Colour (1)

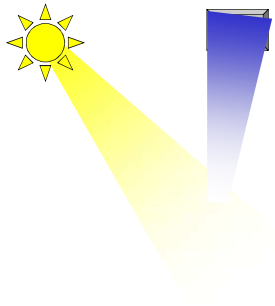
Colours and their origin
- spectral characteristics
- human visual perception

Colour spaces

Raster data
- colour models
- image representations
- single and multi-band (multi-channel) images
- colour lookup tables

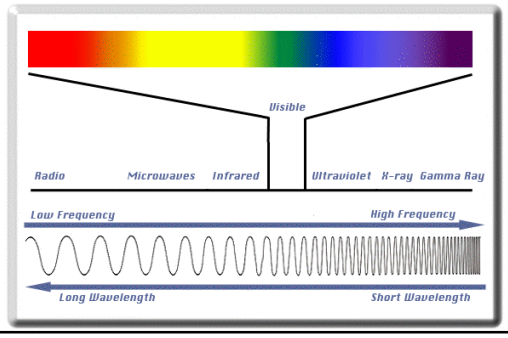
Rendering: Colour

- Given
  - Object surfaces √
  - Light sources √
  - Camera
- Compute
  - Colour of each pixel on the screen √
  - This is colour that bounces off the surface point and goes in the direction of the camera (viewer) √



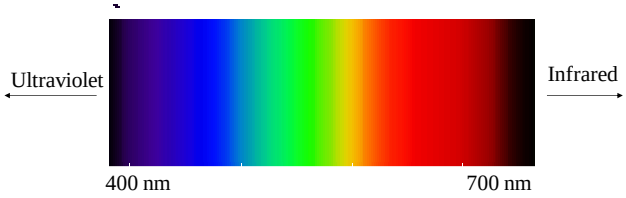
What is colour

Light – a part of electromagnetic spectrum



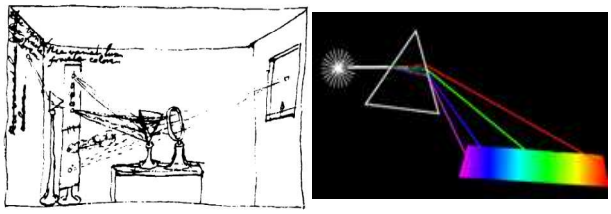
What is colour

Colour spectrum – visible light



What is colour

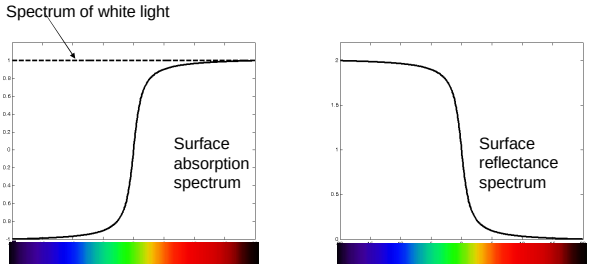
Newton's experiment



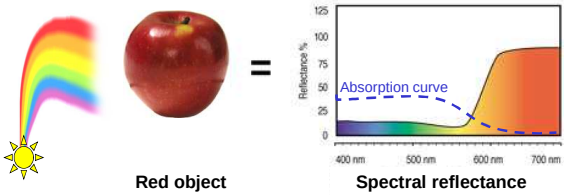
Conclusion:

"White" light is a combinations of many different light wavelengths

What is colour



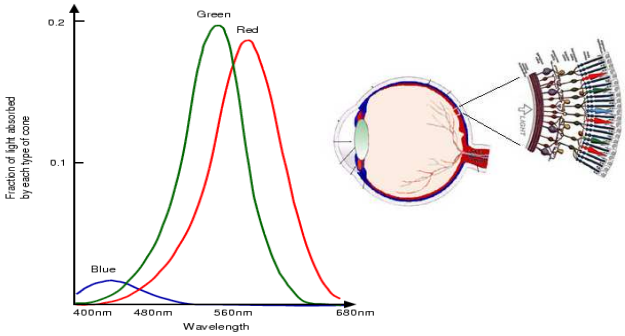
What is colour



Red object **Spectral reflectance**

What is colour

Human colour perception

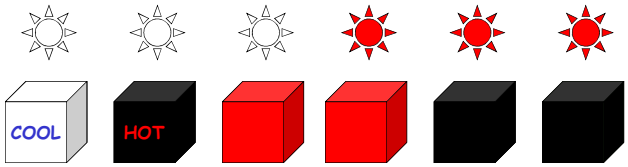


What is colour

- Colour is a percept
  - White is a colour, the perception which is evoked by light that stimulates all three types of colour sensitive cone cells in the human eye in nearly equal amounts and with high brightness. [Wikipedia]
  - Red is a colour, the perception of which is evoked by light that stimulates "red" sensitive cones in the human eye, and no other cones ("green" or "blue")

