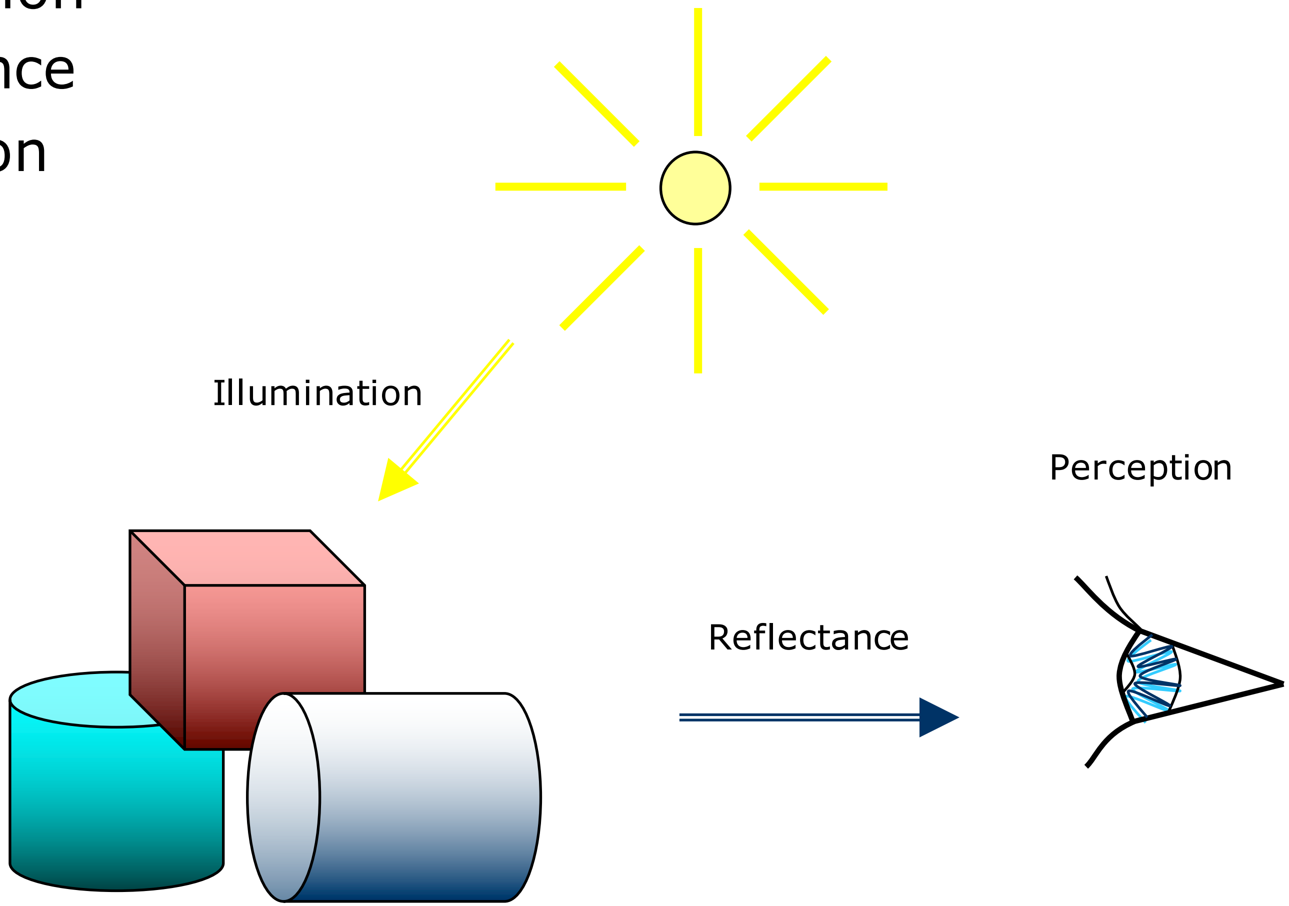
Color Models

Contents

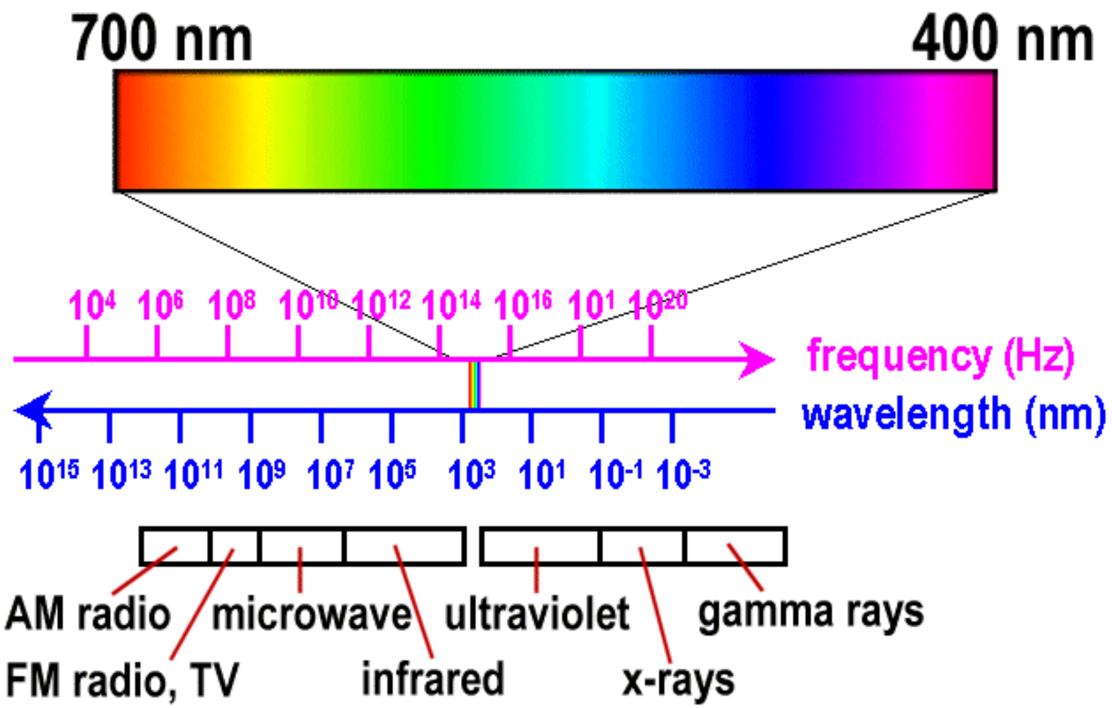
Color elements

- Illumination
- Reflectance
- Perception



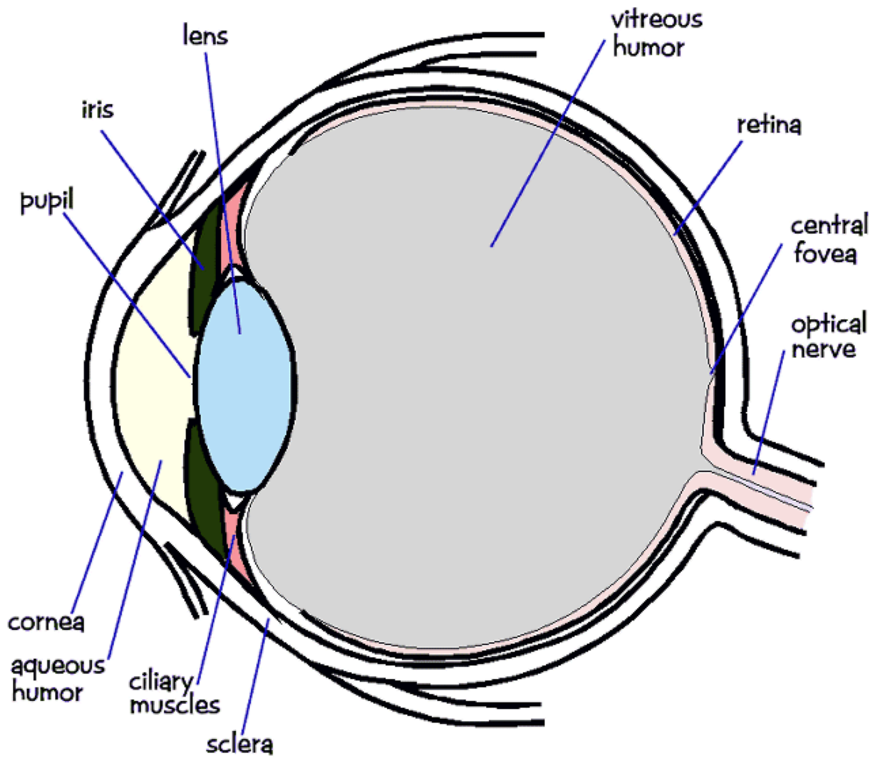
Visible spectrum

- Human eye perceive electromagnetic energy with wavelengths in the range of 400-700 nm as visible light
- It is a very narrow bandwith of the electromagnetic spectrum



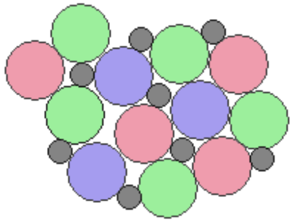
Human eye

- Retina – photosensitive part of the eye
  - Two types of cels: rodsand, cones
  - Cones are responsible for color perception
- Fovea – most densely area of cones
  - Three types of cones: S, M, and L
  - Sensors for blue, green, and red color
  - Peak sensitivity: 430 nm (S-blue), 560 (M-green), 610 nm (L-red)

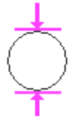


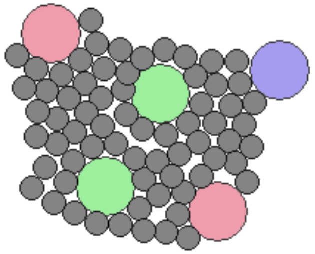
Human eye – the Fovea

Images taken from the course "Computer Graphics" by Pascal Vuylsteker, ANUniv, Australia.

