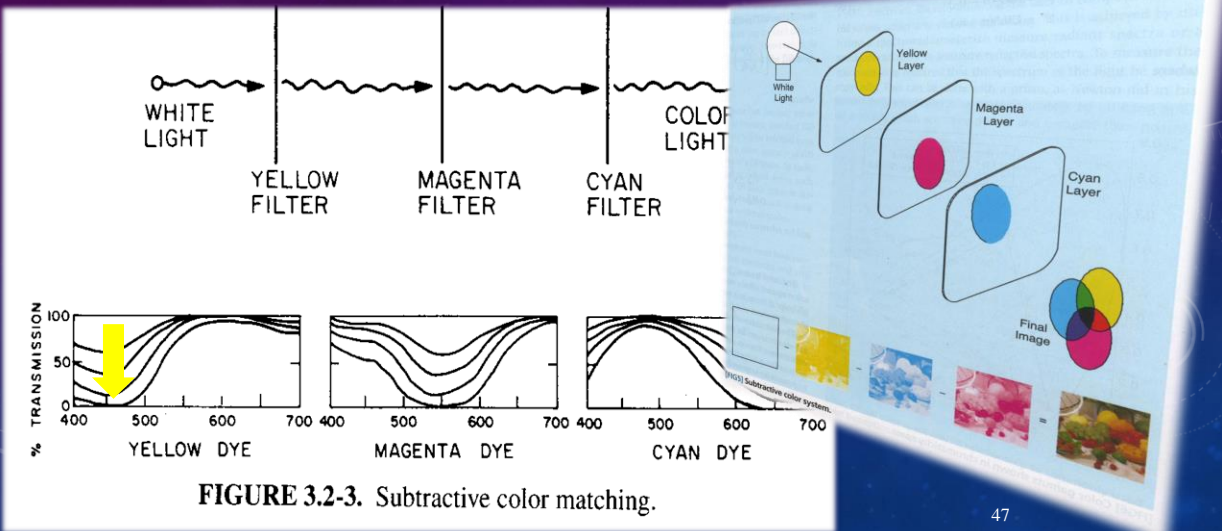
three complementary colors

Yellow(Y) Cyan (C) Magenta (M)

