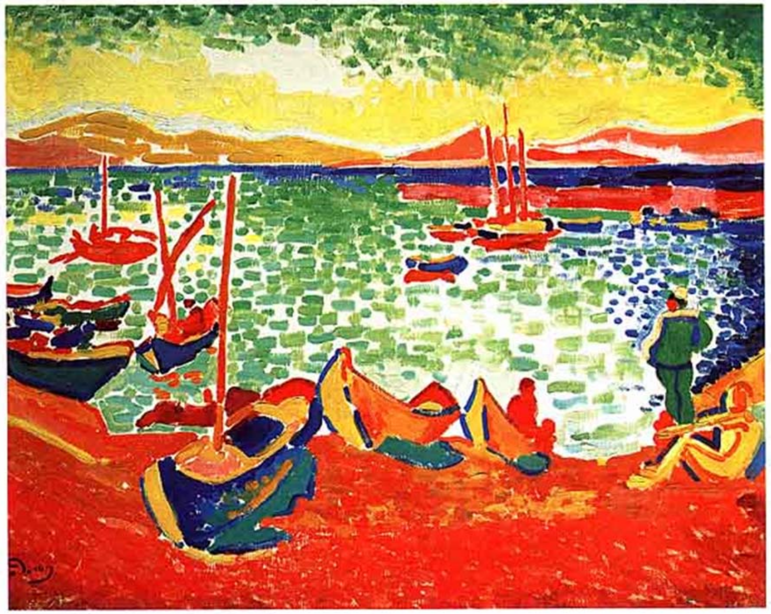
Colour



Colour

- Introduction
- Physical characteristics of colour
- Colour Spaces
- Applications & conclusions

Introduction. Colour

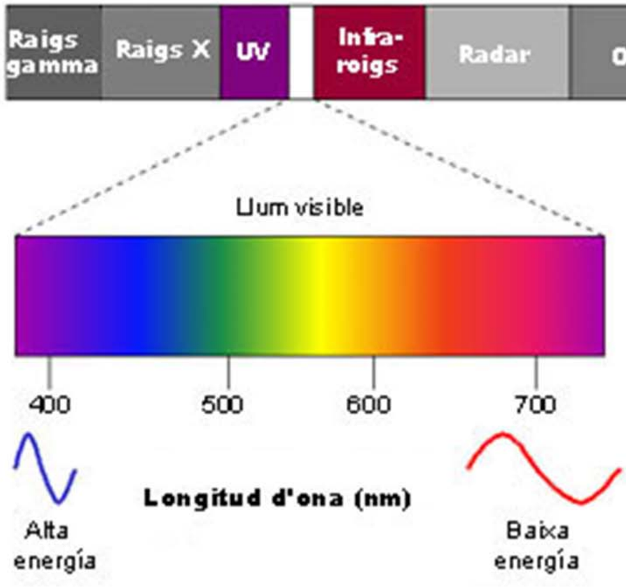
- Is an important part of object perception
- However, is a complex phenomenon (difficult to characterize)
- It is related to the interaction of:
  - Light: spectral properties of the light source
  - Object: size, shape and texture (surface)
  - Observer: spectral sensitivity, lens, etc

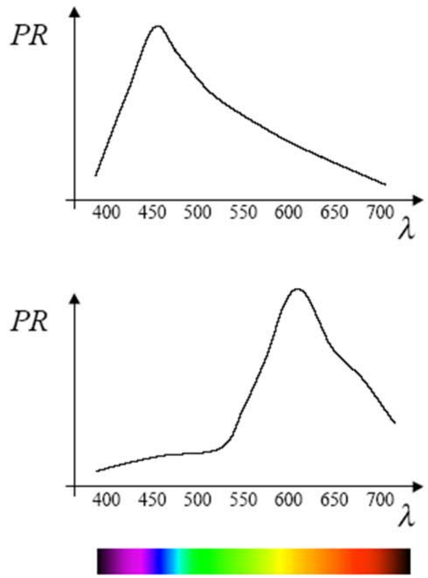
Colour

Physical characteristics

Visible spectra

- Electromagnetic spectra





Blue perception

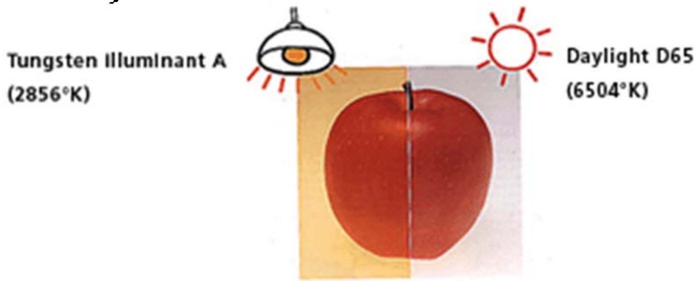
Green perception

Physical stimulus. The Object

Illuminants

- Colour temperature (K). Temperature at which an ideal blackbody radiator emits radiation of the same colour as a given object
  - A measure of the spectral energy distribution of a light source
  - Low Temp: warm light (yellow/red) → Ex. sunset
  - High Temp: cold light (blue/white)

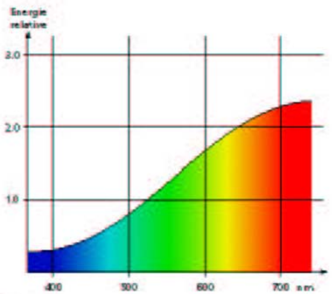
A	**Standard bulb (2856 K)**
C	**Daylight without UV component (6750 K)**
D65	**Daylight with UV component (6500 K)**
F11	**Fluorescent lamp**



Physical stimulus. The Object

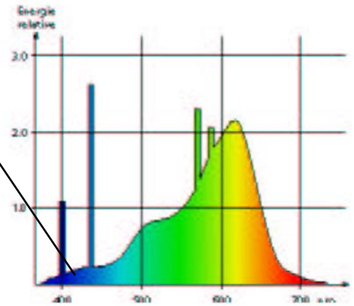
Light Sources

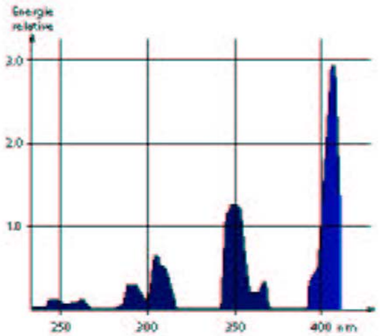
- Power spectra of a non continuous light source: concentrates emission in regions of the spectra
  - Causes distortions in the perception of the color of the objects



