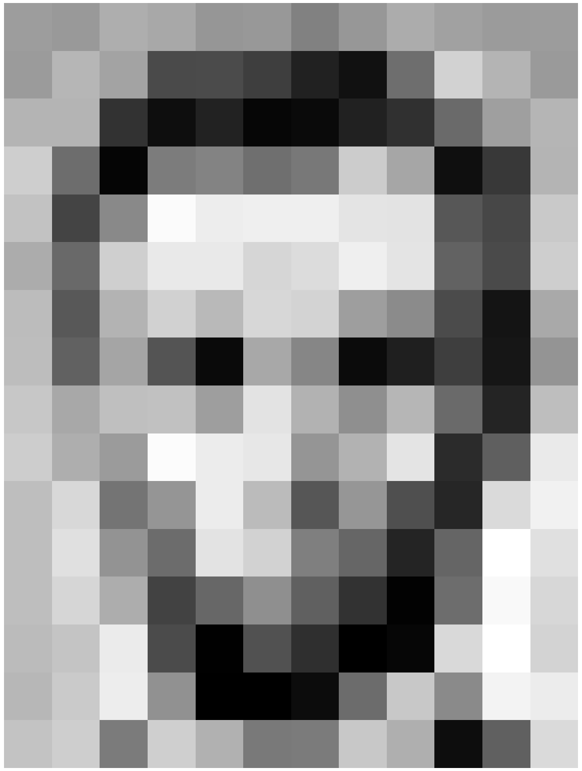
Color

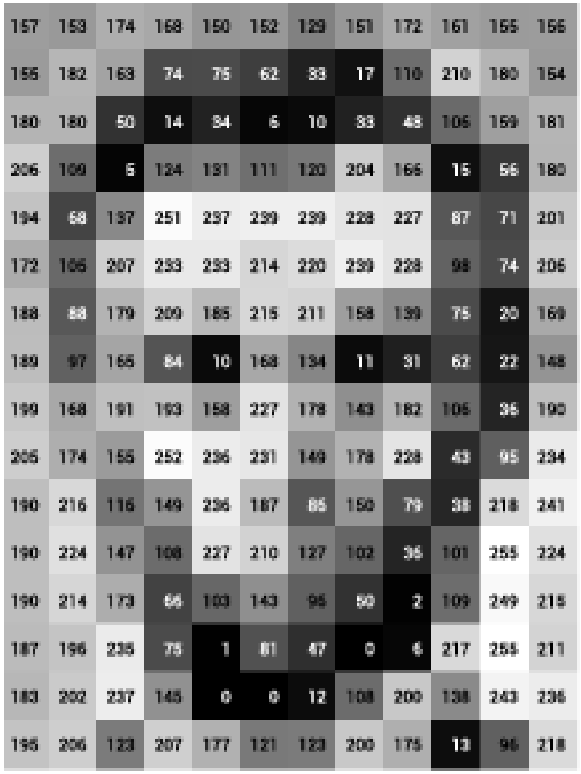
Multimedia Techniques & Applications

Yu-Ting Wu

Gray-Scale Digital Data

- Pixel value for brightness
- 8-bit: black (0), white (255), gray (0 – 255)





157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	95	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

Color is Important

Color is Important (cont.)

How Do We Represent Color Data?

Outline

- Color science
- Tristimulus theory
- RGB color model
- Other color models
- User interface for color selection

Outline

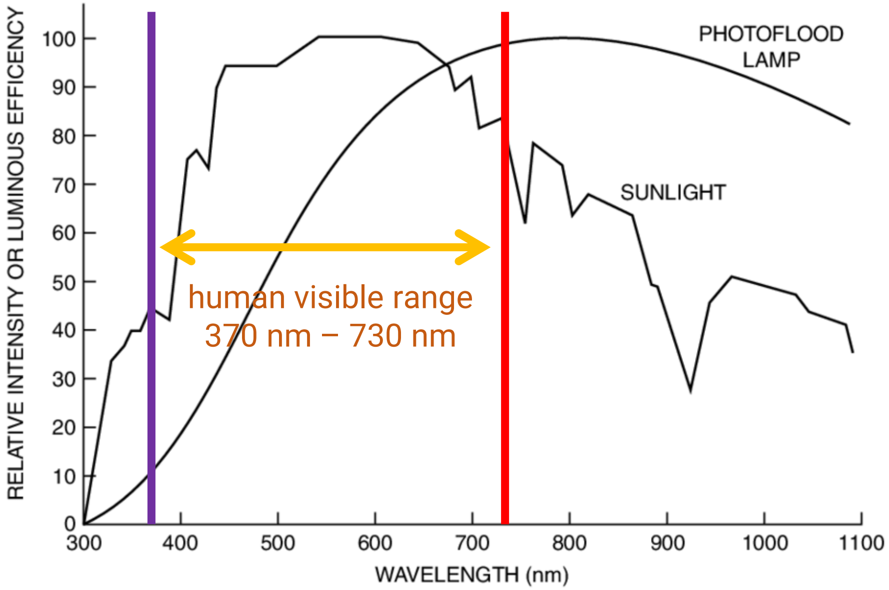
- **Color science**
- Tristimulus theory
- RGB color model
- Other color models
- User interface for color selection

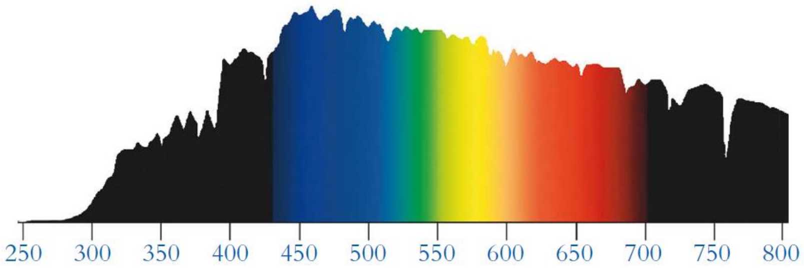
Color Science

- Color is a common experience for humans, but is a rather **complex phenomenon**
- Color science is a topic that attempts to relate the **subjective sensation** of color to **measurable** and **reproducible** physical phenomena
- Obviously, color comes from **lights**, so we will start with the spectral power distribution of light

Spectral Power Distribution

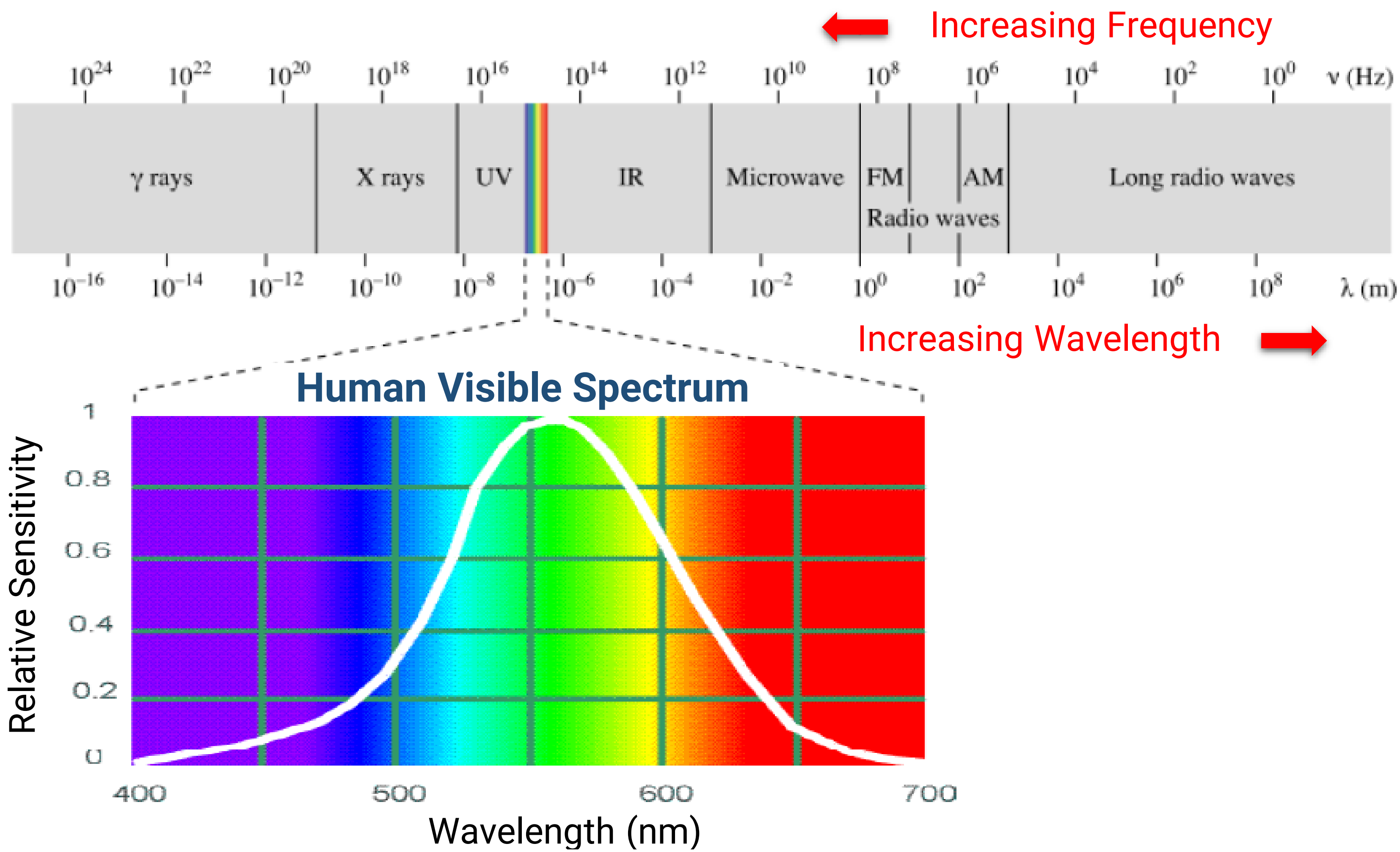
- Light is an electromagnetic wave, and we can measure its wavelength and intensity
- **Spectral power distribution (SPD)** is a description of how the intensity of light varies with its wavelength





SPD of daylight

Spectral Power Distribution (cont.)



