Color & Images

What is a picture?

Question: 30s

What is a picture?

- **Real picture**
  - Function of two variables to a color
- **Numerical picture**
  - Array of pixels (*picture element*)
- Information required
  - Number of rows, columns
  - Encoding for each pixel (nb bits, levels of grays, levels of colours)
  - Compression?
- Many picture formats:
  - Encapsulation: header, data
  - Not necessarily connected to compression

Image file format

- Example (representative) : Tiff
- Header (8 bytes) :
  - 0-1 : little-endian (II) or big-endian (MM)
  - 2-3 : « 42 » (002A)
  - 4-7 : offset for 1st image file directory (IFD)
- IFD (Image File Directory) :
  - 2 bytes: nb of entries
  - 12 bytes per entry: name, type, pointer or value
  - 4 bytes: offset for next IFD
  - Can have several pictures in a single file!

Entries examples

- Size (pixels), dimension (cm)
- Resolution (pixels / cm)
- Color model (RGB, CMYK, YCbCr...)
- Compression (nothing, pack, JPEG...)
- Data (required, at least one)
- Color profile
- Author name, copyright license...

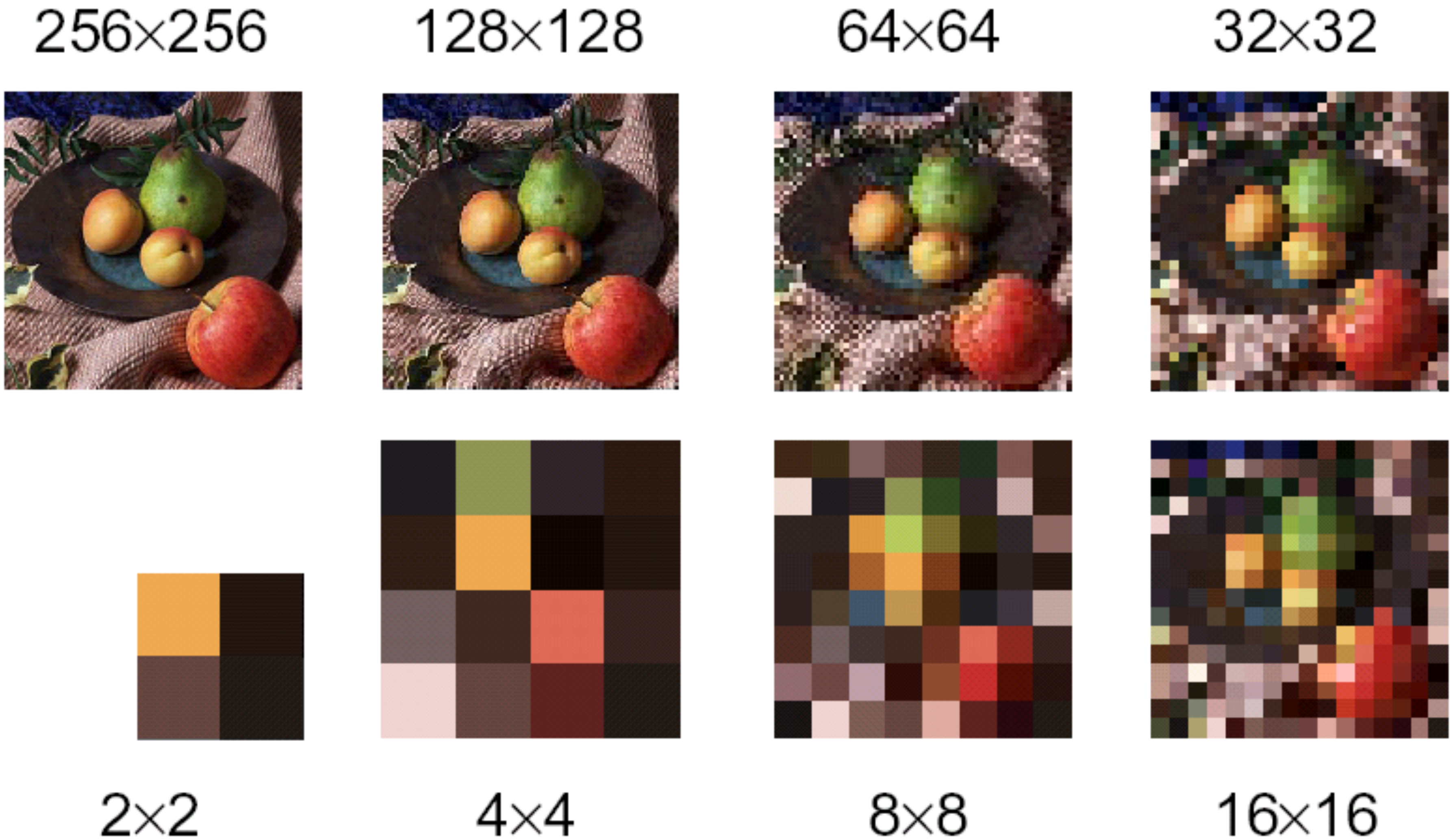
- Several images:
  - mask with picture, multi-resolution

Analog to digital

- Real picture / array of pixels
- Continuous intensity / discretized values
- Physical colour / RVB values

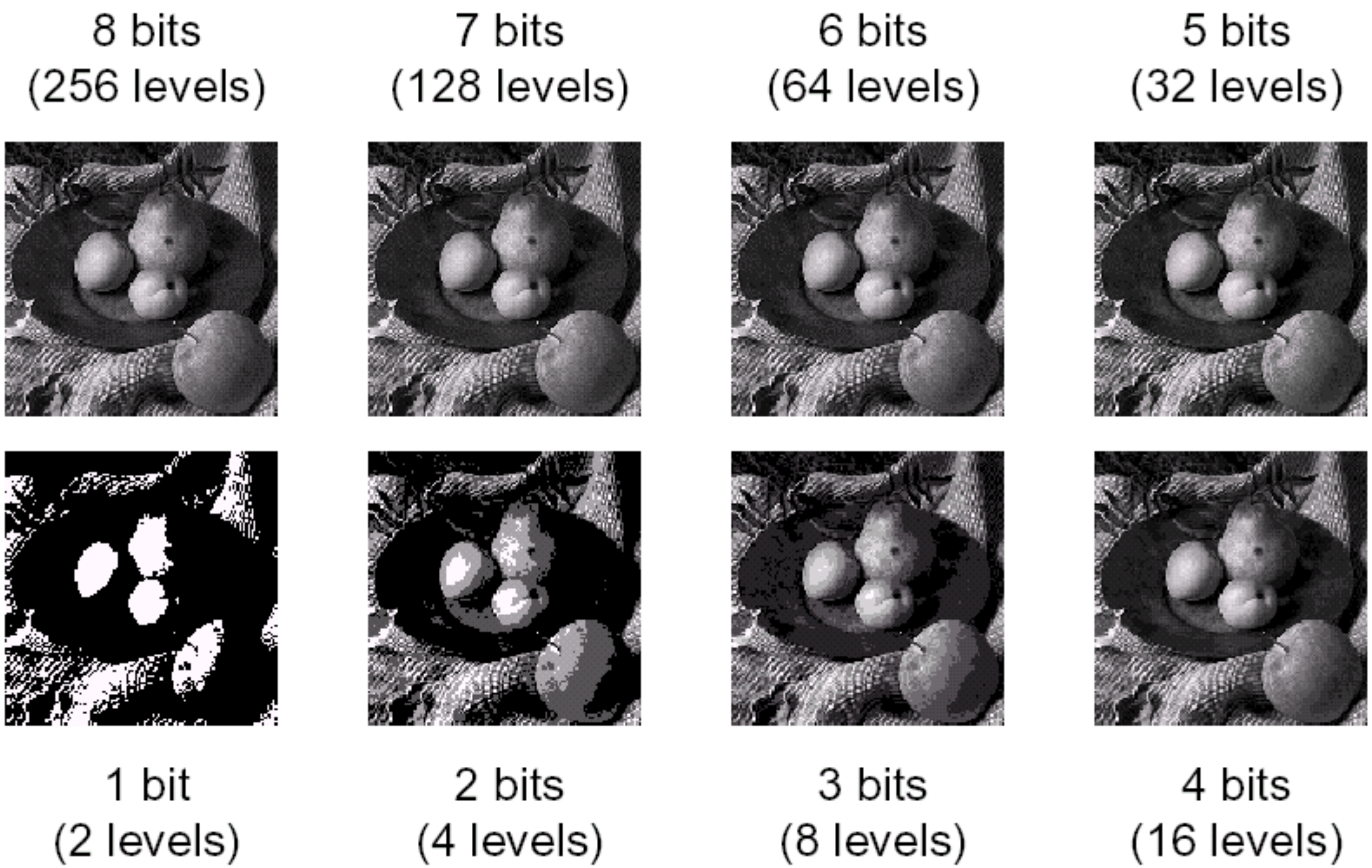
We're loosing something!