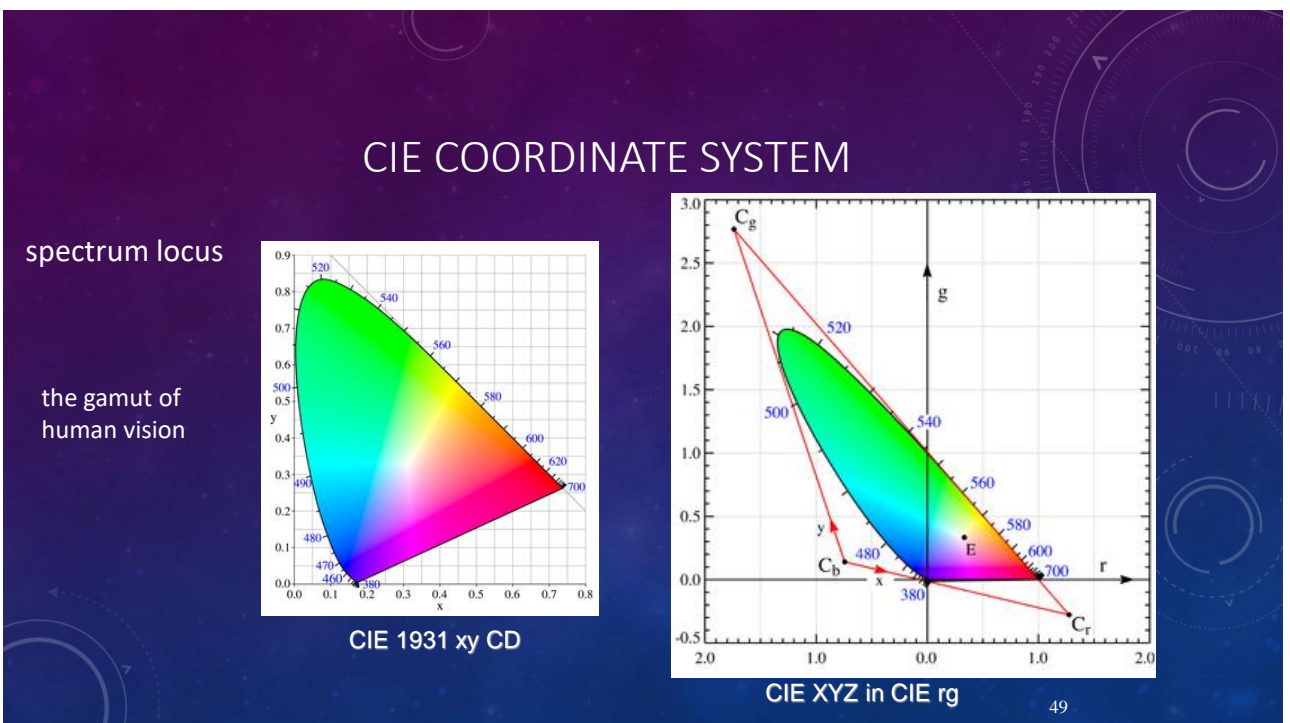
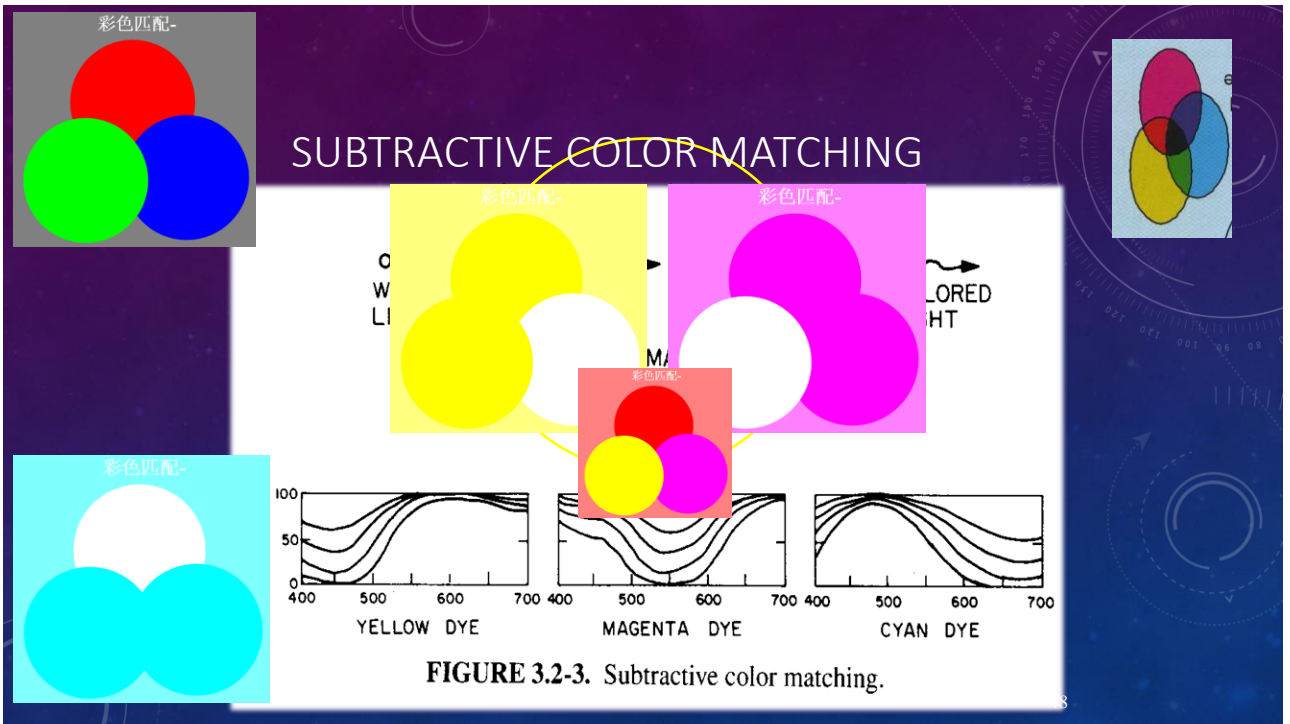
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dyestuffs染料

SUBTRACTIVE COLOR MATCHING

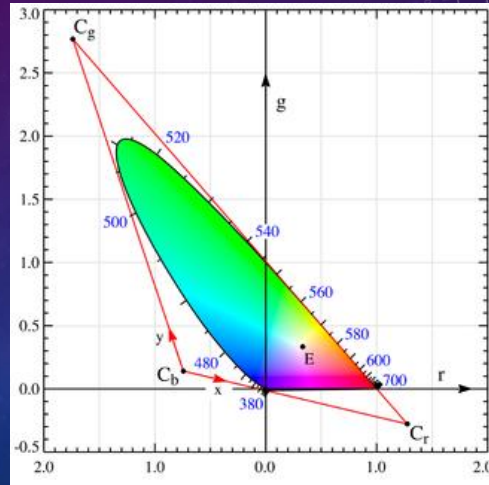
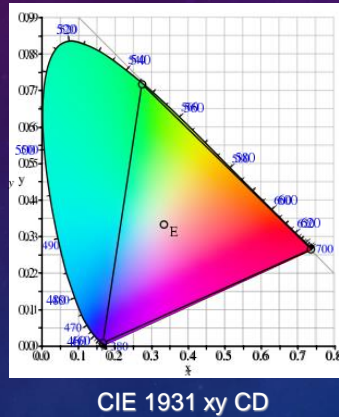