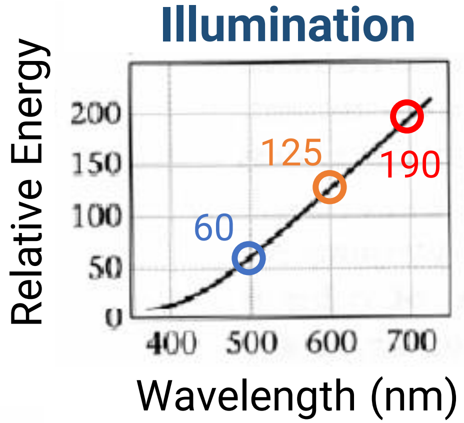
Human Luminance Sensitivity Function

Color

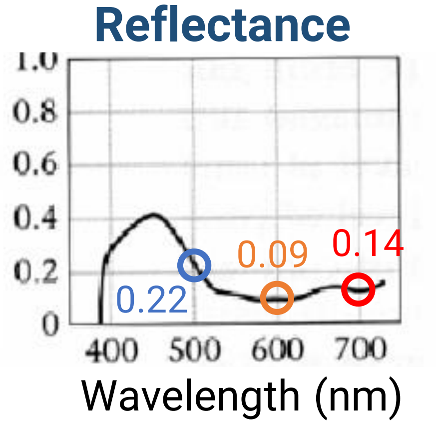
- Reflected color is the result of interaction of **light source spectrum** with **surface reflectance**

Color

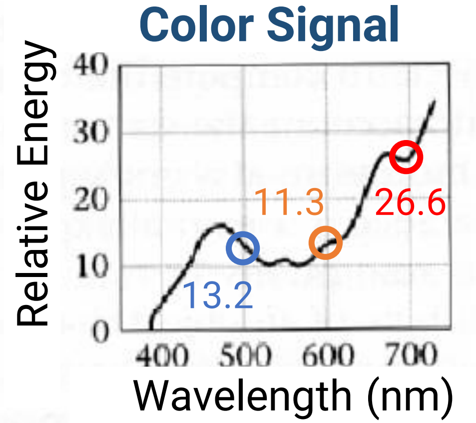
- Reflected color is the result of interaction of **light source spectrum** with **surface reflectance**



*



=



Outline

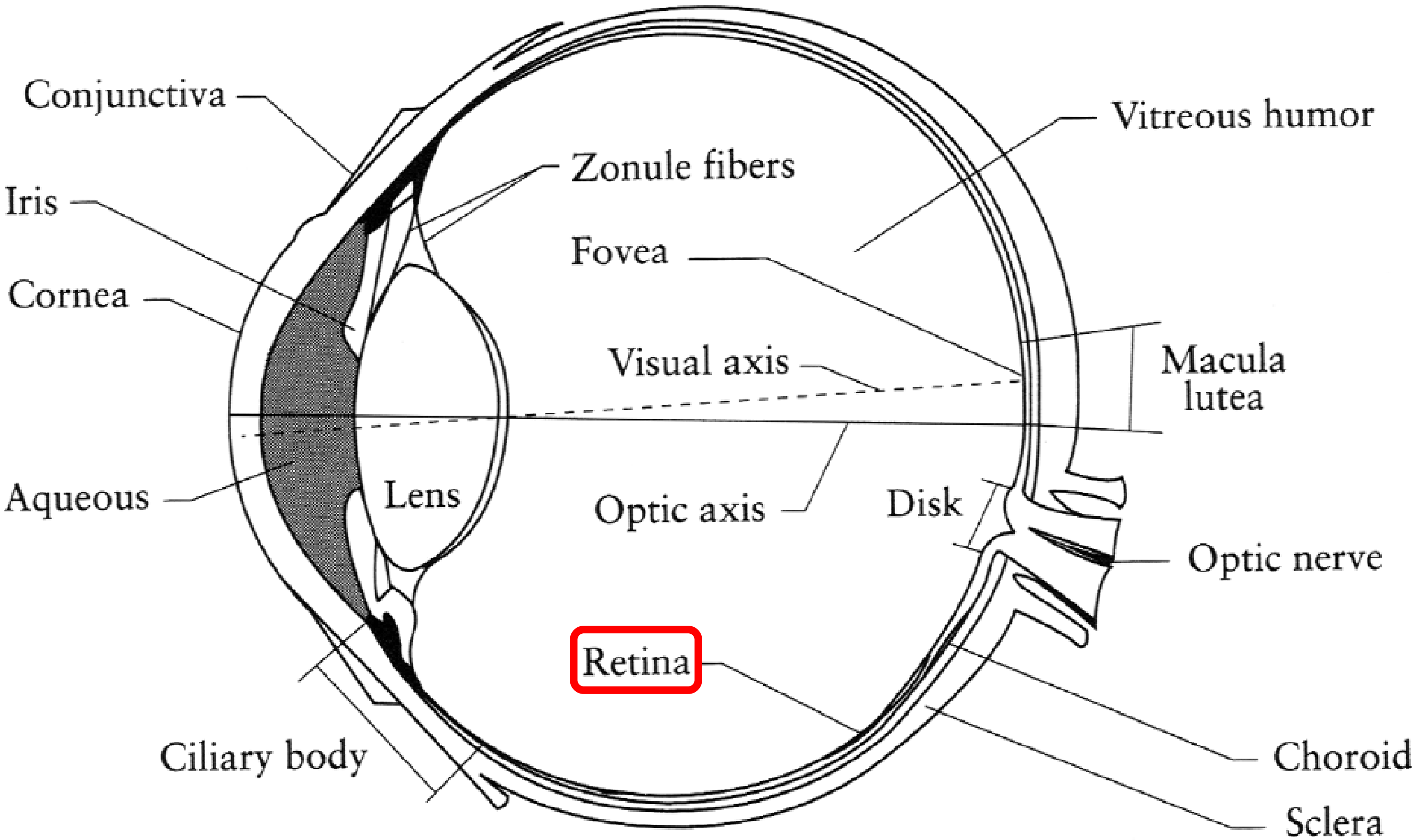
- Color science
- **Tristimulus theory**
- RGB color model
- Other color models
- User interface for color selection

Tristimulus Theory

- SPDs are too cumbersome for representing the color in computer graphics
- Need a more compact, efficient, and accurate way to represent color signals
  - Find proper basis functions to map the infinite-dimensional space of all possible SPDs to a **low-dimensional space of coefficients**
- We use the **tristimulus theory**
  - All visible SPDs can be accurately represented with **three values**

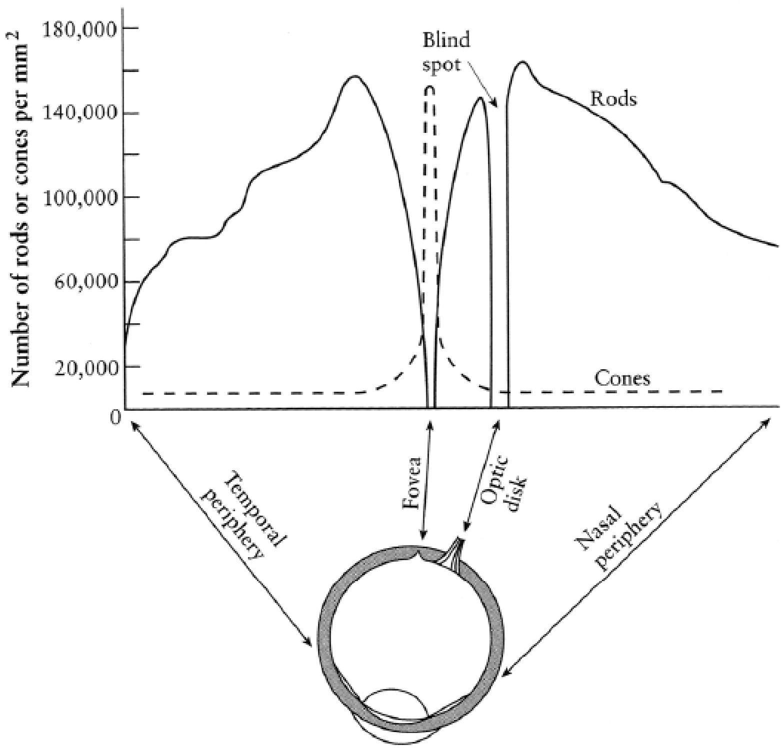
  = Any color can be specified by just three values, giving the weights of each of the three components

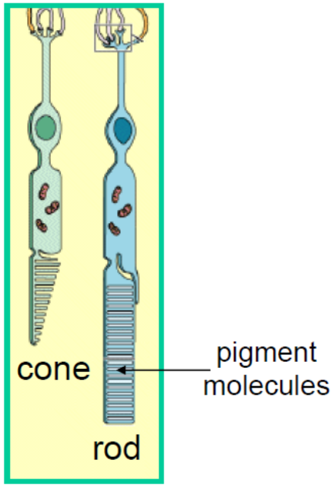
Human Eye

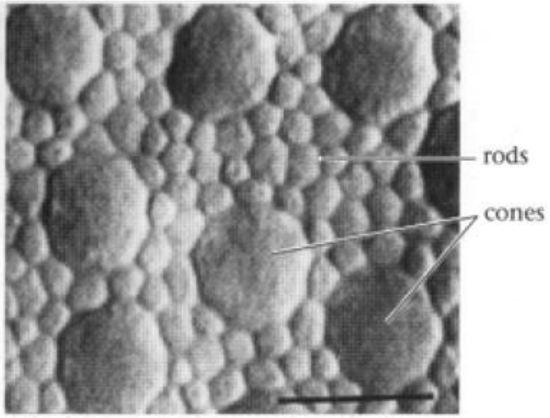

Conjunctiva
Iris
Cornea
Aqueous
Ciliary body
Zonule fibers
Fovea
Visual axis
Lens
Optic axis
Retina
Disk
Vitreous humor
Macula
lutea
Optic nerve
Choroid
Sclera

