COLOR

Introduction to Computer Vision

CSE 152

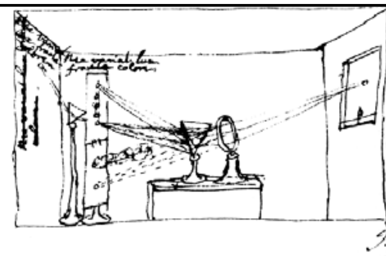
Lecture 7

Announcements

- Homework 1 is due Apr 24, 11:59 PM
- Reading:
  – Chapter 2 Image formation

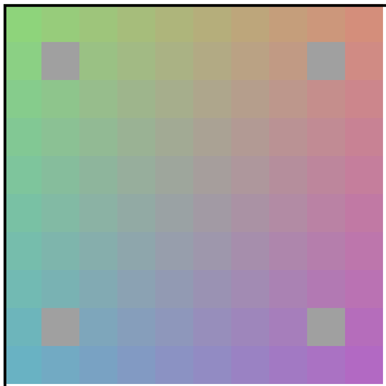
The appearance of colors

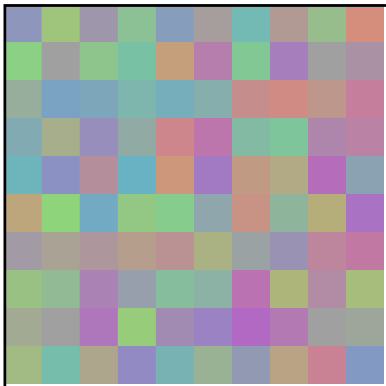
- Color appearance is strongly affected by (at least):
  – Spectrum of lighting striking the retina
  – other nearby colors (space)
  – adaptation to previous views (time)
  – "state of mind"

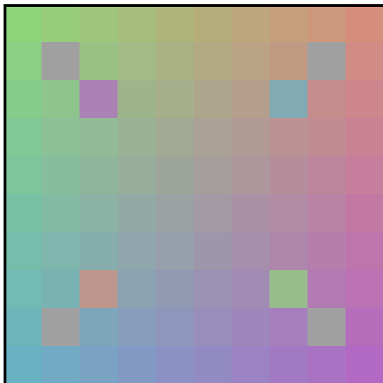


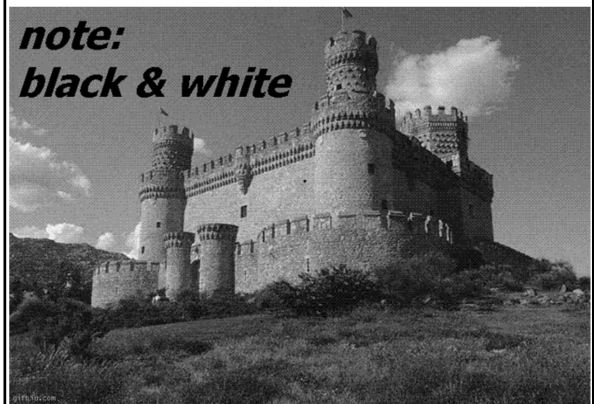
4.1 **NEWTON'S SUMMARY DRAWING** of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

From Foundations of Vision, Brian Wandell, 1995, via B. Freeman slides

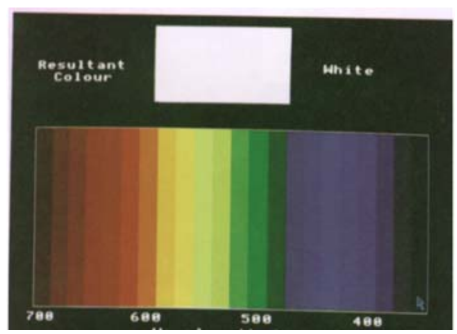








Light Spectrum

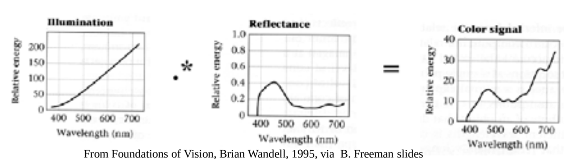


Talking about colors

1. Spectrum –
   - A positive function over interval 400nm-700nm
   - “Infinite” number of values needed.
2. Names
   - red, harvest gold, cyan, aquamarine, auburn, chestnut
   - A large, discrete set of color names
3. R,G,B values
   - Just 3 numbers

