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Colour Representation

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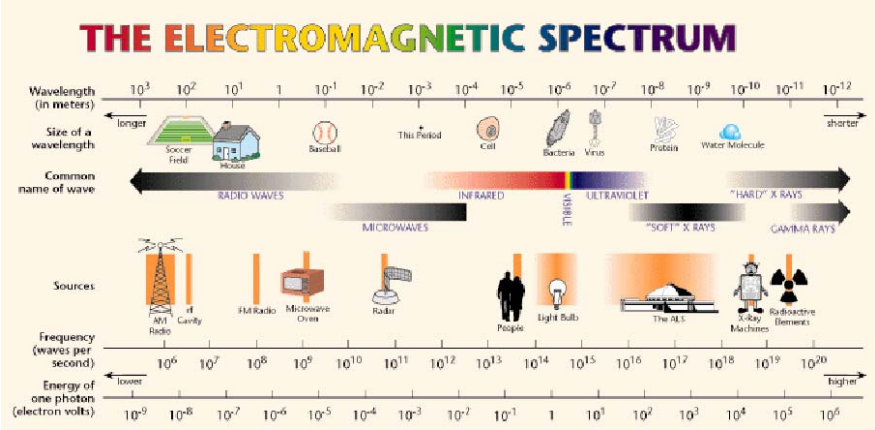
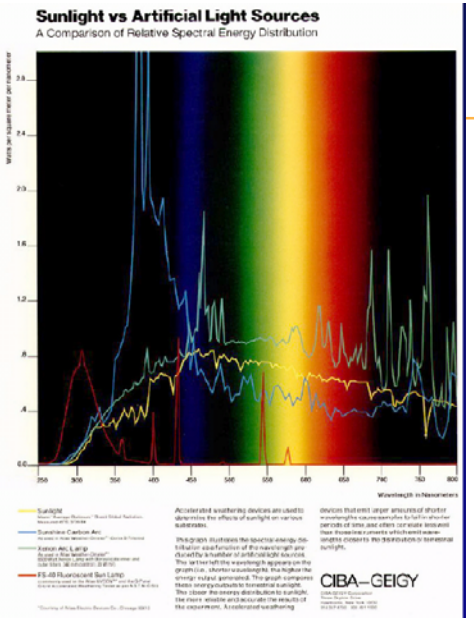
What is Light?

- electromagnetic radiation, 400-700nm





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Spectra

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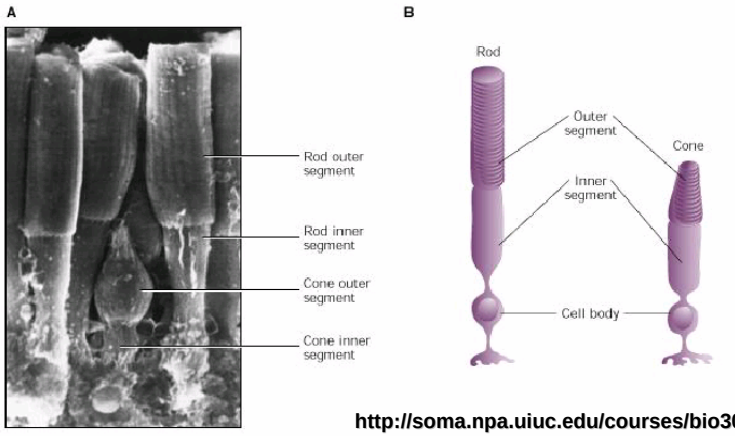
The Retina

- rods and cones



http://soma.npa.uiuc.edu/courses/bio303/Ch11.html

Cones

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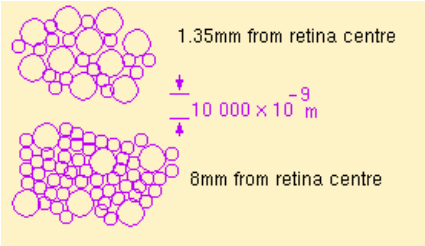
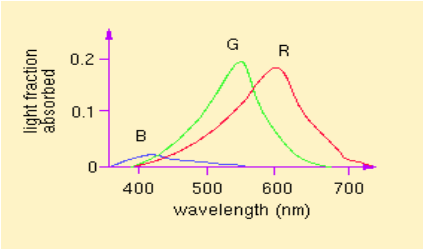
- cones
  - concentrated in fovea
  - three types of cones in human eye





Tristimulus Colour Theory

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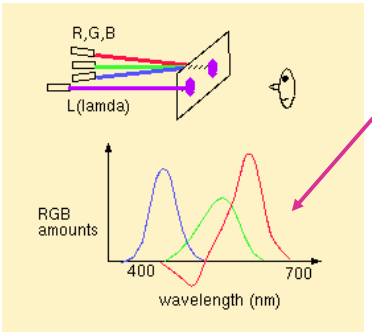
- match any given wavelength with a mix of some specific wavelengths:

R=700nm, G=546nm, B=436nm



RGB colour matching curves

$$R = \int P(\lambda)\,\bar{r}_\lambda\,d\lambda$$
$$G = \int P(\lambda)\,\bar{g}_\lambda\,d\lambda$$
$$B = \int P(\lambda)\,\bar{b}_\lambda\,d\lambda$$

XYZ Colour Matching

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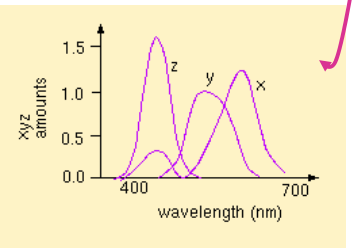
- CIE: Commision Internationale d'Eclairage
- goal is to develop a colour standard that uses only positive mixing coefficients

XYZ colour matching curves



$$X = k \int P(\lambda)\,\bar{x}_\lambda\,d\lambda$$
$$Y = k \int P(\lambda)\,\bar{y}_\lambda\,d\lambda$$
$$Z = k \int P(\lambda)\,\bar{z}_\lambda\,d\lambda$$

XYZ and RGB Colour Spaces

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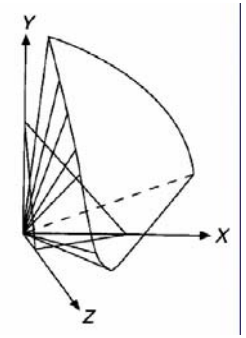
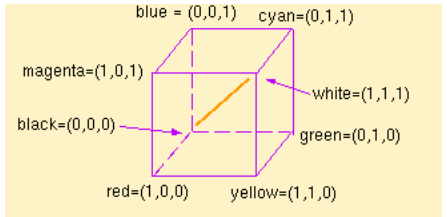
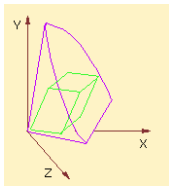
XYZ colour space



RGB colour space





RGB cube in the XYZ colour space

The RGB Color Model

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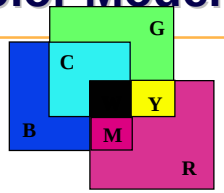

$$Col = rR + gG + bB \qquad r, g, b \in [0,1]$$

Yellow= Red+Green (1,1,0)

Cyan = Green+Blue (0,1,1)

White = Red+Green+Blue (1,1,1)

Gray = 0.5 Red+0.5 Blue+0.5 Green(0.5,0.5,0.5)

Main diagonal of RGB cube represents shades of gray

XYZ and RGB colour spaces

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- colour transformation matrix:
  (for monochromatic R=700nm, G=546nm,B=436nm)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.36460 & -0.51515 & 0.00520 \\ -0.89653 & 1.42640 & -0.01441 \\ -0.46807 & 0.08875 & 1.00921 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- each monitor has its own RGB-to-XYZ transformation matrix
  - suppose we have a colour $R_A G_A B_A$ on monitor A and wish to view the same colour on monitor B:

$$\textcircled{2}\ \begin{bmatrix} R_B \\ G_B \\ B_B \end{bmatrix} = \begin{bmatrix} \\ M_B^{-1} \\ \\ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \textcircled{1}\ \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \\ M_A \\ \\ \end{bmatrix} \begin{bmatrix} R_A \\ G_A \\ B_A \end{bmatrix}$$

$$C_B = M_B^{-1} M_A C_A$$

CIE Chromaticity Diagram

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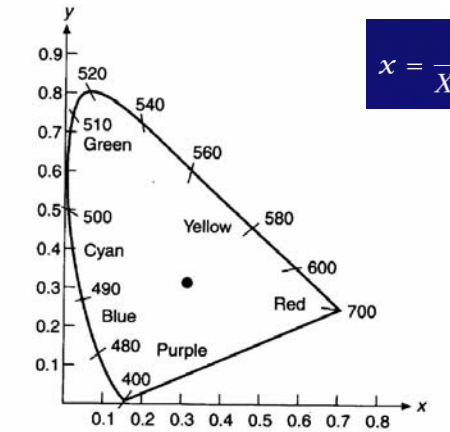
- produce a 2D colour space by projecting onto the plane given by X+Y+Z = 1

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



RGB vs XYZ revisited

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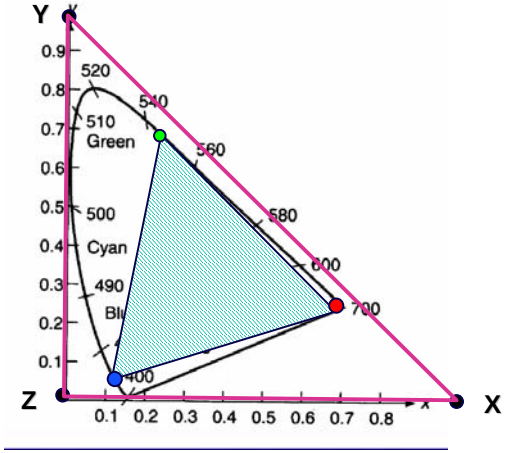
- another view of why the R curve goes negative