Continuous light

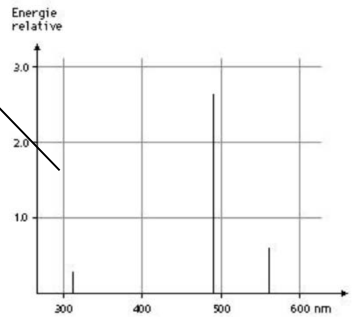
Fluorescent





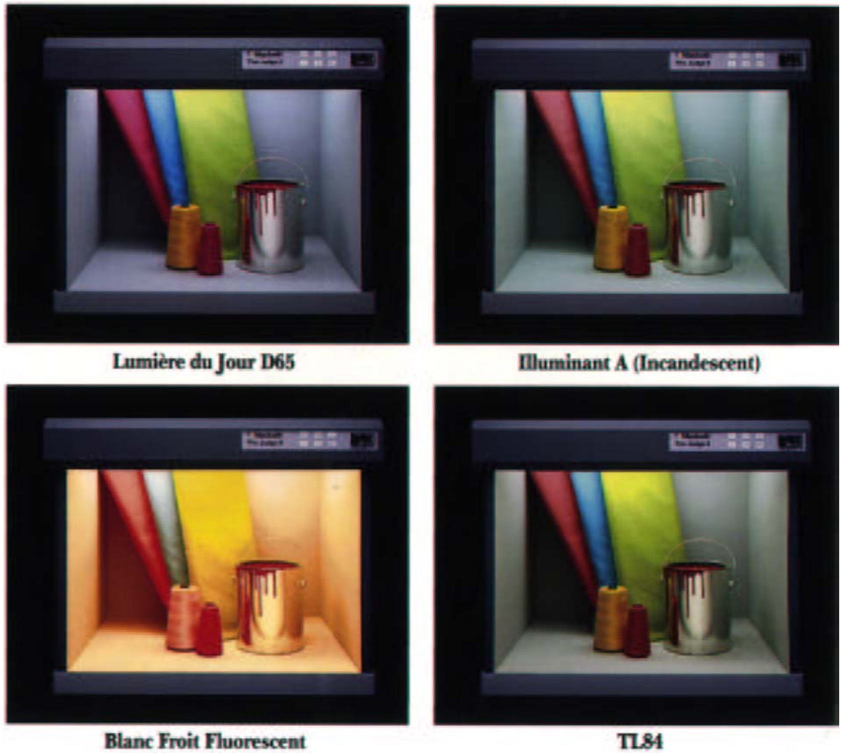
Non continuous

Laser



Physical stimulus. The Object

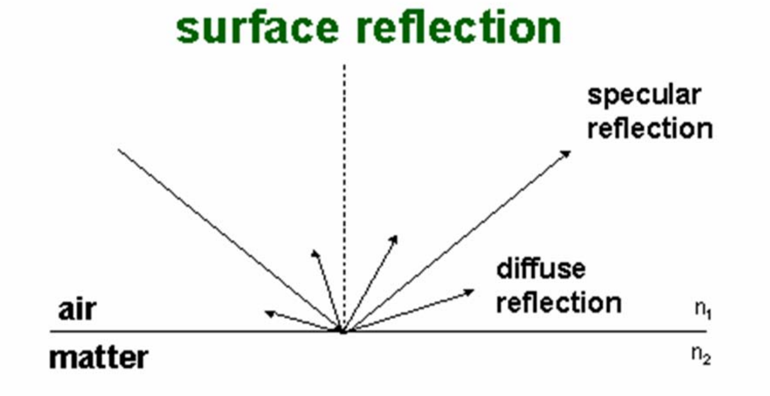
Colour rendering: variability of colour perception due to different light sources



Physical stimulus. The Object

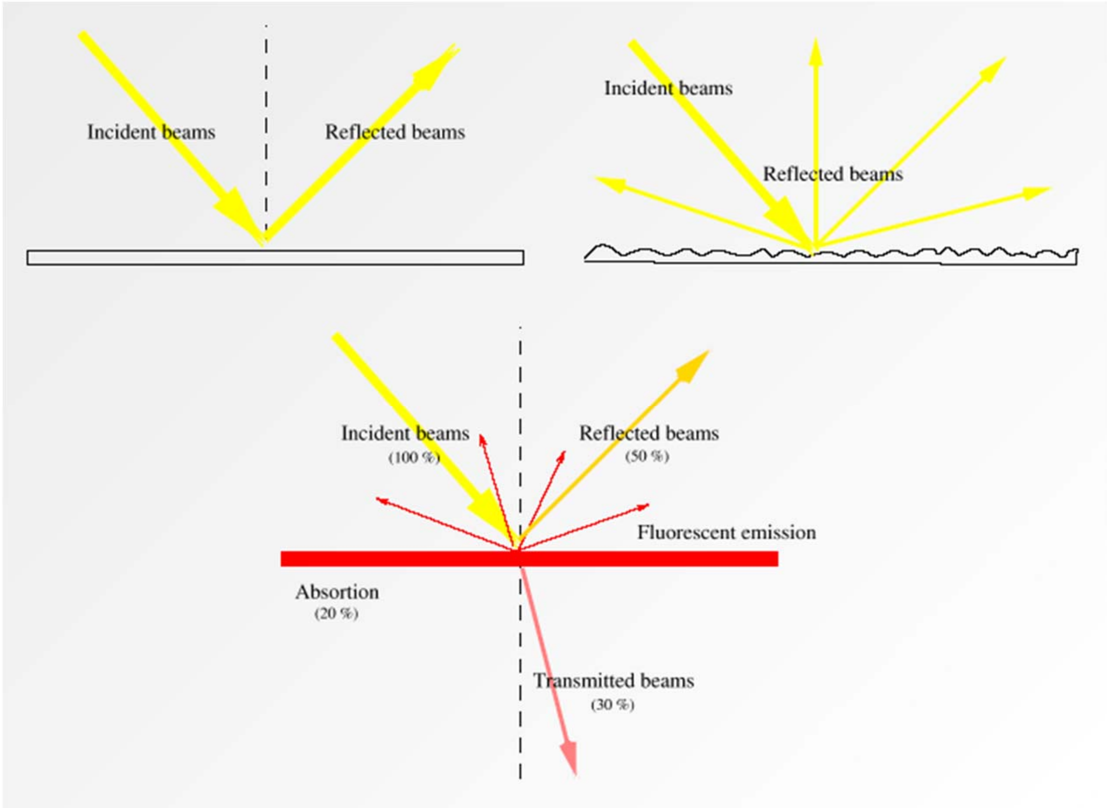
Effects of the surface

- Transmittance. Ratio between the transmitted and incident light in a surface
- Reflectance
  - Specular. The light is reflected with the same incidence angle with respect to the normal to the surface (eg. mirror)
  - Diffuse
- Absorption



Physical stimulus. The Object

Effects of the surface

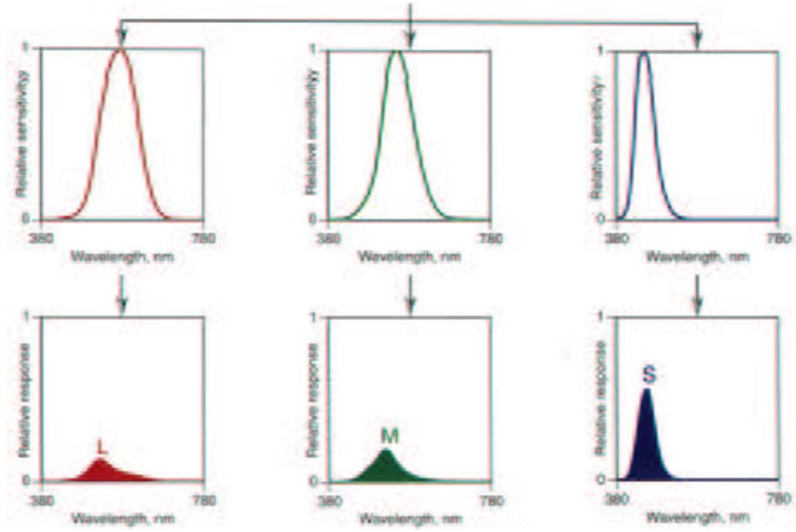


Colour perception

Which colour do we perceive?

Stimuli + Spectral sensitivity

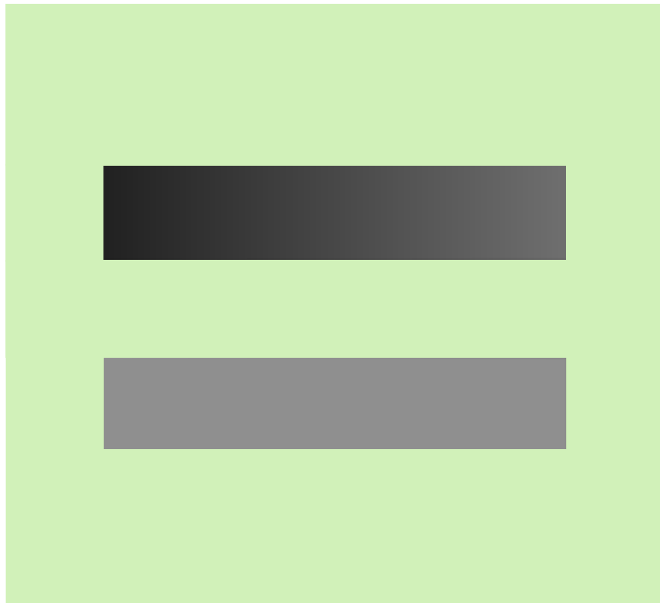
- Integration of the incident light for the 3 components
- **Tricromacity**



