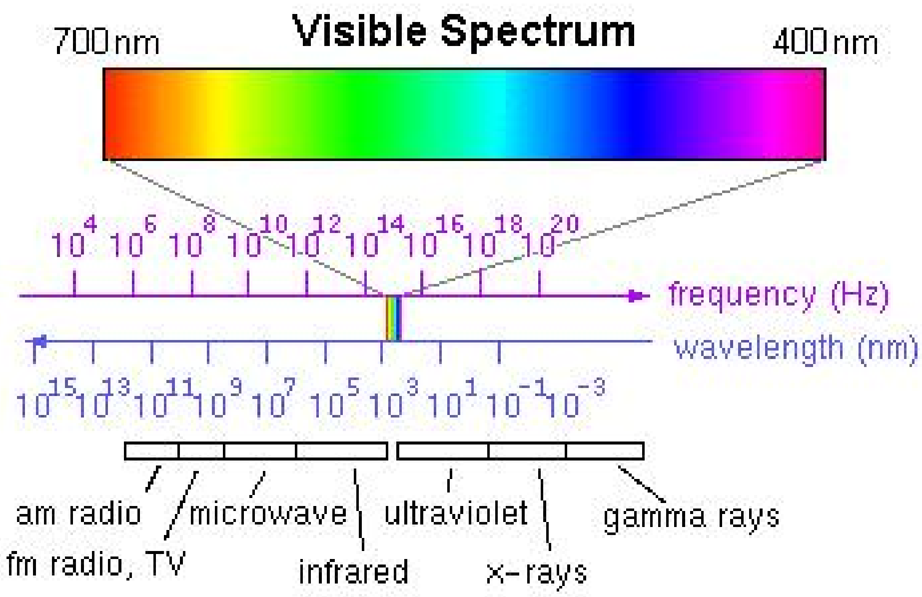
Colour

Colour ~ electromagnetic spectrum

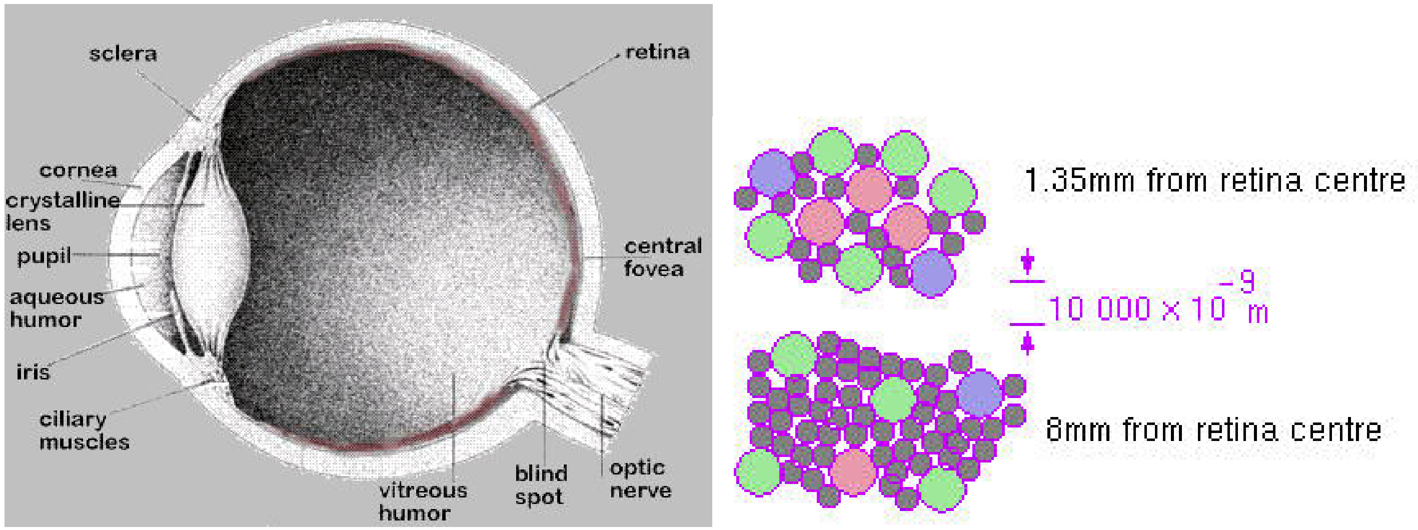
- We perceive electromagnetic energy having wavelengths in the range 400-700 nm as visible light.

- The perceived color of visible light is as much psychological as it is physical.



