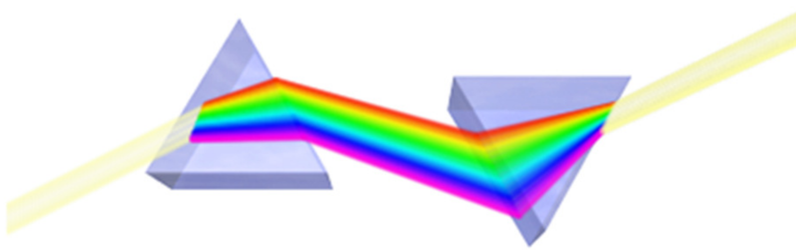
Color



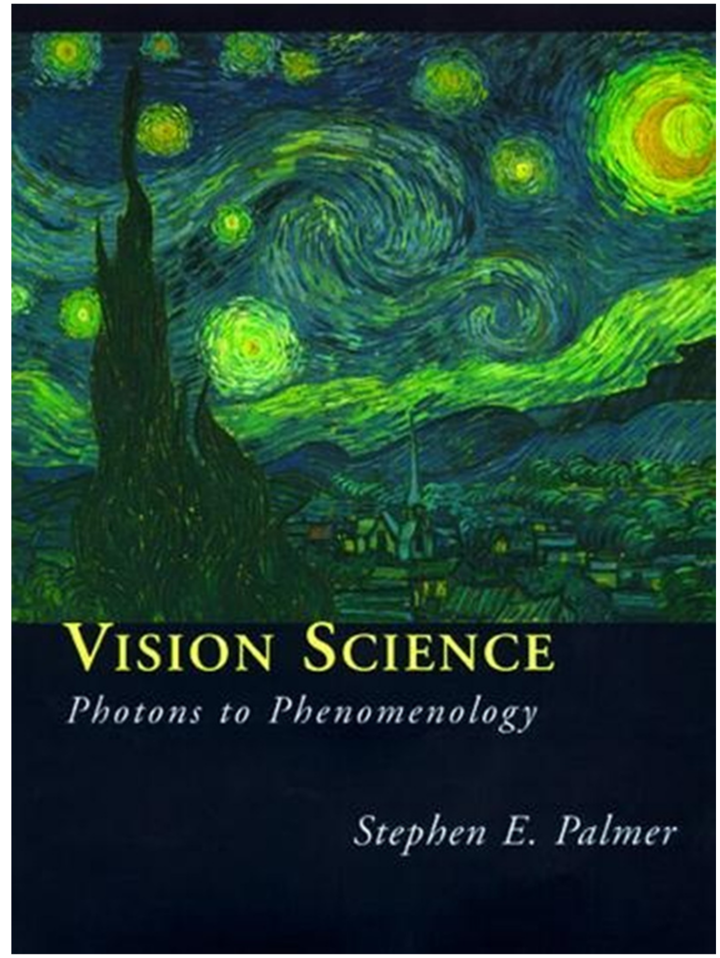
Based on Kristen Grauman's
Slides for Computer Vision

Today

- Color Spaces
- Perception of color
  - Human photoreceptors
  - Environmental effects, adaptation
- Color in Graphics and Programming

What is color?

- The result of interaction between physical light in the environment and our visual system.
- A *psychological property* of our visual experiences when we look at objects and lights, *not a physical property* of those objects or lights.