Sampling: screen resolution



Sampling: intensity

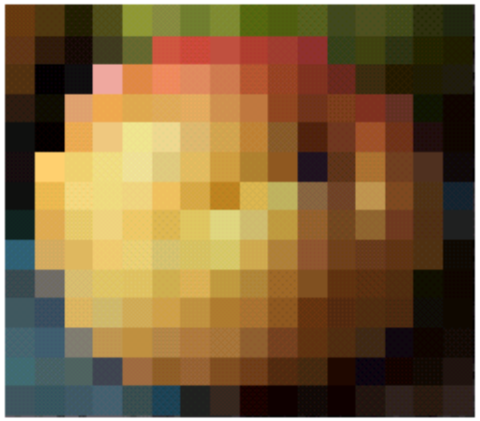
- 8 bits for level of intensity (levels of gray)
- Thus 8*3 = 24 bits for colours (RVB)

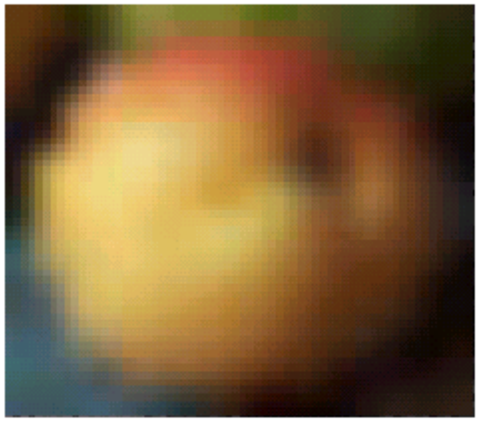


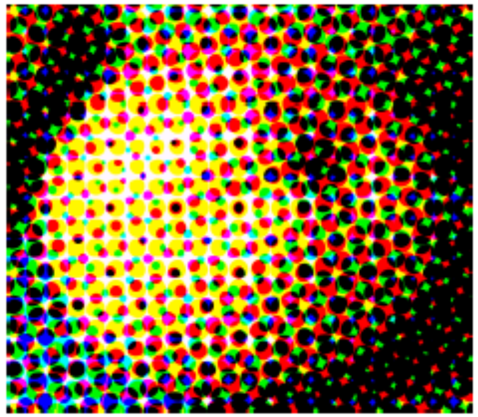
Trade-off?

- **Resolution** : dpi (dots per inch)
  - 100 for a screen
  - 300-1200 for a printer

- Different upsampling methods:
  - Size-varying disks (printer)
  - Variable intensity (screen)

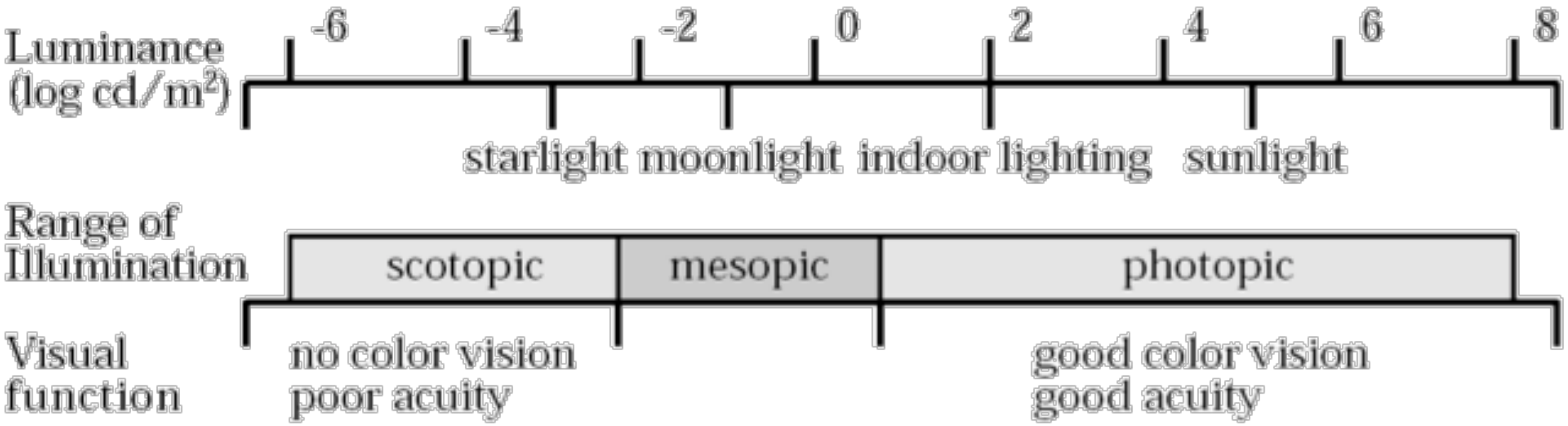

Nearest-neighbour


Gaussian


Half-toning

Light intensity

- 8 bits per cololr channel: 16m colours but only 768 levels of lighting available
- In real life: lighting ratio of $1:10^{10}$ between night and day
- Eye: logarithmic sensitivity



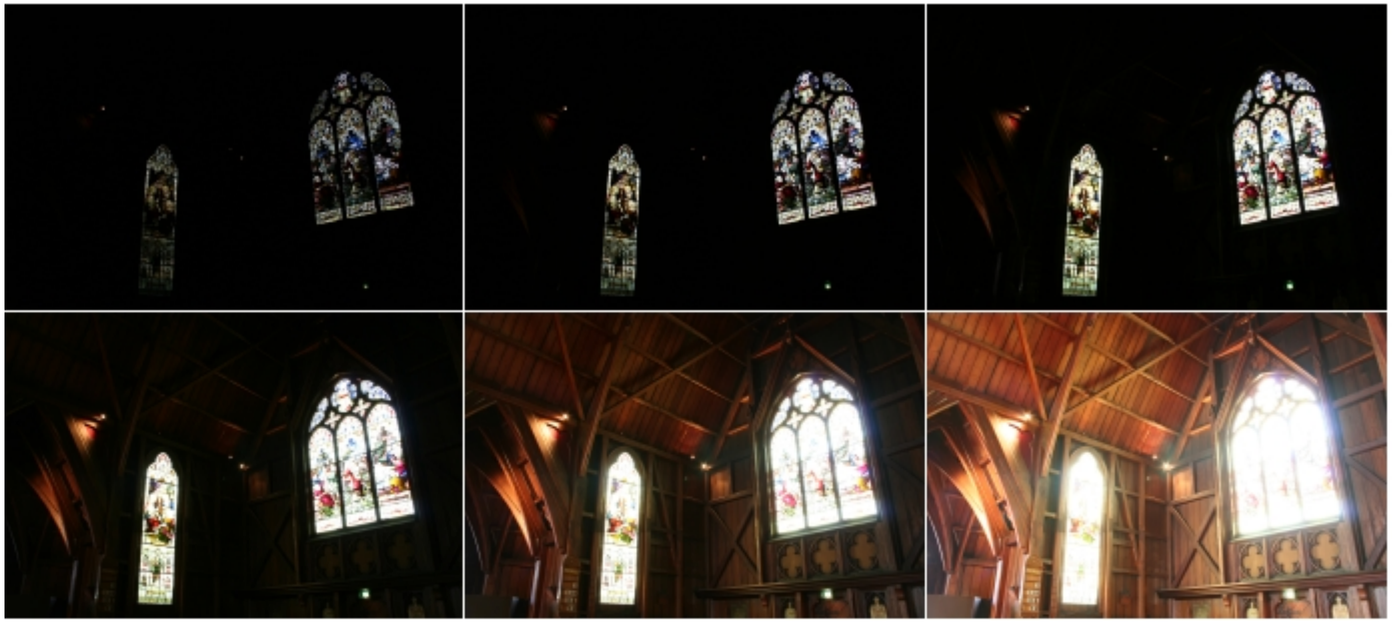
Ferwerda et al. '96

HDR (High Dynamic Range)

- Picture with larger range of intensity
  - 96 bits per pixel = 1 float
- How to acquire them? How to display them?
  - Screens and sensors are still 24 bits…

HDR (High Dynamic Range)

- Acquisition:
  - Specialized cameras:
    - Fuji FinePix S3 Pro et Fuji FinePix F700
  - Several pictures with a standard camera



HDR (High Dynamic Range)

- Displays
  - Special screens
    - BrightSide DR37-P

  - Tone mapping on standard displays

Colour

- Question 1mn: **What is it???**

Colour – Definitions

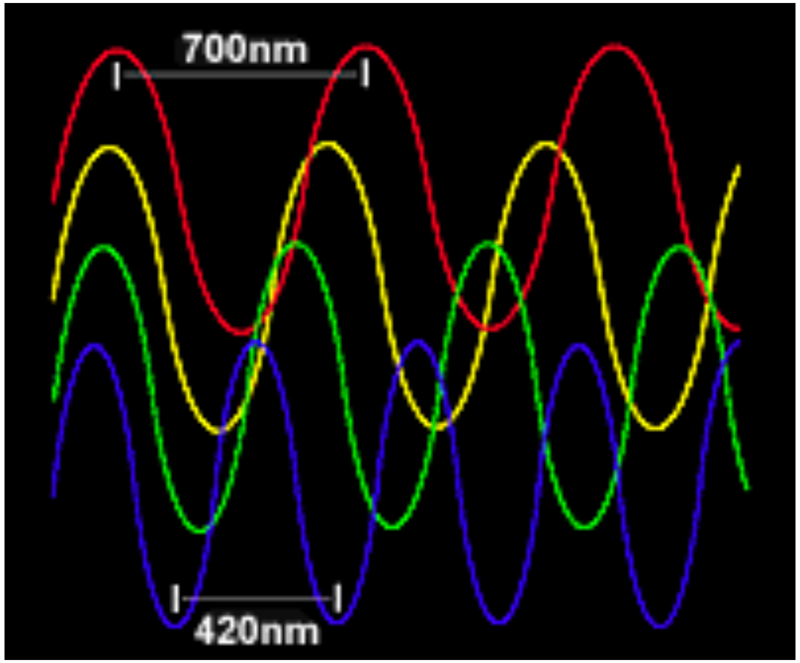
- **Art**
  - Hue, saturation, luminance/brightness
- **Physical**
  - Spectrum, stimulus
- **Biological**
  - Perceptually uniform spaces
- **Mathematical**
  - Universal basis functions
- **Computer Science**
  - RGB, CMYK, HSV…

Light spectrum

- Light = electromagnetic wave
- Variable wavelength λ
  - From 420 nm (purple) to 700 nm (red)

