

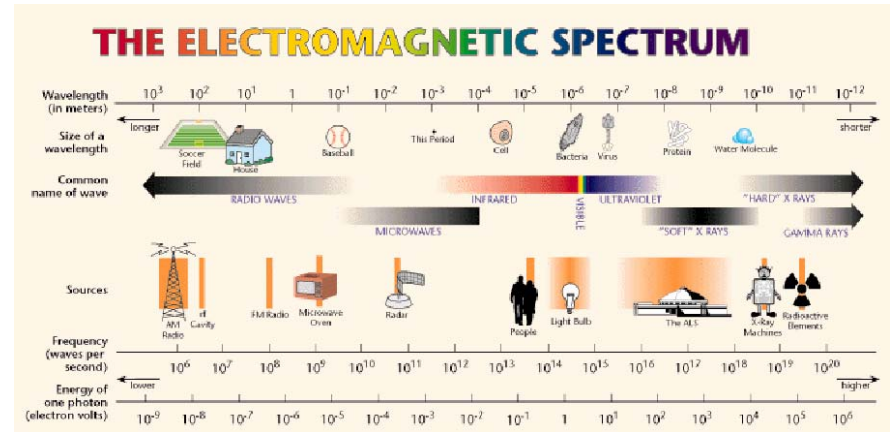


Colour Representation



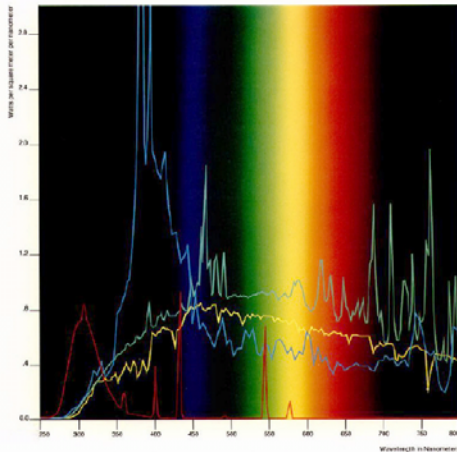
What is Light?

- electromagnetic radiation, 400-700nm



Sunlight vs Artificial Light Sources

A Comparison of Relative Spectral Energy Distribution



Accelerated weathering devices are used to determine the effects of sunlight on various substrates. This graph displays the spectral energy distribution (SED) of sunlight and various artificial light sources. The x-axis is the wavelength in nanometers (nm) and the y-axis is the relative spectral energy distribution (RSED). The graph compares the SED of sunlight with the SED of various artificial light sources. The graph shows that sunlight has a much higher energy distribution in the visible spectrum (400-700 nm) compared to artificial light sources. The graph also shows that artificial light sources have a much higher energy distribution in the ultraviolet (UV) and infrared (IR) regions compared to sunlight.

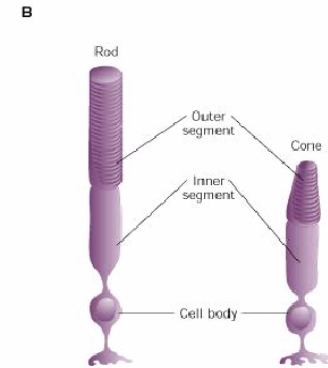
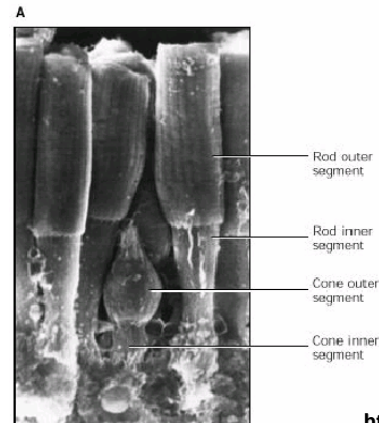
CIBA-GEIGY

Spectra



The Retina

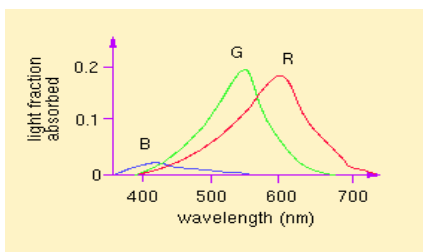
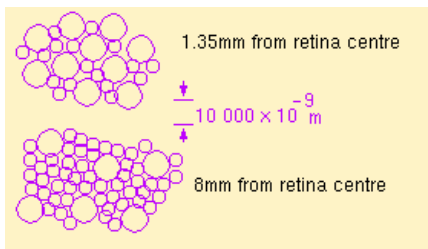
- rods and cones