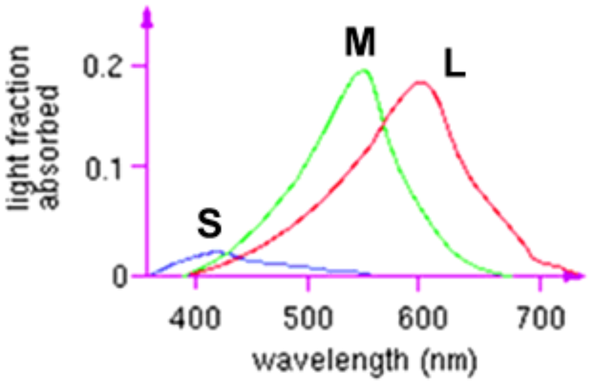


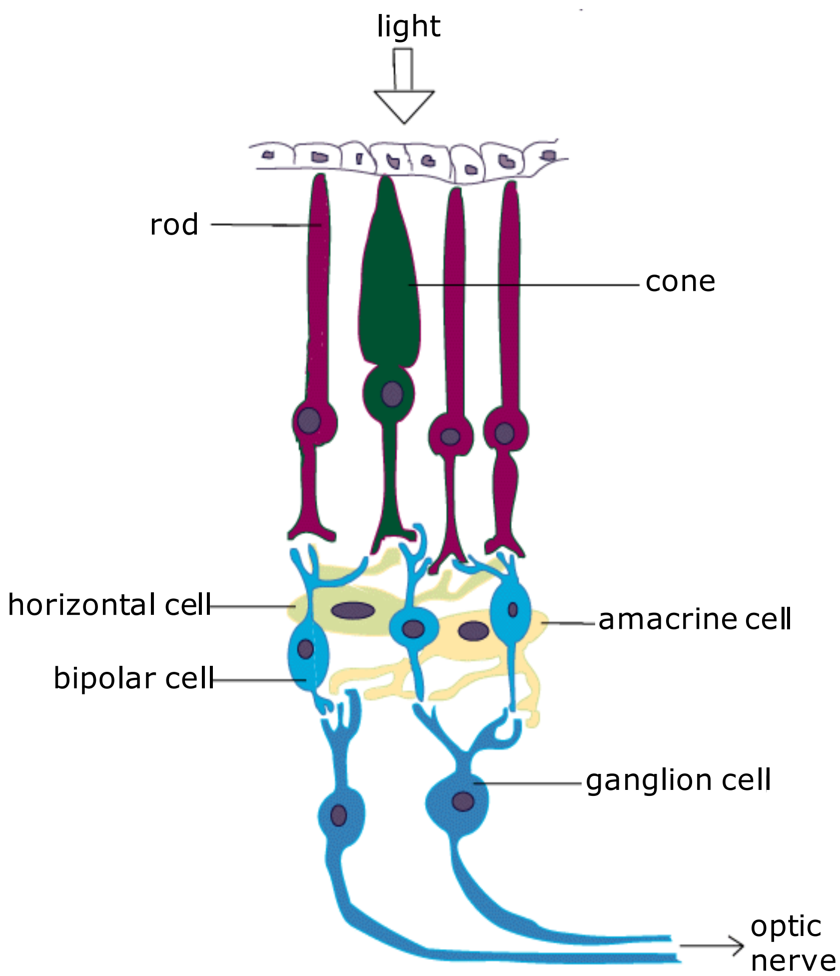
1.35 mm distance from the retina center





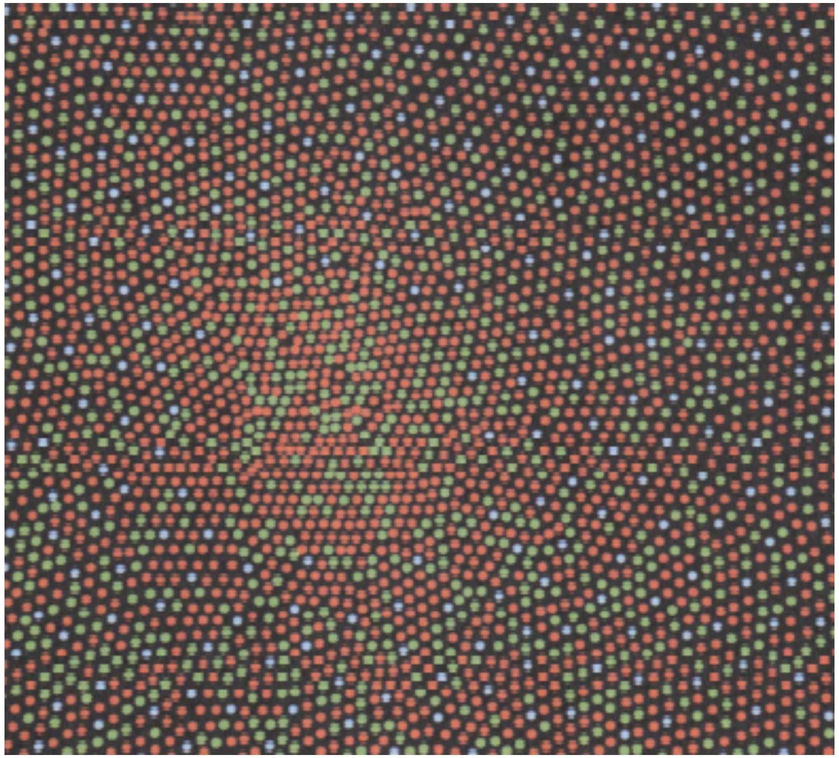
8 mm distance from the retina center





Color perception

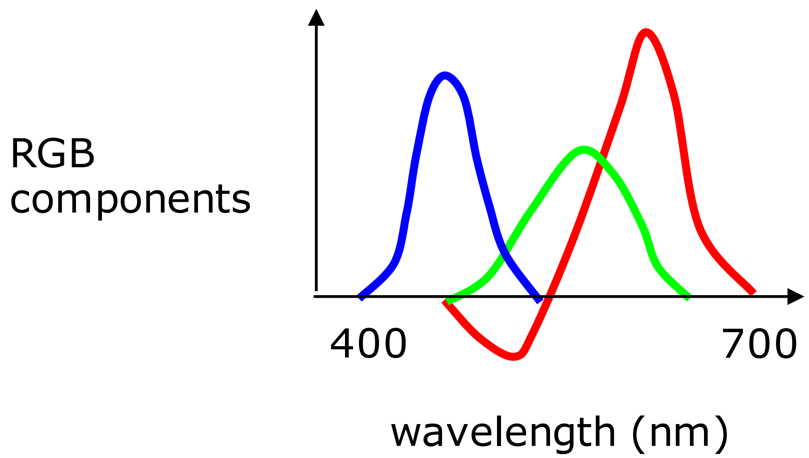
- Gives identical sensation (metamers) for different spectra
- Result of simultaneous stimulation of three cone types (trichromat)
- Affected by contextual effects

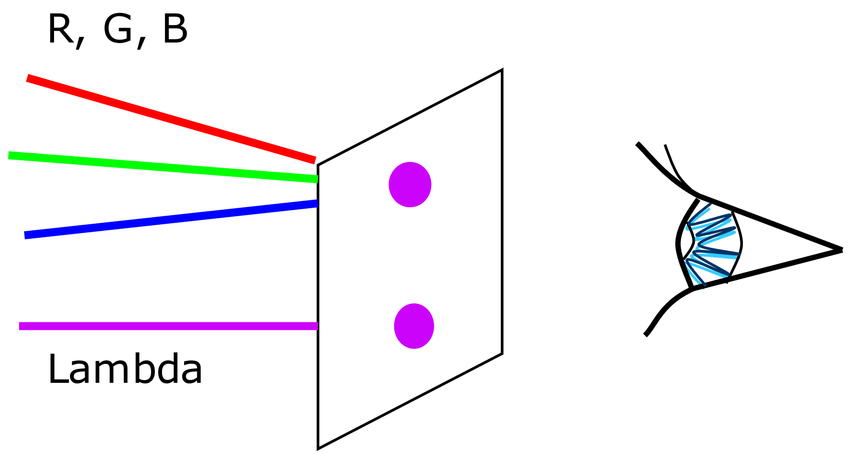


Meryon (a colorblind painter), *Le Vaisseau Fantôme*

Color matching

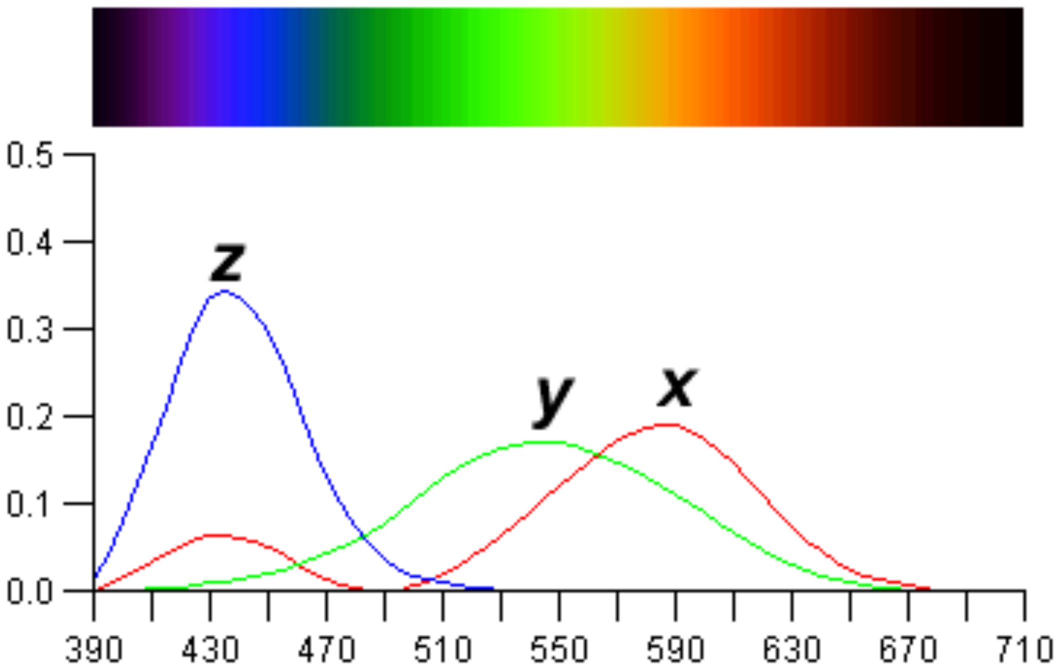
- A given wavelength generated by mixing three pure wavelengths, e.g. R, G, and B
- Color matching by addition, generally
- Negative red – addition before matching the colors on the target





CIE color space

- Uses only positive mixing coefficients
- CIE (Commission Internationale d'Eclairage) defined in 1931 three light sources that give positive matching curves

