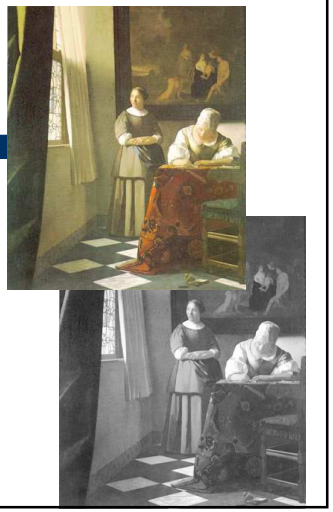
Color

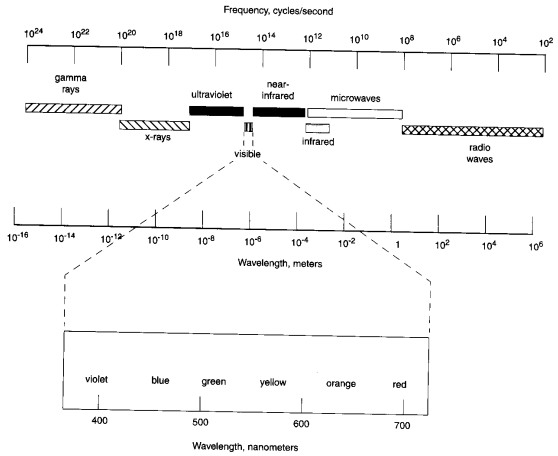
C306

Martin Jagersand

Questions

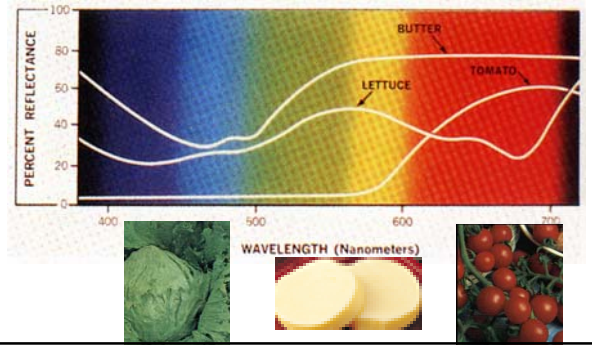
- What are the physics of color?
- How is color sensed?
- How is it represented?
- Applications in image processing?





Color = response curve

What is the inherent dimensionality of color space ?



Sunlight

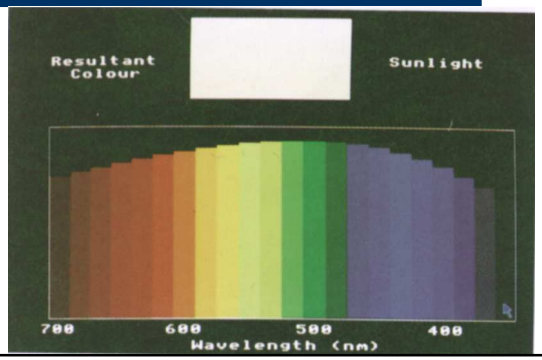
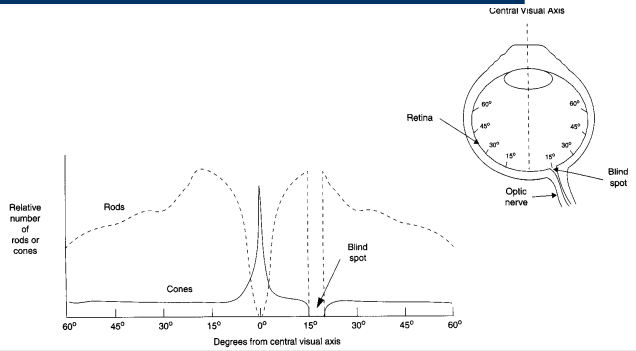
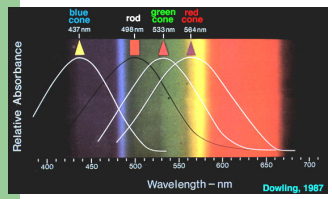