Slide credit: Lana Lazebnik

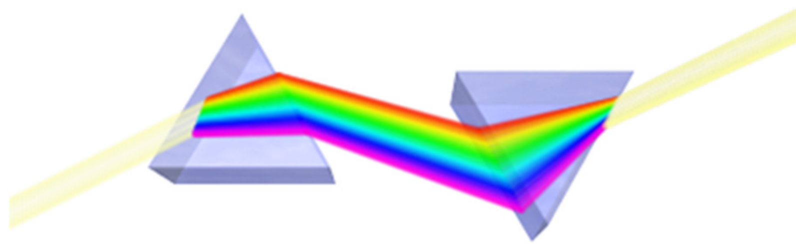
Color and light

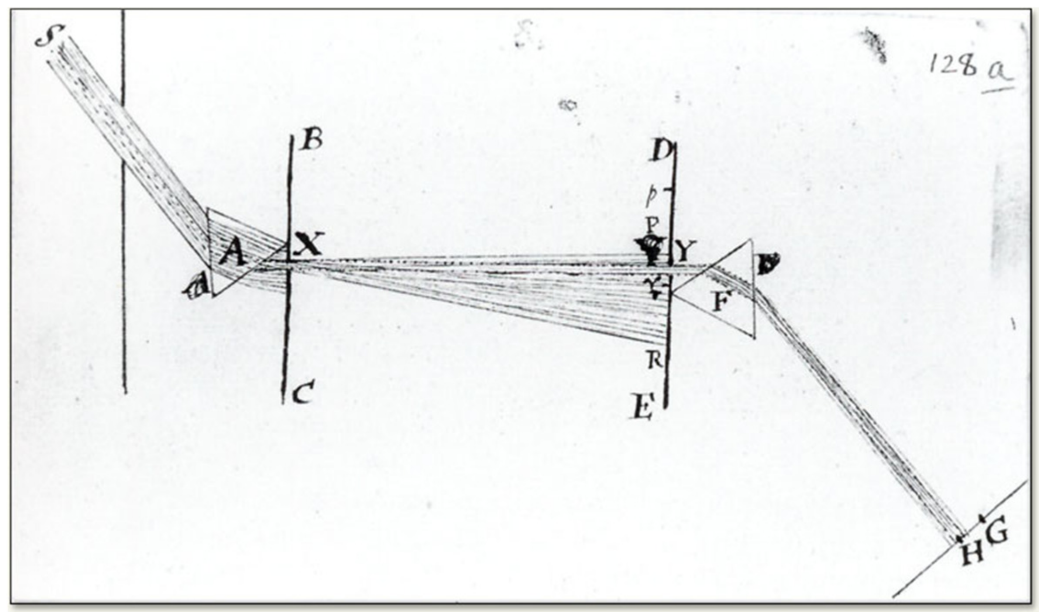
- **Color of light** arriving at camera depends on
  - Spectral reflectance of the surface light is leaving
  - Spectral radiance of light falling on that patch

- **Color perceived** depends on
  - Physics of light
  - Visual system receptors
  - Brain processing, environment

Color and light

White light: composed of almost equal energy in all wavelengths of the visible spectrum