Color Reflectance

Measured color spectrum is a function of the spectrum of the illumination and reflectance

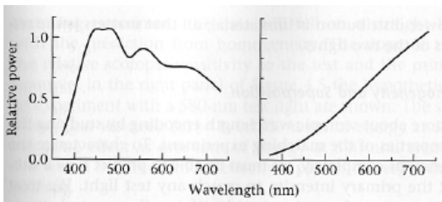


From Foundations of Vision, Brian Wandell, 1995, via B. Freeman slides

Illumination Spectra

Blue skylight

Tungsten bulb



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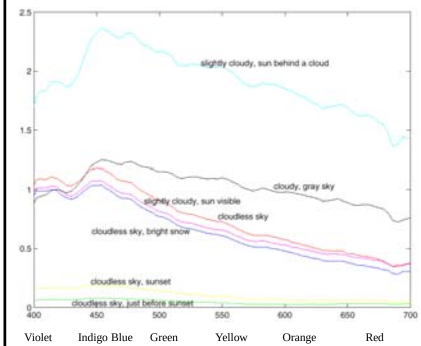
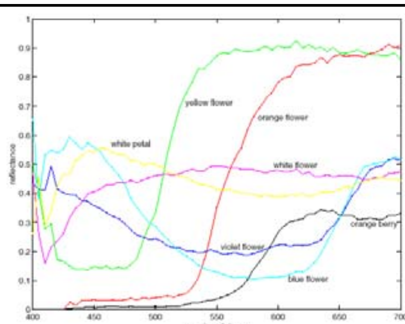
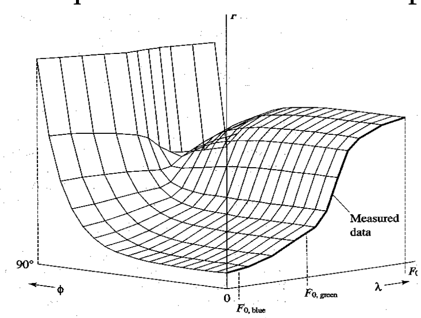


Measurements of relative spectral power of sunlight, made by J. Parkkinen and P. Silfsten. Relative spectral power is plotted against wavelength in nm. The visible range is about 400nm to 700nm. The color names on the horizontal axis give the color names used for monochromatic light of the corresponding wavelength --- the "colors of the rainbow". Mnemonic is "Richard of York got blisters in Venice".



Spectral albedoes for several different leaves, with color names attached. Notice that different colours typically have different spectral albedo, but that different spectral albedoes may result in the same perceived color (compare the two whites). Spectral albedoes are typically quite smooth functions. Measurements by E.Koivisto.

Fresnel Equation for Polished Copper

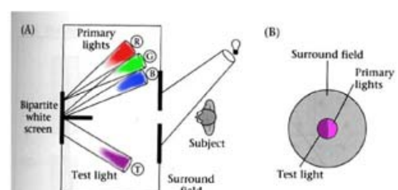


Dialectrics
(e.g., plastics)

Diffuse + specular component

Specularity is the color of the light source

Color matching experiment



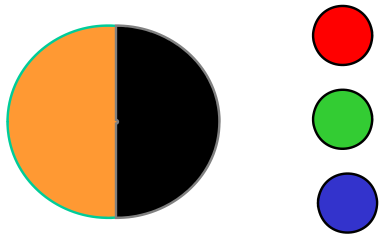
4.10 THE COLOR-MATCHING EXPERIMENT. The observer views a bipartite field and adjusts the intensities of the three primary lights to match the appearance of the test light. (A) A top view of the experimental apparatus. (B) The appearance of the stimuli to the observer. After Judd and Wyszecki, 1975.