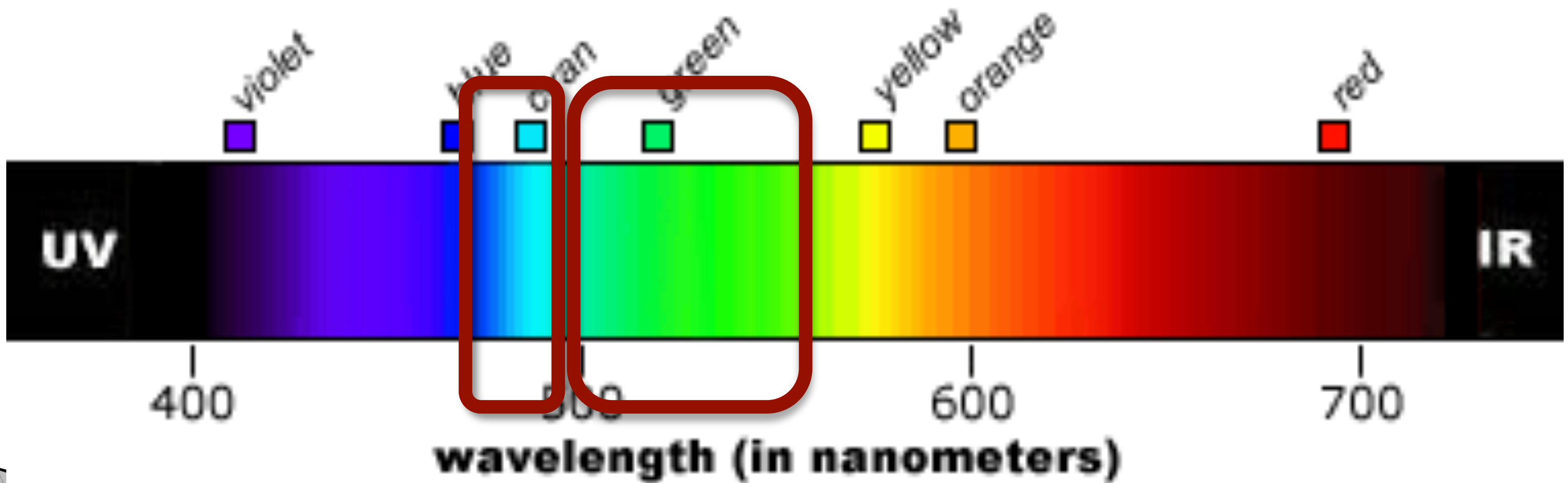
- Frequency: $F = c/\lambda$

- Energy : $E = hF = hc/\lambda$



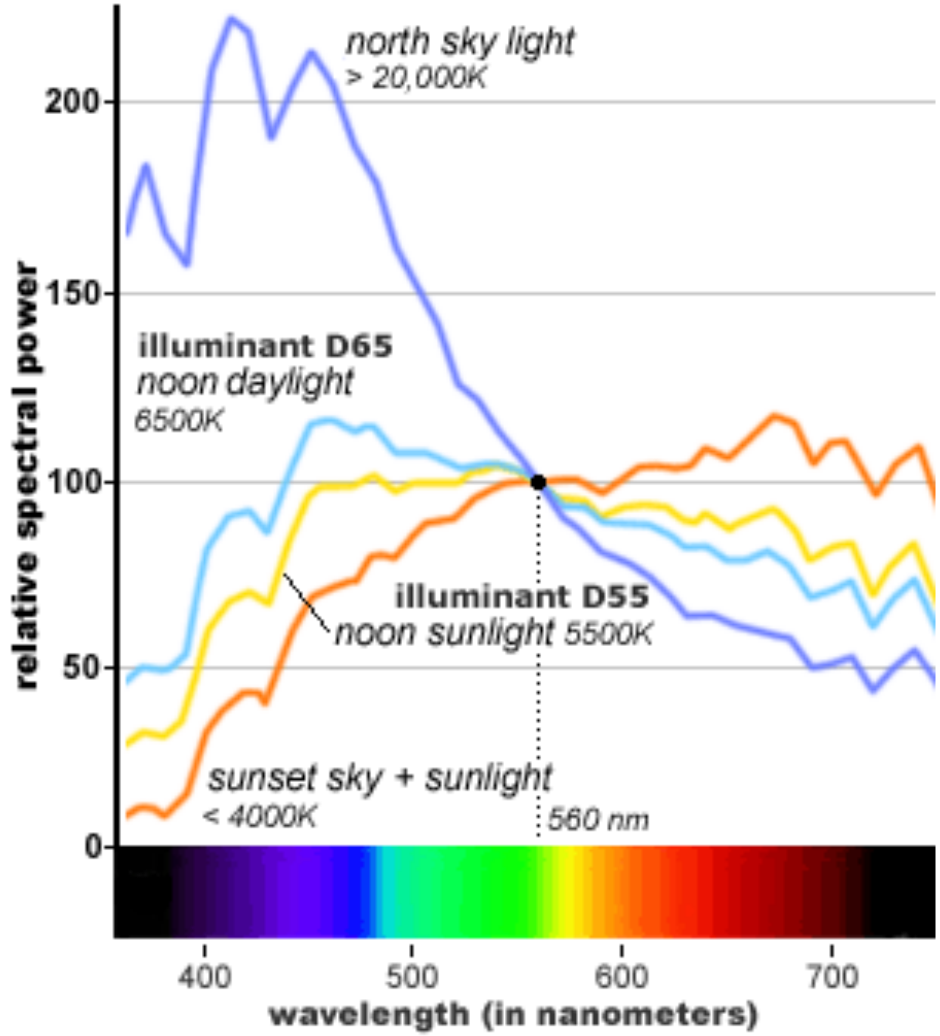
Light spectrum

- Visible spectrum: from purple to red
- Beyond: infra-red / ultra-violet
  - Infra = before, ultra = after
  - Frequency-based ordering
- Wavelength difference perception variable



Light source spectrum

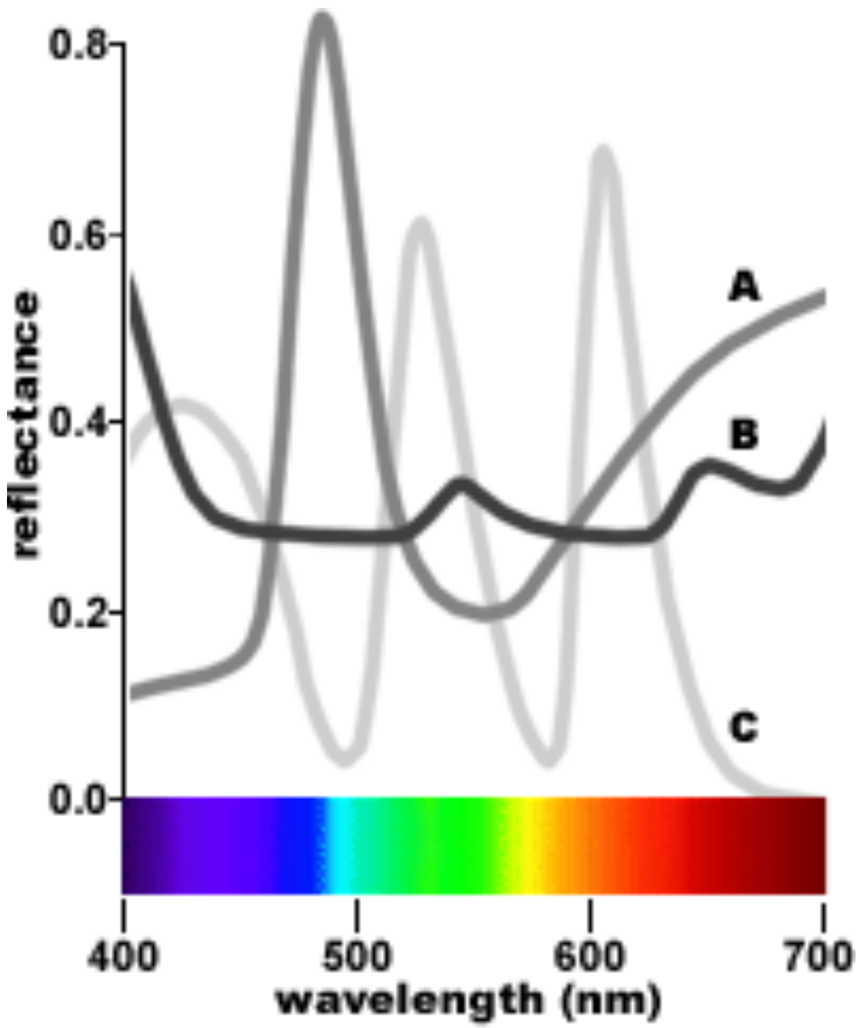
- Depends on the light source
- Classification