Rods and Cones

- Two types of cells on the retina: rods and cones
  - **Rods:** responsible for **intensity (125M)**
  - **Cones:** responsible for **color (6M~7M)**

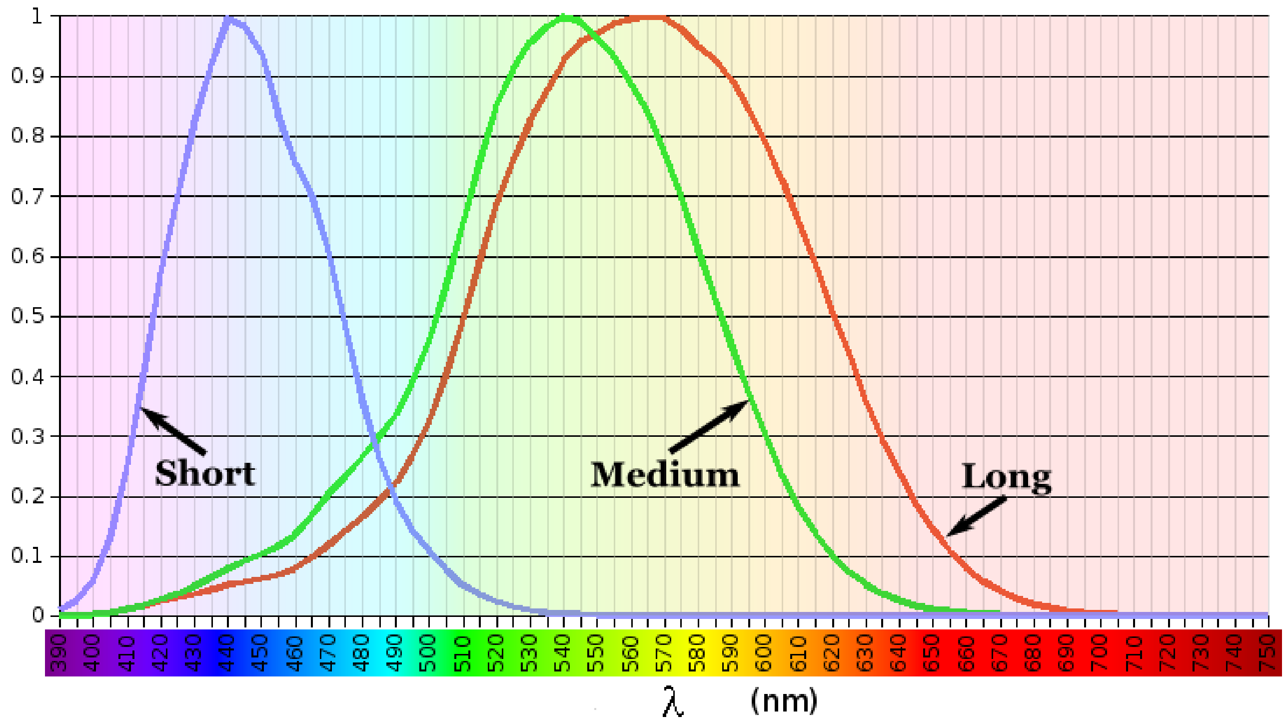






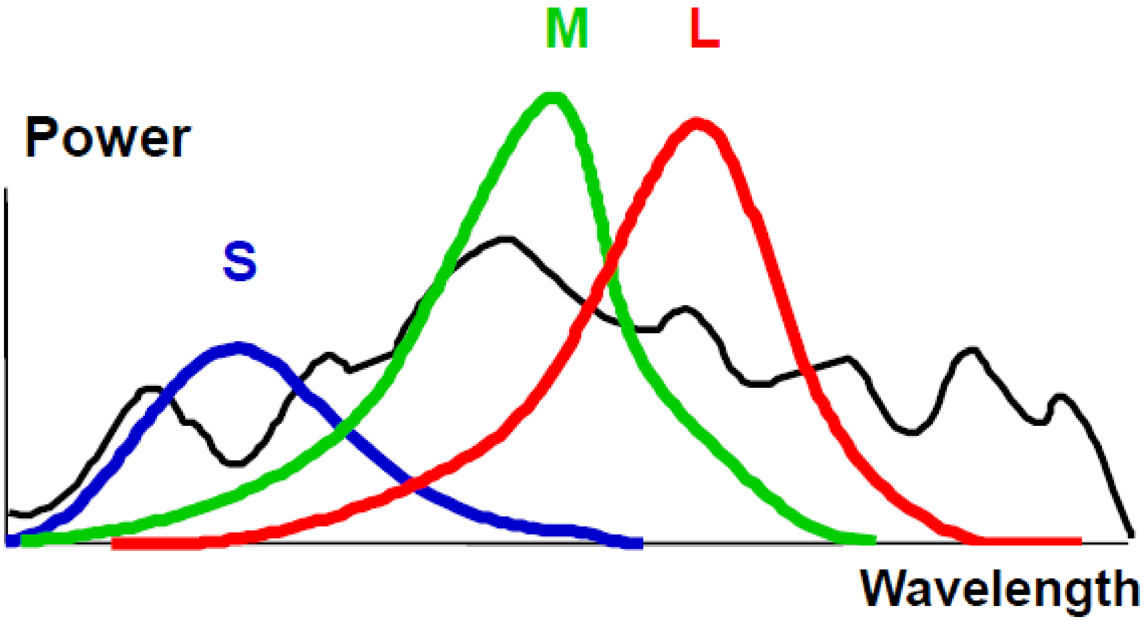
Three Types of Cone Cells

- **L-cones: 564 nm (Long)**
- **M-cones: 534 nm (Medium)**
- **S-cones: 420 nm (Short)**