The Eye

- The photosensitive part of the eye, the retina, is composed of two types of cells, called rods and cones
- Only the cones are responsible for color perception.
- Cones are most densely packed within a region of the eye called the fovea.

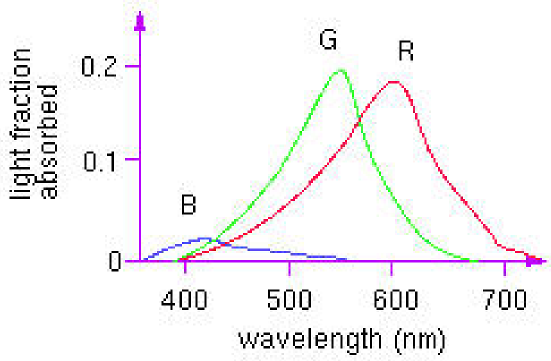


Cone types

- There are three types of cones, referred to either as S, M, and L, which are roughly (very roughly) equivalent to blue, green, and red sensors.

- Their peak sensitivities are located at approximately 430nm, 560nm, and 610nm for the "average" observer.

- Colorblindness results from a deficiency of one cone type.



Color Perception

- Different spectra can result in perceptually identical sensation called metamers

- Color perception results from the simultaneous stimulation of the 3 cone types

- Our perception of color is also affected by surround effects and adaptation

Chromaticity

- hue: f_D= dominant frequency $\sim$ colour
- saturation: purity $\sim E_D - E_W$
  E_D: energy of dominant frequency
  E_W: energy of background frequency
- luminance: intensity (area under spectral curve)
- humans have a logarithmic perception of lightness (colour that is 18% as light will only appear half as bright)

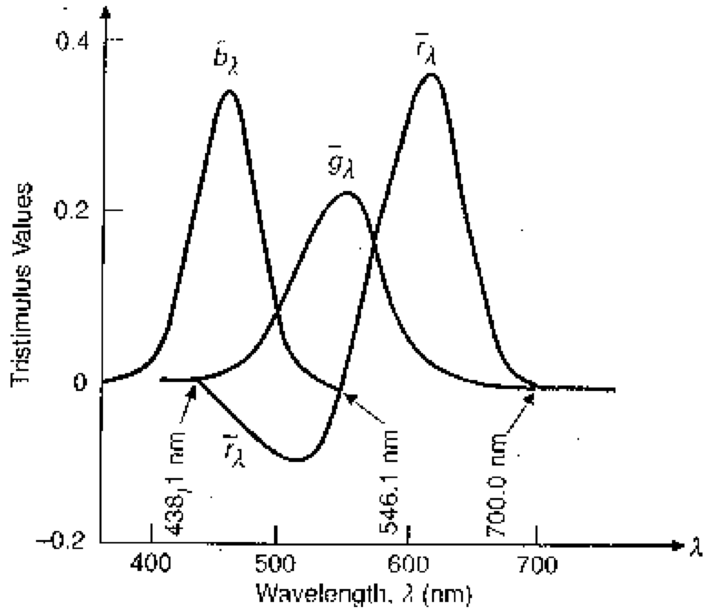
Colour models

- Start with 2 or 3 primary colours
- linear combinations give a colour gamut
- colour gamut, i.e. set of achievable colours, depends on device (monitor, printer, etc.)
- No finite set of primary colours generates the complete visible spectrum

Colour matching functions

- To define a standard perceptual 3D space, experiments have been performed in which observers match the color of a given wavelength by mixing three other pure wavelengths, such as R=700nm, G=546nm, and B=436nm.

- Sometimes red light needs to be added to the target before a match can be achieved. In the graph of primaries R takes on a negative value.