CIE Chromaticity Diagram

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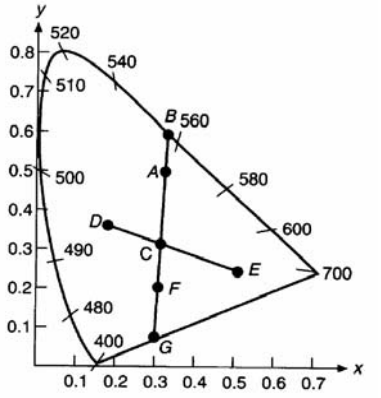
- C: white point
- complementary colours
- dominant wavelength
- non-spectral colors



The CIE Diagram (cont'd)

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Color enhancement of image

- increasing the saturation of the colors
- moves them towards the boundary of the visible region

unsaturated

saturated

The CIE Diagram (cont'd)

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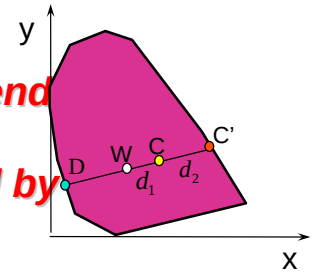
Color "white" is point W=(1/3,1/3,1/3)

Any visible color C is blend hue C' & W

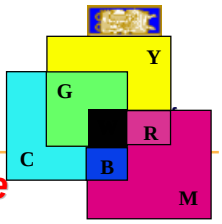
Purity of color measured by its saturation:



$$\text{saturation}\quad (C) = \frac{d_1}{d_1 + d_2}$$

Complement of C is (only) other hue D on line through C' and W

The CMY Color Model



Used mainly in color printing, where light is absorbed by dyes

Cyan, Magenta and Yellow primaries are complements of Red, Blue and Green

Primaries (dyes) subtracted from white paper which absorbs no energy

- Red = White-Cyan = White-Green-Blue (0,1,1)
- Green = White-Magenta = White-Red-Blue (1,0,1)
- Blue = White-Yellow = White-Red-Green (1,1,0)
- (r,g,b) = (1-c,1-m,1-y)

Luminance – Color vs. Grayscale

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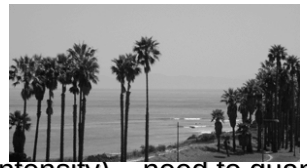
Need tool to switch color to grayscale (e.g. B&W printer)



- Use luminance (intensity) – need to quantify
- Human eye more sensitive to changes in luminance than to changes in hue or saturation

(a) Isoluminant colormap created by user study

YIQ Color Model

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Used for TV transmission

Luminance Y – affine combination of R,G&B

I & Q – null blend of R,G&B

Conversi

$$(y, i, q) = (r, g, b)\begin{bmatrix} 0.30 & 0.60 & 0.21 \\ 0.59 & -0.28 & -0.52 \\ 0.11 & -0.32 & 0.31 \end{bmatrix}$$

Green component dominates luminance value

Setting Luminance

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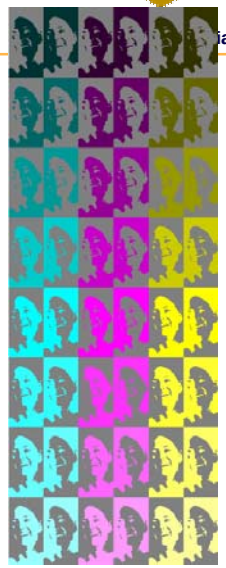
Based on human perception

Example tool to set luminance value:



Color Quantization

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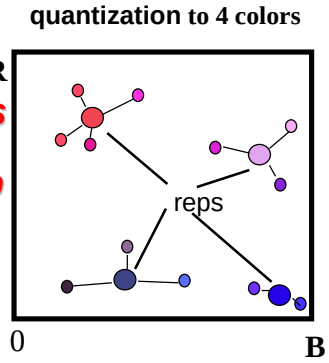
High-quality color resolution for images - 8 bits per primary = 24 bits = 16.7M colors

Reducing number of colors – select subset (colormap/palette) & map all colors to them

- Device capable of displaying only a few different colors simultaneously
- E.g. an 8 bit display
- Storage (memory/disk) cost



Color Quantization Example

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256 colors

64 colors

16 colors

4 colors

Color Quantization Issues

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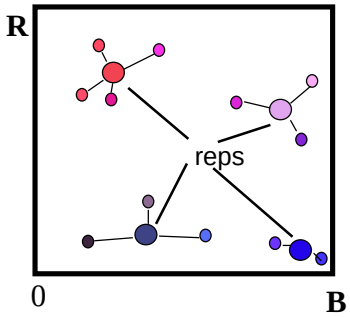
How representative colors are chosen?

- Fixed representatives, image independent - fast
- Image content dependent - slow

Which image colors are mapped to which representatives?

- Nearest representative - slow
- By space partitioning - fast

quantization to 4 colors



Quantization

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256 colors

uniform

median-cut

8 colors