Metamers

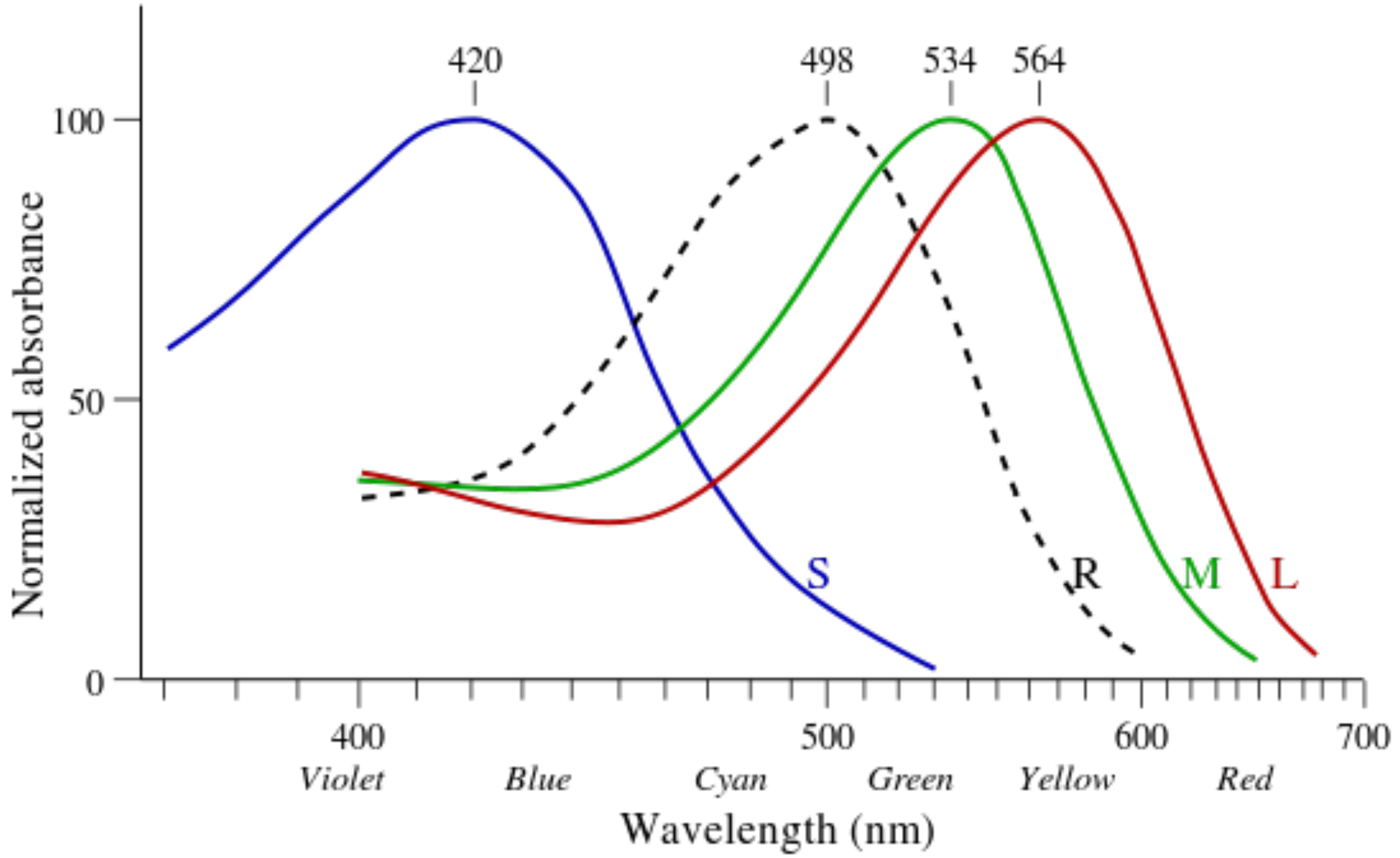
- Appearance = product illuminant/material
- 2 different spectrums
- Same (visible) color
- Source spectrum dependent

- …but not necessarily



Human perception

- Retina: cones, rods



Retina

- Rods: scotopic vision (night vision)
- Cones:
  - Color vision + sharp edge vision
  - 3 wavelengths: Short, Medium, Long
  - Not red-green-blue

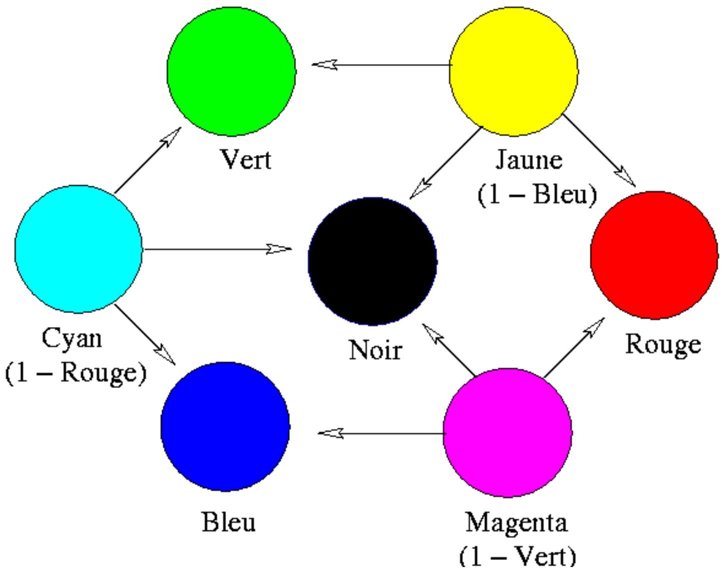
- Tri-chromatic vision
- Tri-chromatic display

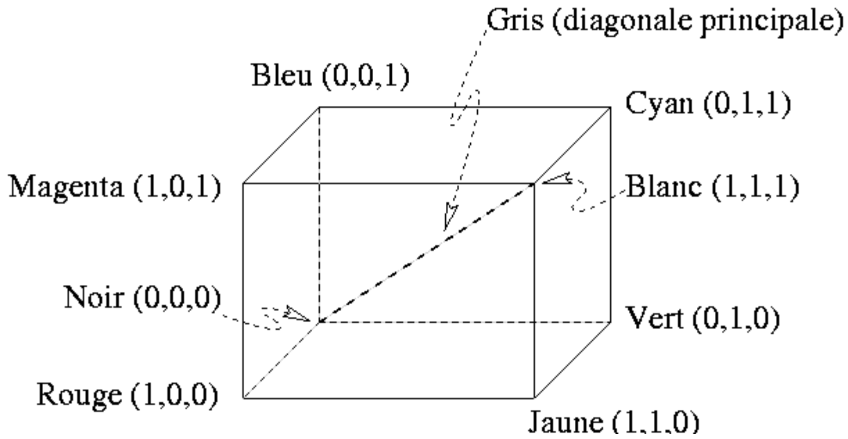
- One slight problem...

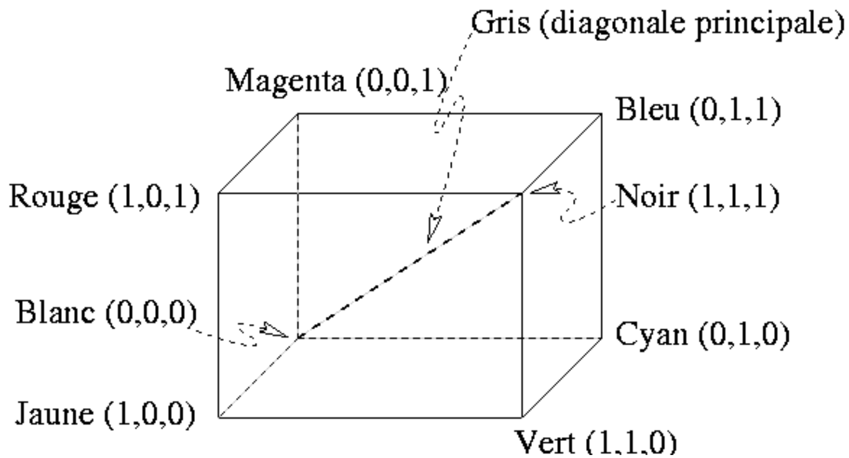
Tri-chromatic systems

- Screens (RGB), printers (CMYK)