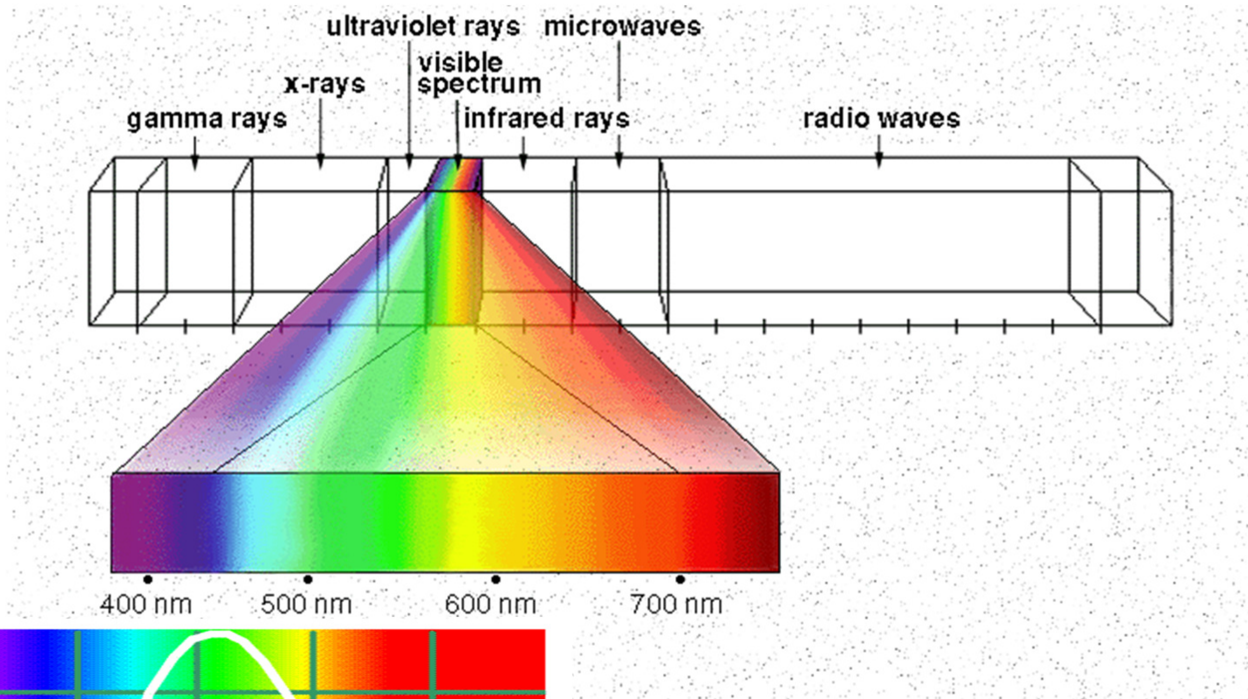


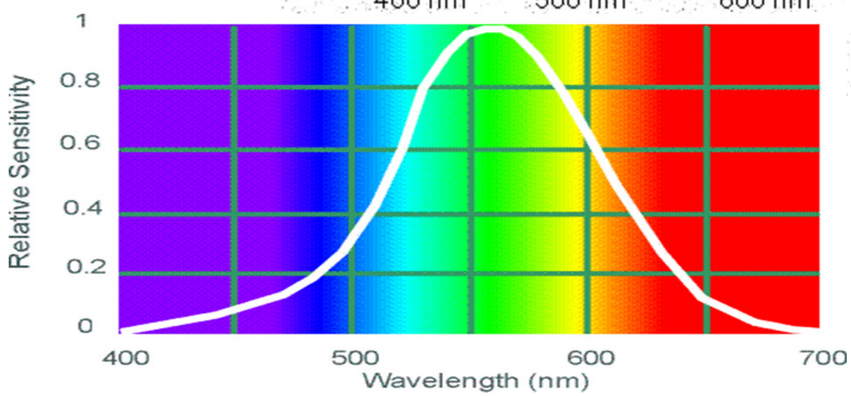


Newton 1665

Image from http://micro.magnet.fsu.edu/

Electromagnetic spectrum