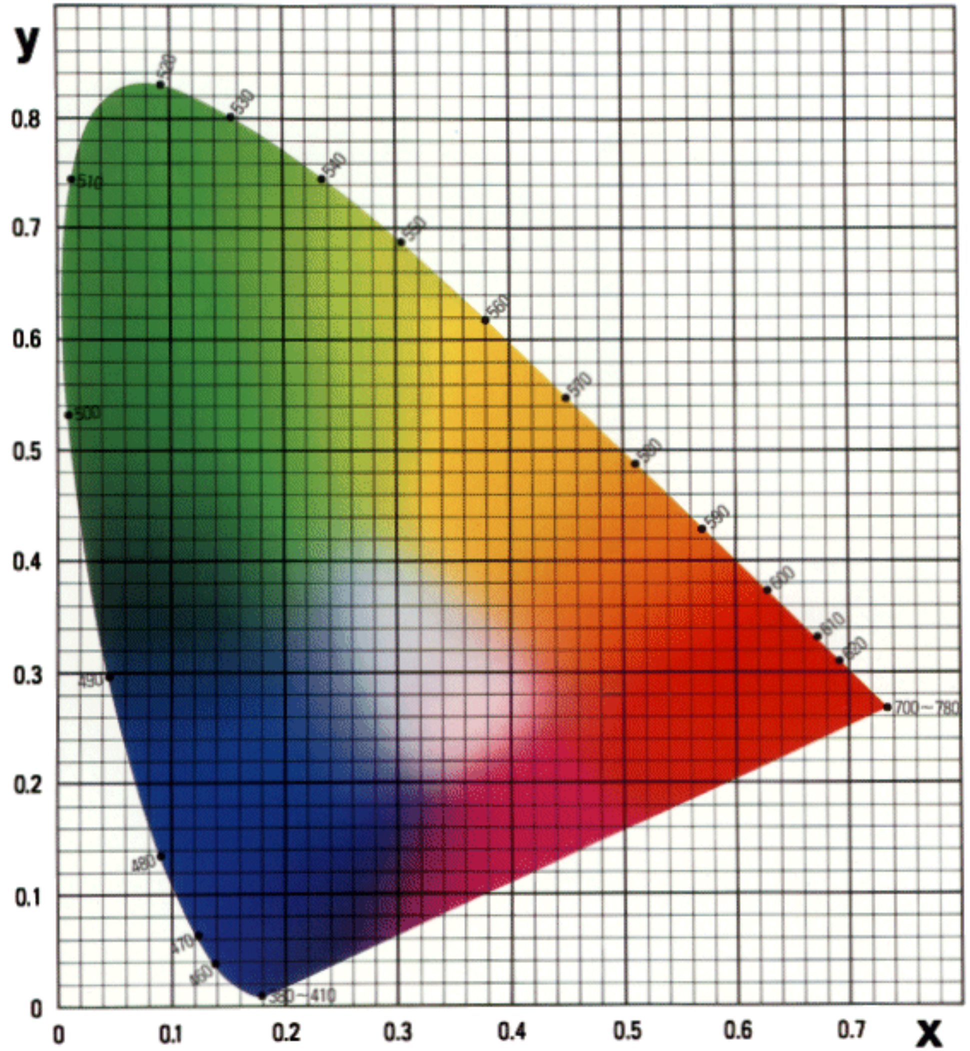


CIE chromaticity diagram

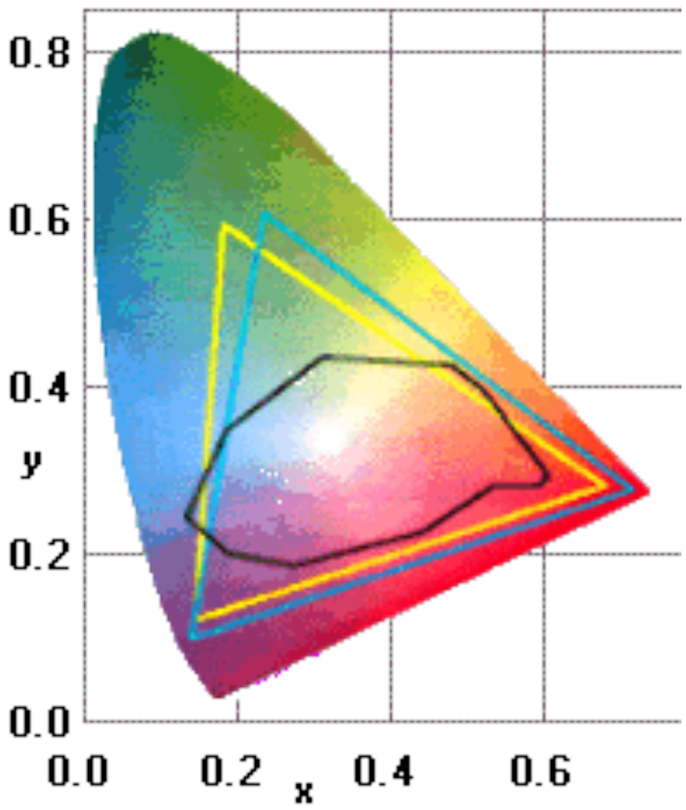
- Graphical relationships between spectrum and X, Y, and Z quantities
- X+Y+Z=1
- Normalization:

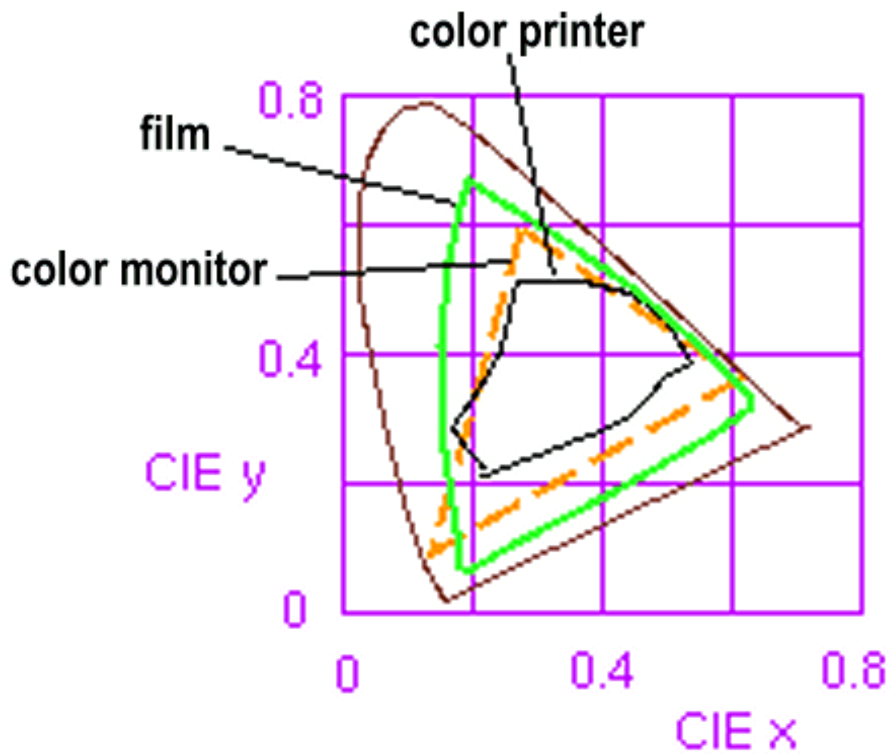
$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z} = 1 - x - y$$