RGB: additive, displays



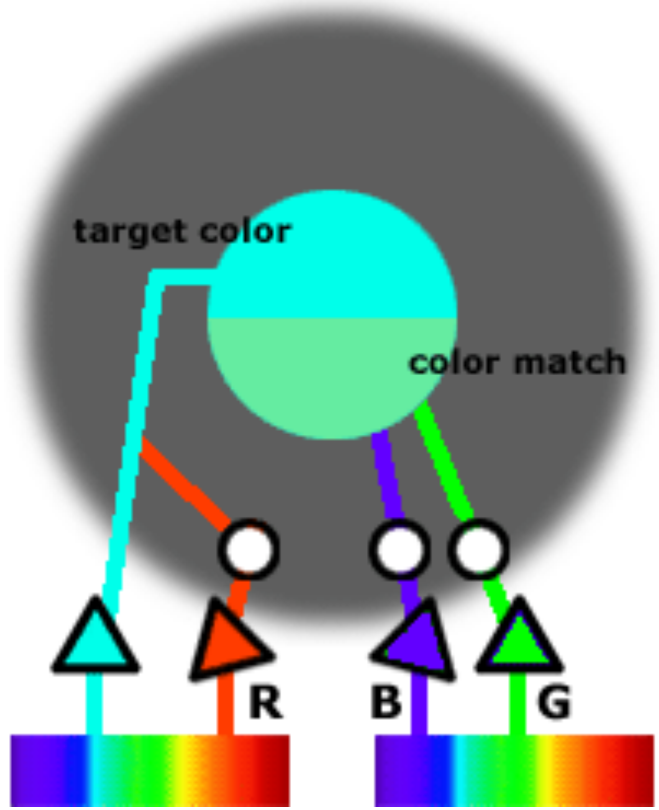




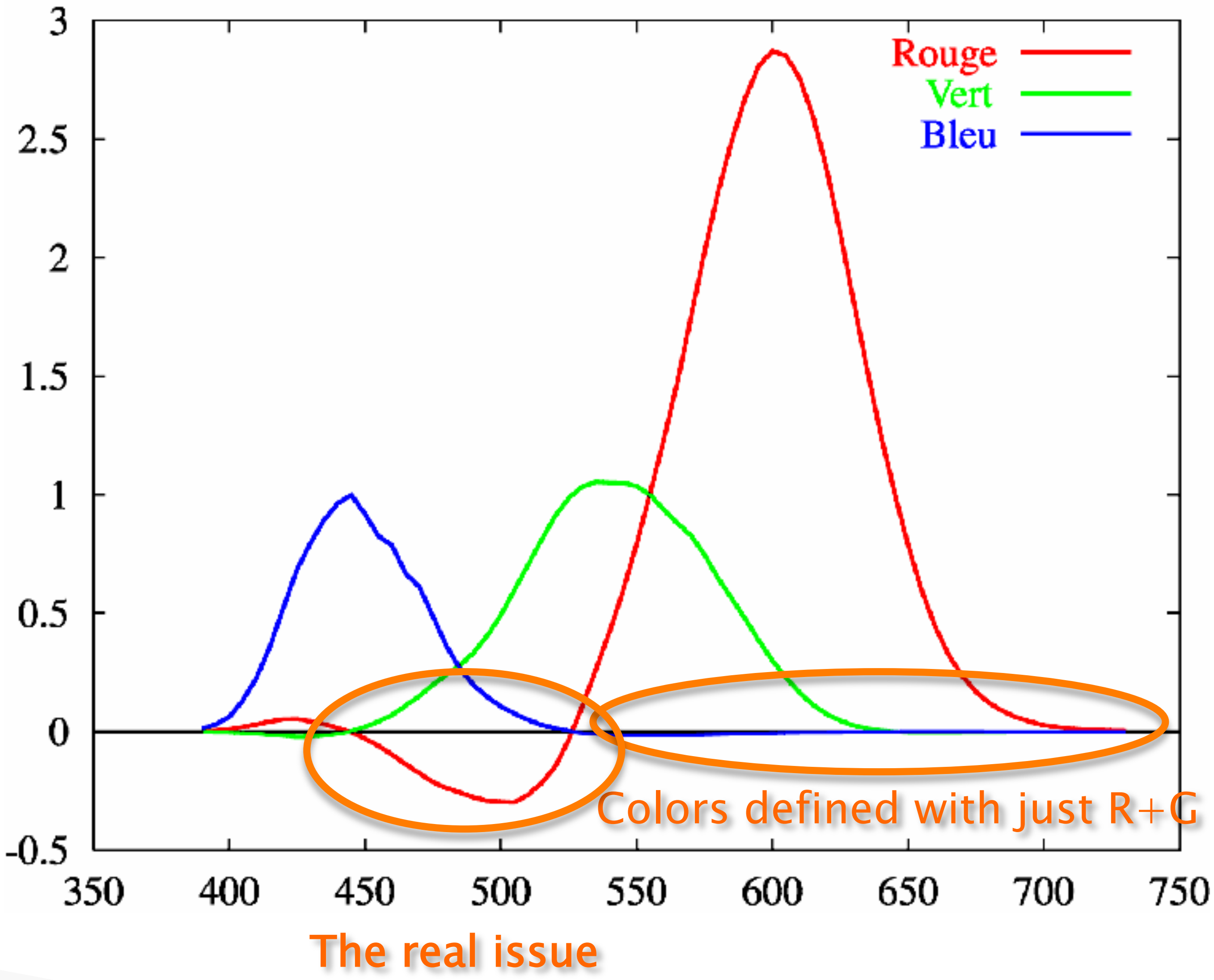
CMY: subtractive, painting, printers

Color matching experiments

- Input = 1 wavelength
- Combining 3 primaries until no visible difference
- User study
- Which RGB coefficients?
- Goal: accurate representation of light spectrum



Experimental results

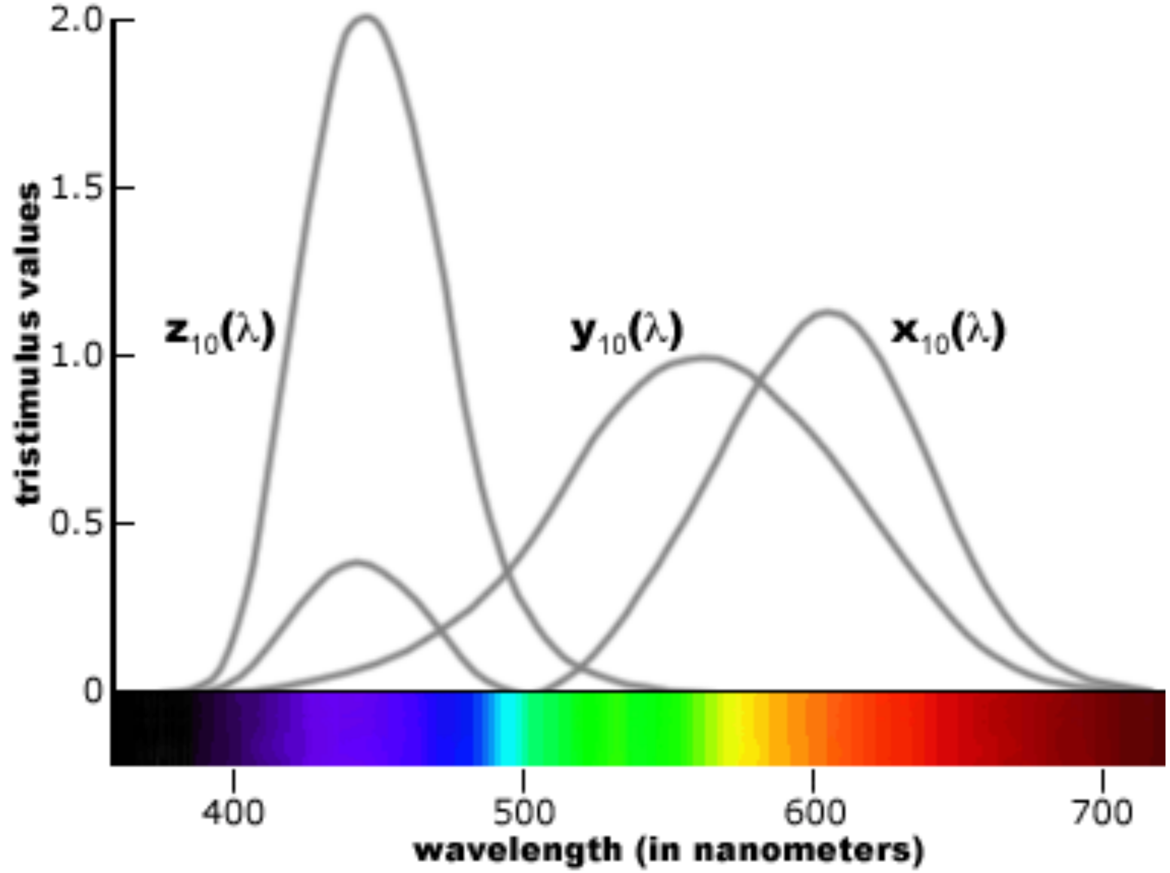


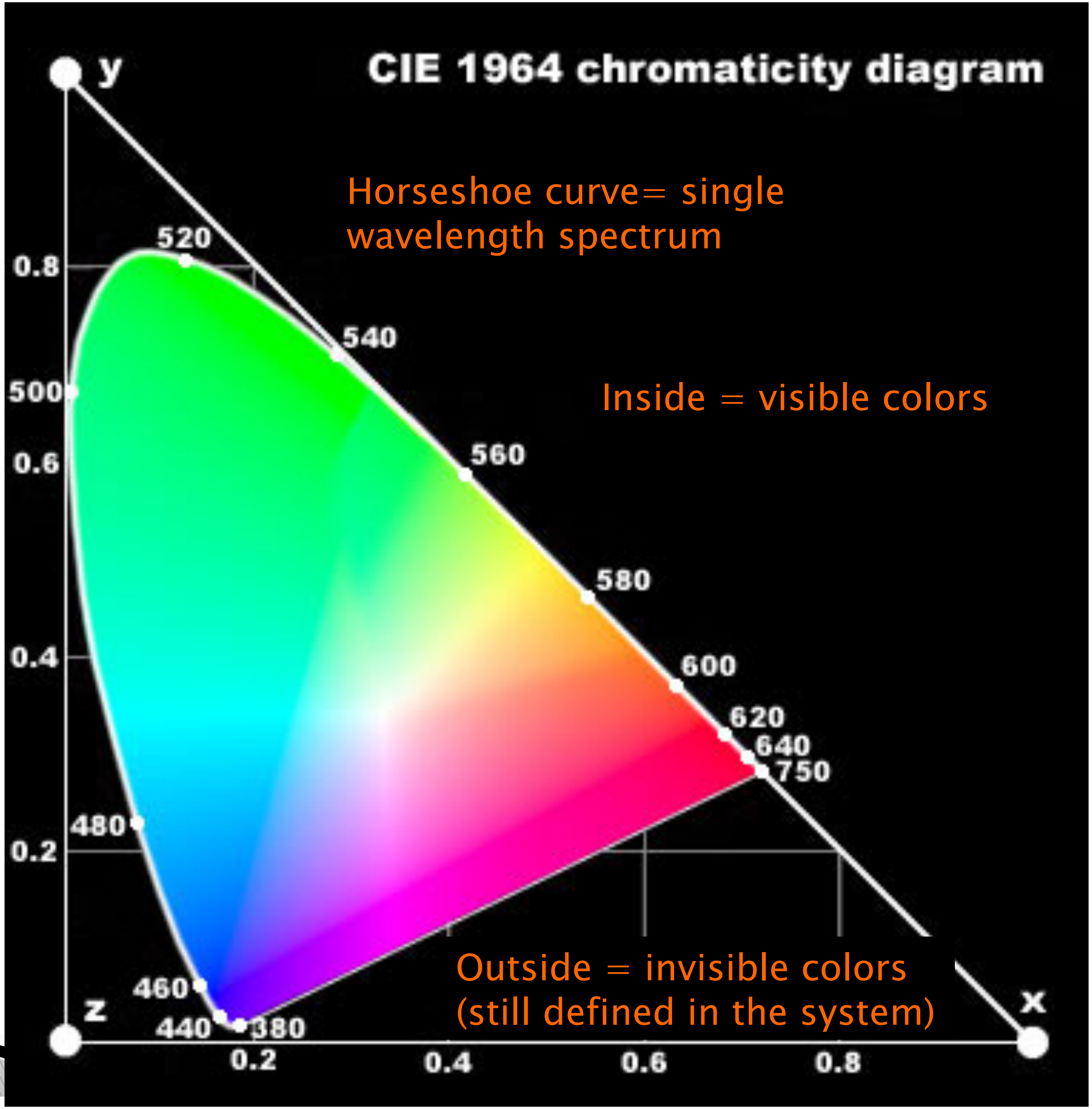
New set of basis functions

- Primary colors (RGB) have a problem:
  - The set of all visible colors cannot be covered with positive coordinates
- Need new basis functions
  - Covering all visible spectrum
  - With positive coordinates
  - Linear in RGB
- Commission Internationale de l'Éclairage
  - www.cie.co.at
  - 1931