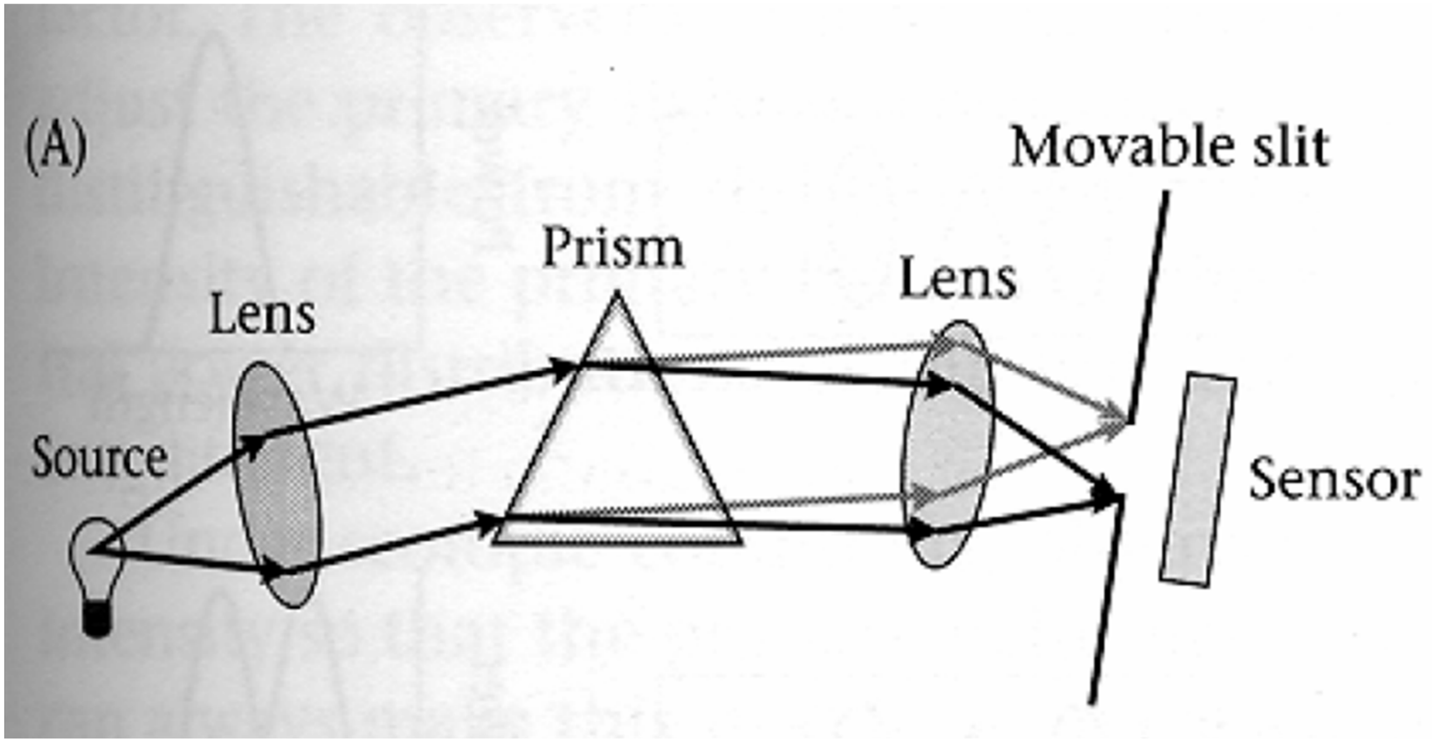


Human Luminance Sensitivity Function

Typical Grayscale conversion:
Gray = 0.3 * R + 0.59 * G + .11 * B
NOT
Gray = R / 3 + G / 3 + B / 3