Chromatic capacity of output devices

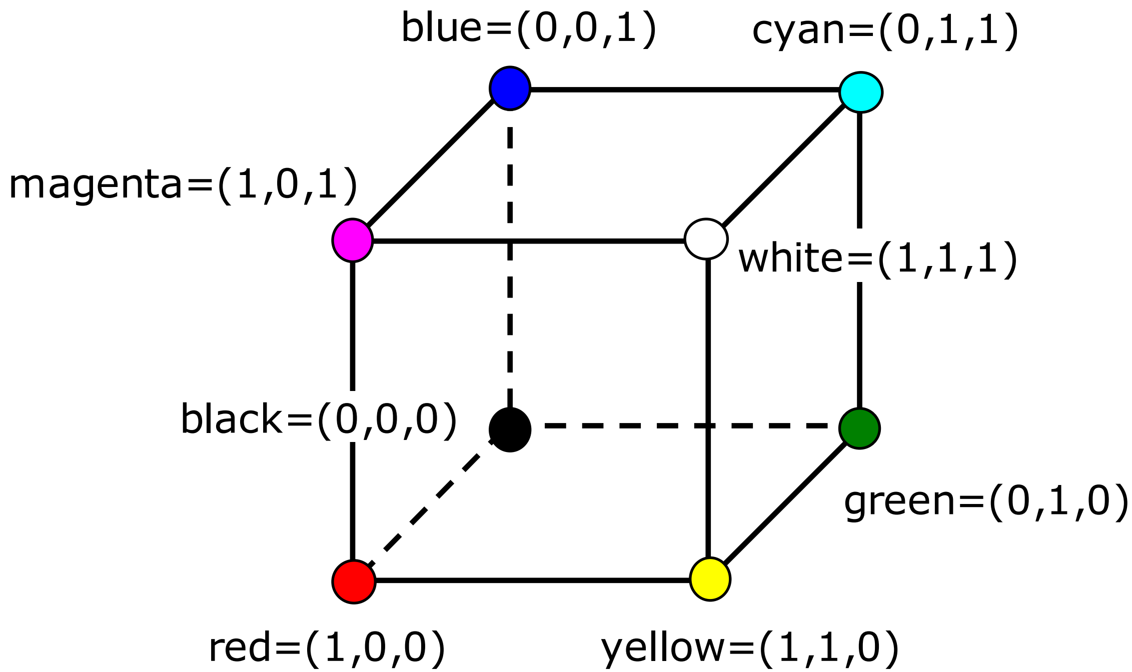




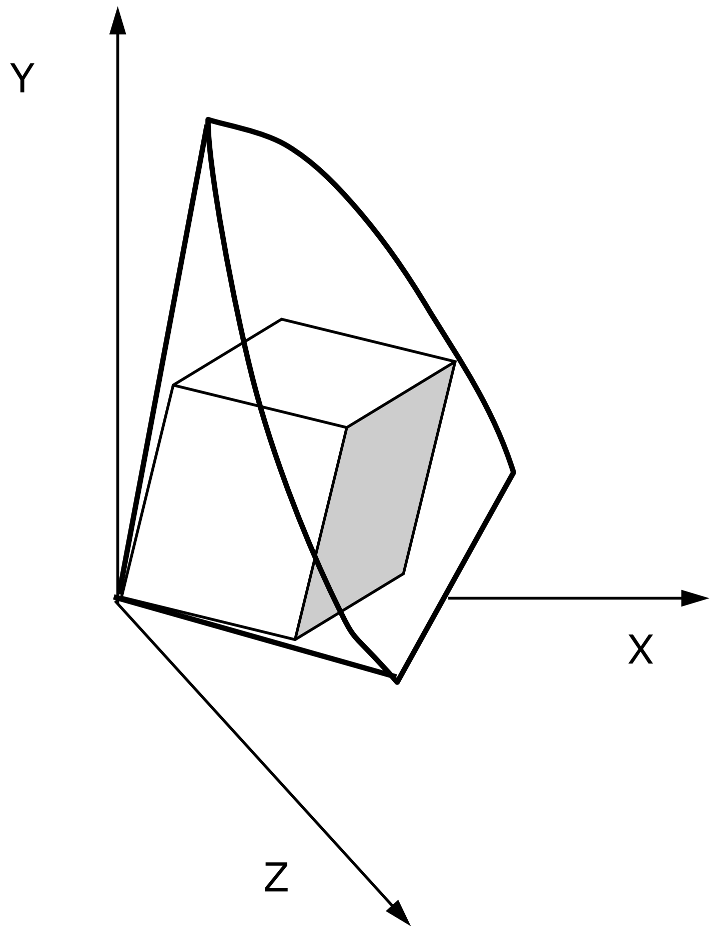
- Spectrophotometer – a device to measure the spectral energy distribution. It can provide the CIE XYZ tristimulus values
- Complementary colors – mixed together give the white light

RGB color cube

- Additive color model represented by the RGB color cube
- R, G, and B are colors produced by the red, green, and blue phosphours



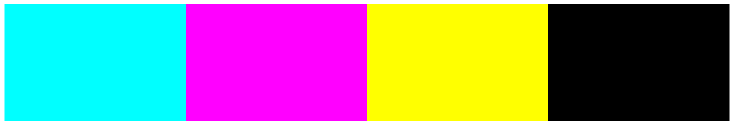
RGB cube and CIE relationship



Color printing

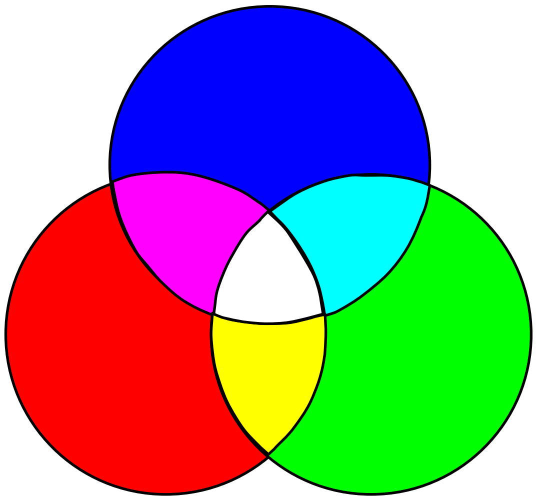
- Blue paper reflects blue and absorbs other wavelengths
- Example: to produce blue, one could mix cyan and magenta inks. Both reflect blue and each absorbs one of green and red
- Inks interact in non linear ways
- Difficult to convert a given monitor color to an equivalent printer color