Colour perception

Receptive fields

- Contrast enhancement
- Constant illumination



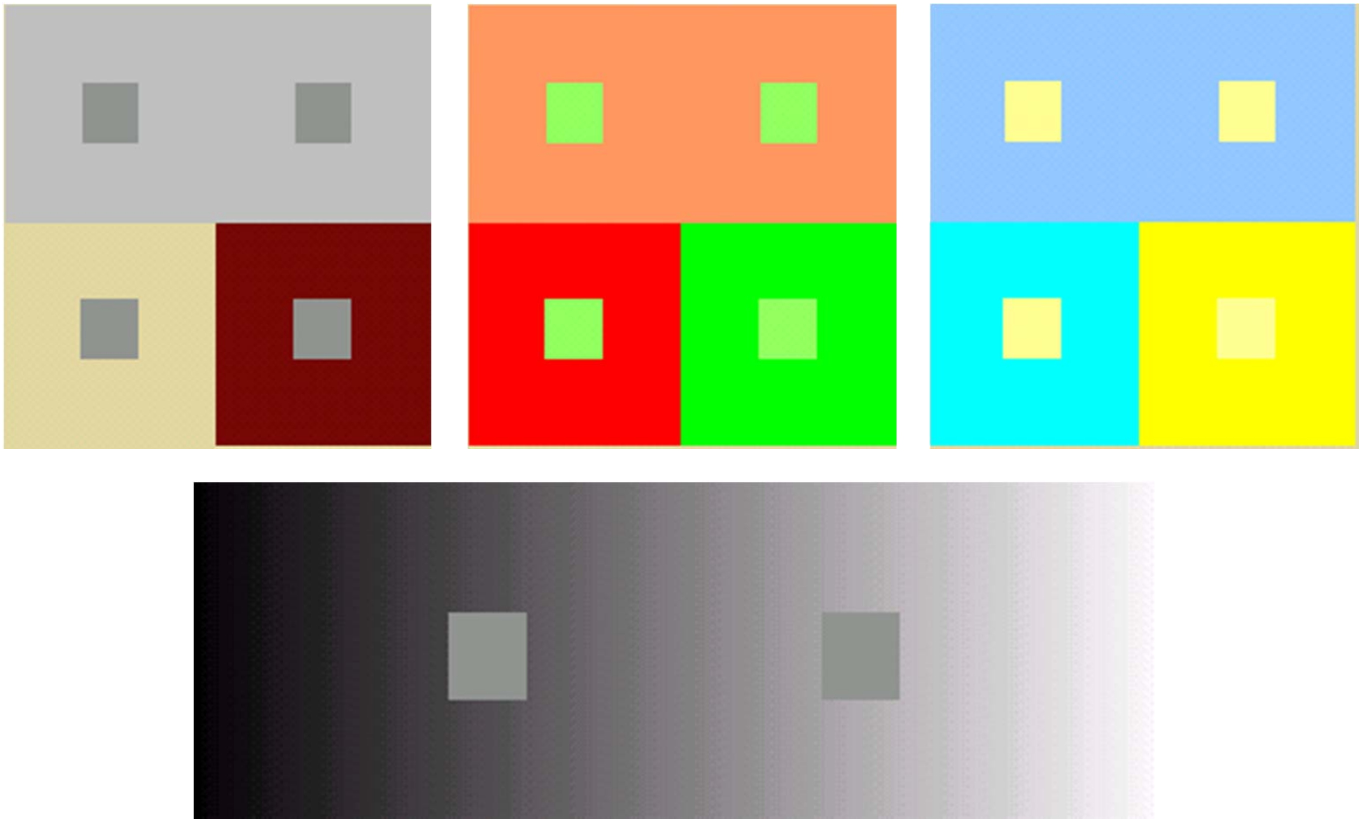
Colour perception

- **Stroop Effect** A demonstration of the reaction time of a task

XXX
XXX
XXX
XXX
XXX
XXX
XXX
XXX
XXX

Colour perception

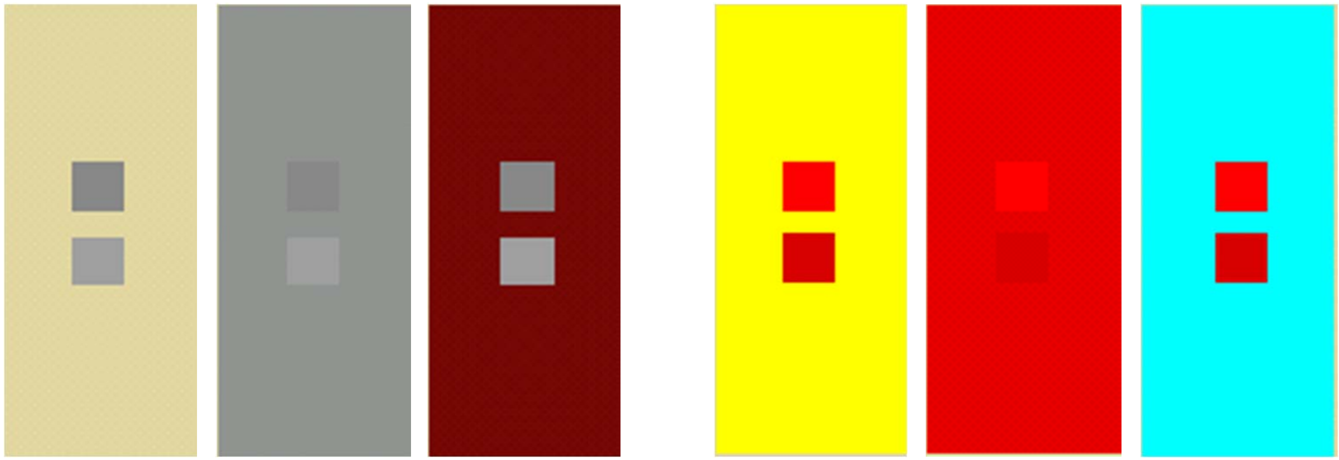
- **Simultaneous contrast** How the colours of two different objects affect each other



Colour perception

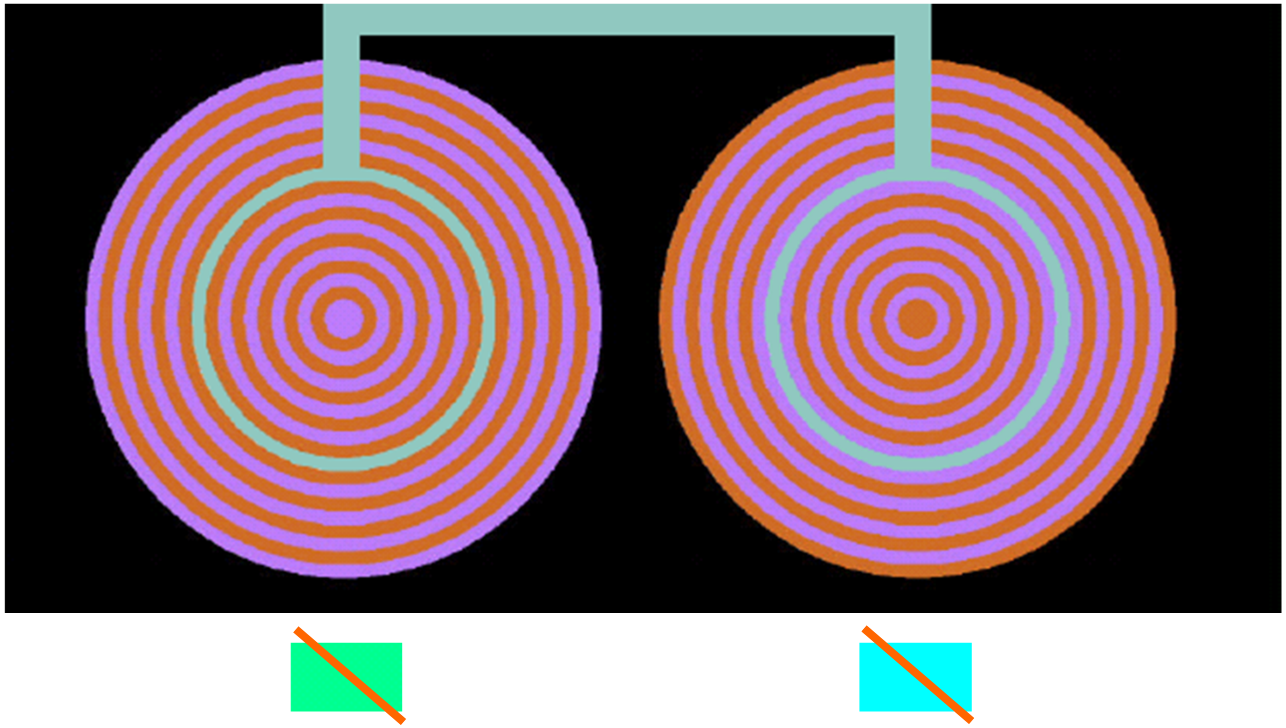
- **Crispening**

Colour discrimination is best for stimuli that are at or near the adaptation light and the discrimination worsens for stimuli that differ substantially from the adapting conditions