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Not on a computer Screen

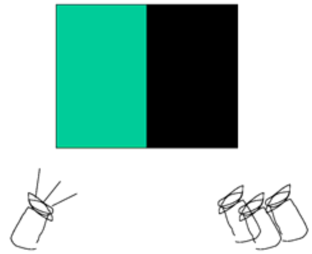
Slide from T. Darel

Color Matching

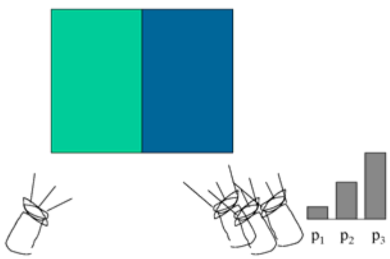


Not on a computer Screen

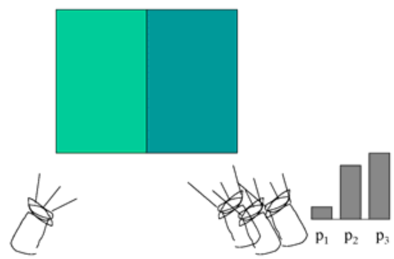
Color matching experiment 1



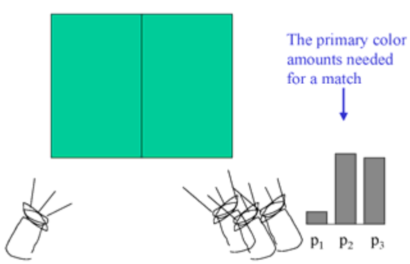
Color matching experiment 1



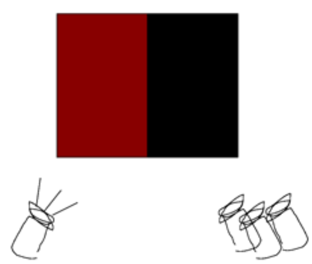
Color matching experiment 1



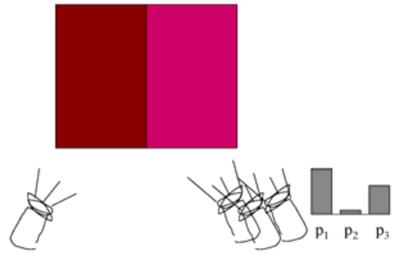
Color matching experiment 1



Color matching experiment 2

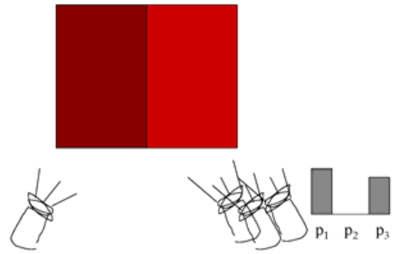


Color matching experiment 2



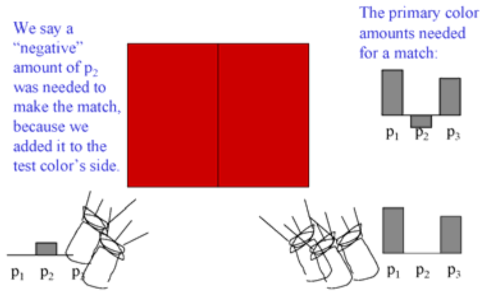
slide from T. Darrel

Color matching experiment 2



slide from T. Darrel

Color matching experiment 2

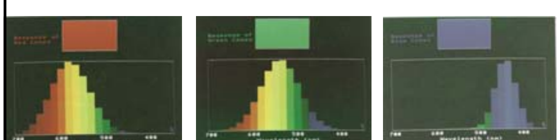


slide from T. Darrel

The principle of trichromacy

- Experimental facts:
  - Three primaries will work for most people if we allow subtractive matching
    - Exceptional people can match with two or only one primary.
    - This could be caused by a variety of deficiencies.
  - Most people make the same matches.
    - There are some anomalous trichromats, who use three primaries but make different combinations to match.

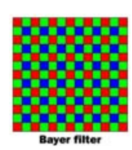
Color receptors



"Red" cone "Green" cone "Blue" cone

Response of k'th cone = $\int \rho_k(\lambda) E(\lambda) d\lambda$

Color Cameras: Three kinds of pixels



Single sensor with color mosaic overlaid

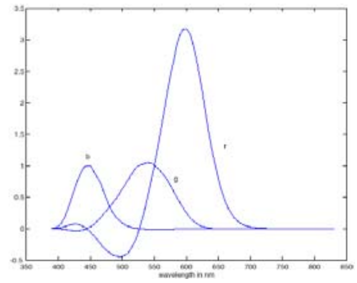
Color matching functions

- Choose primaries, say $P_1(\lambda)$, $P_2(\lambda)$, $P_3(\lambda)$
- For monochromatic (single wavelength) energy function, what amounts of primaries will match it?
- i.e., For each wavelength λ, determine how much of A, of B, and of C is needed to match light of that wavelength alone.

$$a(\lambda)$$
$$b(\lambda)$$
$$c(\lambda)$$

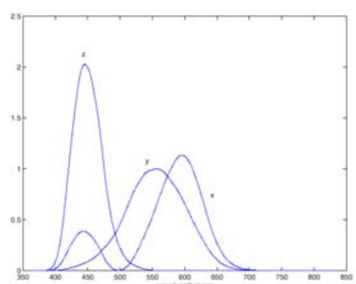
- These are color matching functions

RGB



RGB: primaries are monochromatic, energies are 645.2nm, 526.3nm, 444.4nm. Color matching functions have negative parts -> some colors can be matched only subtractively.