Photo receptor distribution in the human eye



Color perception



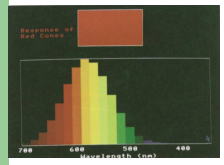
$$\begin{pmatrix} 100 \\ 212 \\ 50 \\ 42 \\ 175 \\ 66 \\ 244 \\ 255 \\ 255 \\ 31 \\ 0 \\ 196 \end{pmatrix}$$

Human RGB Reponses

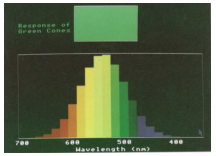
$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} \begin{pmatrix} 115 \\ 47 \\ 28 \end{pmatrix}$$

What happens as the intensity of the light changes?

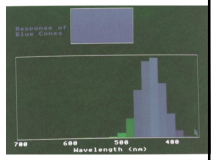
Color receptors



"Red" cone



"Green" cone



"Blue" cone

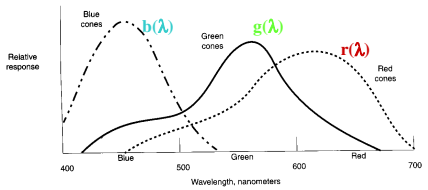
Response of k'th cone =

$$\int \rho_k(\lambda) E(\lambda) d\lambda$$

Principle of univariance: cones give the same kind of response, in different amounts, to different wavelengths. Output of cone is obtained by summing over wavelengths.
Responses measured in a variety of ways

RGB response

Response of each R,G or B is integral of incoming light with sensitivity function



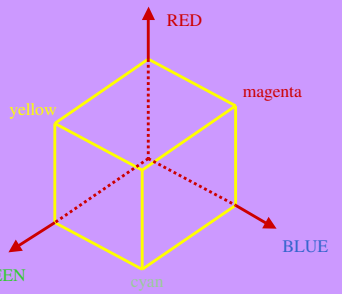
$$\text{RED} = \int_{\lambda=400nm}^{\lambda=700nm} r(\lambda)I(\lambda)d\lambda$$

$$\text{GREEN} = \int_{\lambda=400nm}^{\lambda=700nm} g(\lambda)I(\lambda)d\lambda$$

$$\text{BLUE} = \int_{\lambda=400nm}^{\lambda=700nm} b(\lambda)I(\lambda)d\lambda$$

Standard Color System

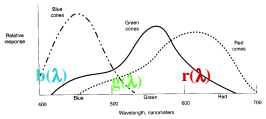
RGB is a standard system, but is formally defined in terms of the CIE system.

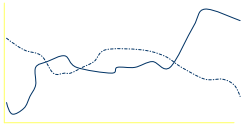


RGB

METAMERISM

- Two different Spectral Energy Distributions with the same RED, GREEN, BLUE response are termed ***metamers***.





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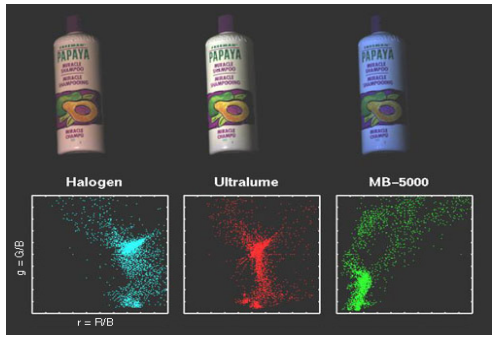
Filtering Colors

Short wavelength Long wavelength

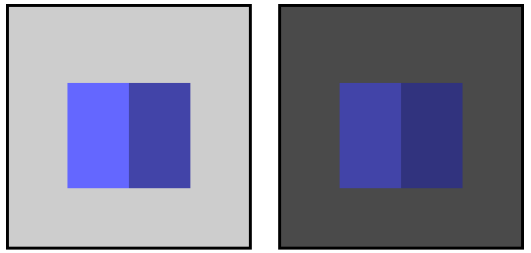
Color Constancy

How do humans adapt to the variability of color?