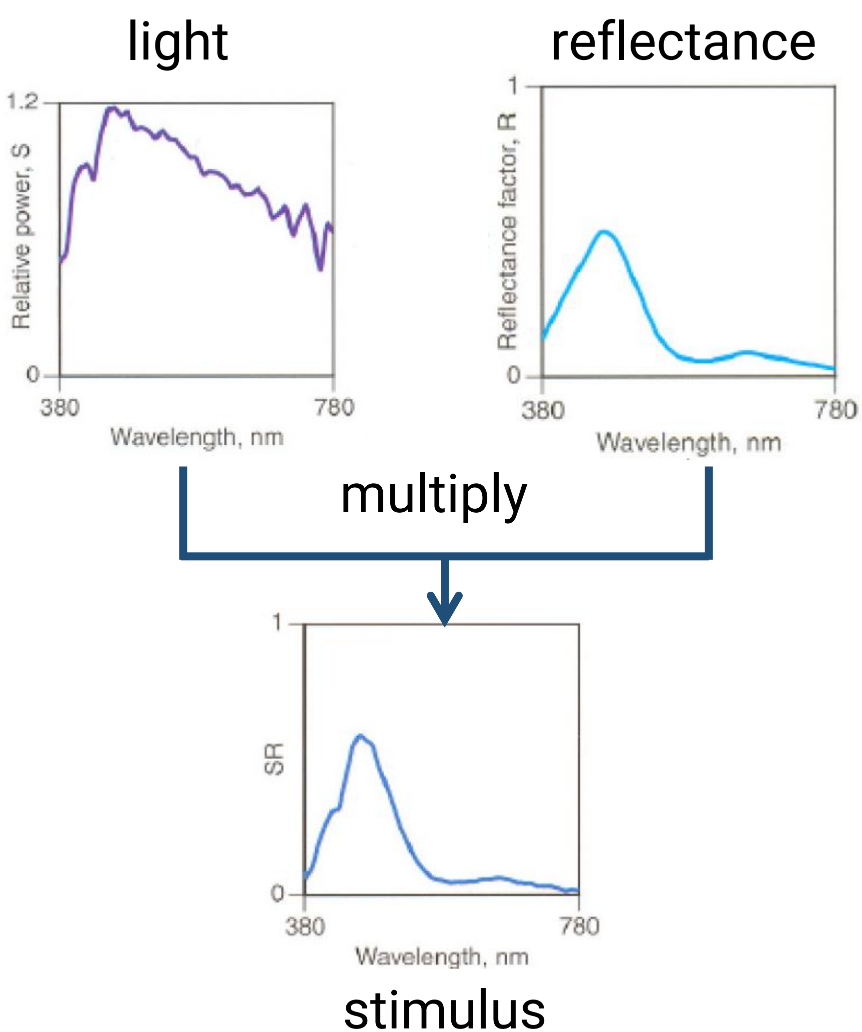


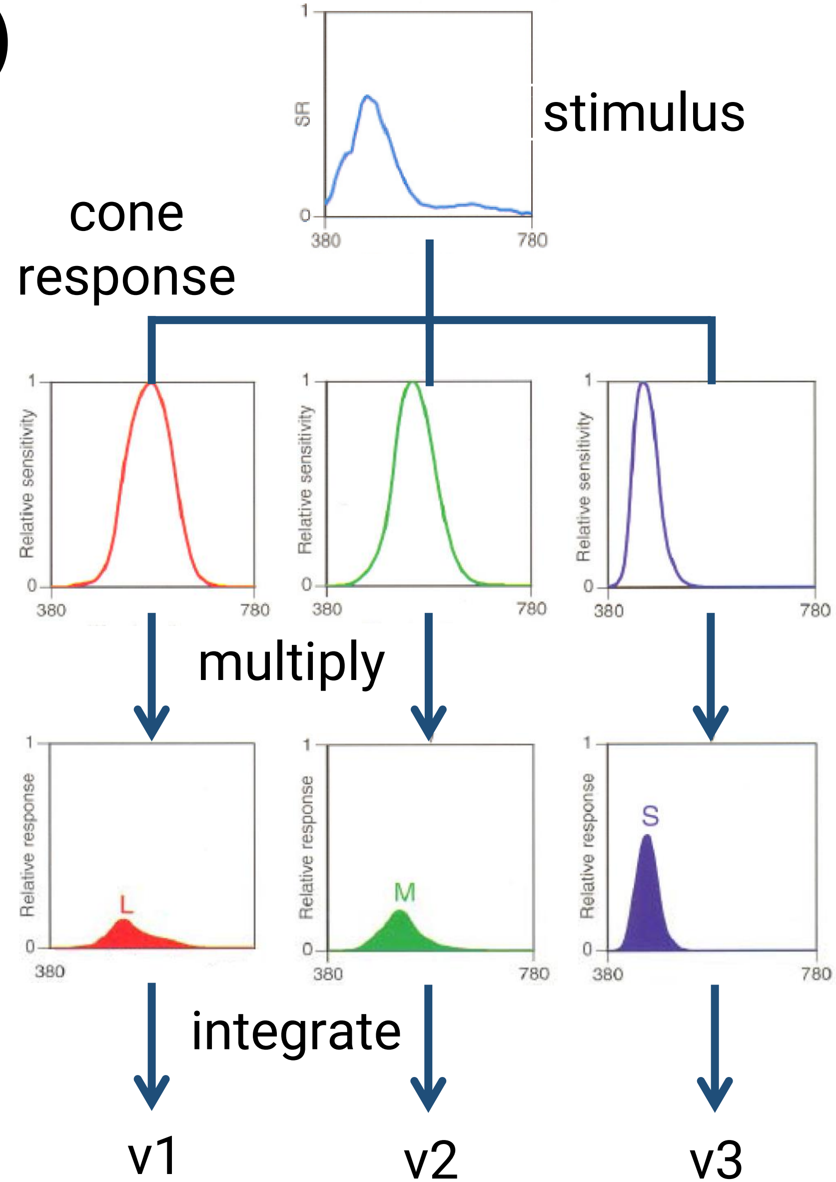
Color Perception

- Rods and cones act as **filters** on the spectrum
  - To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths
  - Each cone yields one number and we just got three numbers in total!



Color Perception (cont.)



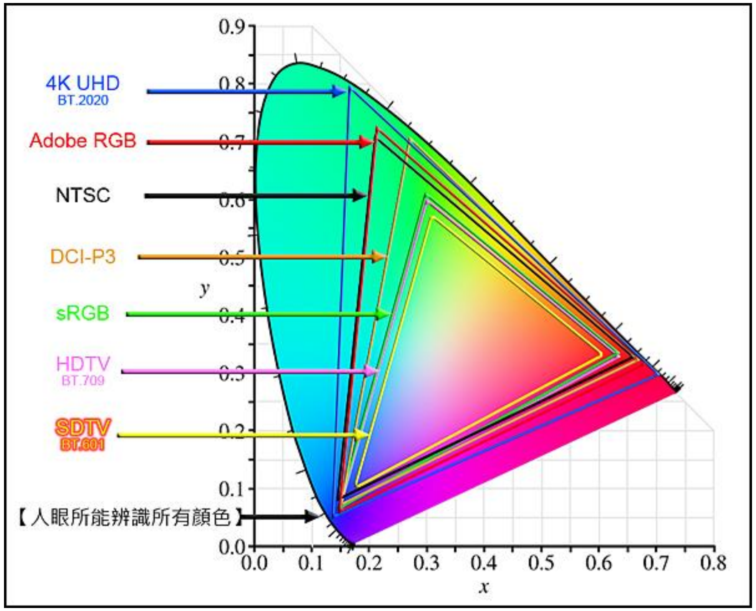


Outline

- Color science
- Tristimulus theory
- **RGB color model**
- Other color models
- User interface for color selection

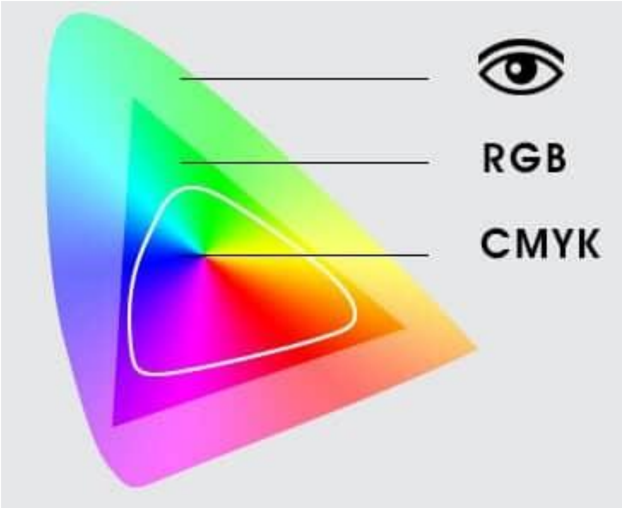
RGB Color Model

- The **tristimulus theory** and the **response curves of LMS cones** lead to the RGB model
  - Any color can be represented by three values, giving the proportions of red (R), green (G), and blue (B) light
  - However, no standard SPDs are defined for R, G, and B



RGB Color Gamut

- Although RGB model provides a good representation for color, it cannot represent all visible color of human eye
- RGB primaries do produce the **largest** gamut from simple addition of three primaries
- Red, green, and blue are called the **primary color** of light (additive mixing)



RGB Color Model Representation

- We can write a color with RGB model in the form of

(r, g, b),

where r, g ,b are the **amounts (proportion of the pure light)** of red, green, and blue light making up the color

Red (100%, 0%, 0%)	Black (0%, 0%, 0%)	Cyan (0%, 100%, 100%)
Green (0%, 100%, 0%)	White (100%, 100%, 100%)	Magenta (100%, 0%, 100%)
Blue (0%, 0%, 100%)	Gray (50%, 50%, 50%)	Yellow (100%, 100%, 0%)

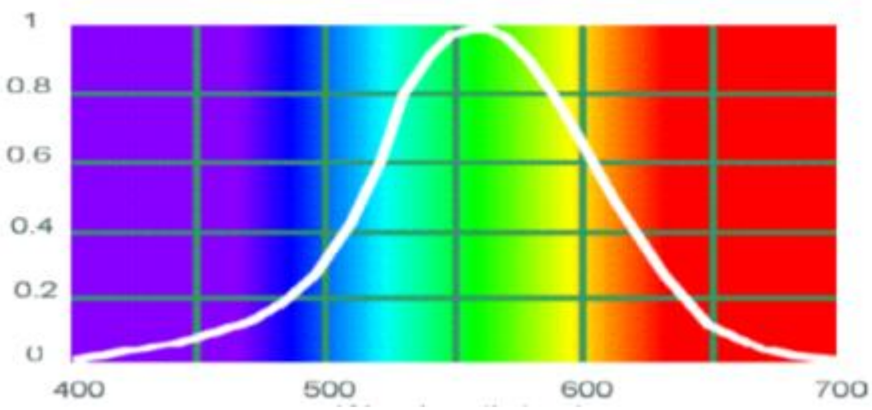
Color Depth

- The number of bits used for a color
- The most common choice is **8 bits** (1 byte) for each primary color, making 24 bits (3 bytes) in total
  - The range of each value falls within [0, 255], making a total of 256 x 256 x 256 = 16777216 different colors

Red (255, 0, 0)	Black (0, 0, 0)	Cyan (0, 255, 255)
Green (0, 255, 0)	White (255, 255, 255)	Magenta (255, 0, 255)
Blue (0, 0, 255)	Gray (127, 127, 127)	Yellow (255, 255, 0)

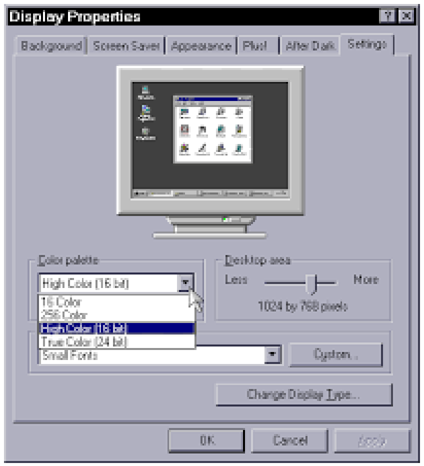
Color Depth (cont.)