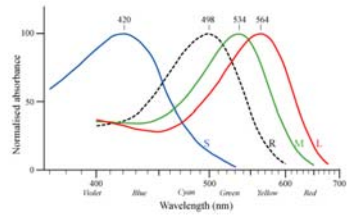
CIE XYZ



CIE XYZ: Color matching functions are positive everywhere, but primaries are imaginary. Usually draw x, y, where x=X/(X+Y+Z)
y=Y/(X+Y+Z)

Three types of cones: R,G,B

Response of k'th cone = $\int \rho_k(\lambda)E(\lambda)d\lambda$



There are three types of cones
- S: Short wave lengths (Blue)
- M: Mid wave lengths (Green)
- L: Long wave lengths (Red)

→

- Three attributes to a color
- Three numbers to describe a color

Color spaces

- Linear color spaces describe colors as linear combinations of primaries
- Choice of primaries=choice of color matching functions=choice of color space
- Color matching functions, hence color descriptions, are all within linear transformations
- RGB: primaries are monochromatic, energies are 645.2nm, 526.3nm, 444.4nm. Color matching functions have negative parts -> some colors can be matched only subtractively.
- CIE XYZ: Color matching functions are positive everywhere, but primaries are imaginary. Usually draw x, y, where x=X/(X+Y+Z)
  y=Y/(X+Y+Z)

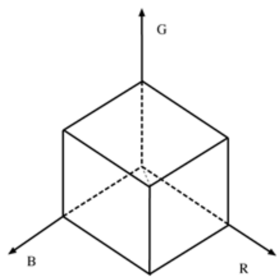
Color Spaces

There are many different color spaces, with each describing a color using three numbers:

1. RGB
2. HLS
3. YCrCb
4. HSV
5. CMY
6. YIQ (NTSC),
7. YUV (PAL),
8. CIExyz,
9. CIELAB
10. SUV

In general a color represented in one color space (say HLS) can be converted and represented in a second color space (say RGB), unless the result falls outside of the gamut of the second space.

RGB Color Cube



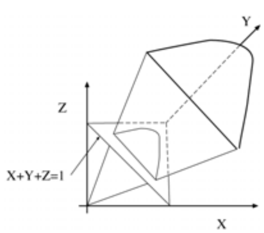
- Block of colours for (r, g, b) in the range (0-1).
- Convenient to have an upper bound on coefficient of each primary.
- In practice:
  - primaries given by monitor phosphors
  - (phosphors are the materials on the face of the monitor screen that glow when struck by electrons)

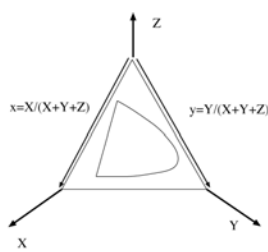
YIQ Model

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.532 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

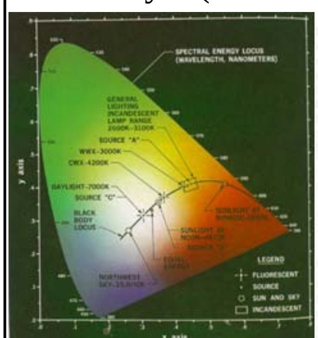
- Used by NTSC TV standard
- Separates Hue & Saturation (I,Q) from Luminance (Y)

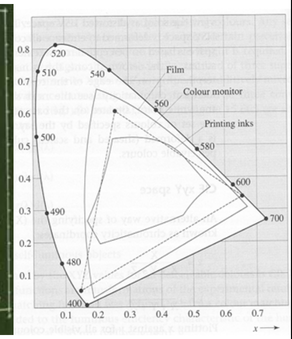
CIE -XYZ and x-y





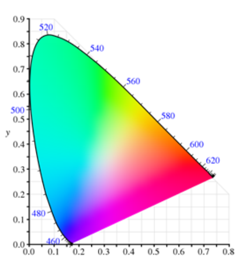
CIE xyY (Chromaticity Space)