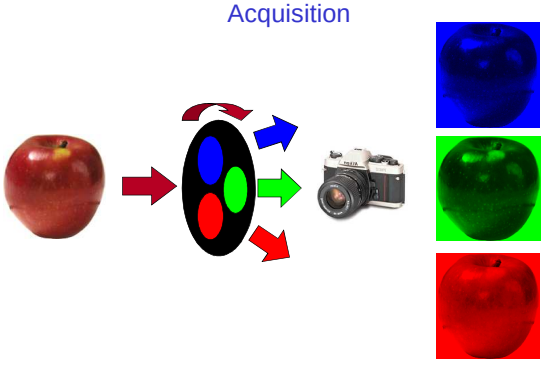
Deciphering colour

Object + Light



Colour images

Acquisition



Colour images

- Colour images have two components:
  - raster data - an array of pixels;
  - colour model - a description of how pixels are mapped to colours.
- A pixel is defined in terms of its components in a particular colour space

Colour spaces

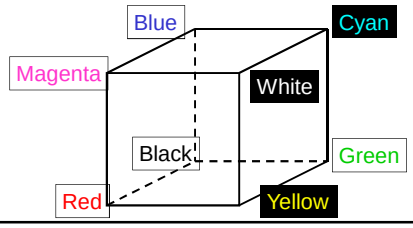
- A colour space represents a system for measuring colours
- Most colours can be represented using three colour components
- They are called the primary colours (or the primaries)

Colour spaces

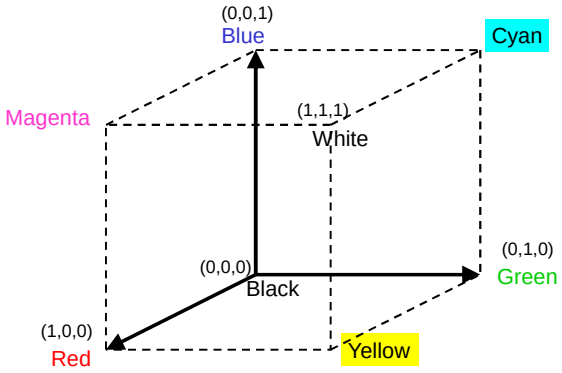
- There are many colour spaces.
- The choice of a particular space depends on the context in which we want to describe colours. The four most common colour spaces are:
  - RGB
  - HSV
  - CMY (K)
  - XYZ

RGB

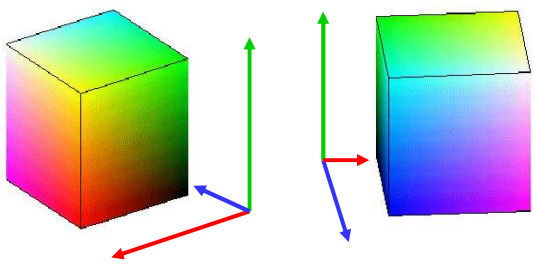
- Primaries: Red - Green - Blue
- Similar to colours detected by colour receptors in the eye
- Used in display technology



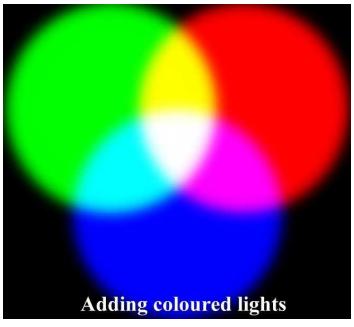
RGB



RGB



RGB – an additive system



Vector notation for colours (1)

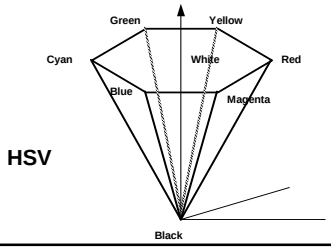
[Primary1 Primary2 Primary 3]
[R G B]

red = [1 0 0]
green = [0 1 0]
blue = [0 0 1]

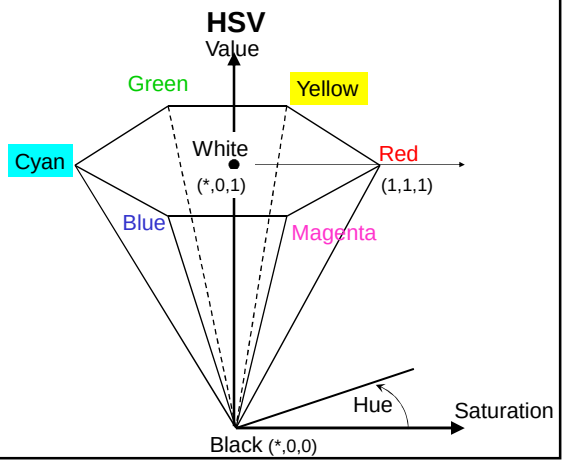
yellow = red + green = [1 1 0]
magenta = [1 0 1]
cyan = [0 1 1]
orange = [1 0.5 0]

HSV / HSL

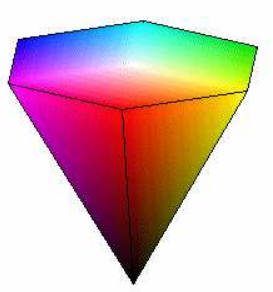
- Primaries: Hue - Saturation – Value
- Or: Hue – Saturation – Lightness
- Colour space related to subjective description of colours