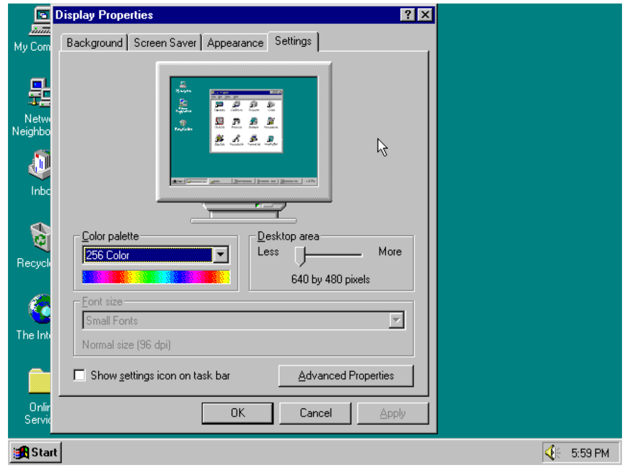
- Typically, 24-bit color is sufficient for human eyes
- Other possibilities (usually in earlier devices)
  - 1-bit color: two different colors (black or white)
  - 4-bit color: 16 different colors
  - 8-bit color: 256 different colors (earlier games or internet)
  - 16-bit color: 65536 different colors (**5** bits for red and blue, **6** bits for green)

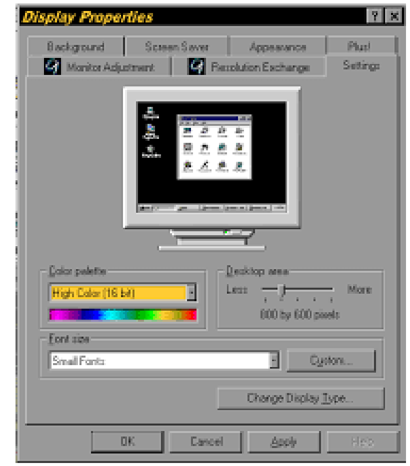


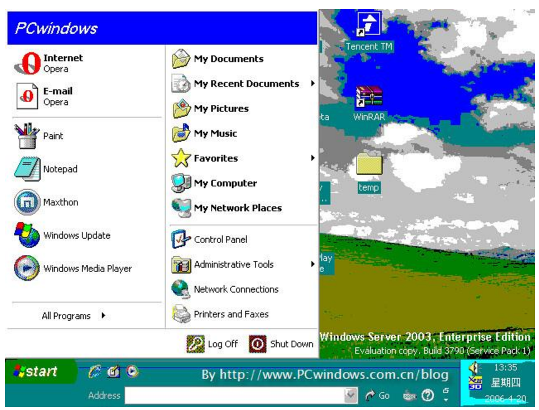
Human Luminance Sensitivity Function

Color Depth (cont.)







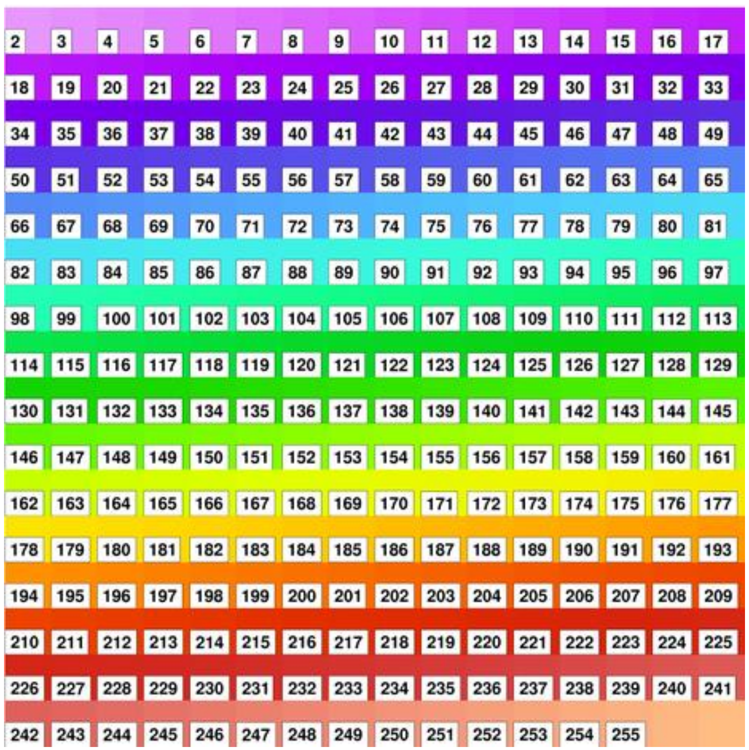


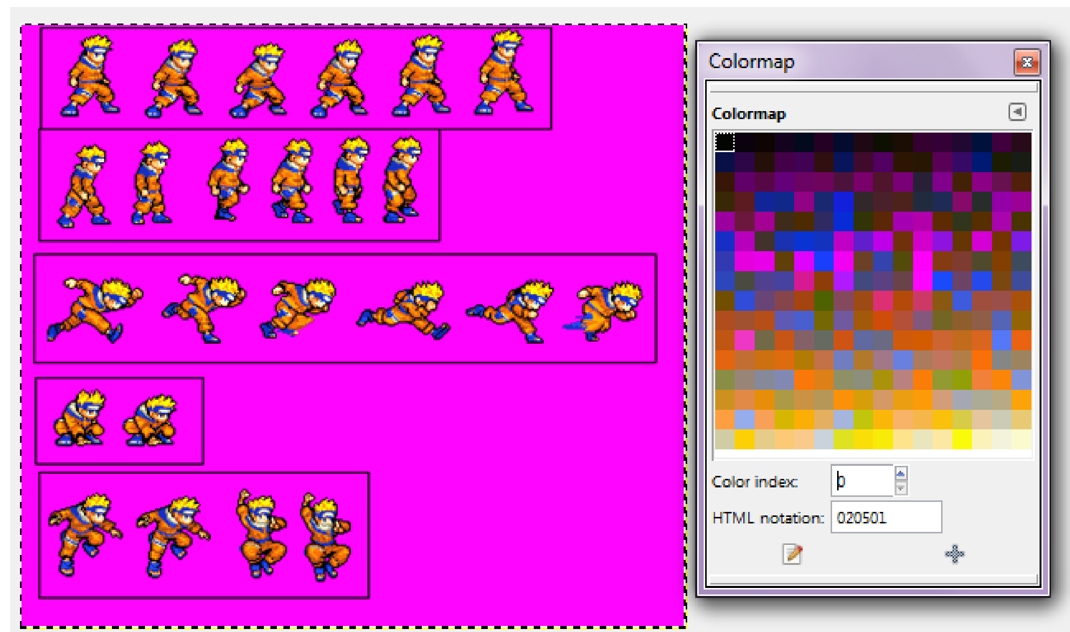
Windows with 16 different colors

Game with 256 different colors

Indexed Color

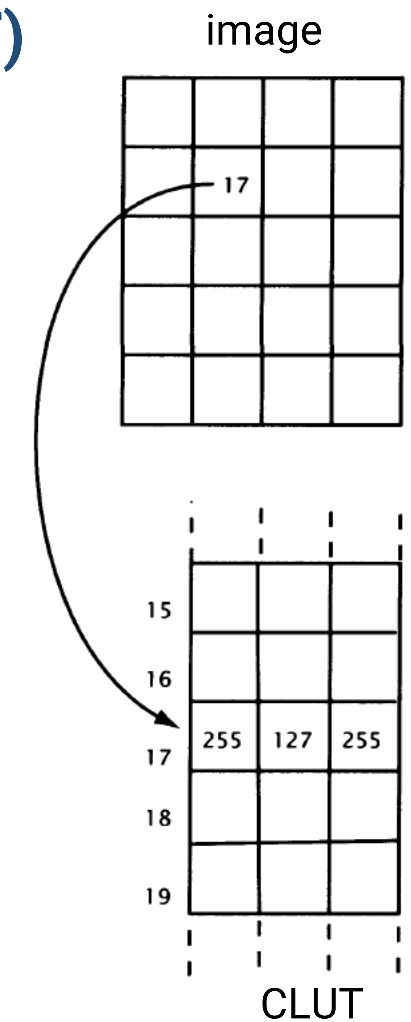
- For some applications, colors can also be stored or represented by an indexed table
- Using a **palette** of *N* specific colors with **each image**





Indexed Color (cont.)

- Implementation: **Color Lookup Table (CLUT)**
  - When an image is displayed, the graphics system looks up the color from the palette corresponding to each **single byte value stored at each pixel**
  - Need to load the correct palette
  - Use the default system palette if no palette is supplied (can have a bad look though)



Outline

- Color science
- Tristimulus theory
- RGB color model
- **Other color models**
- User interface for color selection

CMYK

- **C**yan **(C)**, **M**agenta **(M)**, **Y**ellow **(Y)**, and Blac**k** **(K)**
- Subtraction of light

$$\boldsymbol{W = R + G + B}$$

$$\boxed{C} = G + B = W - \boxed{R}$$

$$\boxed{M} = R + B = W - \boxed{G}$$

$$\boxed{Y} = R + G = W - \boxed{B}$$

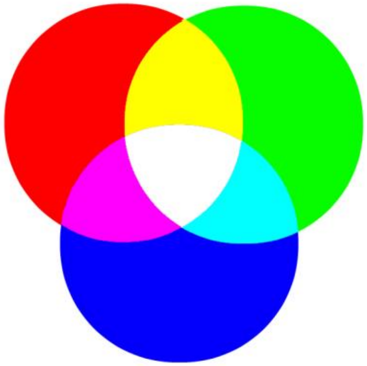
complementary color

Cyan
(0%, 100%, 100%)

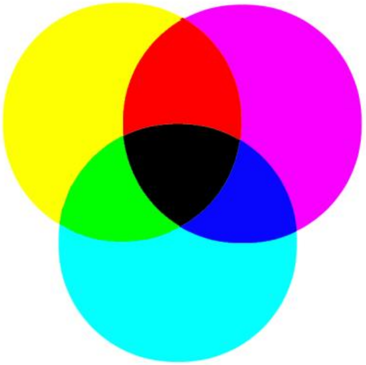
Magenta
(100%, 0%, 100%)

Yellow
(100%, 100%, 0%)

  - Appropriate to ink and paint (absorb lights)