Image credit: nasa.gov

Measuring spectra

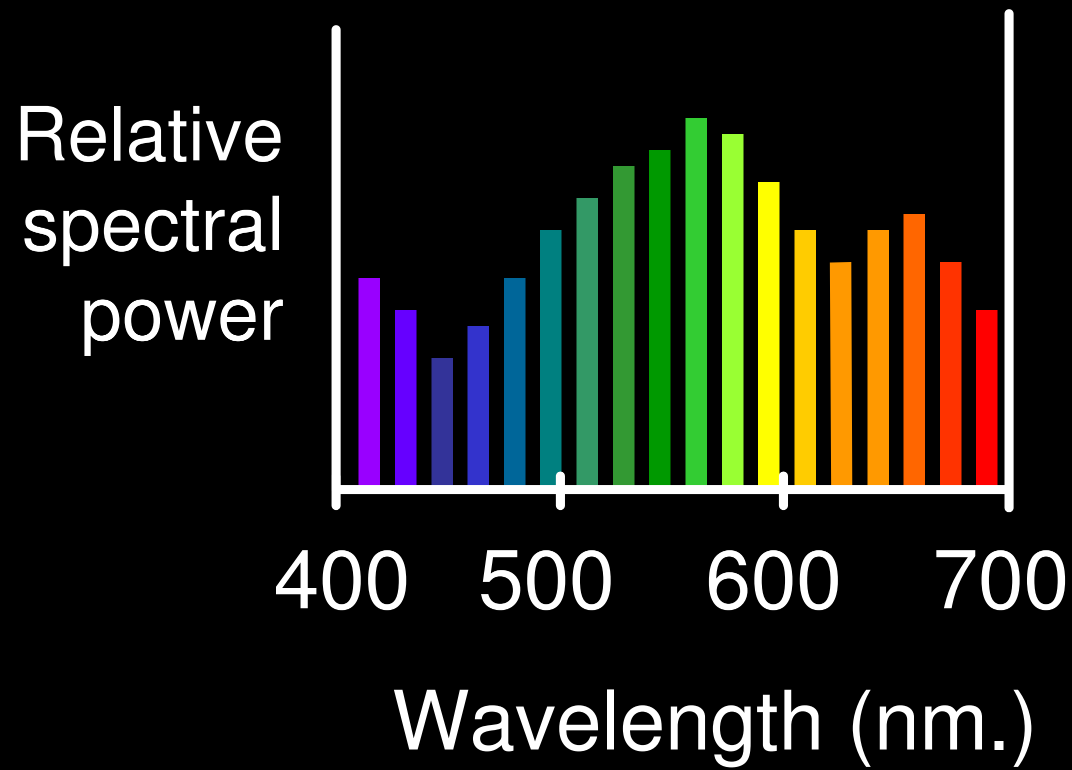


Spectroradiometer: separate input light into its different wavelengths, and measure the energy at each.