CIE XYZ

- 1 spectrum for each basis function (x,y,z)
- Color spectrum ➔ XYZ coordinates
  - Dot product
- Positive coeffs




CIE 1964 chromaticity diagram
y
x
z
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
520
540
500
560
580
600
620
640
750
480
460
440
380
Horseshoe curve= single wavelength spectrum
Inside = visible colors
Outside = invisible colors (still defined in the system)

CIE XYZ

- RGB to XYZ conversion is linear (a matrix)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.341 & 0.189 & 0.388 \\ 0.139 & 0.837 & 0.073 \\ 0.000 & 0.040 & 20.026 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Combining colors: linear
  - On screen
  - Printers: non-linear effects, related to ink order
  - Color gamut for a display: a triangle

Chromaticity

- Y = luminance (brightness)
- 2D chromaticity diagram:

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z} \quad \therefore \quad x + y + z = 1$$

Diagramme de chromaticité de la CIE (1931)

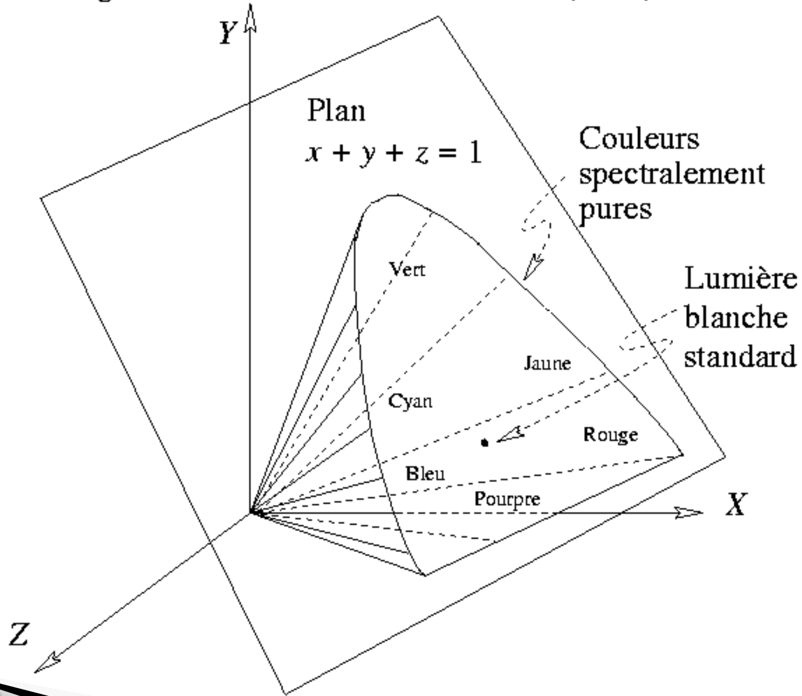
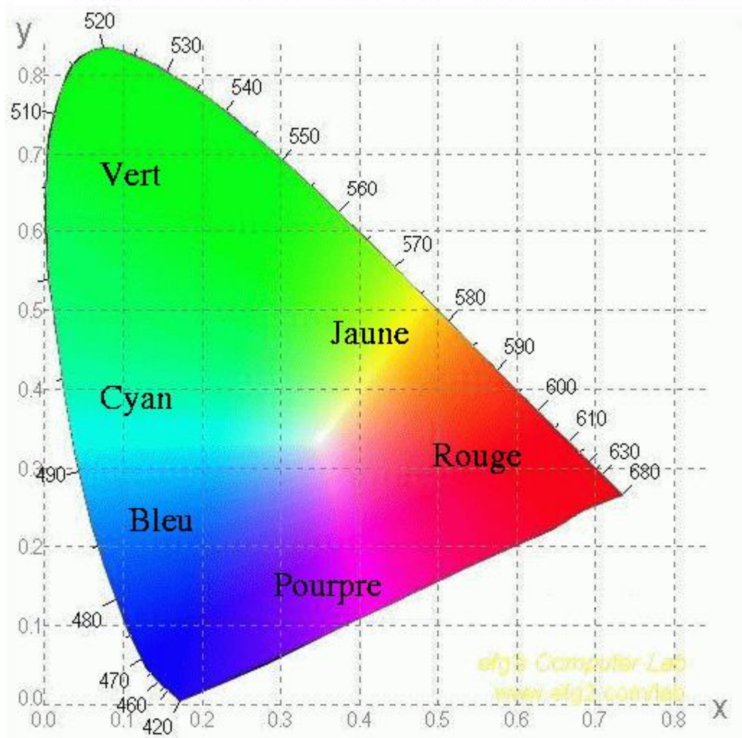
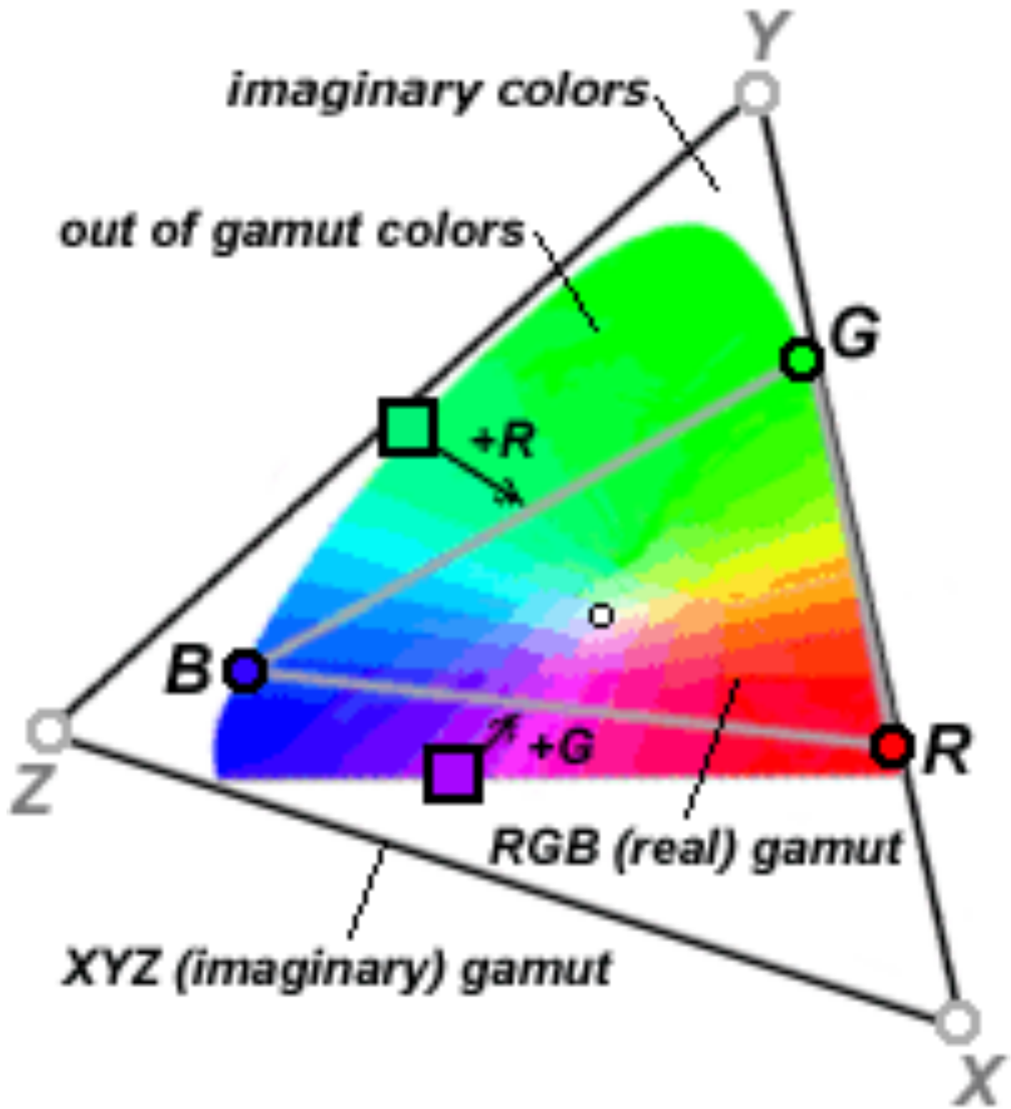


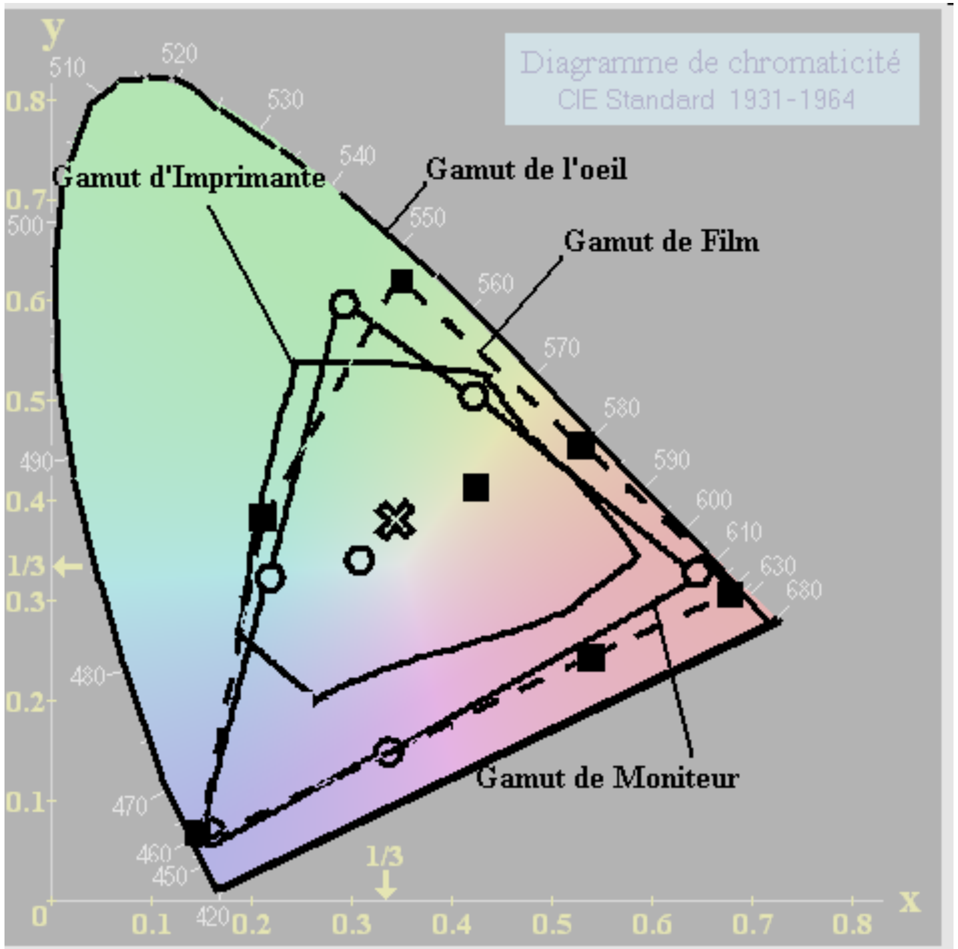
Diagramme de chromaticité de la CIE (1931)