- Printers use the black ink to ensure a high quality black color (K).
- Printers use the CMYK model (Cyan, Magenta, Yellow, and Black)

CMYK Model:



Color matching

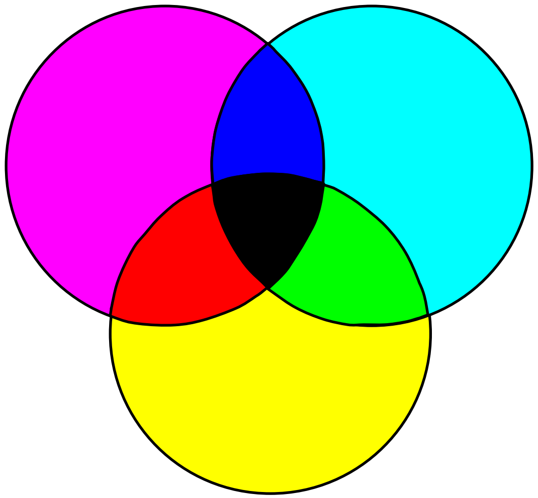
Additive: Red, Green, Blue



Add light:

CRT, video projector

Subtractive: Cyan, Magenta, Yellow



Remove light:

By filters, printer, photos

Color conversion

- Transformation from RGB to CIE XYZ

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} X_R & X_G & X_B \\ Y_G & Y_G & Y_B \\ Z_B & Z_G & Z_B \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- The conversion to and from the printer colors is quite difficult. First approximation:

  C = 1 – R
  M = 1 – G
  Y = 1 – B

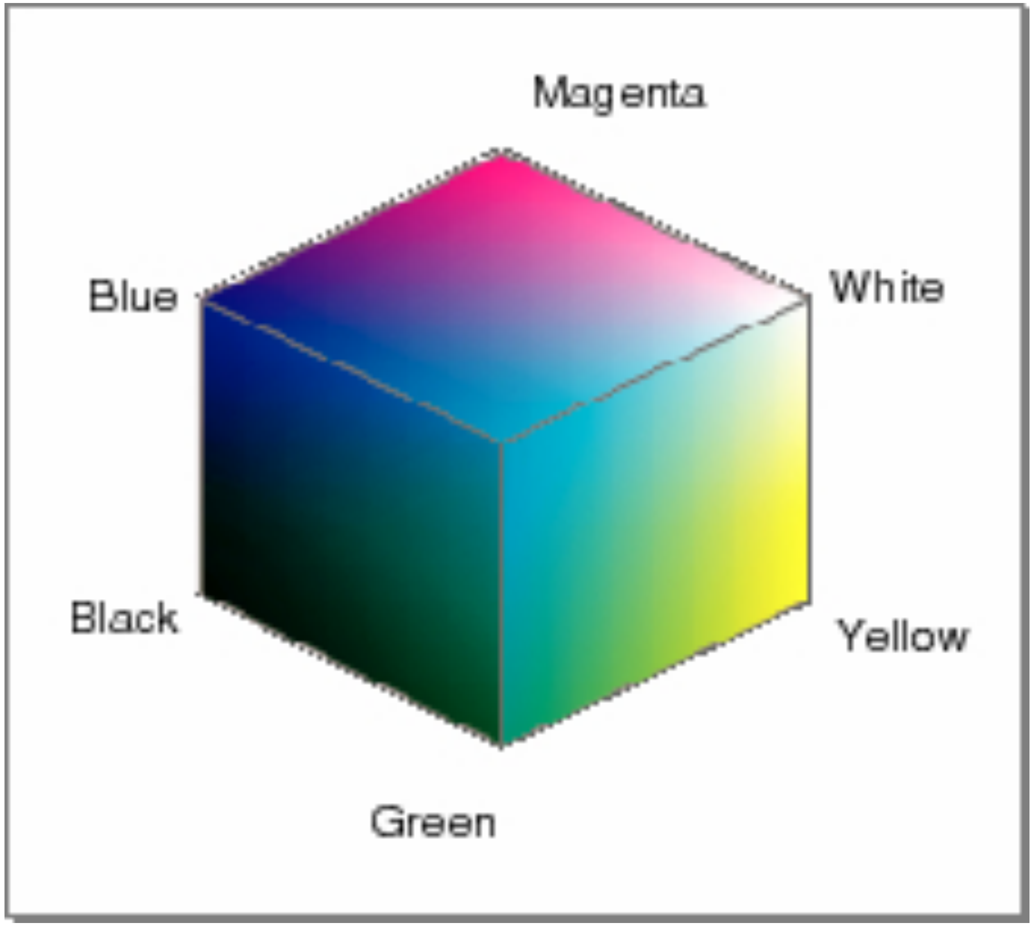
- The forth color K, can be used to substitute equal quantity in CMY:

  K = min(C, M, Y)
  C’ = C – K
  M’ = M – K
  Y’ = Y – K

RGB based color spaces

- **RGB space**
  - three-dimensional color space whose components are the red, green, and blue intensities that make up a given color
  - most commonly used color spaces in computer graphics
  - RGB color spaces are device dependent and additive
  - any color expressed in RGB space is some mixture of three primary colors: red, green, and blue
  - most RGB-based color spaces can be visualized as a cube, with corners of black, the three primaries (red, green, and blue), the three secondaries (cyan, magenta, and yellow), and white.
- The groups of color spaces within the RGB base family include
  - RGB spaces
  - HSV and HLS spaces

RGB color space



sRGB space

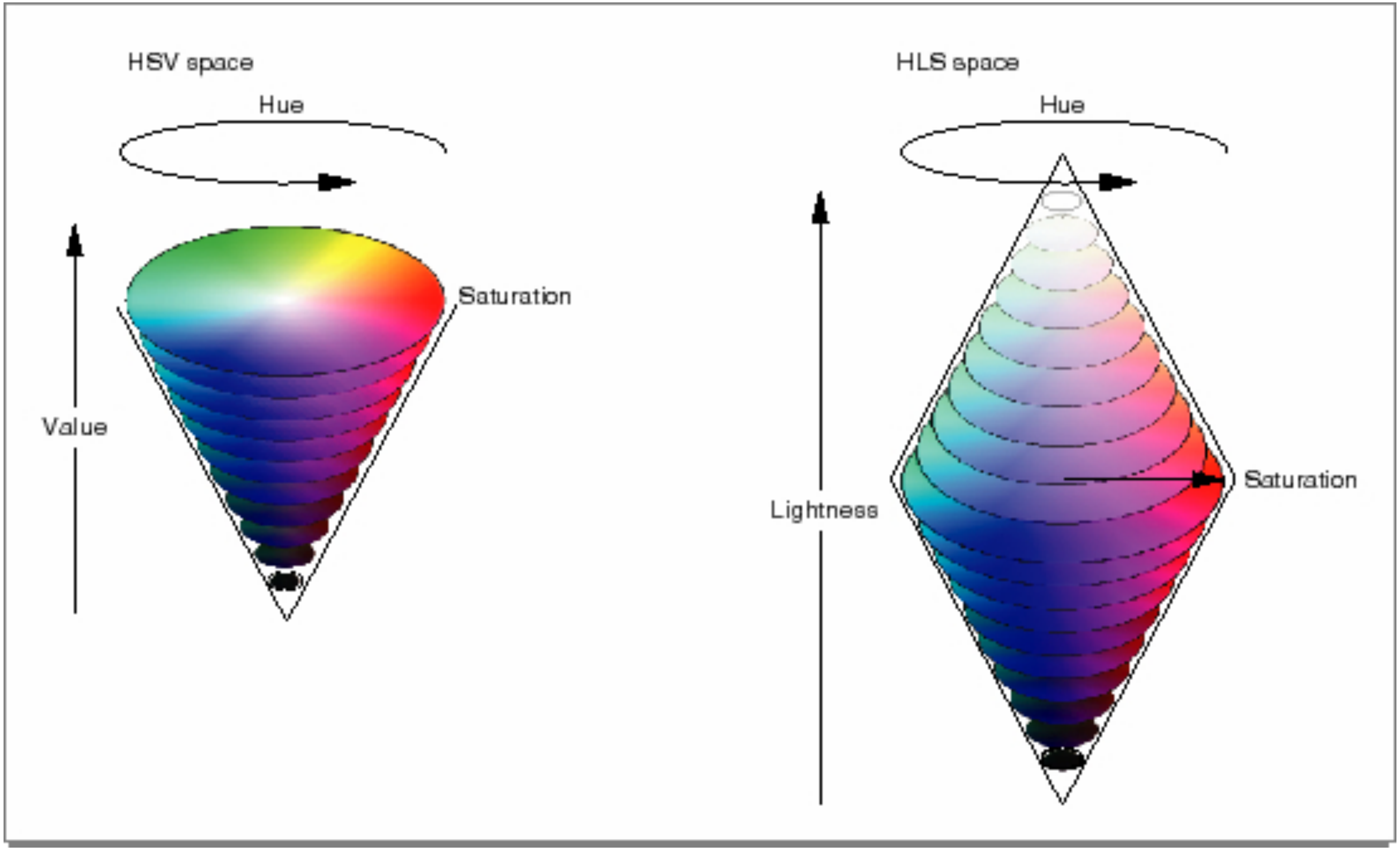
- based on the ITU-R BT.709 standard
- gives a complimentary solution to the current strategies of color management systems
- offers an alternate, device-independent color definition that is easier to handle for device manufacturers and the consumer market
- can be used if no other RGB profile is specified or available.

HSV and HLS color spaces

- **HSV space** and **HLS space** are transformations of RGB space that can describe colors in terms more natural to an artist
- HSV stands for *hue, saturation,* and *value*.

  Was created in 1978 by Alvey Ray Smith
- HSB space, or *hue*, *saturation*, and *brightness*. It is synonymous with HSV space.
- HLS stands for *hue, lightness,* and *saturation.*

HSV (or HSB) and HLS color spaces



HSV and HLS color spaces

- The components in HLS space are analogous, but not completely identical, to the components in HSV space
- The *hue* component in both color spaces is an angular measurement, analogous to position around a color wheel. A hue value of 0 indicates the color red; the color green is at a value corresponding to 120°, and the color blue is at a value corresponding to 240°.
- The *saturation* component in both color spaces describes color intensity. A saturation value of 0 (in the middle) means that the color is "colorless" (gray); a saturation value at the maximum (at the outer edge) means that the color is at maximum "colorfulness" for that hue angle and brightness.
- The *value* component in HSV describes the brightness. In both color spaces, a value of 0 represents the absence of light, or black. In HSV space, a maximum value means that the color is at its brightest. In HLS space, a maximum value for lightness means that the color is white, regardless of the current values of the hue and saturation components

Colors in graphics design

- Designing colorful Web pages isn't difficult when you understand color theory. By following basic guidelines and experimenting, you can create vibrant and effective designs that will enhance your message and attract visitors to your pages again and again

- Color weel
- Adjacent colors
- Complementary colors
- Triad colors
- Warm and cool colors

Primary colors of the color wheel

Adjacent colors

Usually, three or four colors are used in adjacent-color palettes. Such color schemes are an excellent choice for the novice designer—they are predictable and easy to select.