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

Cones

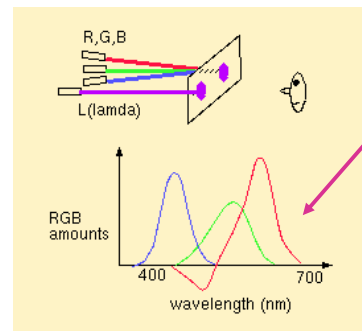
- cones
 - concentrated in fovea
 - three types of cones in human eye



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Tristimulus Colour Theory

- match any given wavelength with a mix of some specific wavelengths:
R=700nm, G=546nm, B=436nm



RGB colour matching curves

$$R = \int P(\lambda) \bar{r}_\lambda d\lambda$$

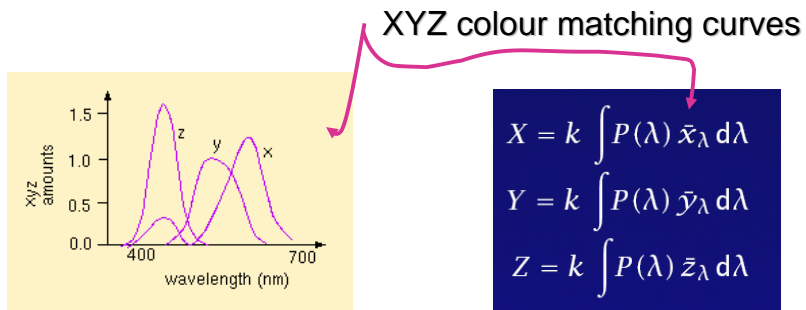
$$G = \int P(\lambda) \bar{g}_\lambda d\lambda$$

$$B = \int P(\lambda) \bar{b}_\lambda d\lambda$$

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XYZ Colour Matching

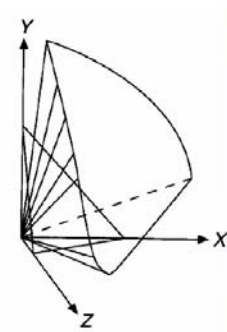
- CIE: Commision Internationale d'Eclairage
- goal is to develop a colour standard that uses only positive mixing coefficients



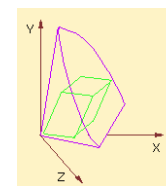
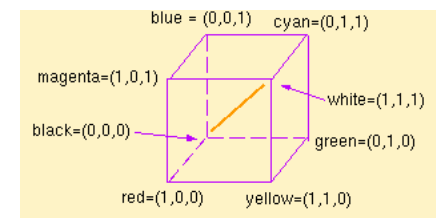
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XYZ and RGB Colour Spaces

XYZ colour space



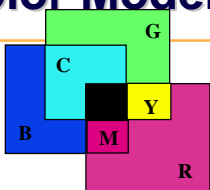
RGB colour space



RGB cube in the XYZ colour space

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The RGB Color Model



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

- 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

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

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

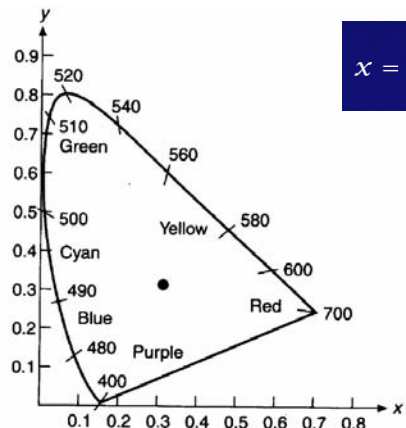
- each monitor has its own RGB-to-XYZ transformation matrix
 - suppose we have a colour $R_A G_A B_A$ on monitor A and wish to view the same colour on monitor B:

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

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

CIE Chromaticity Diagram

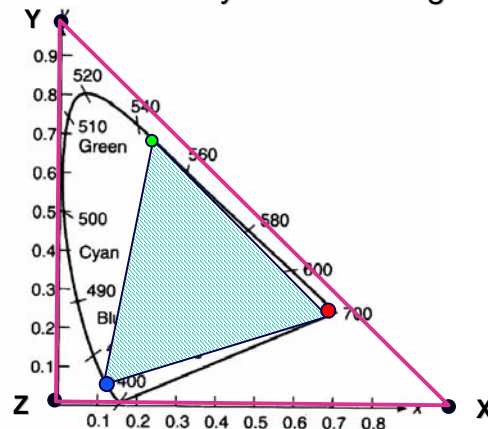
- produce a 2D colour space by projecting onto the plane given by $X+Y+Z = 1$



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

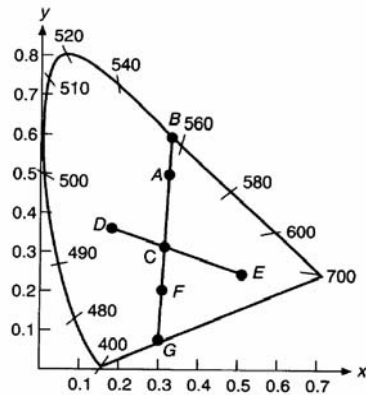
RGB vs XYZ revisited

- another view of why the R curve goes negative



CIE Chromaticity Diagram

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



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The CIE Diagram (cont'd)

Color enhancement of image

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



unsaturated



saturated

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The CIE Diagram (cont'd)

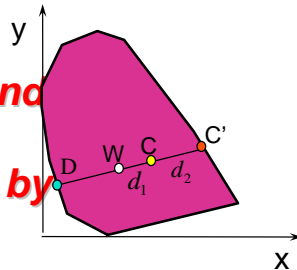
Color "white" is point
 $W=(1/3,1/3,1/3)$

Any visible color C is blend
hue C' & W

Purity of color measured by
its saturation:

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

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



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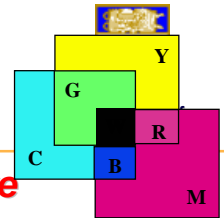
The CMY Color Model

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)
- $(r,g,b) = (1-c,1-m,1-y)$



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Luminance – Color vs. Grayscale

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

Used for TV transmission

Luminance Y – affine combination of R,G&B

I & Q – null blend of R,G&B

Conversion

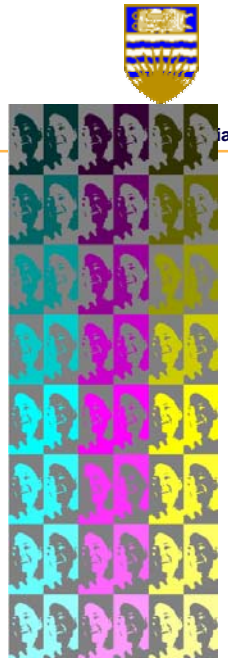
$$(y, i, q) = (r, g, b) \begin{bmatrix} 0.30 & 0.60 & 0.21 \\ 0.59 & -0.28 & -0.52 \\ 0.11 & -0.32 & 0.31 \end{bmatrix}$$

Green component dominates luminance value

Setting Luminance

Based on human perception

Example tool to set luminance value:



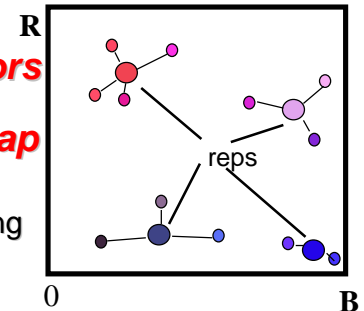
Color Quantization

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

quantization to 4 colors



Color Quantization Example



256 colors



64 colors



16 colors



4 colors

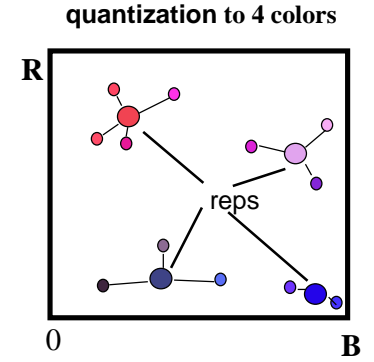
Color Quantization Issues

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



256 colors

uniform



median-cut



8
colors