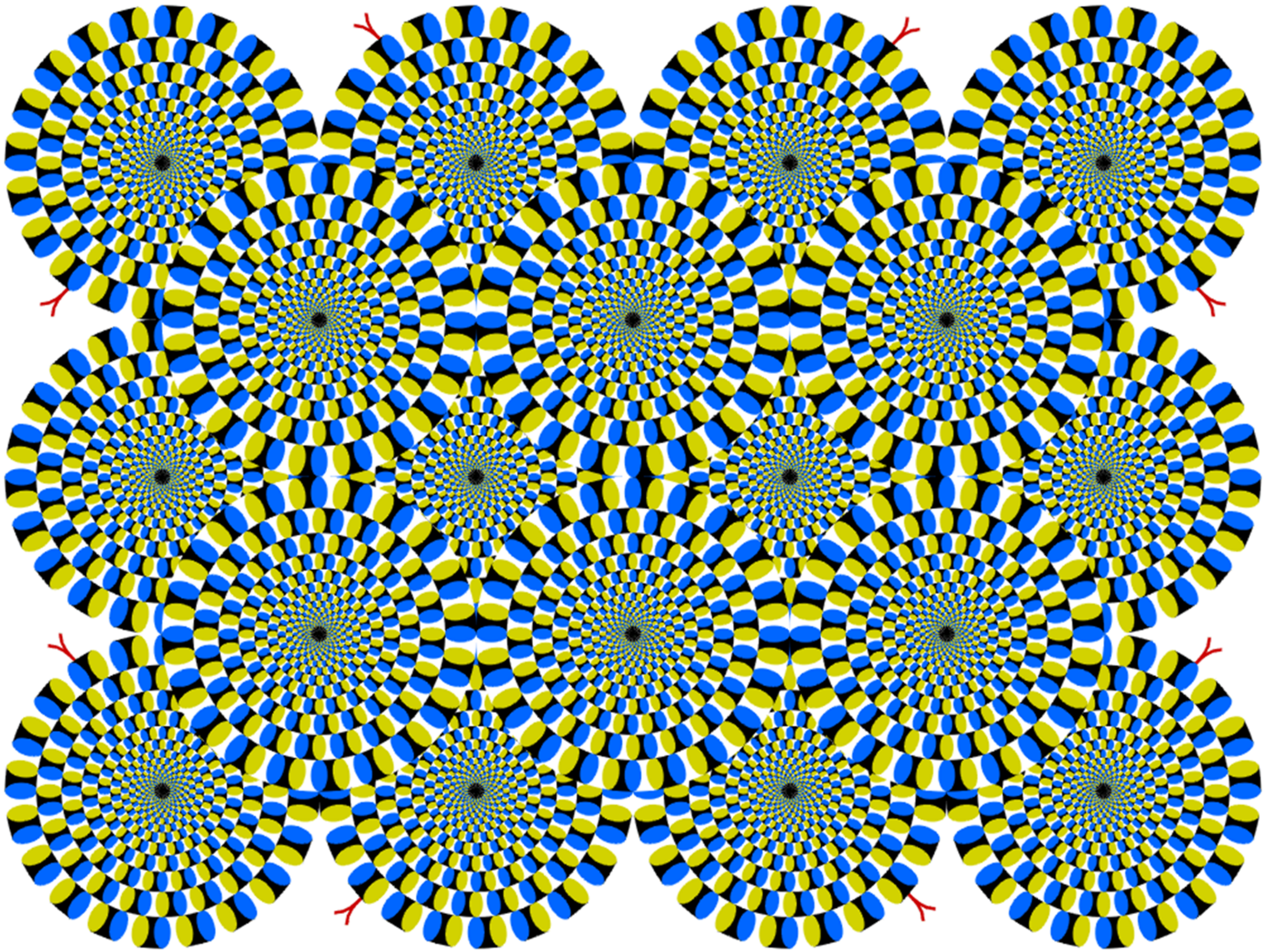


Colour perception

- **Colour induction phenomena:**



Colour perception



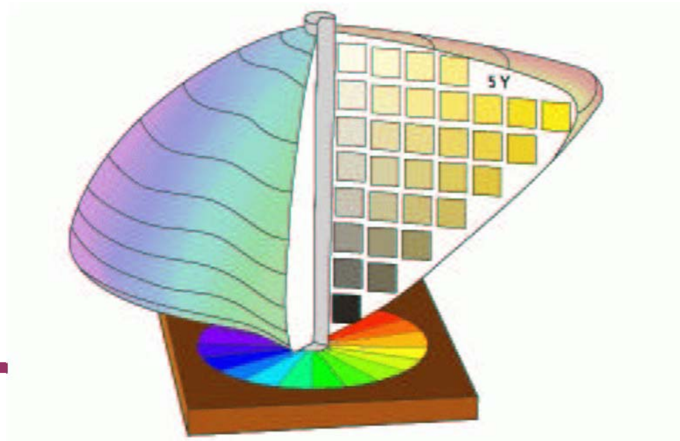
Colour perception

Colour perception

Colour description

Need of colour description

- Language labels: red, green, …
- Hue, illumination and chromacity (saturation)
  - Hue: colour attribute
  - Luminosity: light component (from white to black) of a colour
  - Saturation: intensity of this colour (from grey to colour)



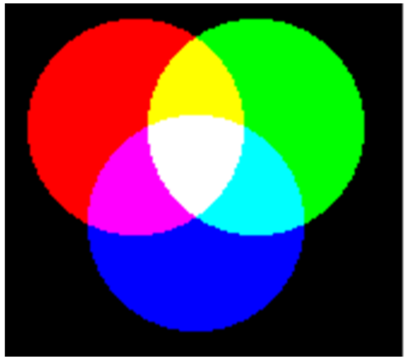
Colour spaces

Colour spaces

- 3 dimensional representations of colour
- Each point represents a different colour
- Classification based on
  - Visual human system (RGB, HIS)
  - Technical systems (colorimetry, xyz)
  - Image processing (Ohta, ...)
  - ...

Colour specification

- Colour models: additive vs subtractive



  - Additive: RGB
    - Monitors, cameras
  - Subtractive: CMY-K
    - Light absorption
    - Printing

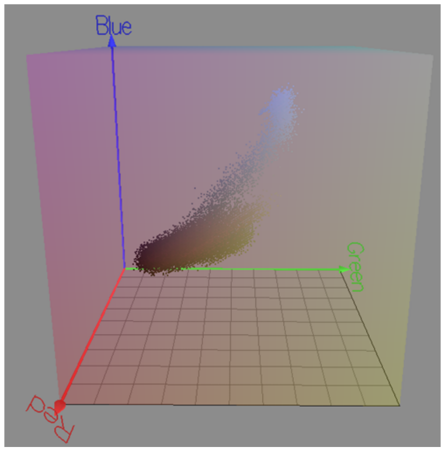
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Colour spaces

RGB

- Cube representation
- Intensity independence (r+g+b=1)

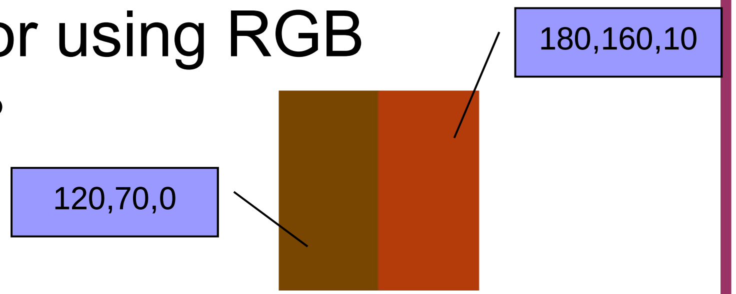
$$r = \frac{R}{R+G+B} \quad g = \frac{G}{R+G+B} \quad b = \frac{B}{R+G+B}$$



Colour spaces

RGB. Problems

- Not able to represent all colors that humans can perceive (ex. RGB monitors)
- Is not easy to express a color using RGB
  - What is RGB value for brown?

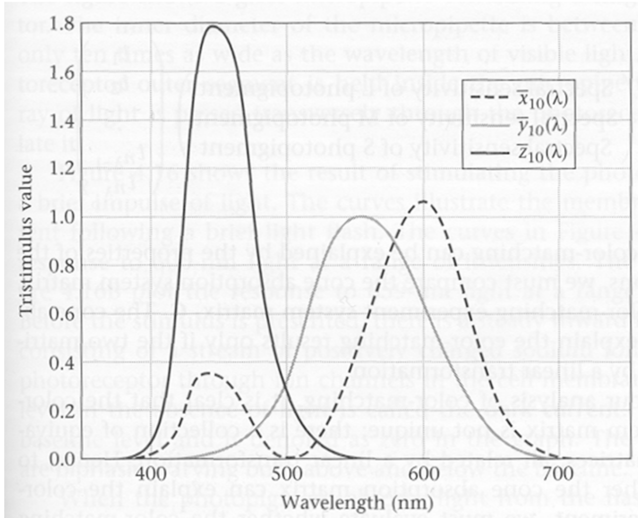


- Perceptually not lineal
  - A smaller distance between 2 points in RGB does not mean that are perceptually more similar that 2 points with a larger RGB distance

Colour spaces

CIE XYZ (1931)

- Positive Color functions
- Origin: Technical developments



- Y component corresponds to intensity
- Conversion from RGB to XYZ considering an illuminant E

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.7690 & 1.7518 & 1.1300 \\ 1.0000 & 4.5907 & 0.0601 \\ 0.0000 & 0.0565 & 5.5943 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