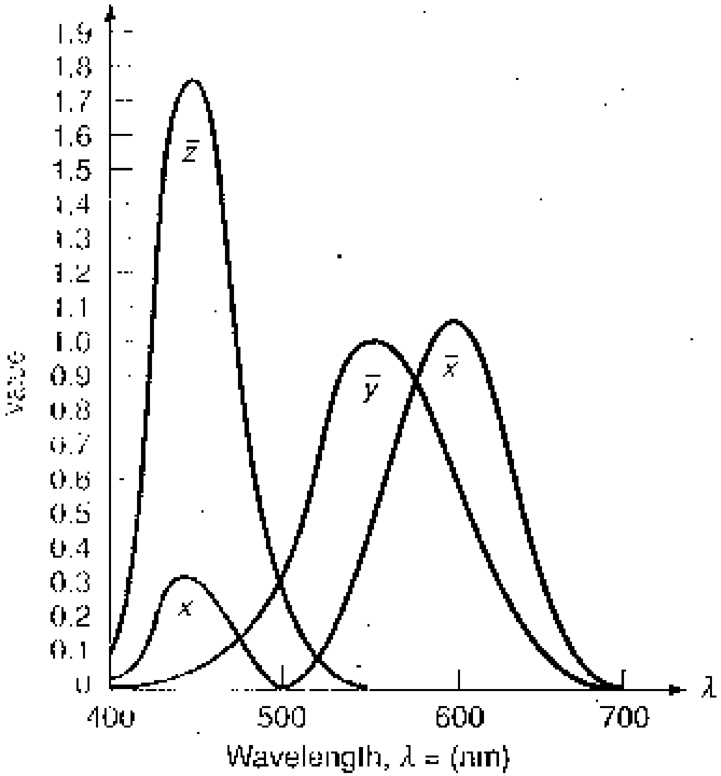
CIE space

CIE (Commission Internationale de L'Éclairage) space (1931): Define 3 primary colours $\mathbf{X}, \mathbf{Y}, \mathbf{Z}$, with associated hypothetical energy distributions $x_\lambda, y_\lambda, z_\lambda$, such that colour $\mathbf{C}$ with distribution $P(\lambda)$ is a linear combination with positive weights

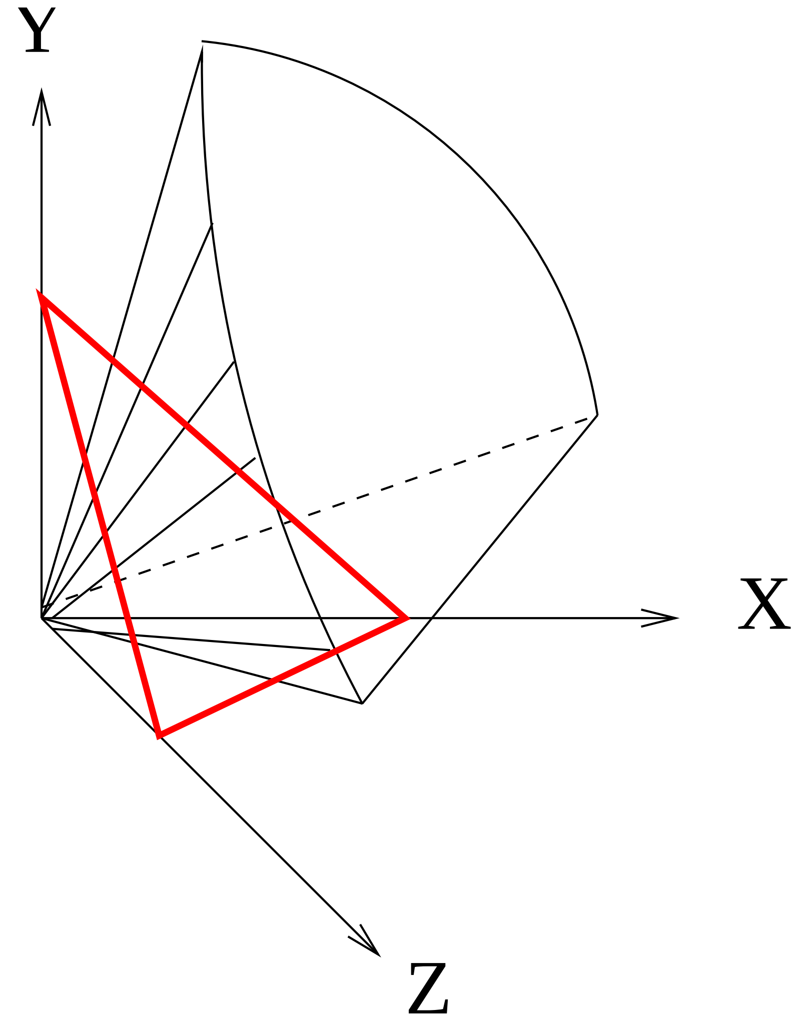
$$\mathbf{C} = X\mathbf{X} + Y\mathbf{Y} + Z\mathbf{Z}$$

with $X = k \int P(\lambda) x_\lambda$, etc. Here k is a calibration constant.
X, Y, Z are called tristimulus values.