Foundations of Vision, B. Wandell

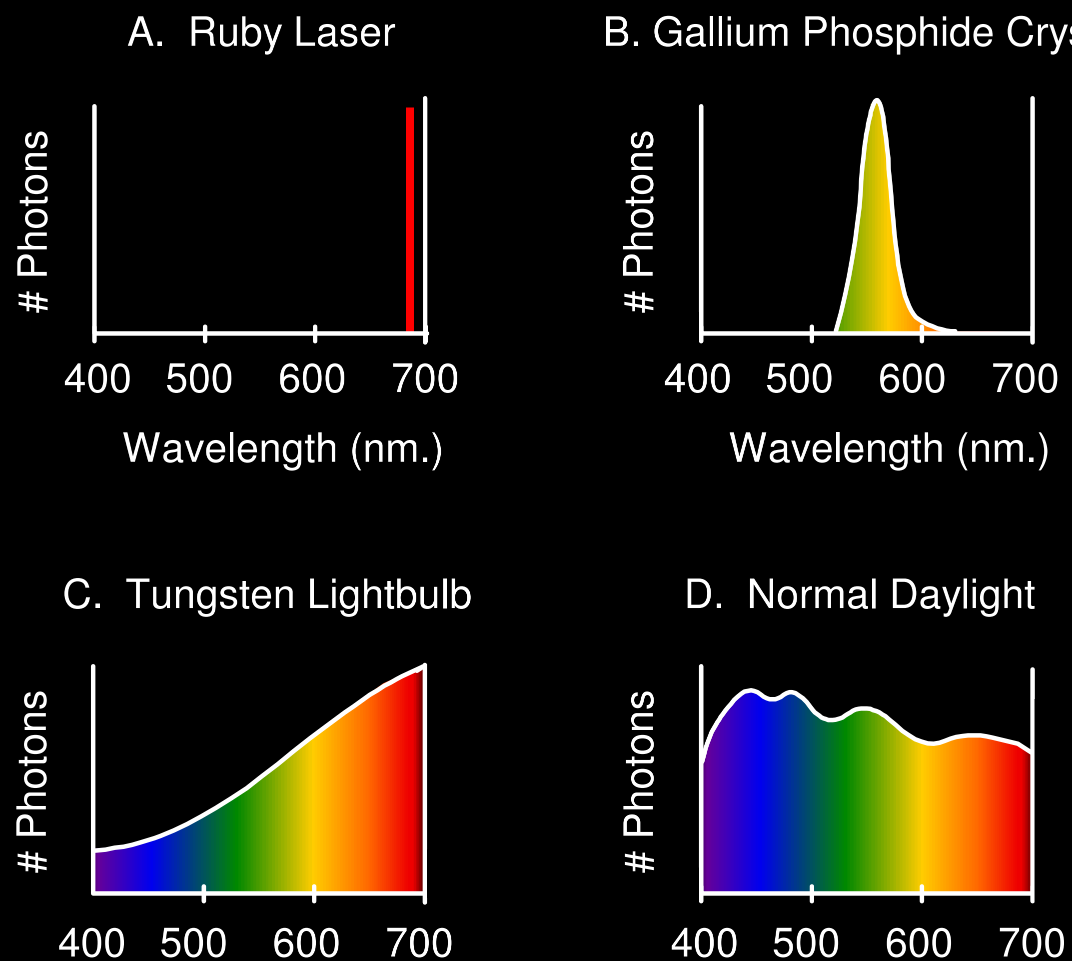
The Physics of Light

Any source of light can be completely described physically by its spectrum: the amount of energy emitted (per time unit) at each wavelength 400 - 700 nm.



Spectral power distributions

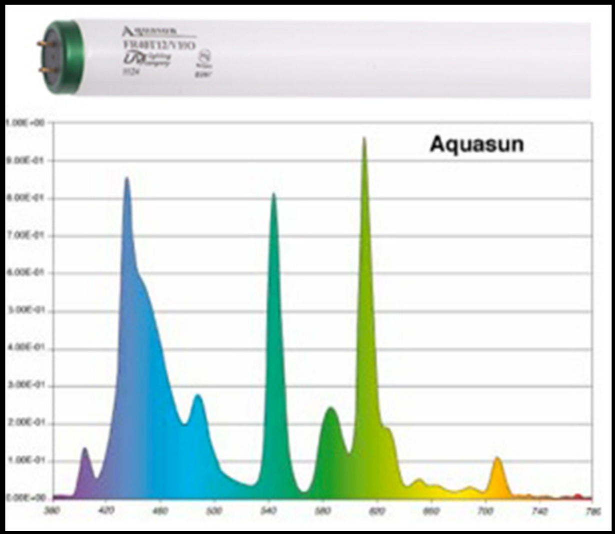
Some examples of the spectra of light sources