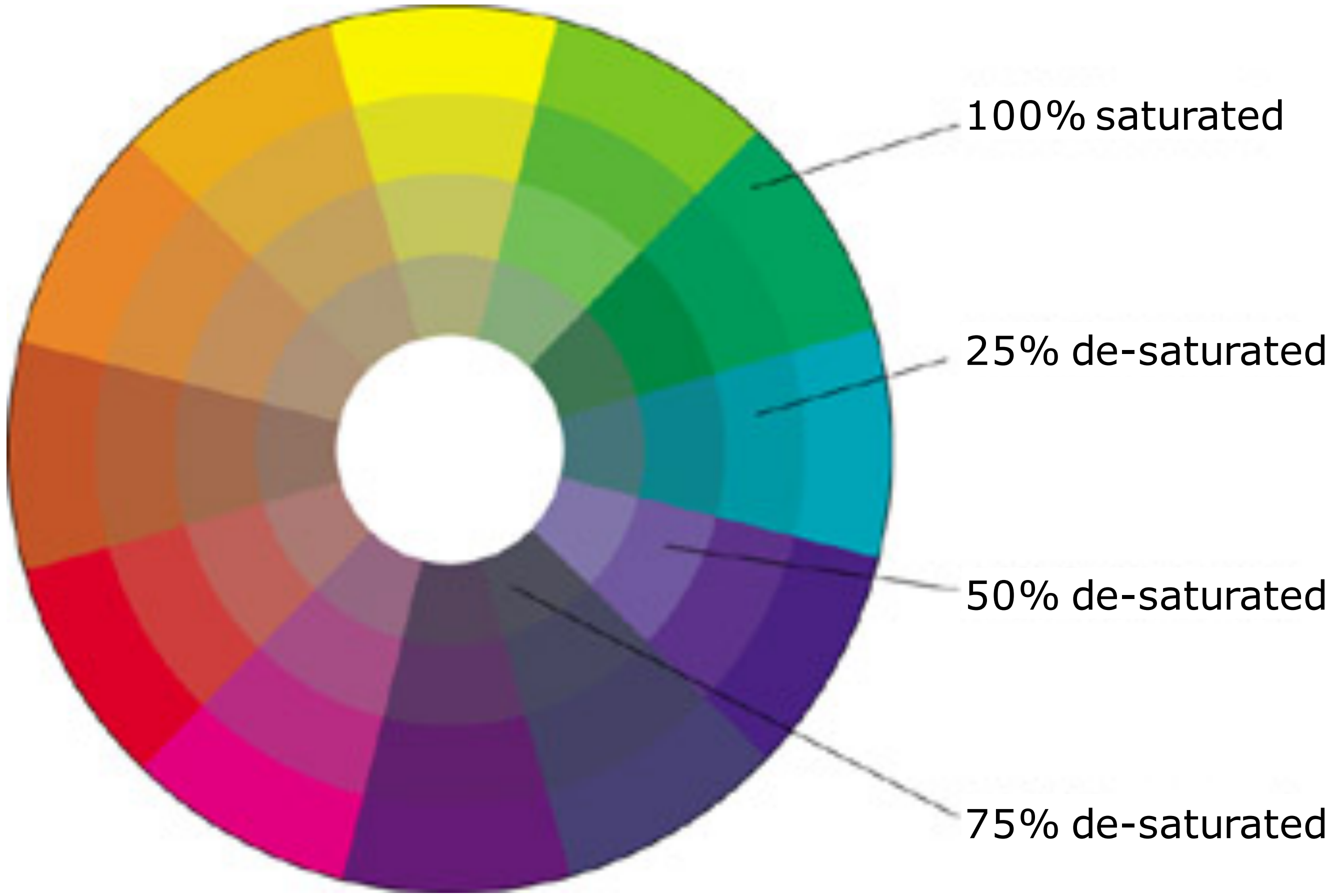
Complementary colors

Complementary colors are colors that are opposite on the color wheel. These combinations of colors are certainly attention grabbing. However, complementary color schemes can also produce undesirable effects when used excessively.

Triad colors

Triads - colors that are equidistant on the color wheel. For instance, orange, green, and violet. The primary colors (red, yellow, and blue) are another example of triad colors. Palettes based on triads are a popular design choice