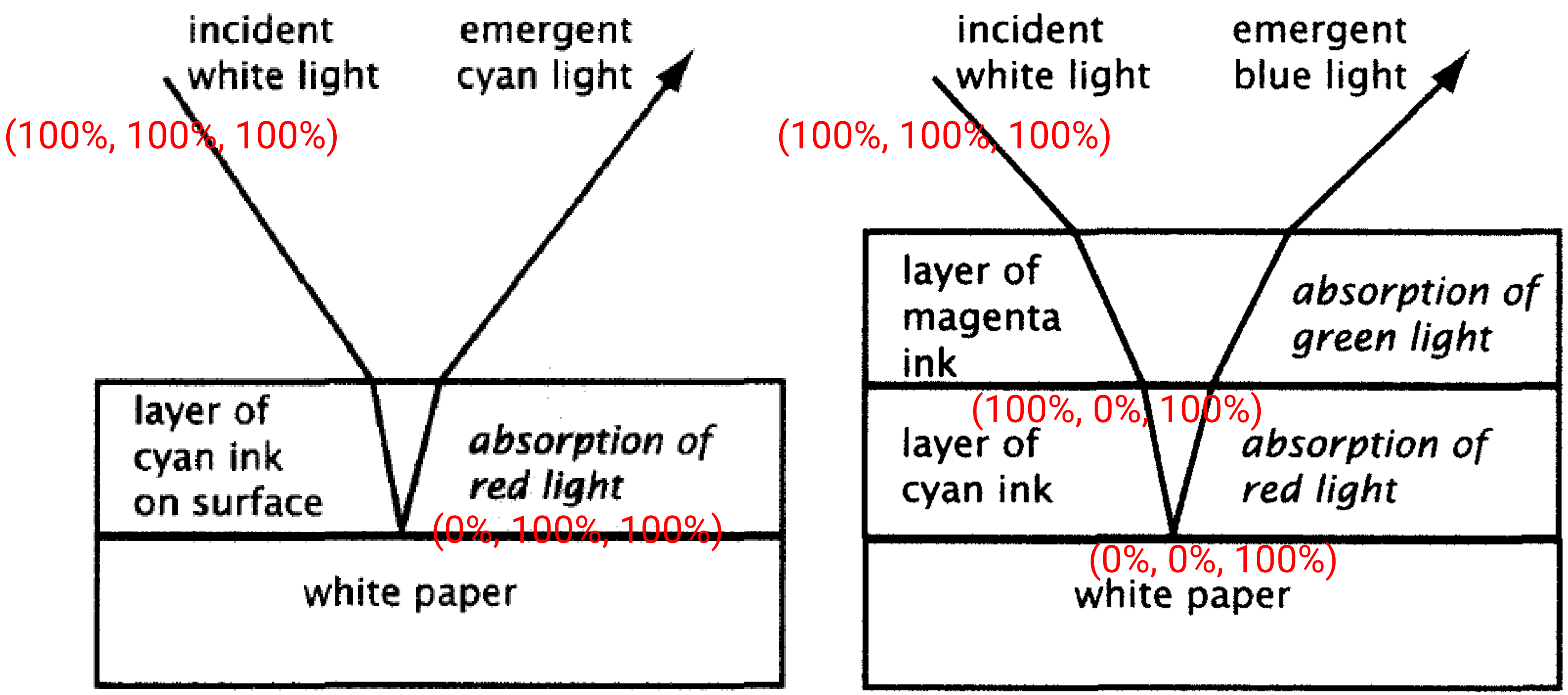
R + G + B = White



C + M + Y = K (Black)

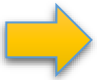
CMYK (cont.)

- Effect of color ink



CMYK (cont.)

- In practice, it is not possible to manufacture **perfect inks** which absorb only light of precisely the complementary color
- As a result, the gamut of colors that can be printed using cyan, magenta, and yellow is not the same as the RGB gamut



➡ Ensure all the colors in your printed data are within the CMYK color gamut!

- Furthermore, applying CMY inks does not produce a very good black color
  - So augmented with the black color

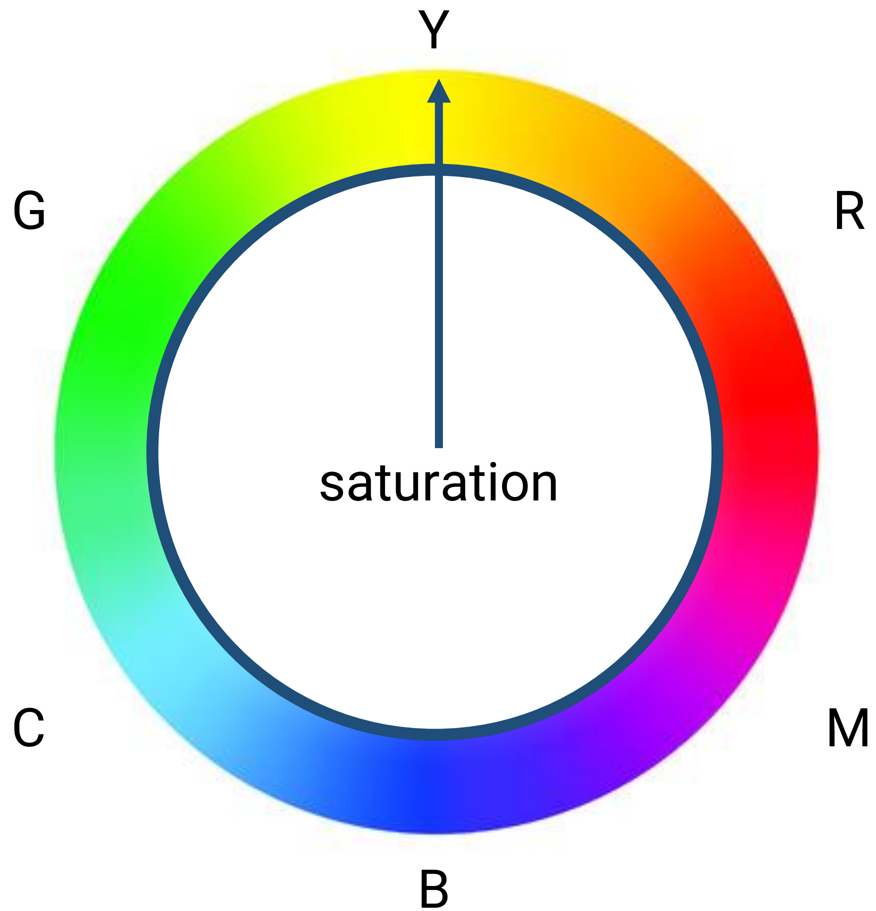
HSV

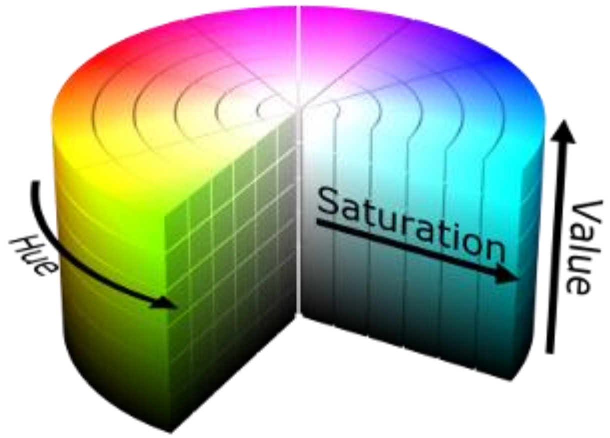
- Breaking a color down into its primary components makes sense from a theoretical point of view but does not correspond to the way we experience colors in the world
  - E.g., cyan is a kind of blue (not green + blue)
  - RGB distance is not a good measure

- **HSV color models**
  - **Hue**: the dominant wavelength and the pure color of light
  - **Saturation**: a measure of a color’s purity
    - Saturated colors are pure hues
    - Saturation decreases as white is mixed in
  - **Brightness (Value)**: a measure of how light or dark a color is

HSV (cont.)

- Color wheel





Color Harmonization

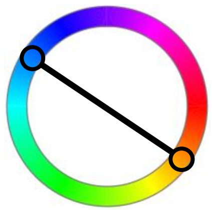
- Daniel et al., SIGGRAPH 2006

original image

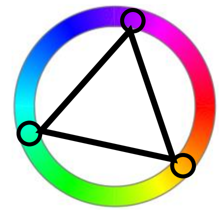
harmonized image

Background

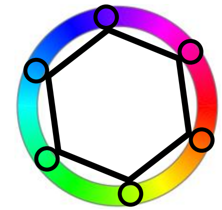
- Itten [1960]: harmony means **relationships** on the **hue** wheel