Color representation paradox

- Visible primaries (RGB):
  - Can’t mix all visible colors
- Can represent all colors:
  - Invisible primaries (XYZ)





Color correction:

Gamut for printer, displays, scanners

Linear / non-linear conversion

Colors unique to each device

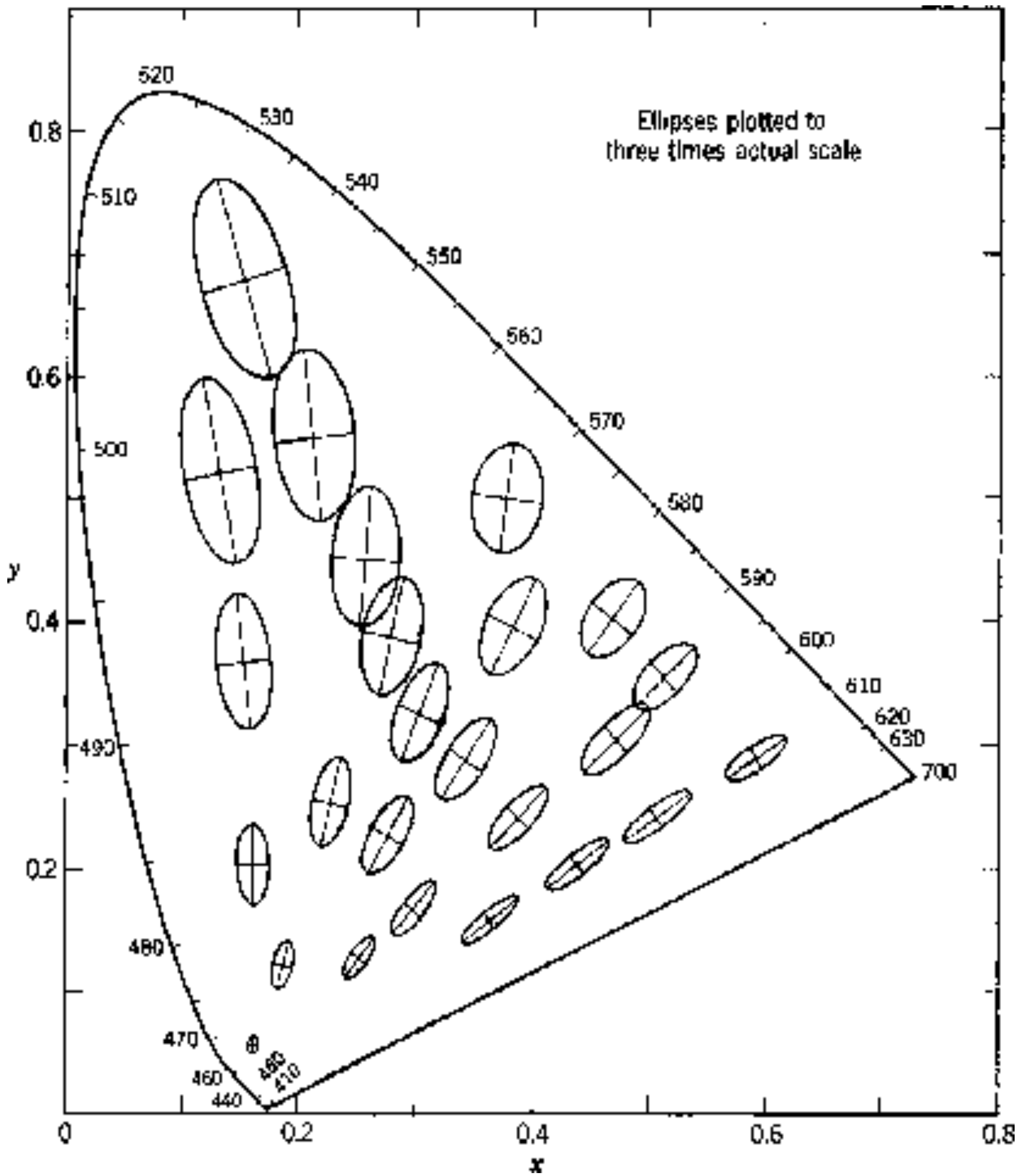
Closest possible color

Colour perception

- Distance between two colors
  - In color space: easy (norm)
  - For human vision: useful
- Ideally, there should be a connection between the two
- *Perceptually uniform* color space
  - Always the same connection, regardless of the color
- Just noticeable differences
  - Smallest distance between two colors perceived as different

Color perception

Just noticeable differences in *xy* space



We need a new color space

- Based on XYZ
- Perceptually uniform
- Two new spaces: L*a*b* et L*u*v*

- L* = luminance (perceptually uniform)

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16$$

Y_n = reference white point

L*u*v*

- Projective space:

$$u' = \frac{4X}{X + 15Y + 3Z}$$

$$v' = \frac{9Y}{X + 15Y + 3Z}$$

- Adjusted with reference white point:

$$u^* = 13L(u' - u'_w)$$

$$v^* = 13L(v' - v'_w)$$

L*u*v*

Chromaticity:

$(u^{*2}+v^{*2})^{½}$

Hue angle:

atan(u^*/v^*)

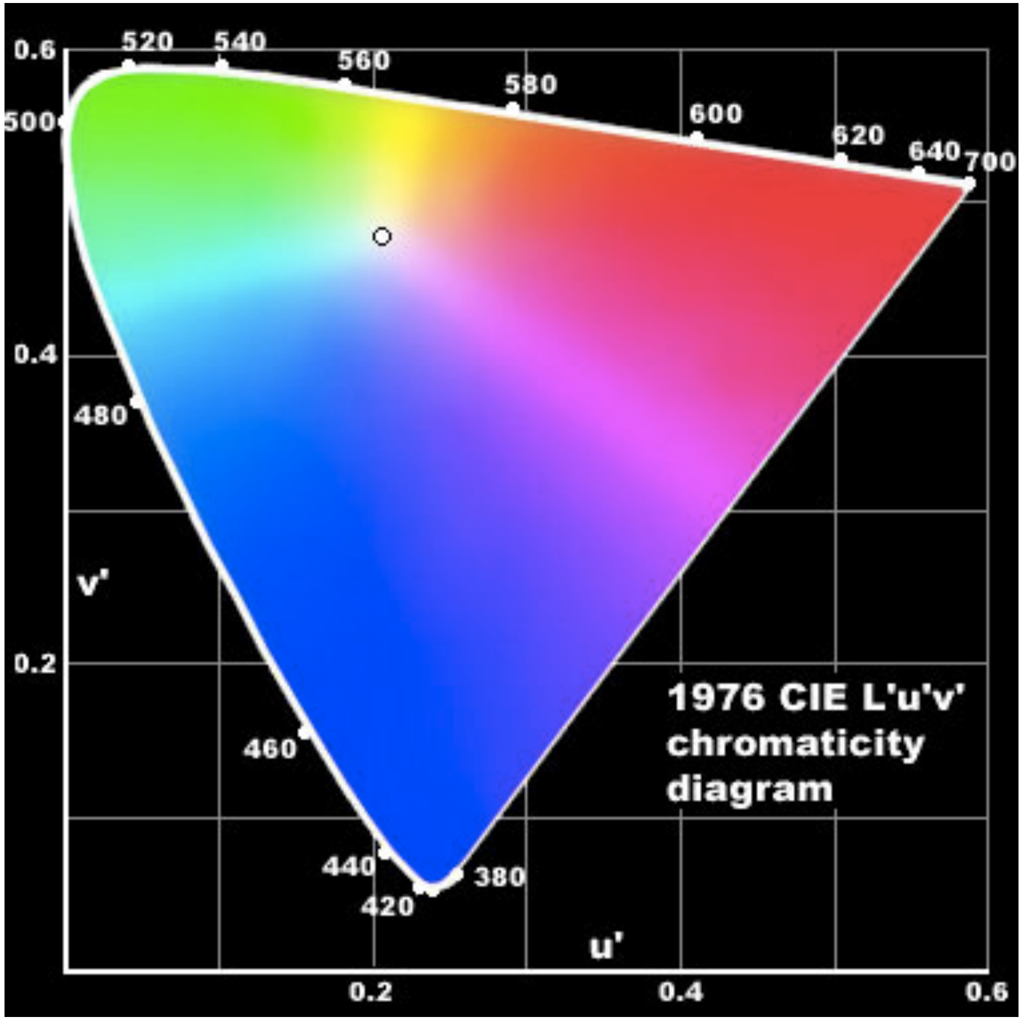
Distance:

L2 norm < 10?

perceptually identical

Color combination

still linear



L*a*b*

- Non-linear
- Orthogonal
- Chromaticity:
  $(u^{*2}+v^{*2})^{½}$

- Hue angle:
  atan(u^*/v^*)