Color Specification: Chromaticity

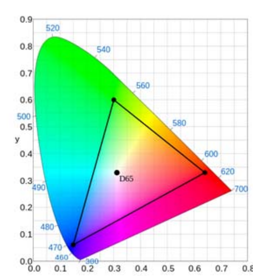
- Chromaticity coordinates
  - (*x*, *y*, *z*)
    where $x + y + z = 1$
  - Usually specified by (*x*, *y*)
    where $z = 1 - x - y$



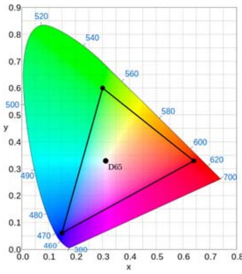
The CIE 1931 color space chromaticity diagram

Chromaticities

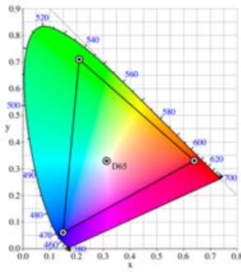
- Set of chromaticities
  - Red
  - Green
  - Blue
  - White (point)



Chromaticity Diagrams

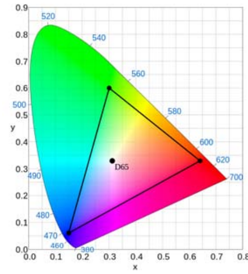


Rec. 709 and sRGB
35.9% of visible colors



Adobe RGB
52.1% of visible colors

Chromaticity Diagrams



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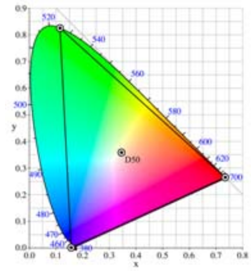
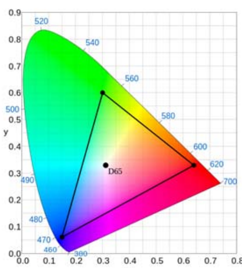
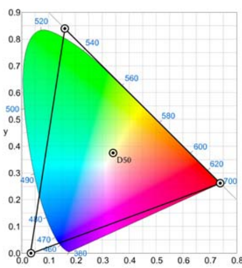


Wide gamut RGB
77.6% of visible colors

Chromaticity Diagrams



Rec. 709 and sRGB
35.9% of visible colors

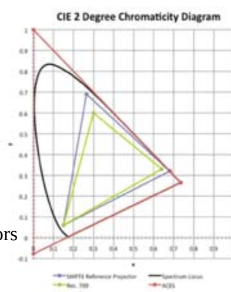


ProPhoto RGB
90% of visible colors

Academy Color Encoding Specification (ACES)

ACES

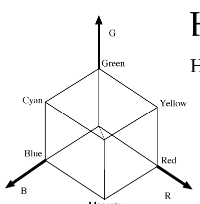
Color	CIE x	CIE y	CIE z	
Red	0.73470	0.26530	0.00000	
Green	0.00000	1.00000	0.00000	
Blue	0.00010	-0.07700	1.07690	
White	0.32168	0.33767	0.34065	Approximately D60

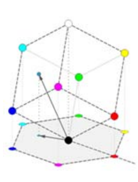


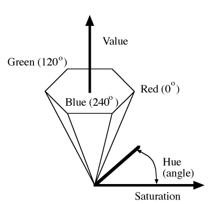
100% of visible colors

HSV Hexcone

Hue, Saturation, Value

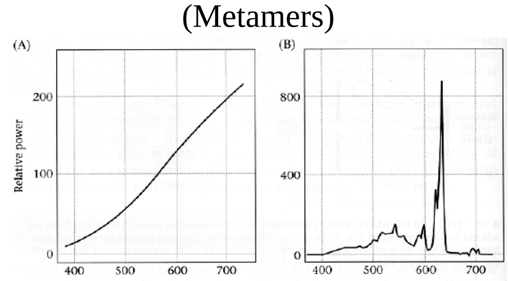






Hexagon arises from projection of cube onto plane orthogonal to (R,G,B) = (1,1,1)

Metameric Lights (Metamers)



4.11 **METAMERIC LIGHTS.** Two lights with these spectral power distributions appear identical to most observers and are called metamers. (A) An approximation to the spectral power distribution of a tungsten bulb. (B) The spectral power distribution of light emitted from a conventional television monitor whose three phosphor intensities were set to match the light in panel A in appearance.