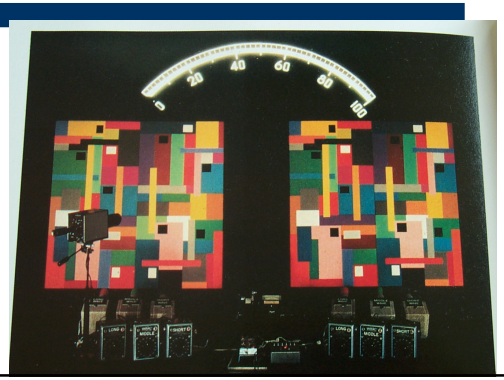


Color Constancy

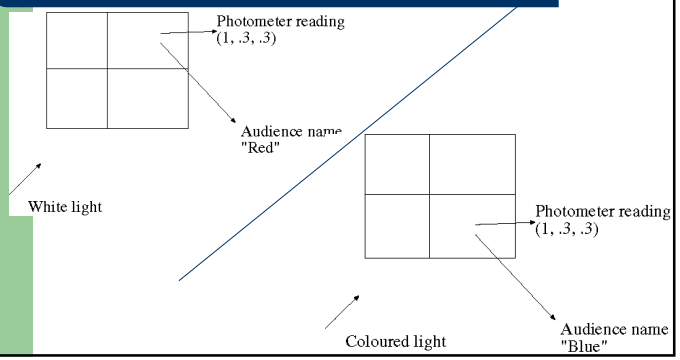
Recognizing color differences



Color Constancy: Land's demonstration



Land's Demonstration

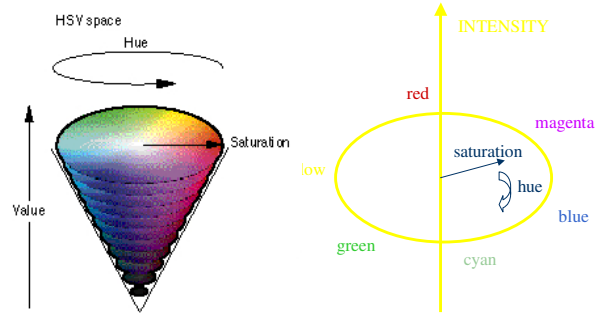


Other color spaces: YUV or YIQ

- Invented for color television
- Backward compatible with B/W TV
- Y given higher bandwidth than I/Q

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} .3 & .59 & .11 \\ .6 & -.28 & -.32 \\ .21 & -.52 & .31 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Other color spaces: HSI



HSI: Factoring out intensity

I = (**R** + **G** + **B**)/3

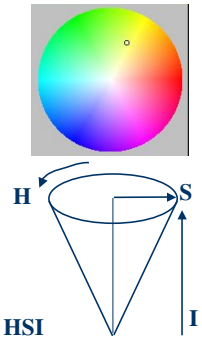
S = (1 - min (**R**,**G**,**B**)/ **I**)

H = 0 + (**G**-**B**)/Δ if max is **R**

= 1/3 + (**B**-**R**)/Δ if max is **G**

= 2/3 + (**R**-**G**)/Δ if max is **B**

(Δ is (max-min) of **RGB**)



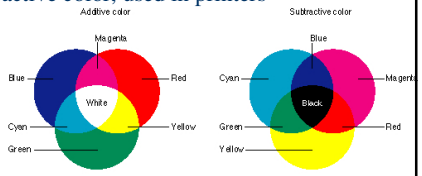
Summary: Other Color Spaces

- RGB: sensor-based description
- HSI: axes better aligned with intrinsic surface reflectance
- CMY, CMYK: subtractive color, used in printers