CIE colour matching functions



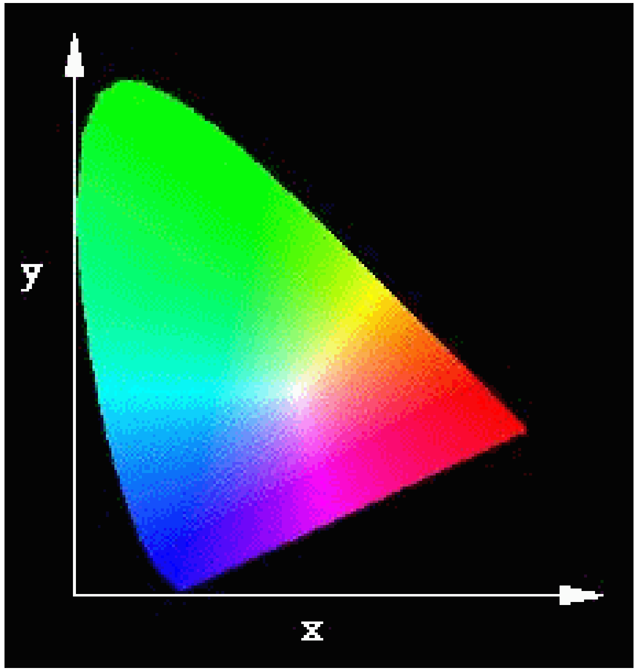
CIE space



Chromaticity diagram

- Disregard intensity information: take cross section with plane $X + Y + Z = 1$

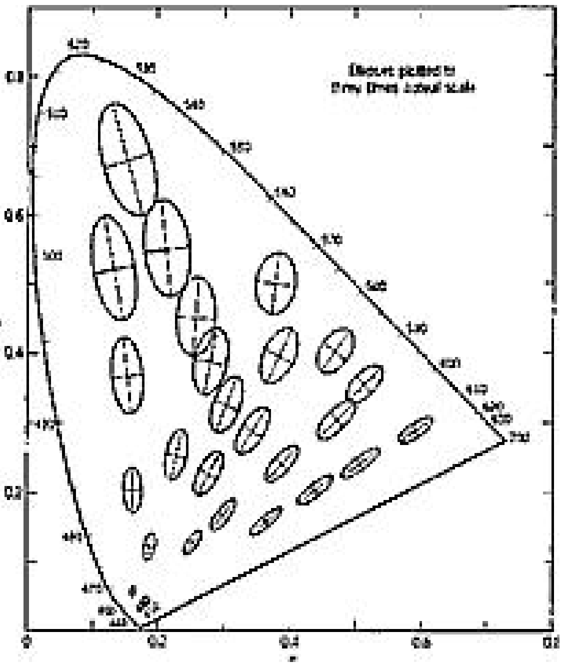
- Colour is specified by its trichromatic coefficients: $x = \frac{X}{X+Y+Z}, y = \frac{Y}{X+Y+Z}, z = \frac{Z}{X+Y+Z}$