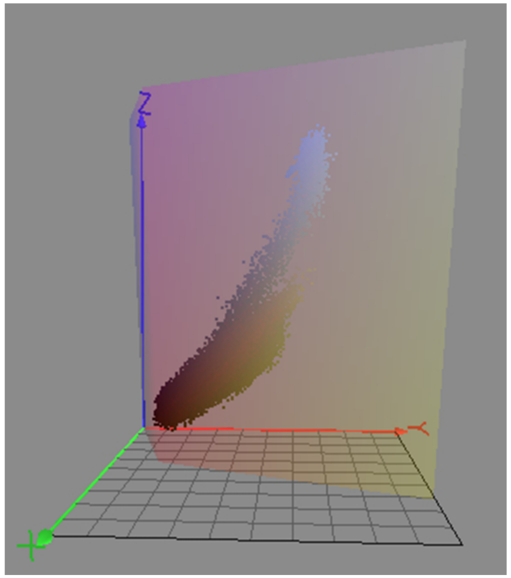
$$\forall \lambda \quad E(\lambda) = 1$$

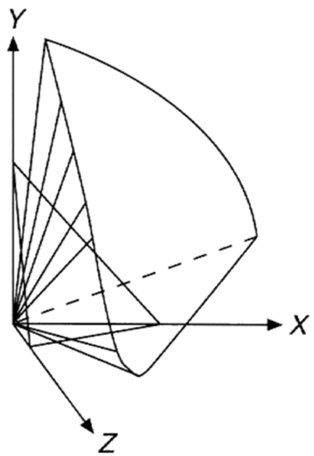
Colour spaces

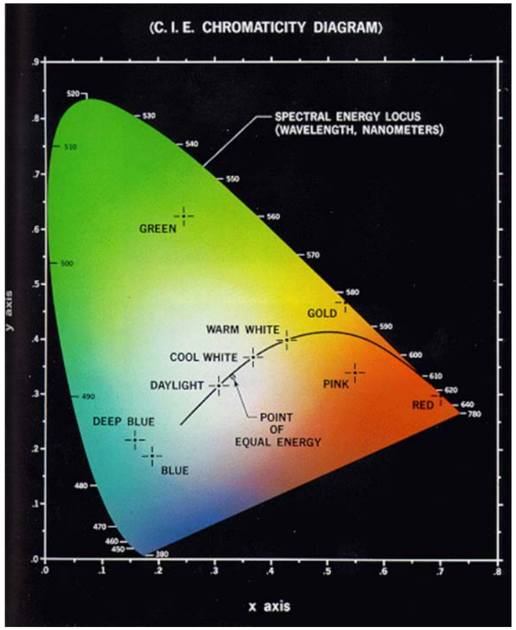
CIE XYZ (1931)

- Cromacity image: projection X-Y

$$x = X / (X + Y + Z)$$
$$y = Y / (X + Y + Z)$$



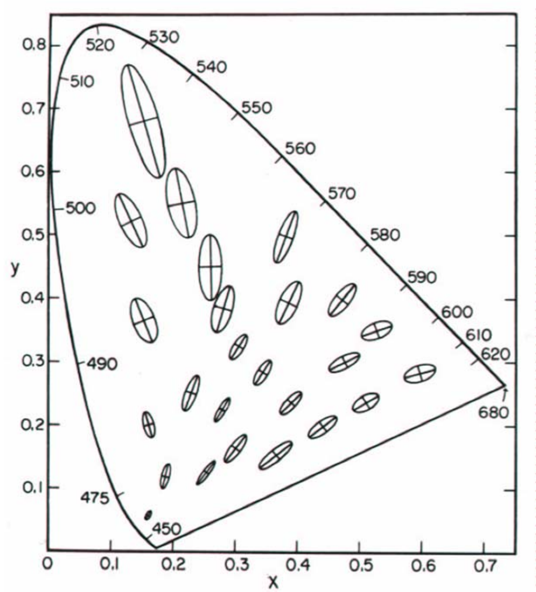




Colour spaces

CIE XYZ (1931)

- Problem: no linearity with colour perception
- MacAdam Ellipses:
  - Each ellipse denotes colour matching of an observer

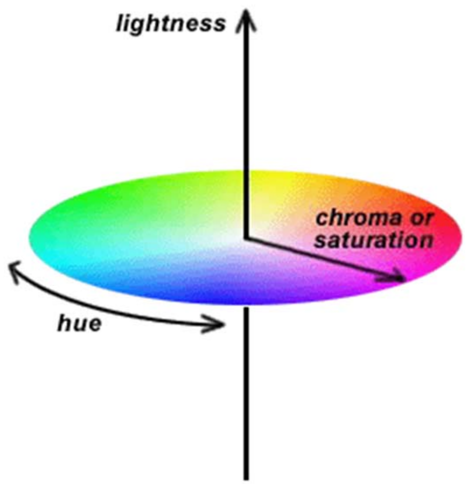


- Need of other colour spaces
  - CIELuv
  - CIELab

Colour spaces

CIELuv and CIELab

- Measure of light in *L (vertical axes)
- Planes with coordinates (u*,v*) or (a*,b*)
- Points far from *L axes represent colour
- Measure of cromacity C* and Hue angle H*



$$C^*_{uv} = \sqrt{u^{*2} + v^{*2}} \qquad h_{uv} = \arctan\left(\frac{v^*}{u^*}\right)$$

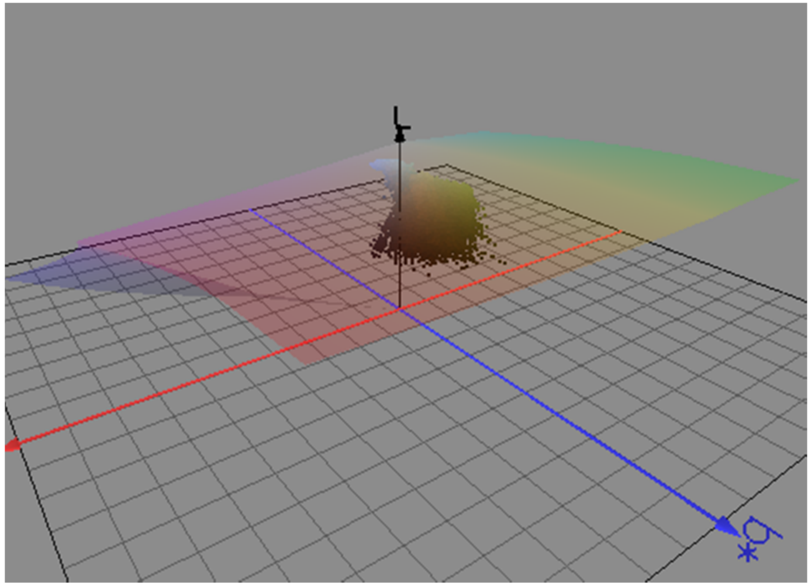
$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \qquad h_{ab} = \arctan\left(\frac{b^*}{a^*}\right)$$

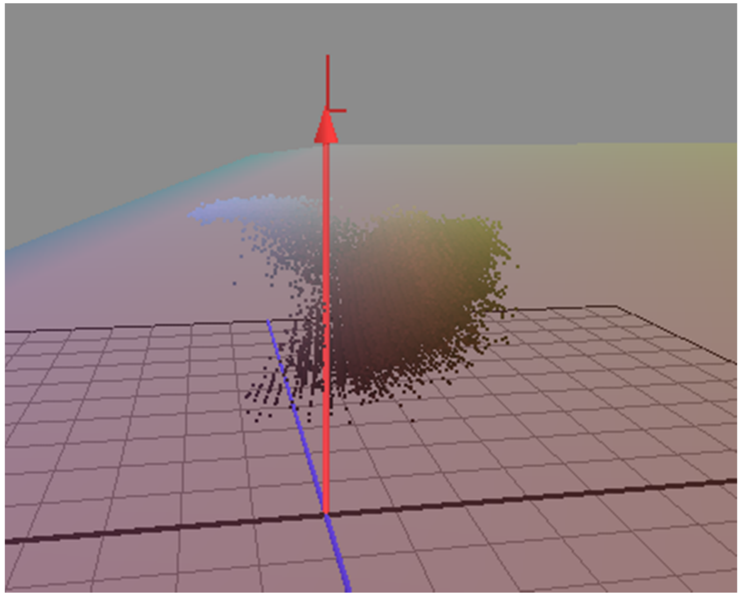
- Colour difference (lineal)

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad \text{or} \quad \Delta E = \sqrt{\Delta L^2 + \Delta {C^*_{ab}}^2 + \Delta {h_{ab}}^2}$$