C = 1-R

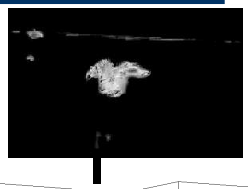
M = 1-G

Y = 1-B

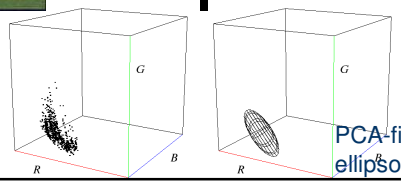


- YIQ : television, YUV: used in JPEG

Homogeneous Region

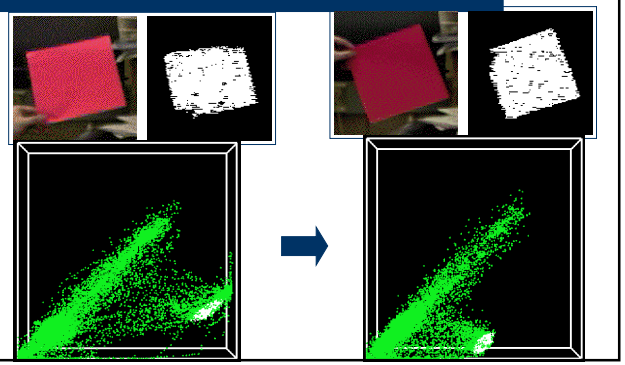


Sample



PCA-fitted ellipsoid

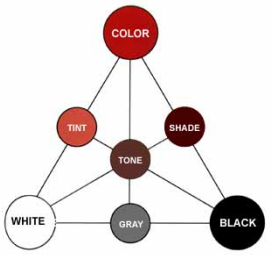
Homogeneous Color Region: Photometry



Applications

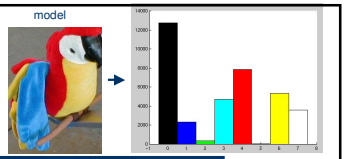
Chromakeying

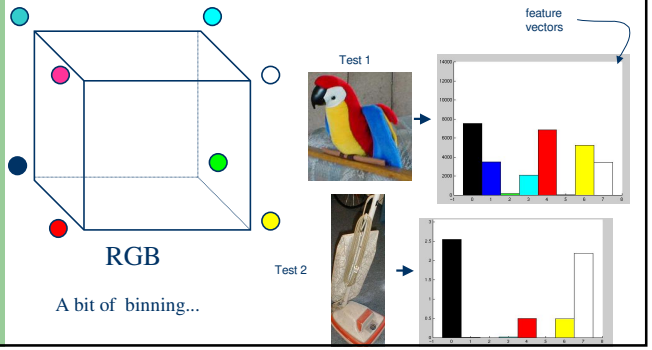
Artists' palette



- Margaret Fleck's work on image filtering
- David Forsyth's work on color constancy

Color Histograms

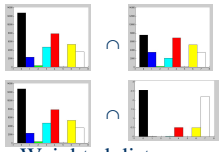




A bit of binning...

Histogram Metrics

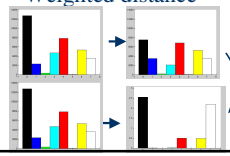
• Intersection



will be greater than

$$\frac{\sum_i \min(M_i, T_i)}{\sum_i T_i}$$

• Weighted distance



will be greater than

$$(M_i - T_i)' \, W \, (M_i - T_i)$$

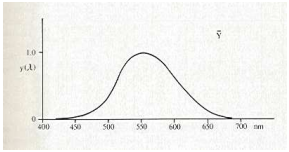
$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & .5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & .5 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Radiometry for color

- All definitions are now “per unit wavelength”
- All units are now “per unit wavelength”
- All terms are now “spectral”
- Radiance becomes spectral radiance
  - watts per square meter per steradian per unit wavelength
- Radiosity --- spectral radiosity

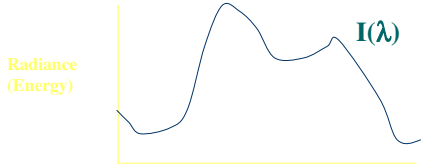
RADIANCE VS. LUMINANCE

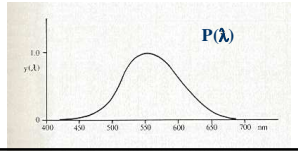
RADIANCE		LUMINANCE
1 Watt/(meter^2 x steradian x cosθ)	=	683 Lumens at 555nm



Luminous Efficacy

SPECTRAL ENERGY DISTRIBUTION AND PHOTOPIC LUMINANCE





Wavelength
λ

$$\text{Luminance} = \int_{\lambda=400nm}^{\lambda=700nm} I(\lambda) P(\lambda) d\lambda$$