Color wheel with levels of saturation

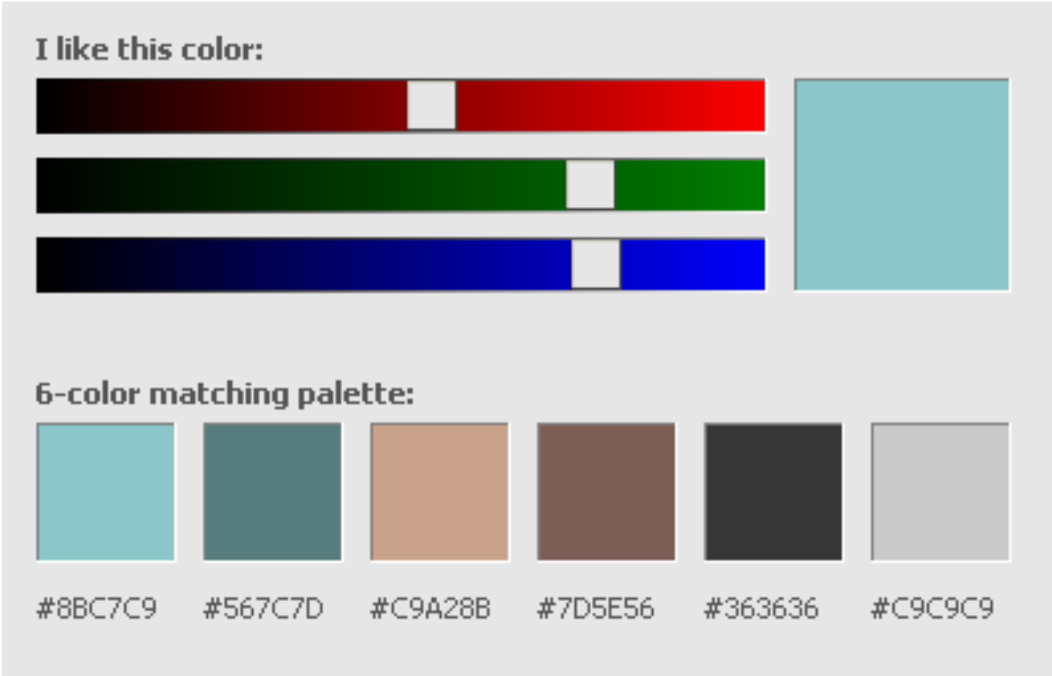


Warm and cool colors

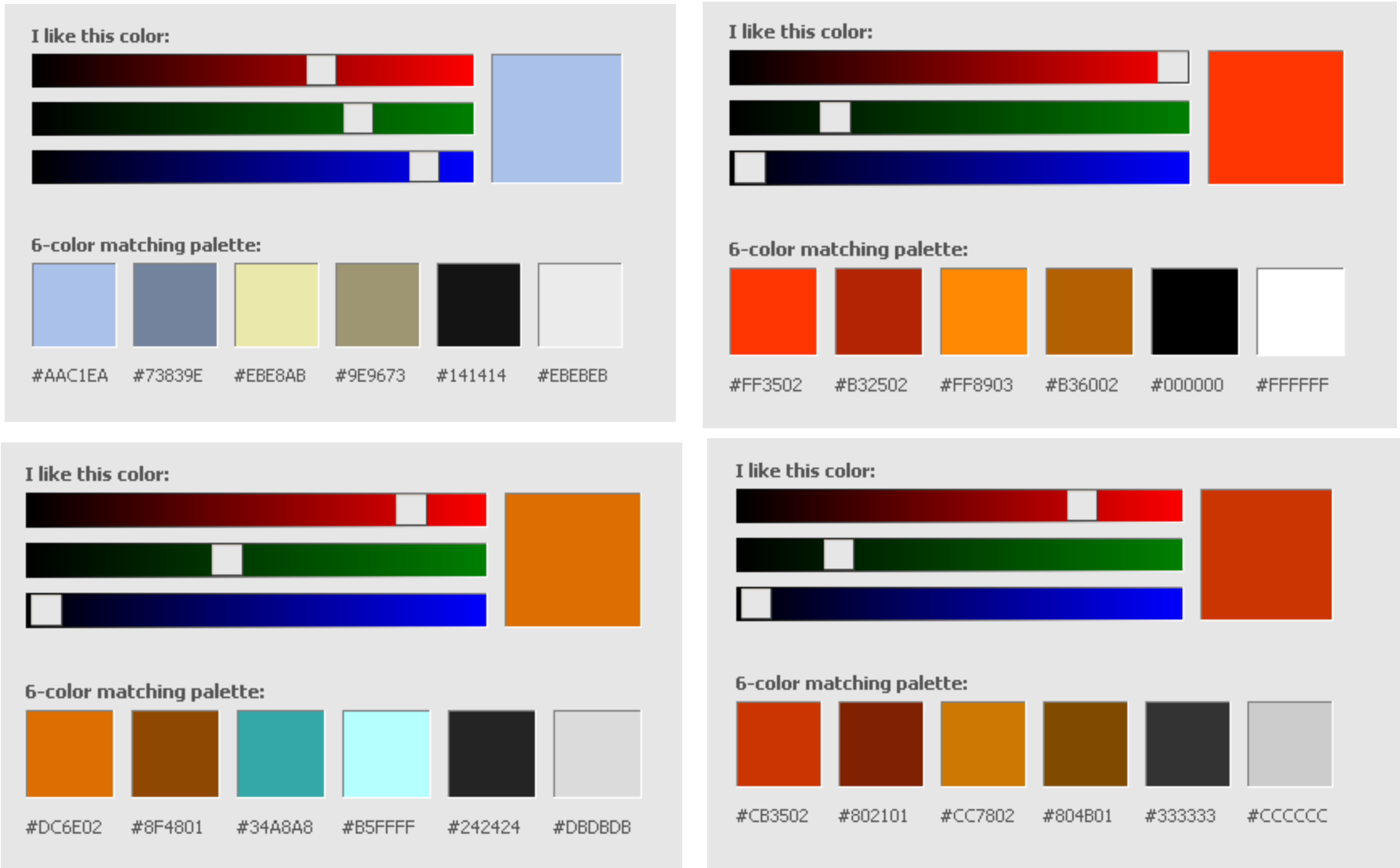
Reds, oranges, and yellows are warm colors. Warm colors appear to move forward in an image, and they convey a sense of energy.

The cool colors, purples, blues, and greens, appear to recede into the background and evoke a feeling of released tension.

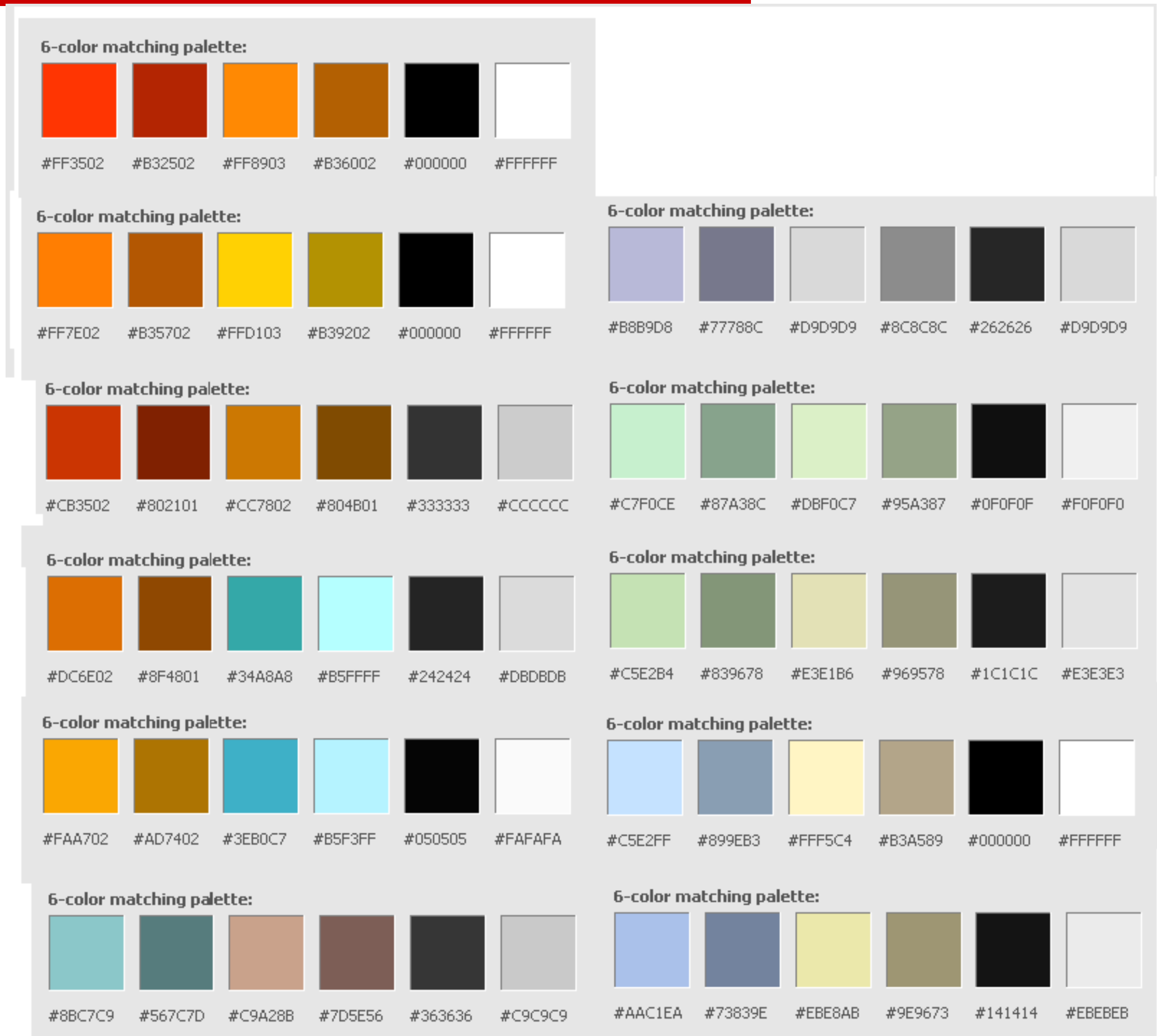
Choosing the colors



Choosing the colors



Choosing the colors



Questions and proposed problems

1. Explain why the color notion is so difficult to be defined and used.
2. Explain why the color is perceived differently by each person.
3. What cells perceived the color in the human eye?
4. Exemplify and explain the additive and subtractive principle of color combination.
5. Explain the color definition by positive matching curves of the CIE color space. What are the X, Y and Z curves?
6. Explain the CIE chromaticity diagram. Why the white color is just in the middle of the diagram? Why there are combinations of X, Y, Z, which do not give any color?
7. What means the chromatic capacity of output devices, and how it can be used?
8. How do you explain the color cube does not match with all CIE color space? Where is located the white color?
9. Explain how and why the printer and the CRT display build the color differently?
10. Why there are different color models? Exemplify by RGB cube, CIE model, HSV, HLS, and HSB.