Colour spaces

CIELuv and CIELab





Perceptual Colour Spaces

HSI: Hue, Saturation and Intensity

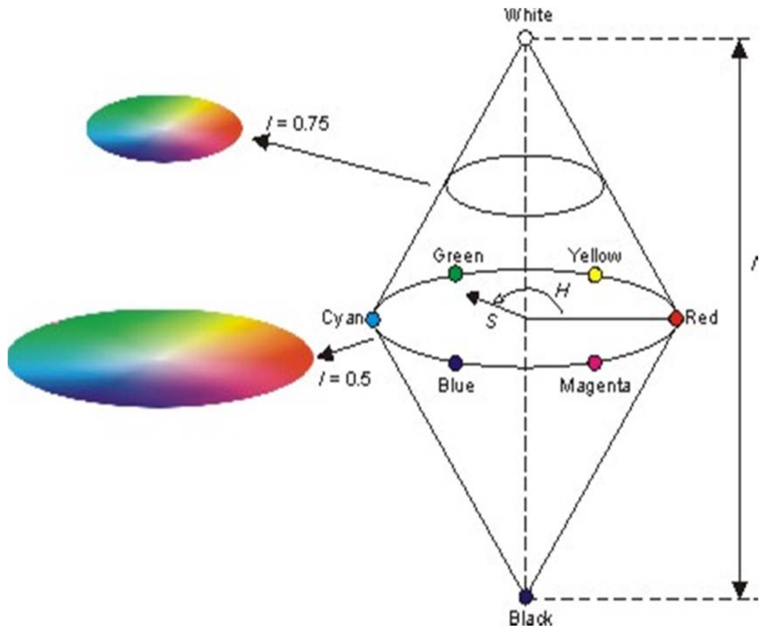
- Intensity: amount of light
- Hue: colour (main wavelegth)
- Saturation: colour "purity"

$$I = 1/3(R+G+B)$$

$$S = 1 - \frac{\min(R,G,B)}{I}$$

$$H = \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{\left[(R-G)^2+(R-B)(G-B)\right]}}\right\} \text{if} \quad B<G$$

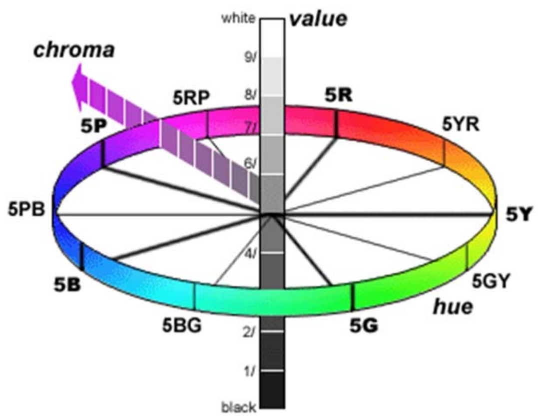
$$H = 360 - \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{\left[(R-G)^2+(R-B)(G-B)\right]}}\right\} \text{if} \quad B>G$$

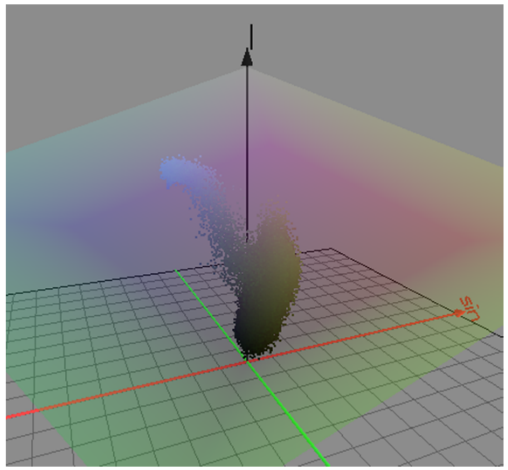


Perceptual Colour Spaces

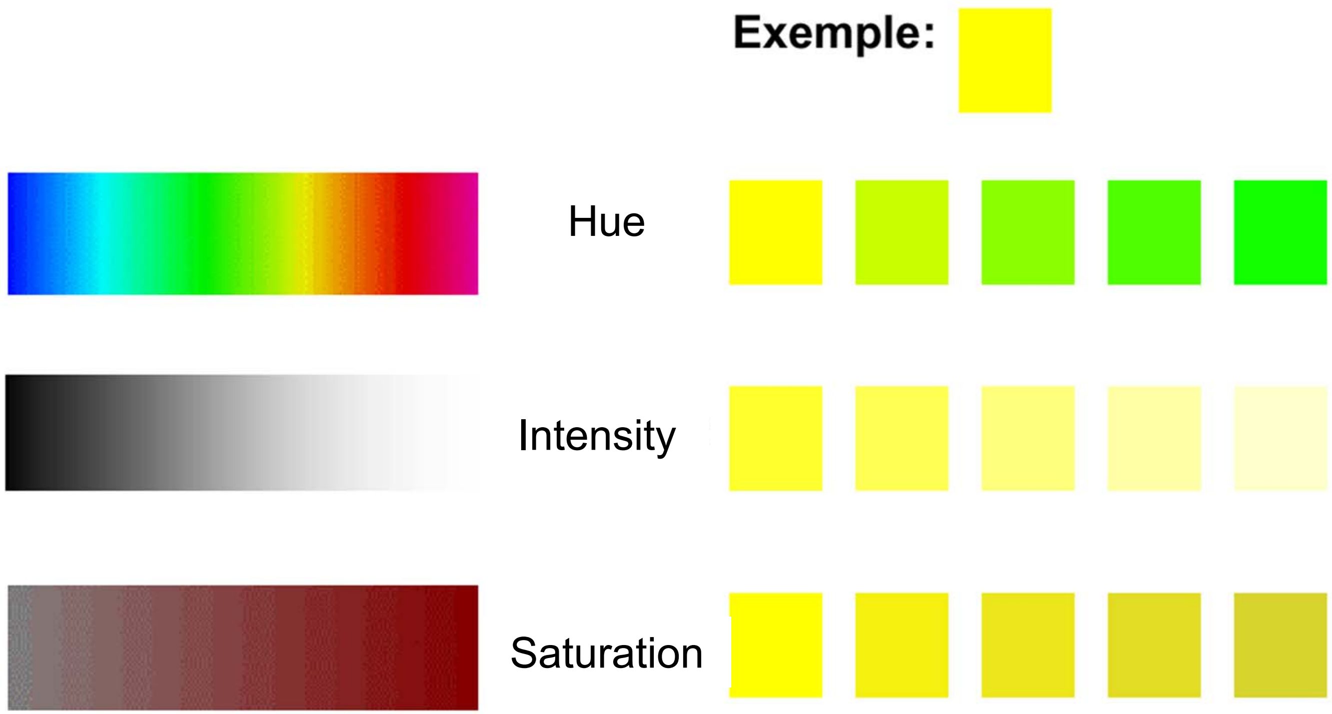
HSI: Hue, Saturation and Intensity

- More similar to our colour perception
- Various Colour models based on HSI
  - (Munsell –red, yellow, green, blue, purple)





Perceptual Colour Spaces



Perceptual Colour Spaces

Espai HSV (Smith):

$$H = \begin{cases} 60 * (b' - g') & if\ R = max(R,G,B) \\ 60 * (2 + r' - b')\ if\ G = max(R,G,B) \\ 60 * (4 + r' - g')\ if\ B = max(R,G,B) \end{cases}$$

$$r' = \frac{max(R,G,B) - R}{max(R,G,B) - min(R,G,B)}$$

$$g' = \frac{max(R,G,B)\ - G}{max(R,G,B)\ - min(R,G,B)}$$

$$S = \frac{max(R,G,B) - min(R,G,B)}{max(R,G,B)}$$

$$b' = \frac{max(R,G,B) - B}{max(R,G,B) - min(R,G,B)}$$

$$V = max(R,G,B)$$

Espai HSV (Tenenbaum):

$$H = arctan\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right) \qquad V = \frac{R+G+B}{3}$$

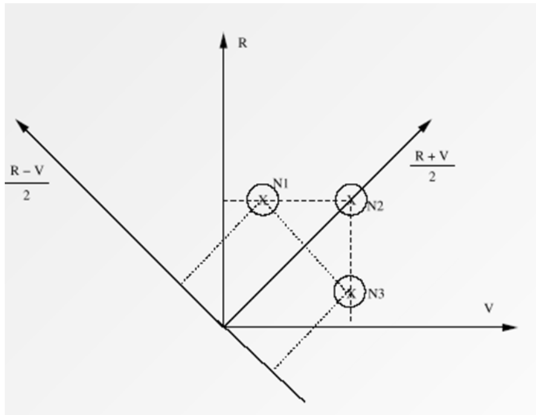
$$S = 1 - 3 * min\left(\frac{R}{R+G+B}, \frac{G}{R+G+B}, \frac{B}{R+G+B}\right)$$

Non Correlated colour spaces

Non correlated

- There is a high correlation (0.78-0.90) between components in some colour spaces, mainly due to the luminosity/Intensity component
- In addition and except for the luminosity, components show little discriminant characteristics (small variance)

$X_1X_2X_3$ Space: Obtain new axes with more uncorrelated and discriminant data using the Karhunen-Loeve transform (KL)



Non Correlated colour spaces

$X_1X_2X_3$

Obtain discriminant colour features using the KL transform:

- Compute the covariance matrix of RGB, P matrix
- In general, for P_1, P_2, P_3 colour components

$$\mathbf{P} = \begin{bmatrix} var(P_1) & cov(P_1,P_2) & cov(P_1,P_3) \\ cov(P_1,P_2) & var(P_2) & cov(P_2,P_3) \\ cov(P_1,P_3) & cov(P_2,P_3) & var(P_3) \end{bmatrix}$$

- [Reminder] Variance and covariance of a random variable

$$\mathbf{P}(i,j) = 1/N \ \textstyle\sum_{k=1}^{N} ({c_k}^i - \bar{c_i})({c_k}^j - \bar{c_j}) \quad \text{if } i \neq j$$

$$\mathbf{P}(i,i) = 1/N \ \textstyle\sum_{k=1}^{N} ({c_k}^i - \bar{c_i})^2$$

Non Correlated colour spaces

$X_1X_2X_3$

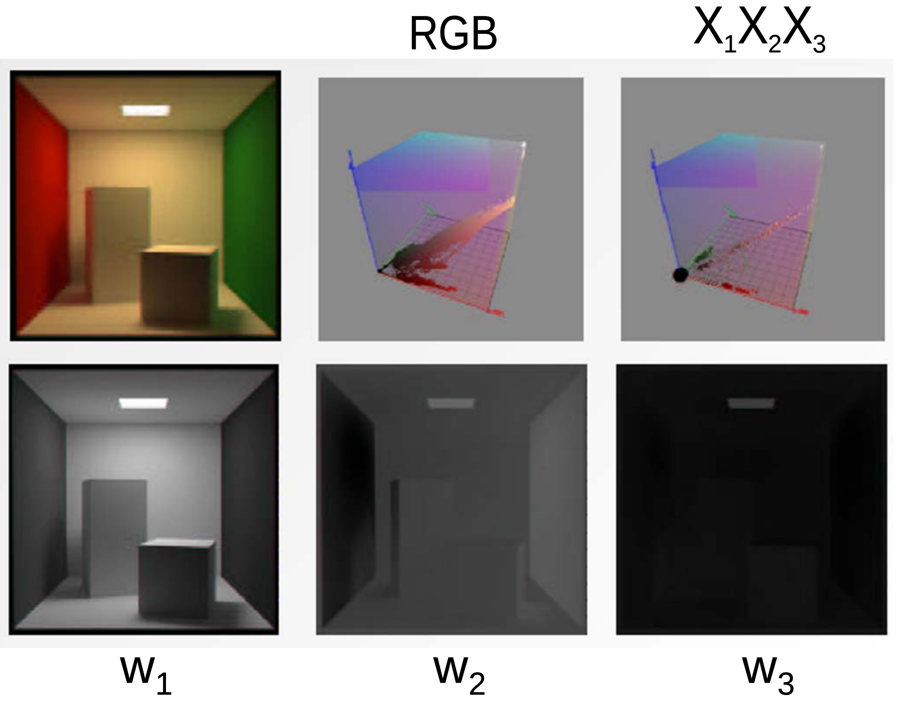
- KL transform:
  - Compute eigen values (λ_1, λ_2, λ_3) and eigen vectors (ω_1, ω_2,ω_3) of the covariance matrix P (being $\lambda_1 > \lambda_2 > \lambda_3$)
  - Usually, from the principal axes of the eigen vectors:
    - ω_1 corresponds to the luminance component
    - ω_2 ω_3 corresponds to colour characteristics (usually just using ω_2 to represents the major colour distribution)

$$X_1 = \omega_1^1\ P_1 + \omega_1^2\ P_2 + \omega_1^3\ P_3$$
$$X_2 = \omega_2^1\ P_1 + \omega_2^2\ P_2 + \omega_2^3\ P_3$$
$$X_3 = \omega_3^1\ P_1 + \omega_3^2\ P_2 + \omega_3^3\ P_3$$

Non Correlated colour spaces

$X_1X_2X_3$: Example of a synthetic image: RGB & $X_1X_2X_3$ colour spaces

- W1: Luminosity
- W2: Differential colour between red and green
- W3: Remaining colour information



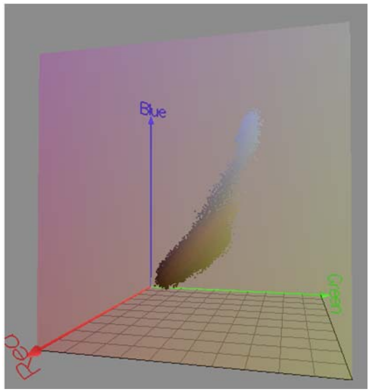
Non Correlated colour spaces

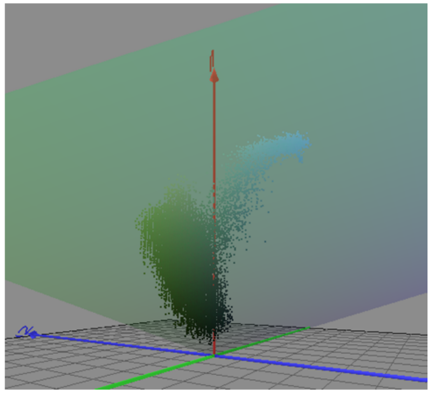
Ohta $I_1I_2I_3$

- The KL computation can be approximated by

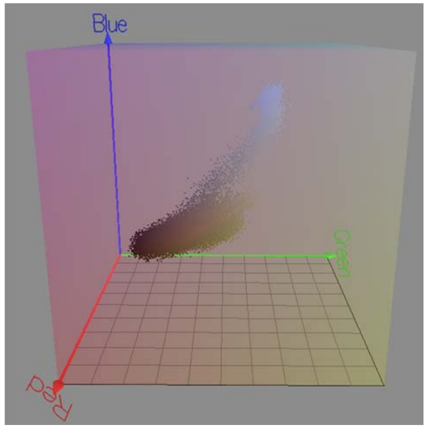
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ 1/2 & 0 & -1/2 \\ -1/4 & 1/2 & -1/4 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Reduces the correlation of RGB
- Useful for compression and clustering applications

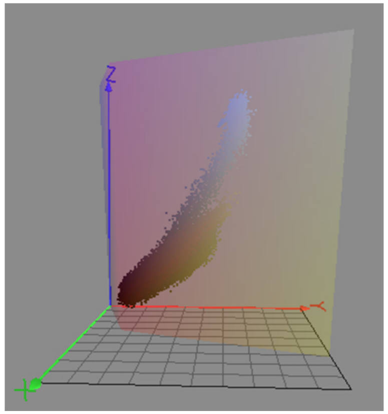




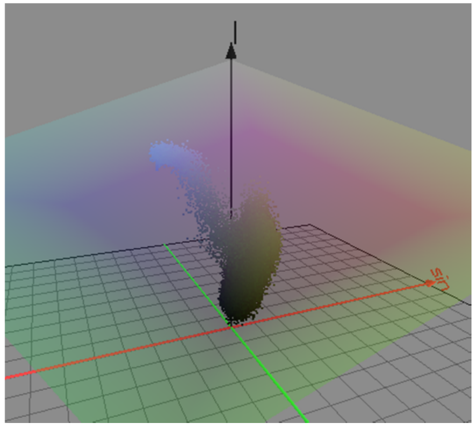
Which colour space?