2-color harmony: complementary colors

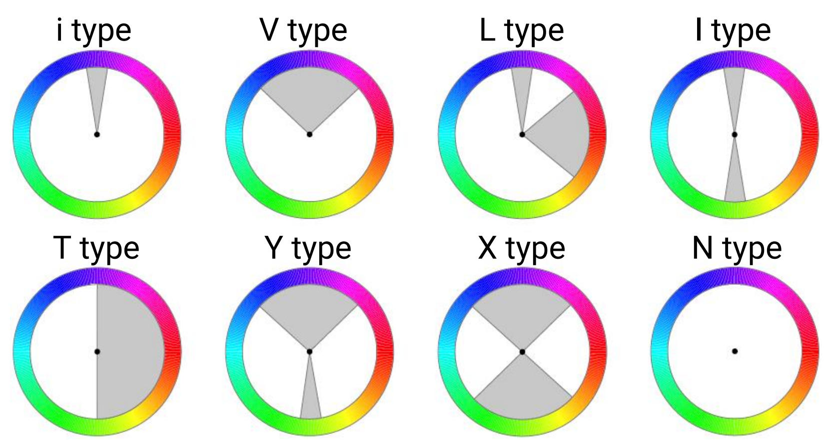


3-color harmony: equilateral triangle



N-color harmony: equilateral N-gon

- Matsuda [1995]: extensive empirical studies, derived **8 hue templates**

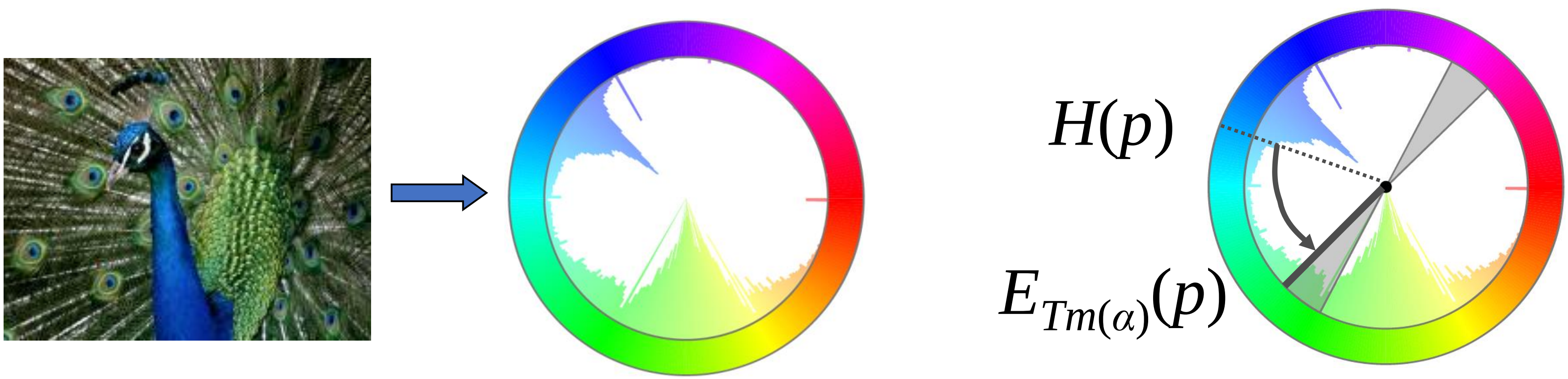


- The templates can be **arbitrarily rotated**

Harmonic Scheme and Harmonic Function

- **Harmonic scheme** is template type T_m + specific orientation α
- Define the **harmonic function**:
  - The harmony of image ***X*** w. r. t. harmonic scheme (T_m, α)

$$F\left(X,(T_m,\alpha)\right)=\sum_{p\in X}\left\|H(p)-E_{Tm(\alpha)}(p)\right\|\cdot S(p)$$

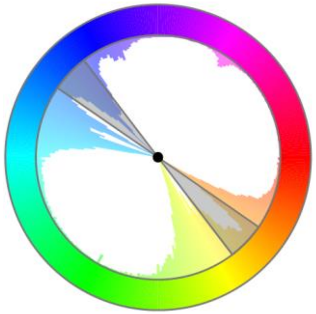


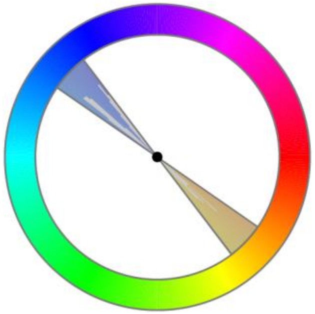
Harmonization

- **Best template**
  - Compute α that minimizes $F(X, (T_m, \alpha))$ for each template T_m using Brent's algorithm
  - The best-fitting harmonic scheme:

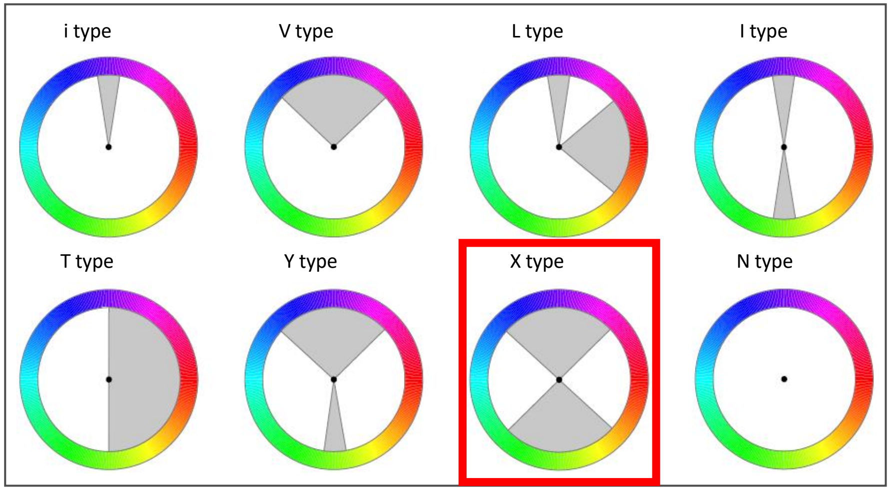
$$(T_{m_0}, \alpha_0) = \arg\min_{(m,\alpha)} F\left(X, (T_m, \alpha)\right)$$

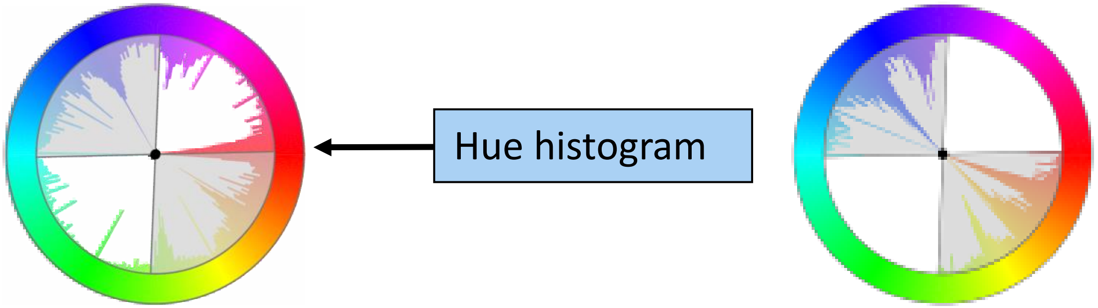
- **Harmonization**
  - Given (T_m, α) we shift the hues so that the hue histogram is contained in (T_m, α)



Color Harmonization Example



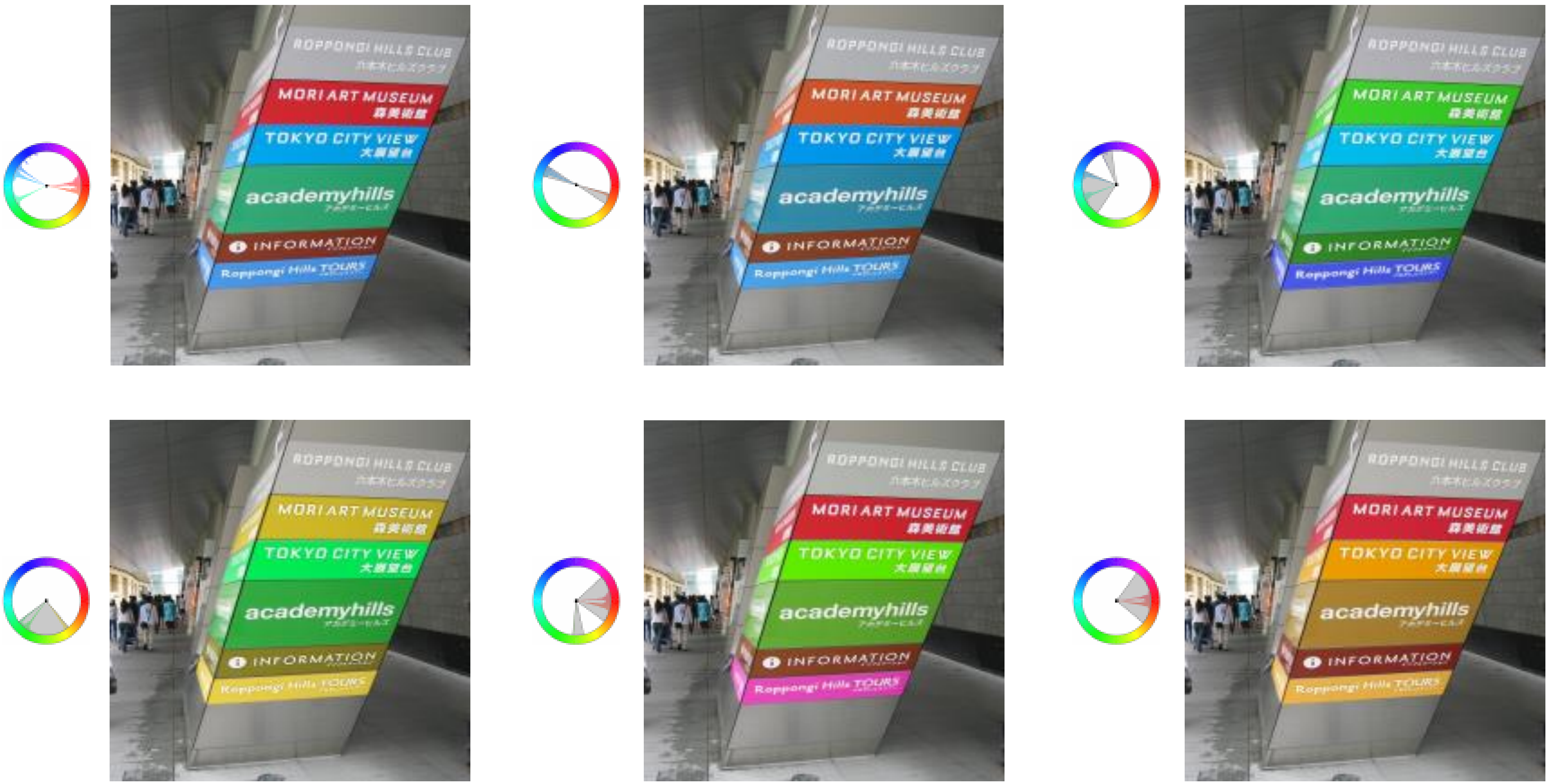


Results

- Matching the colors coming from different sources

Results (cont.)