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CIE COORDINATE SYSTEM

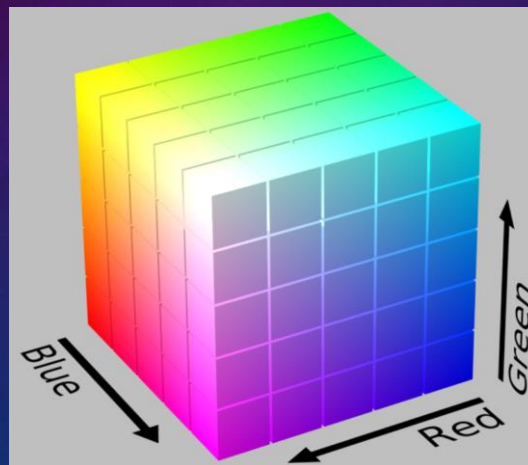
spectrum locus
spectrum colors
pure spectral /
monochromatic colors
line of purples
equal energy
convex



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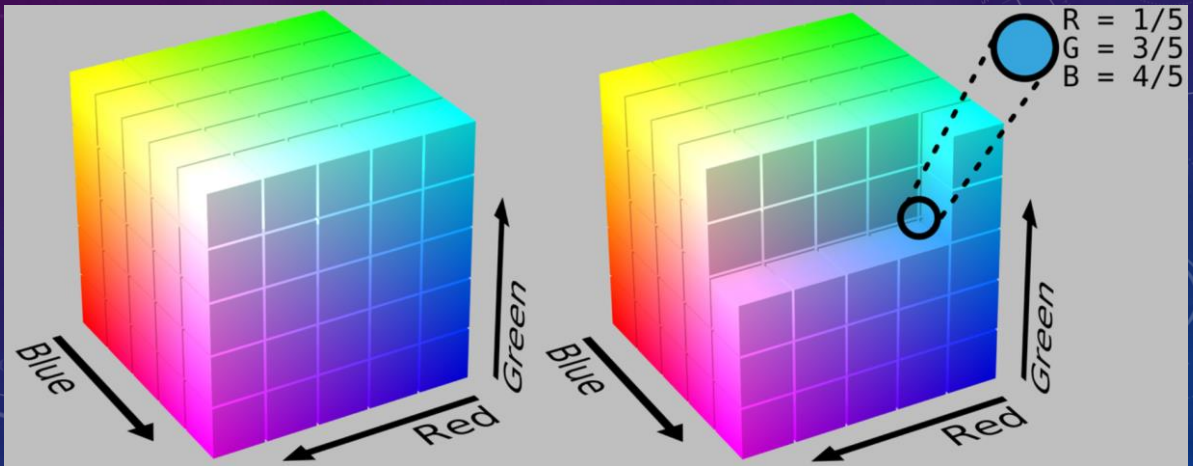
COLOR SPACE

- RGB
- CMY/CMYK
- HSI/HSV



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COLOR SPACE RGB



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COLOR SPACE CMY

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- CMY(cyan/magenta/yellow) model is for color printing.
- The conversion from RGB to CMY is:

$$C = 1.0 - R; \quad M = 1.0 - G; \quad Y = 1.0 - B$$

Where the R,G,B values are in the range [0.0,1.0]

- CMYK

$$C = 1.0 - R - uK_b \quad M = 1.0 - G - uK_b \quad Y = 1.0 - B - uK_b \quad K = bK_b$$

$$\text{Where } K_b = \min\{1.0 - R, 1.0 - G, 1.0 - B\} \quad 0 \leq u, b \leq 1$$

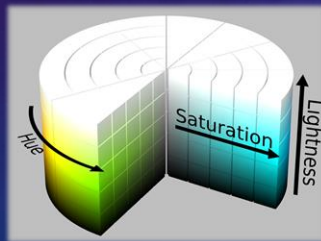
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COLOR SPACE HSI/HSV

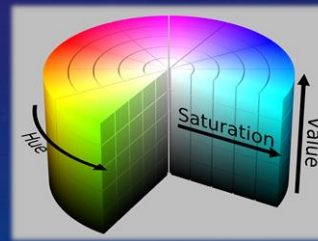
- RGB alternatives

- HSI(hue, Saturation, Intensity/Lightness)
- HSV(hue, Saturation, Value)

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HSI cylinder



HSV cylinder

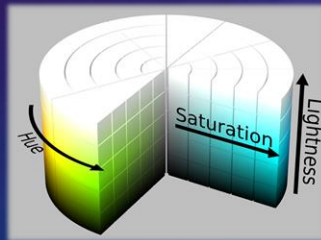
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COLOR SPACE HSI/HSV