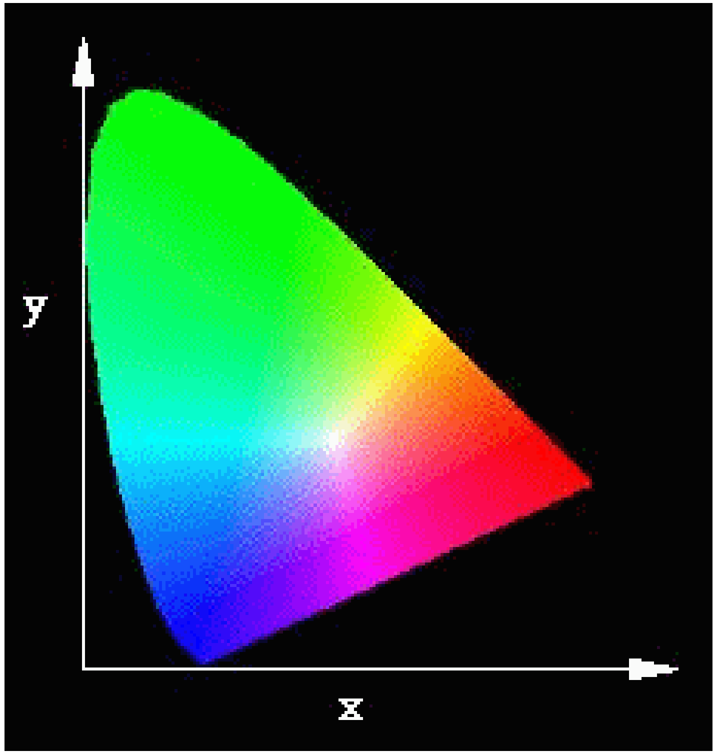
Uniform Colour Space

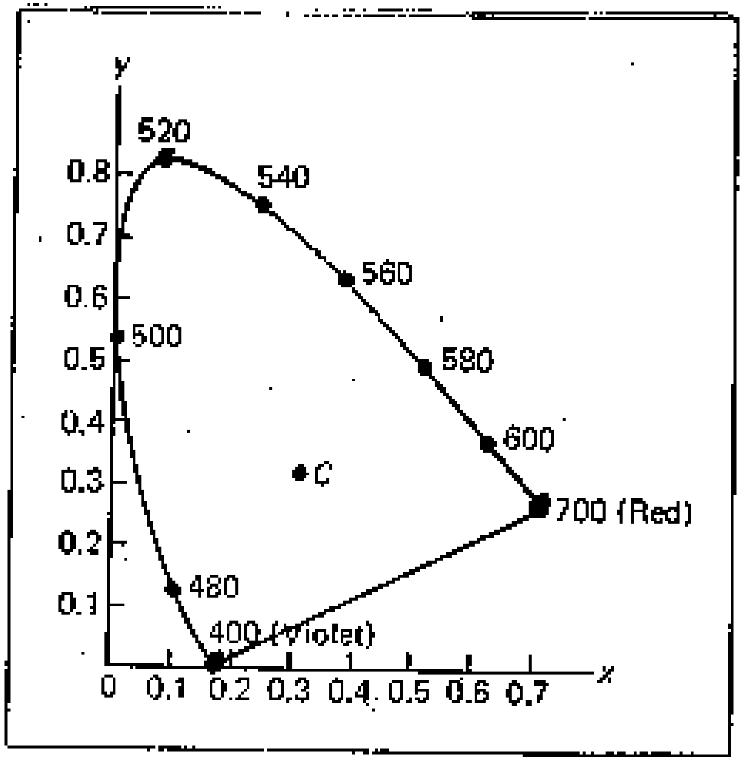
- A colour space in which equal distances approximately represent equal perceived colour differences (e.g. CIE LUV space).

- A colour-difference formula is designed to give a quantitative representation of the perceived colour difference between a pair of coloured samples.