- Distance:
  L2 norm < 10?
  perceptually identical

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16 \text{ for } \frac{Y}{Y_n} > 0{,}008856$$

$$L^* = 903{,}3\,\frac{Y}{Y_n} \text{ otherwise}$$

$$a^* = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right)$$

$$b^* = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right)$$

w. $f(t) = t^{1/3}$ for $t > 0{,}008856$

$f(t) = 7{,}787\,t + 16/116$ otherwise

Color to gray conversion

- Y component: luminance / gray level
- L* component: perceptually uniform luminance

- Local contrast methods:

Original

GIMP greyscale

Our G' p=0.75 k=[0.2,0.6,0.4,0.4]

Still a work in progress

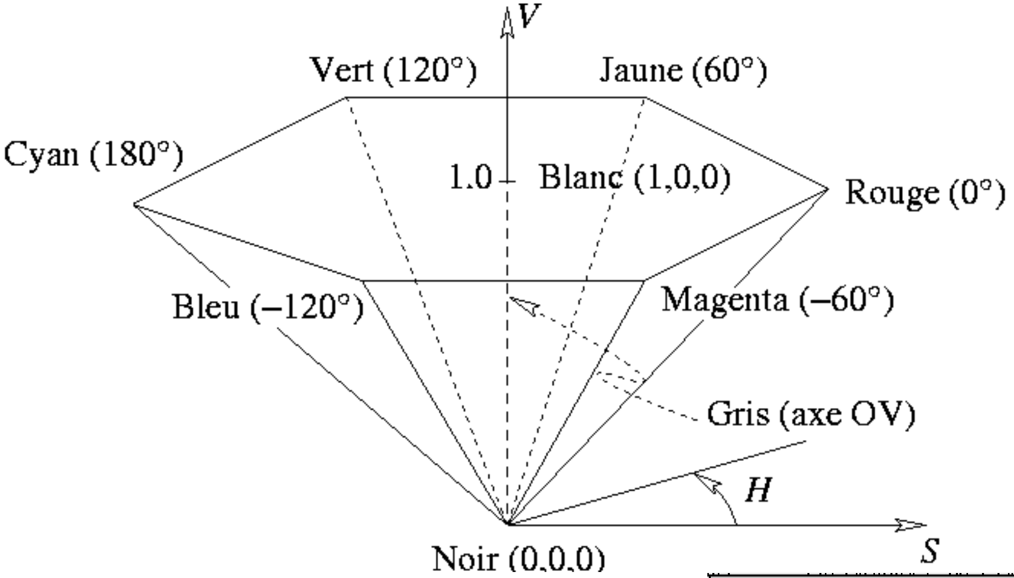
Other color spaces

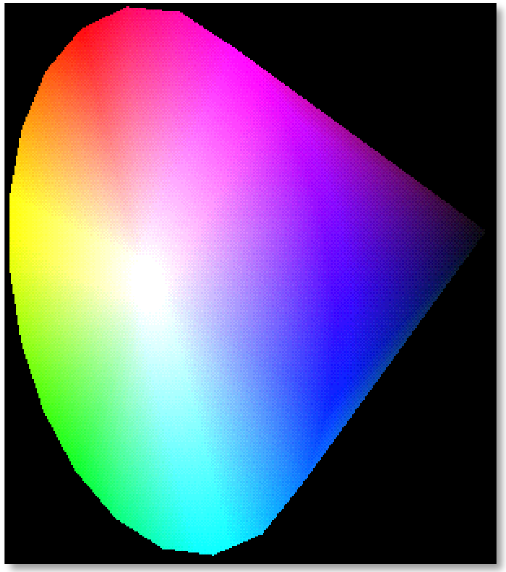
- YC_bC_r, Yuv : video encoding
  - Y = black-and-white (large bandwidth)
  - C_bC_r = chromaticity (smaller bandwidth)

- HSL, HSV, HSB : good for user interface

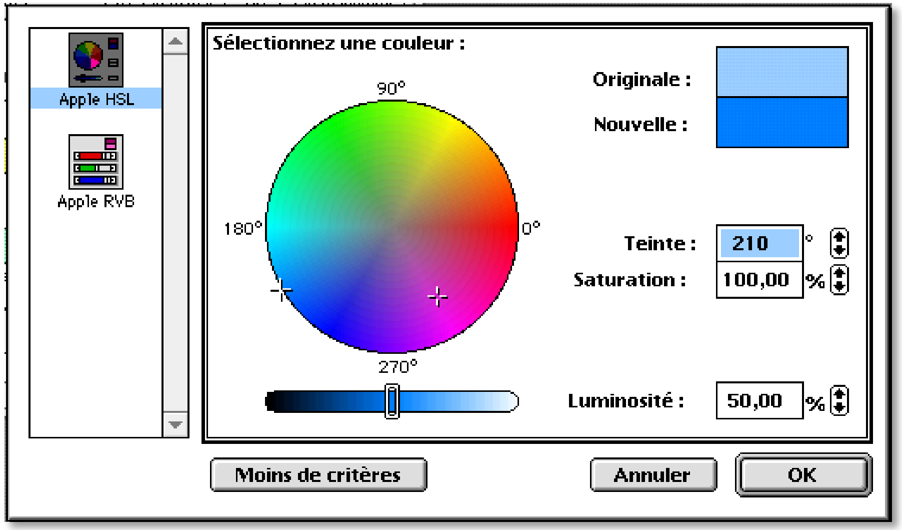
Painter model:
HSB = Hue, Saturatio, Brightness

(HSV: Hue, Saturation, Visibility)





Graphical selection



Summary of colour spaces

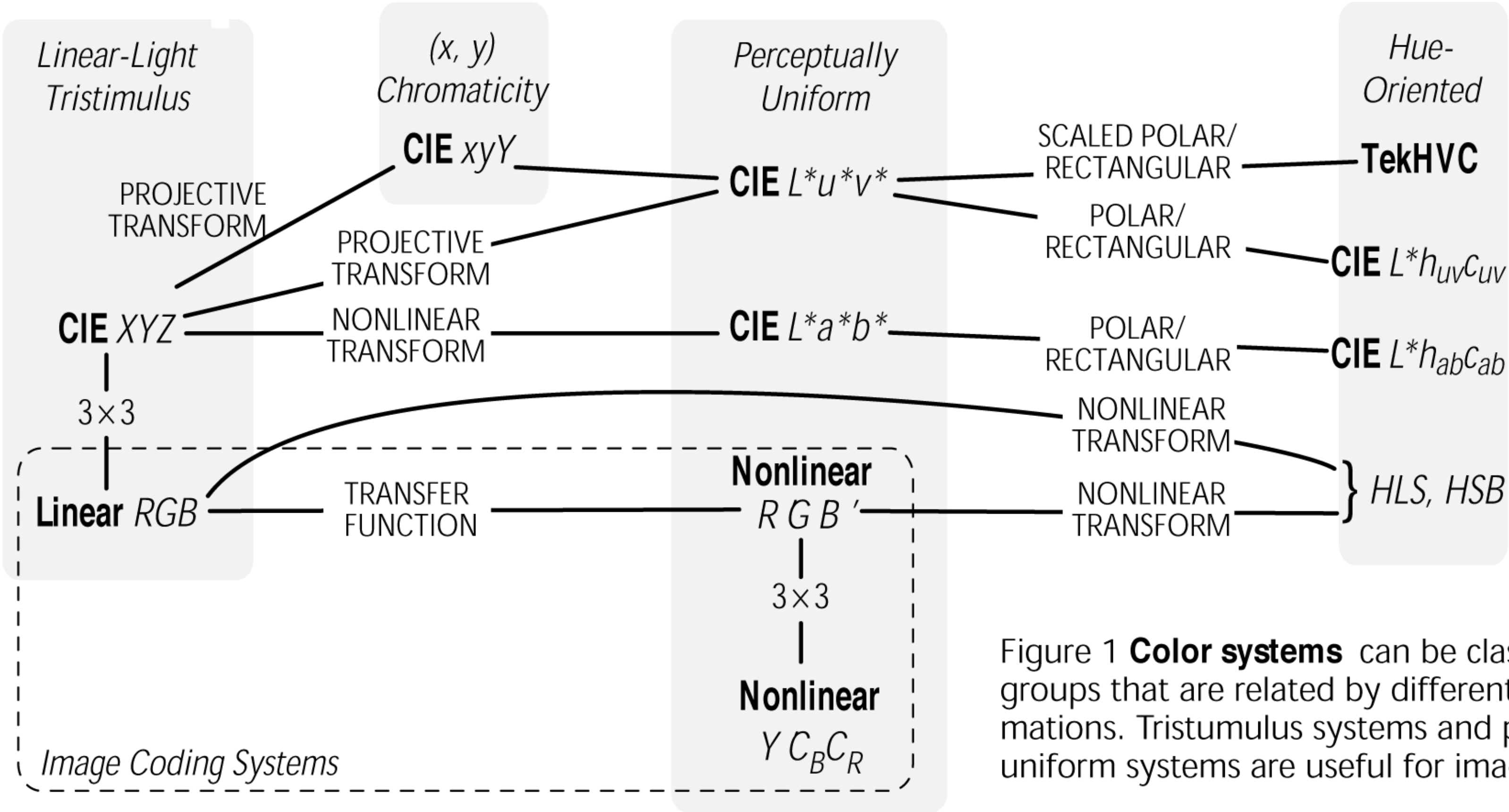


Figure 1 **Color systems** can be classified into four groups that are related by different kinds of transformations. Tristumulus systems and perceptually-uniform systems are useful for image coding.

More information: Wikipedia
Color vision: http://www.handprint.com/LS/CVS/color.html

Fluorescence

- Until now, wavelengths treated independently
- Fluorescence :
  - Absorption at a given wavelength
  - Re-emission at another
  - Energy preservation -> higher wavelength

  - Ex. UV -> visible
  - Frequent in nature
  - Photosynthesis (chlorophyll)

Fluorescence