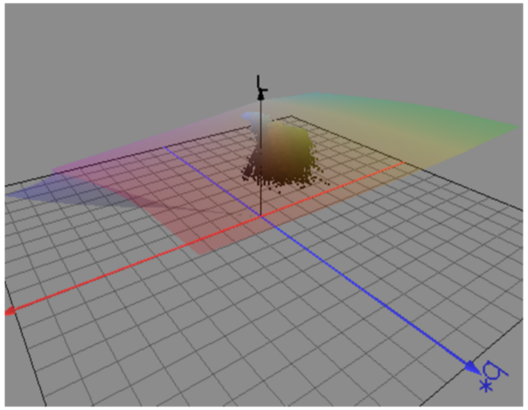
RGB



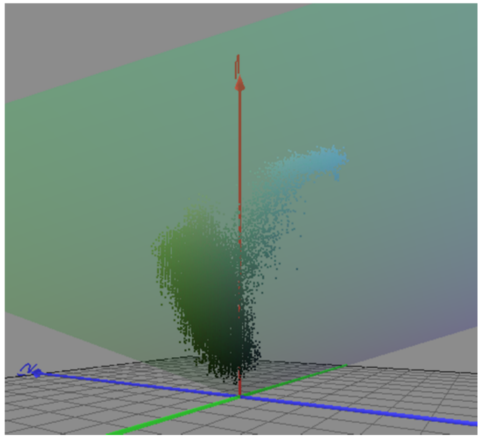
XYZ



HSI

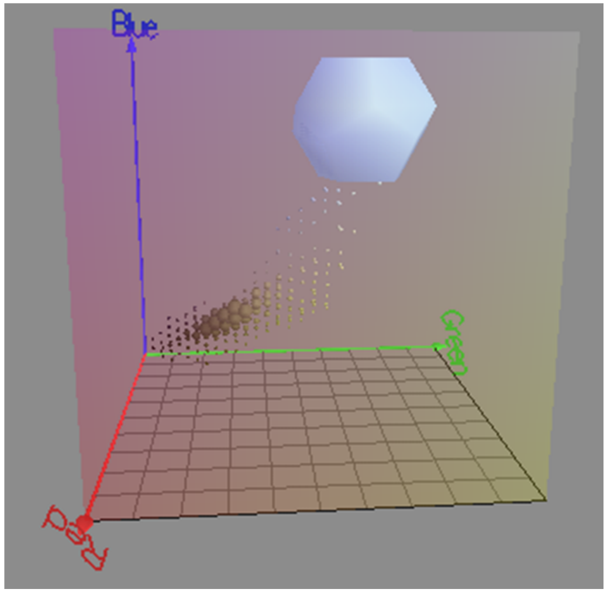


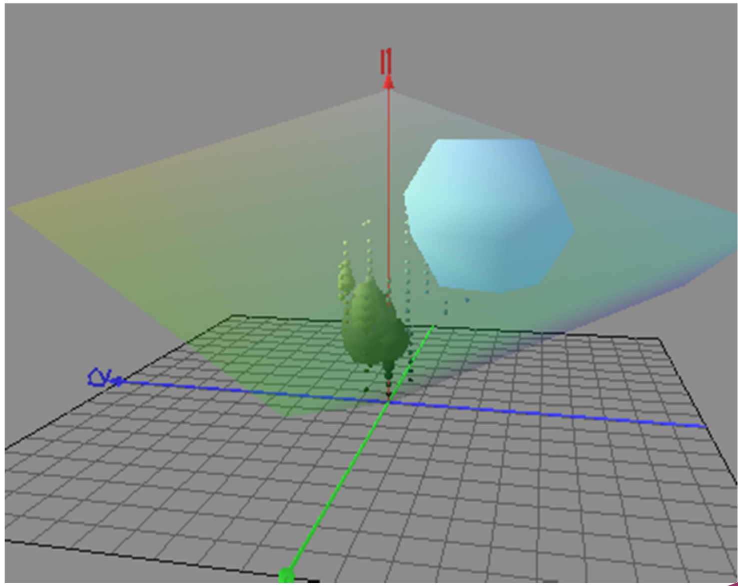
CIELUV



$I_1 I_2 I_3$

Which colour space?

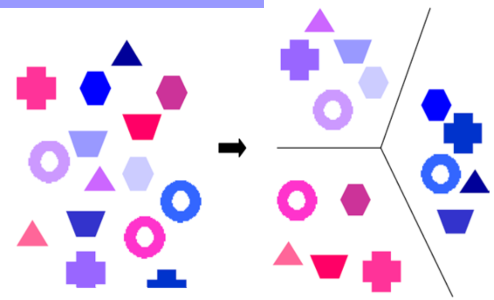




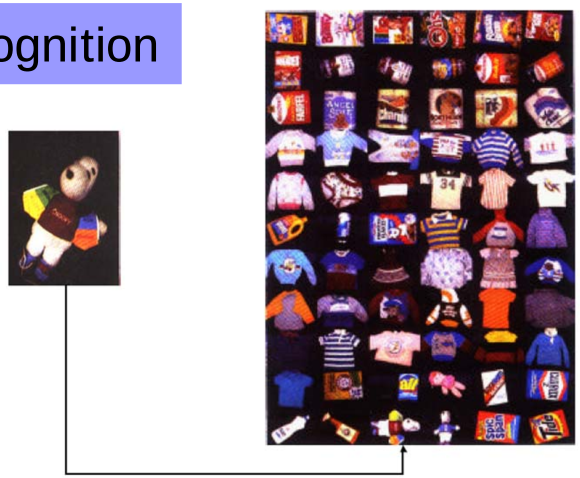
Applications

- Colour applications: along with shape and texture, colour will be used to characterise a region → first step for applications such as
  - Image segmentation and clustering
  - Compression and codification
  - Image recognition and understanding
  - Movement analysis…

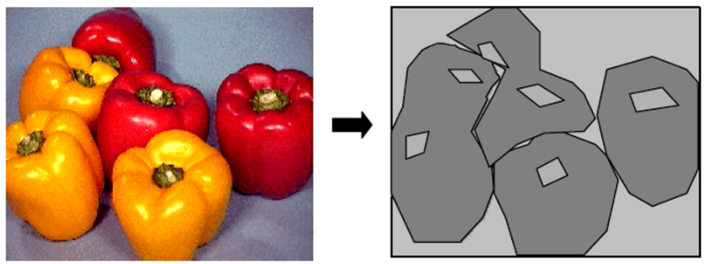
Classification



Recognition



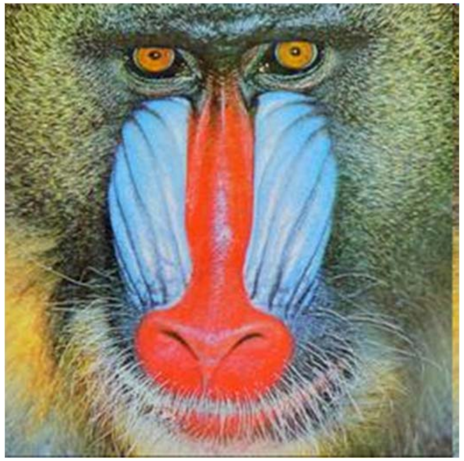
Segmentation

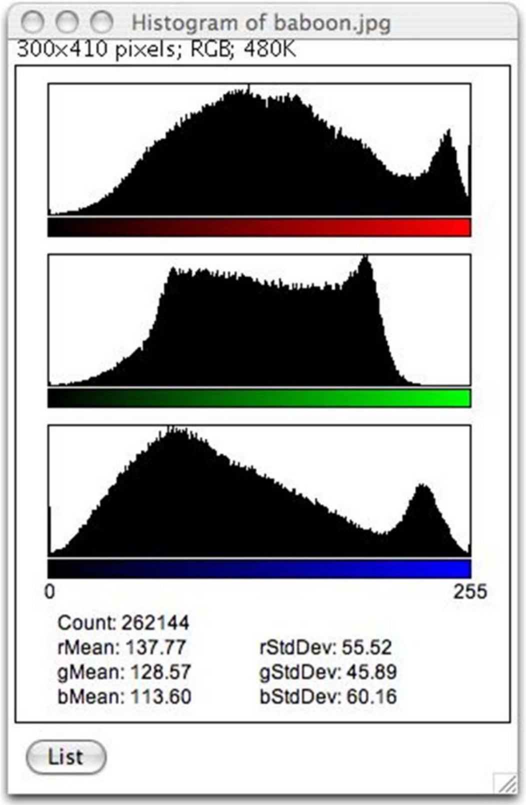


Extracted from J.Vitrià

Applications

Color histograms for image characterization



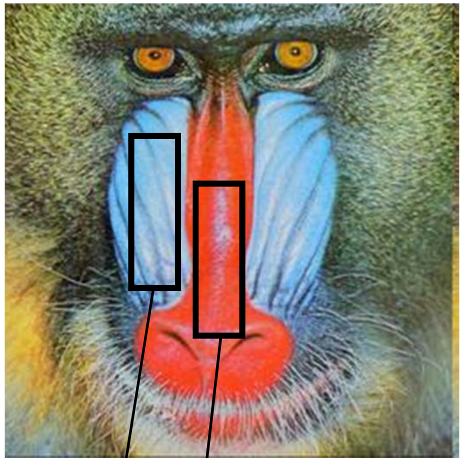


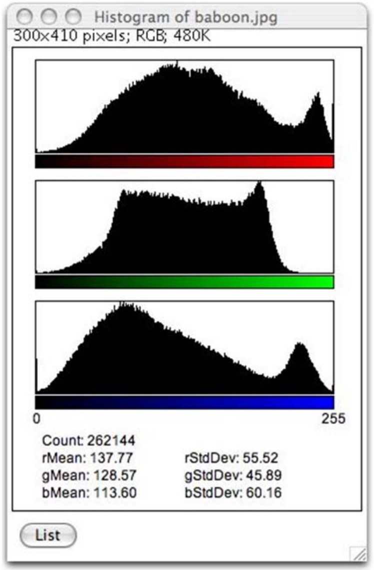
Summary. Colour

- There is not an optimum colour space, depends on the application and the type of images used
- We need to know the properties of each colour space
- The selection of a colour space will have an influence on the final results of the application

- Further information on colour:
  - Colour.org color.org
  - http://www.couleur.org/index.php

Color characterization





Feature vector 1=[mean R, mean G, mean B, mean H, mean S, mean V, …]

Feature vector 2=[mean R, mean G, mean B, mean H, mean S, mean V, …]