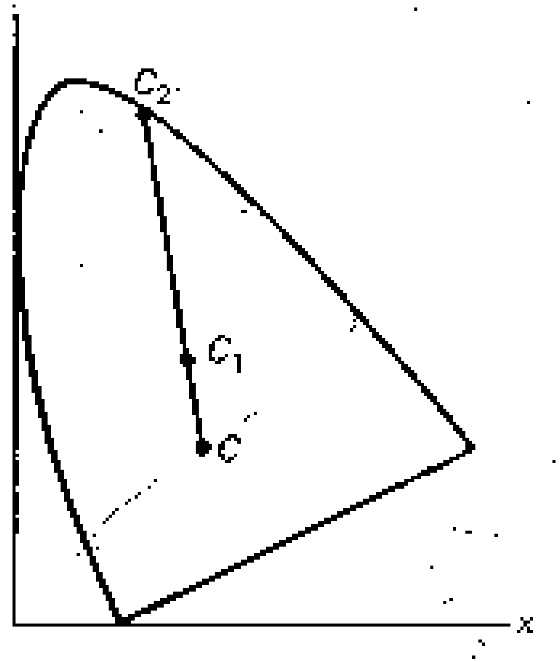


Chromaticity diagram

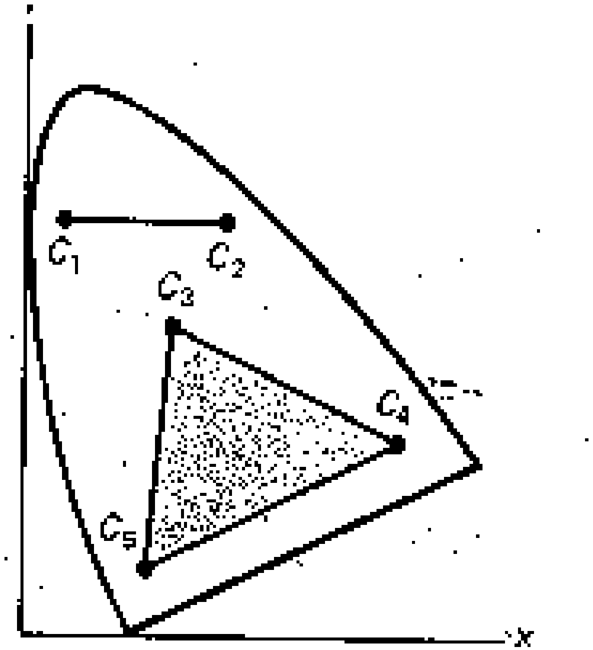




Chromaticity diagram

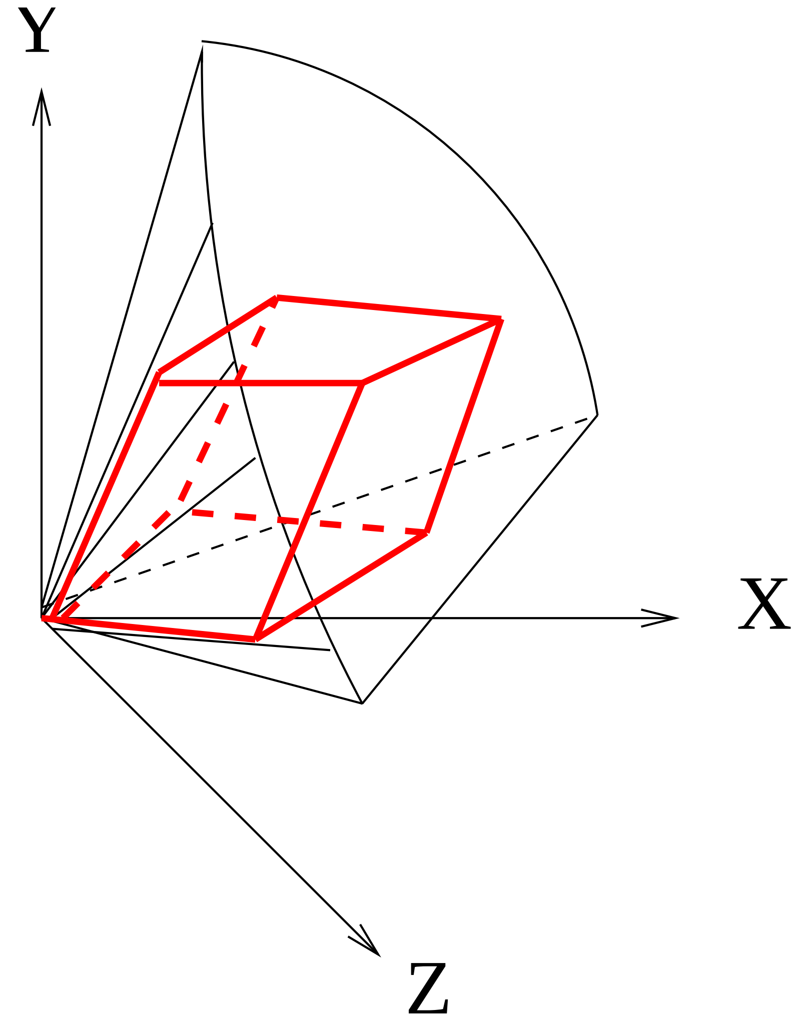


purity, dominant wavelength

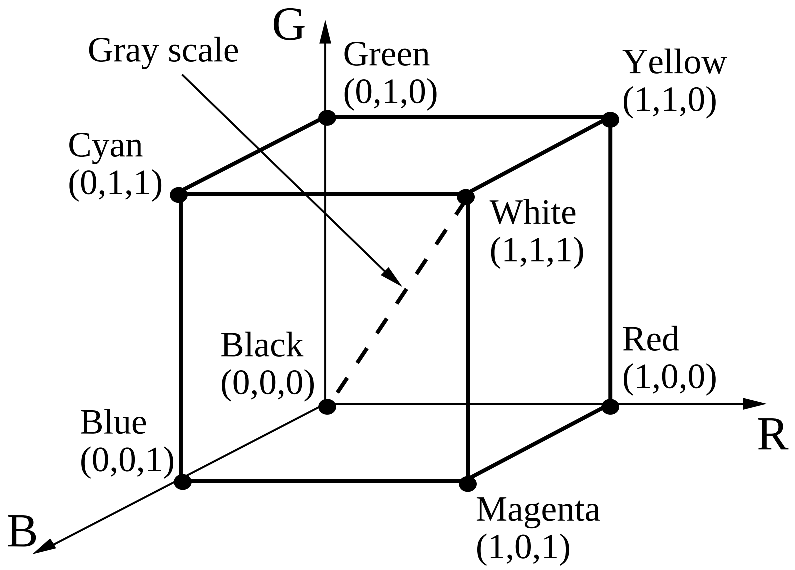


color gamuts

RGB colour model



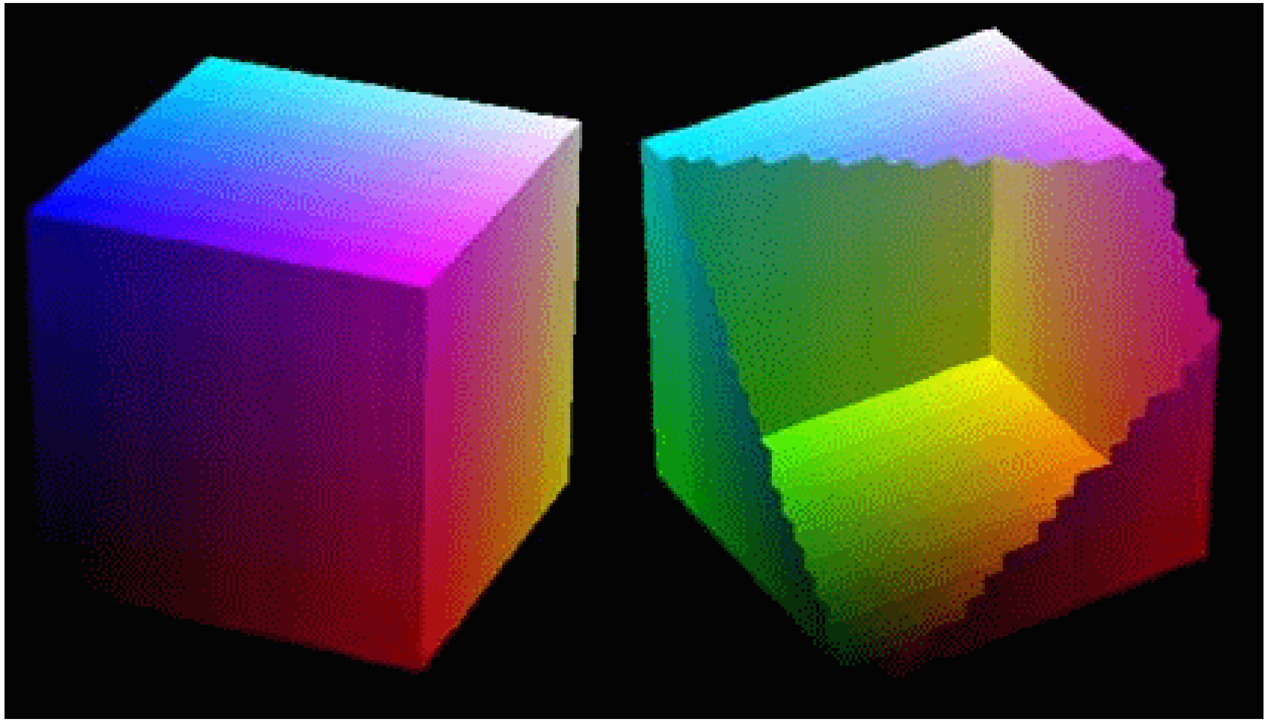