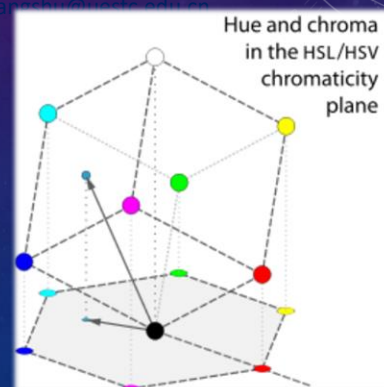
- RGB alternatives

- HSI(hue, Saturation, Intensity/Lightness)
- HSV(hue, Saturation, Value)

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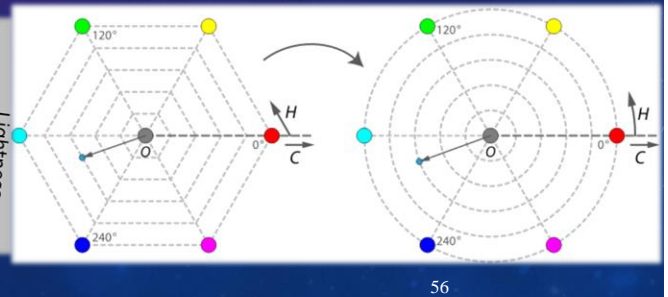
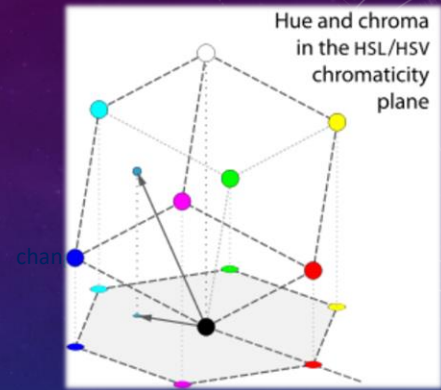
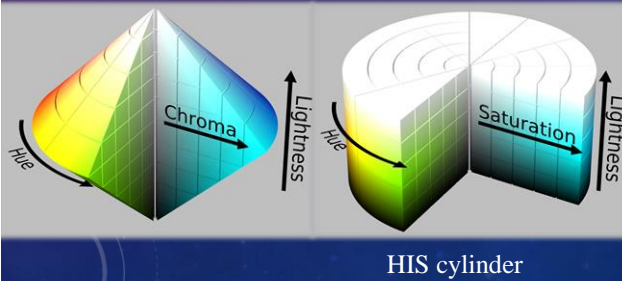
HIS cylinder



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COLOR SPACE HSI

- RGB alternatives
 - HSI(hue, Saturation, Intensity/Lightness)
 - HSV(hue, Saturation, Value)



COLOR SPACE HSI

- RGB alternatives
- Decouples the intensity component
- Natural and intuitive to humans

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COLOR SPACE

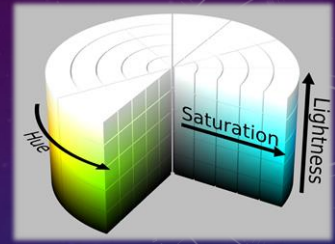
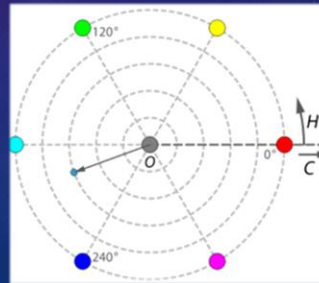
- Converting colors from RGB to HSI

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

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

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

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



$$0 \leq R, G, B \leq 1$$

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COLOR SPACE

- Converting colors from HSI to RGB

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

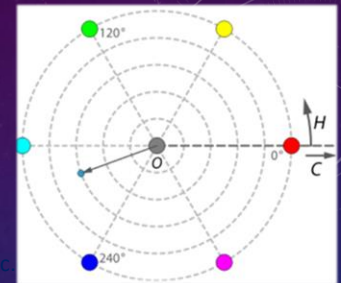
$$Y = I(1 - S)$$

$$Z = 3I - (X + Y)$$

$$H' = H \bmod 120 \quad H \in [0^\circ, 360^\circ]$$

$$\text{quotient} = \begin{cases} 0 & X, Y, Z \rightarrow R, B, G \\ 1 & X, Y, Z \rightarrow G, R, B \\ 2 & X, Y, Z \rightarrow B, G, R \end{cases}$$

$$H \div 120 = \text{quotient} \cdots H'$$



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SUMMARY

- Eye physiology
 - Retina, Rods & Cones
 - Blind spot, periphery vision, optic illusion
- Vision Properties
 - Contrast sensitivity
 - Simultaneous Contrast
 - Chromatic Adaption
 - Modulation Transfer Function
 - Mach Band
 - Critical Fusion Frequency
 - Relative luminous efficiency function
- Color & Color Matching & Color Space

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