- Choosing colors



Results (cont.)

- Cut and paste

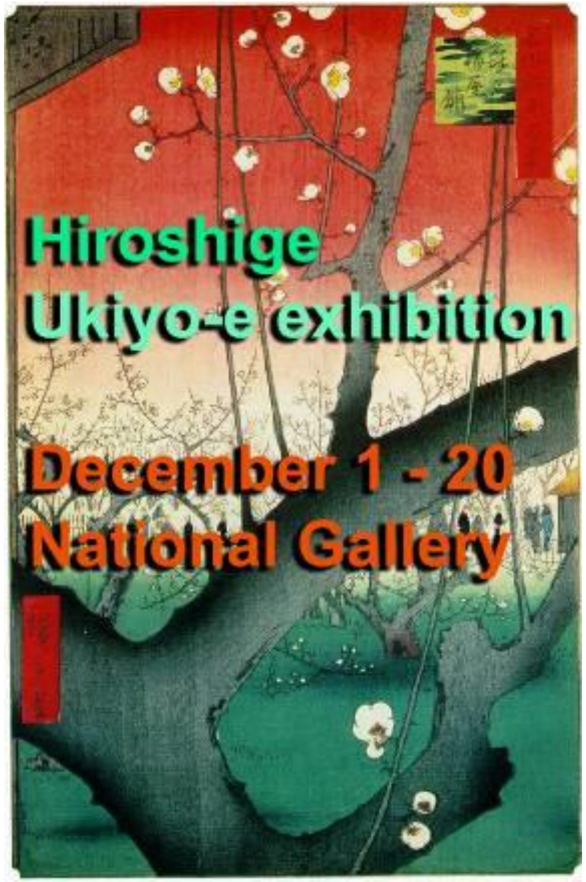

original

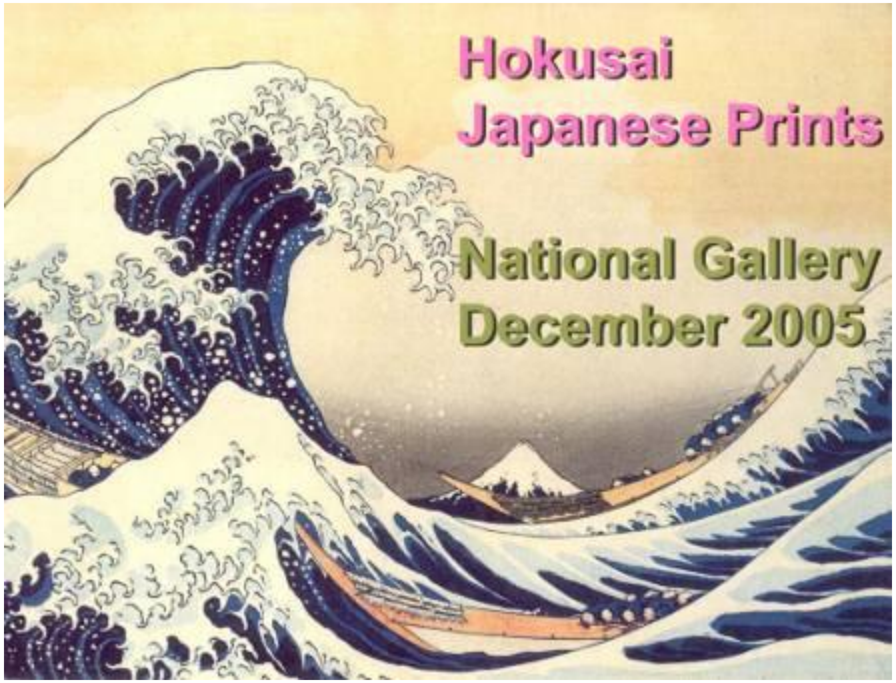

harmonized


harmonized

Results (cont.)

- Text over a poster





YUV

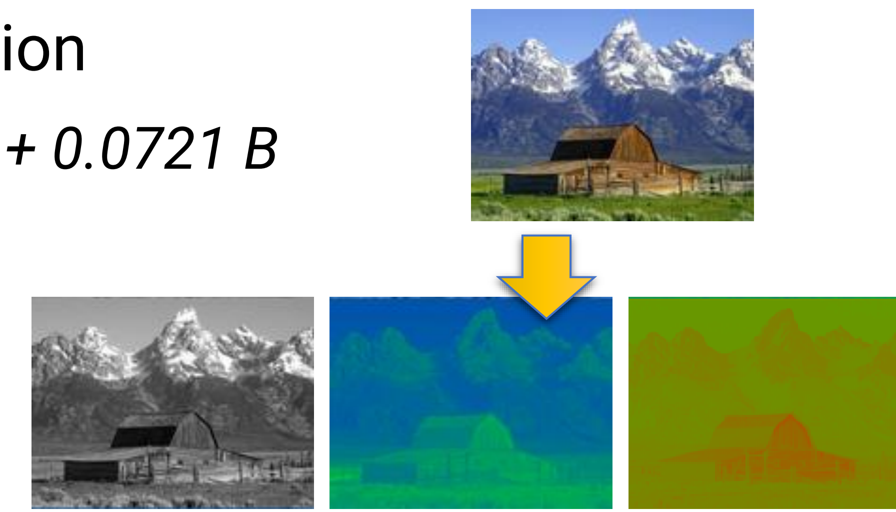
- It is usually useful to **separate the brightness information of an image from its color**
  - E.g., transmit color TV signals that would be compatible with older black and white receivers
  - It becomes possible to use less bandwidth for color transmission than the brightness
- Brightness (Value) calculation

luminance $\boxed{Y} = 0.2125\,R + 0.7154\,G + 0.0721\,B$

- Chroma definition

$$U = B - Y$$

$$V = R - Y$$

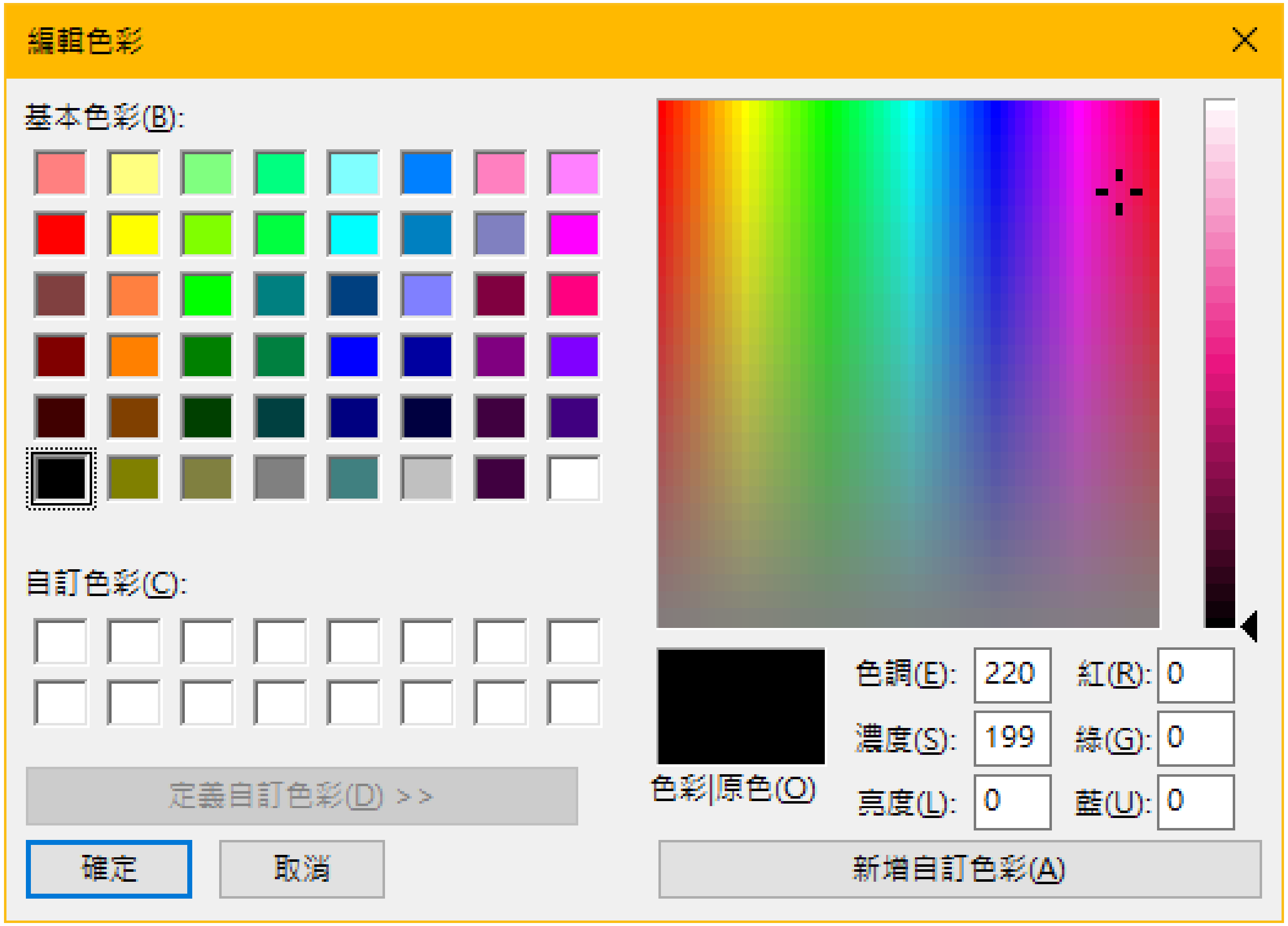


Outline

- Color science
- Tristimulus theory
- RGB color model
- Other color models
- **User interface for color selection**

Example: Power Point

Example: Painter




END OF PRESENTATION
ANY QUESTIONS?