RGB colour model



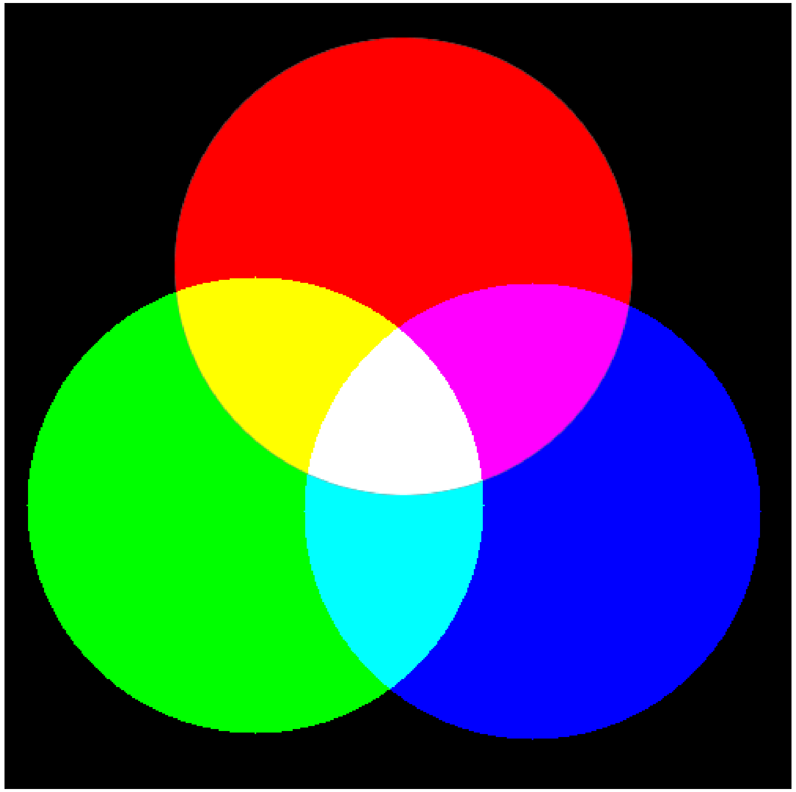
- any color is written as a sum of the primary colors R(ed), G(reen) and B(lue):

$$Color = r\,R + g\,G + b\,B, \quad r, g, b \in [0, 1] \qquad (1)$$

RGB colour model



RGB colour model



additive model, applies to RGB monitor.