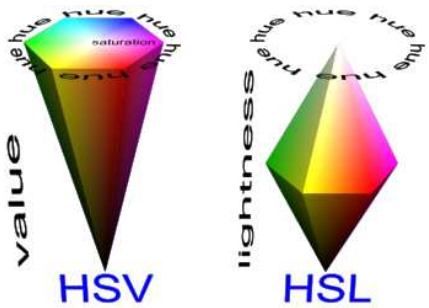
HSV



HSV



HSV and HSL

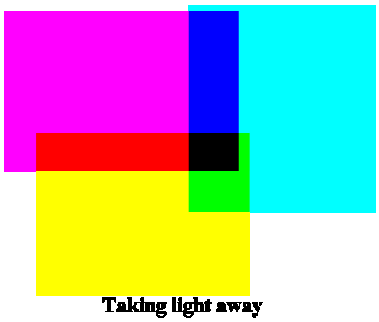


Source: http://www.bersoft.com/bimagem/help/hsv_hsl.png

CMY

- Primaries Cyan Magenta Yellow
- Used in printing technology
- Complement of RGB
- Mixing is subtractive

CMY – subtractive system



CMY – subtractive system

[C M Y]

cyan = [1 0 0] $_{CMY}$
magenta = [0 1 0] $_{CMY}$
yellow = [0 0 1] $_{CMY}$

Example:
A surface appears yellow because, given white light
[1 1 1] $_{RGB}$
yellow pigment absorbs blue component of the spectrum
[1 1 1] $_{RGB}$ – [0 0 1] $_{RGB}$ = [1 1 0] $_{RGB}$
so a mixture of red and green (i.e. yellow) is reflected
[1 1 0] $_{RGB}$

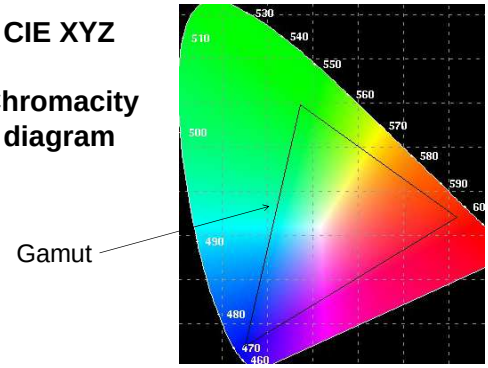
CIE XYZ

- *CIE: Commission Internationale de l'Eclairage*
- Primaries: X, Y, Z
- Based on colour perception by humans
- Device independent

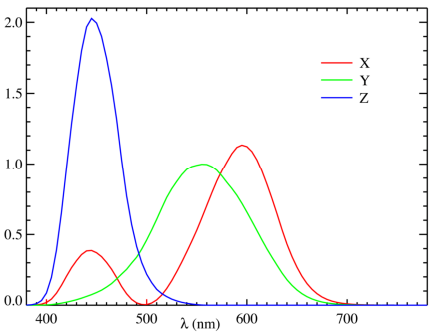
- The most common representation of the CIE XYZ space is the CIE chromacity diagram

CIE XYZ

Chromacity diagram



CIE XYZ – colour matching functions: a "standard" observer



Vector notation for colours (2)

[Primary1 Primary2 Primary 3]

[R G B] pink = [1 0.7 0.7]

[H S V] pink = [0 0.3 1]

[C M Y] pink = [0 0.3 0.3]

Colour picker experiment

Colour space conversion

- Colours can be converted from one space to another
- Conversion from RGB to CMY:
  $[C\ M\ Y] = [1\ 1\ 1] - [R\ G\ B]$
- Example: Convert green from RGB to CMY
  $[C\ M\ Y] = [1\ 1\ 1] - [0\ 1\ 0] = [1\ 0\ 1]$

Conversion from RGB to XYZ

- Each of the R, G and B primaries is a weighted sum of X, Y and Z primaries
- Weights expressed in matrix notation, e.g.

$$\begin{bmatrix} 0.41 & 0.21 & 0.02 \\ 0.36 & 0.71 & 0.12 \\ 0.18 & 0.07 & 0.95 \end{bmatrix}$$

- The matrix values are characteristic for a given graphics device

Conversion from RGB to XYZ

- Conversion implemented as a matrix multiplication

$$[X\ Y\ Z] = [R\ G\ B] \cdot \begin{bmatrix} 0.584 & 0.311 & 0.047 \\ 0.188 & 0.614 & 0.103 \\ 0.179 & 0.075 & 0.939 \end{bmatrix}$$

Homework

- Specify colour definitions for the following colours in the RGB, HSV and CMY colour spaces:
  - Black
  - White
  - Orange
  - Pink
- What colour will you get by illuminating a yellow surface with a green light?
- What colour will you get by illuminating a magenta surface with a yellow light?

(You can check the answers to the last two questions by experimenting with Matlab code in ex4_lighting.m)