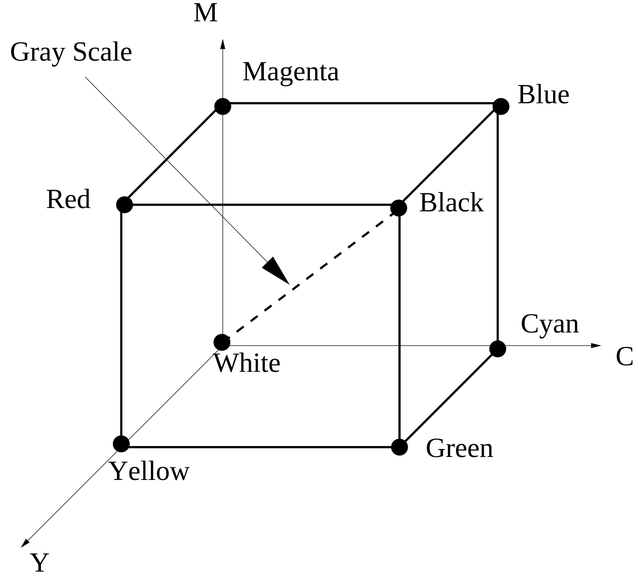
Colour conversion: RGB to CIE

- Linear transformation:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

- The coefficients X_i, Y_i, Z_i are monitor-dependent.

CMY model



- any color is written as a sum of the primary colors C(yan), M(agenta) and Y(ellow):

$$Color = c\,C + m\,M + y\,Y, \tag{2}$$

- subtractive model (applies to light reflection from surfaces, e.g. graphics hardcopy devices)

Colour conversion: RGB to CMY

- Linear transformation:

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

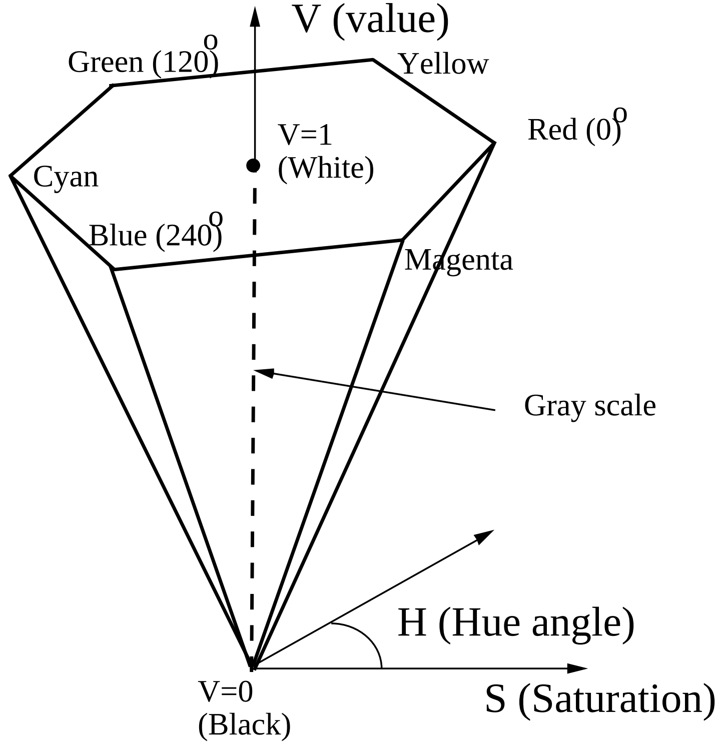
(interchanging colors across the main diagonals)

- CMY to CIE: apply CMY to RGB followed by RGB to CIE.

HSV model

- start from a pure color = hue, then add black to obtain shades, or white to obtain tones of that color
- Parameters: Hue (a pure color), Saturation (purity of the color), and Value (intensity of a color).
- HSV coordinates can be converted to RGB coordinates, and vice versa, but not by a simple linear transformation.

HSV model



- represented by the HSV hexcone: V along vertical axis, H an angle around this axis, S radial distance from it

HSV model