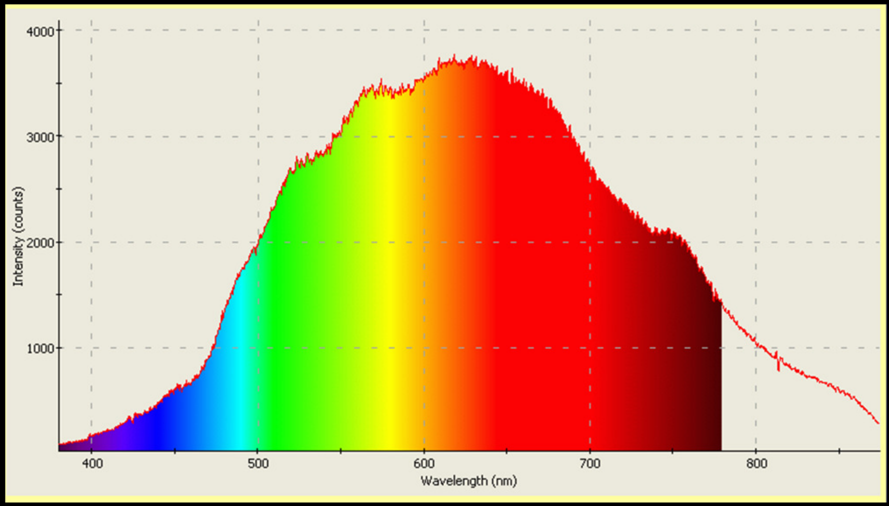
Spectral power distributions

More examples of the spectra of light sources

fluorescent bulb

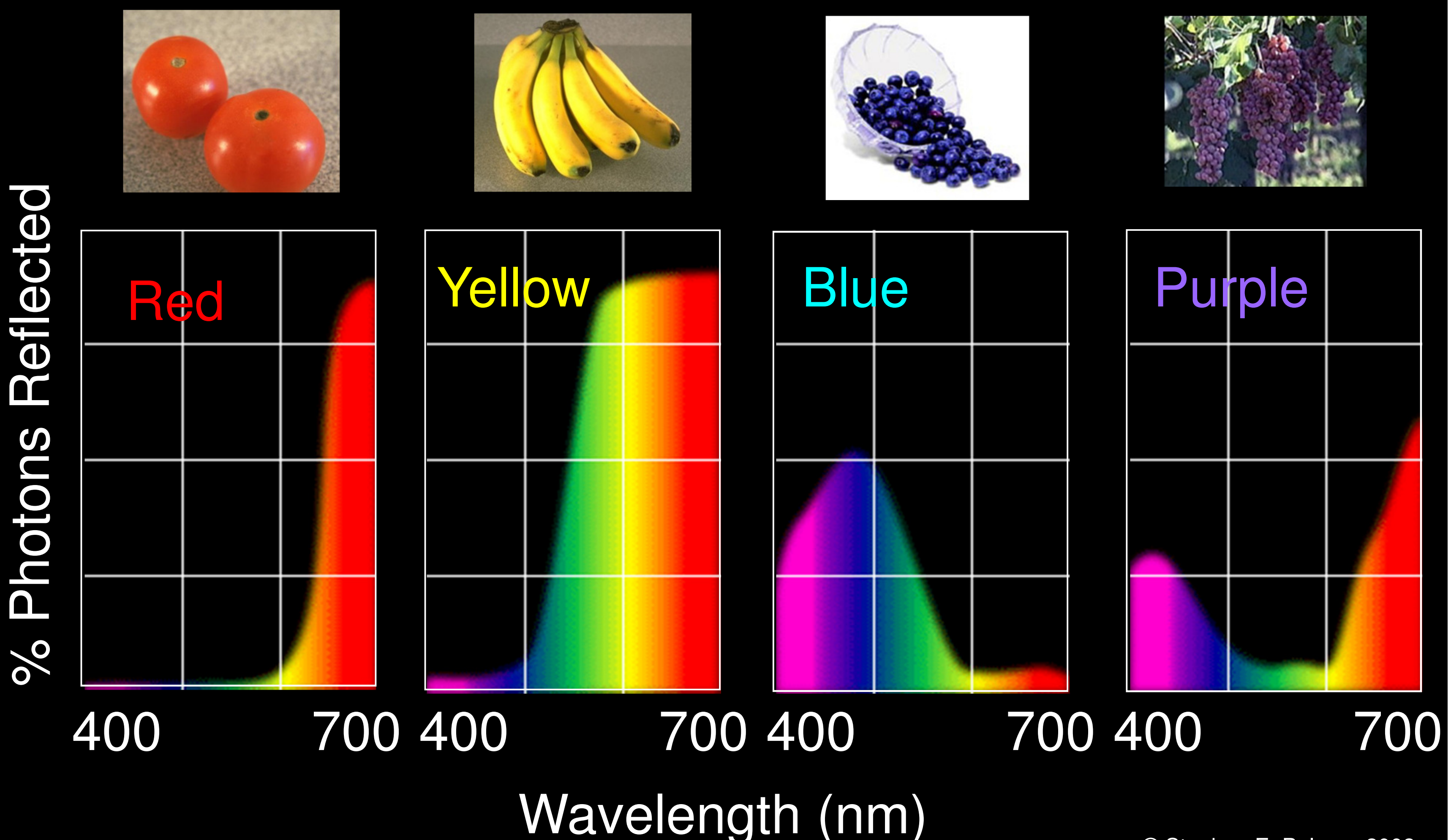


incandescent bulb

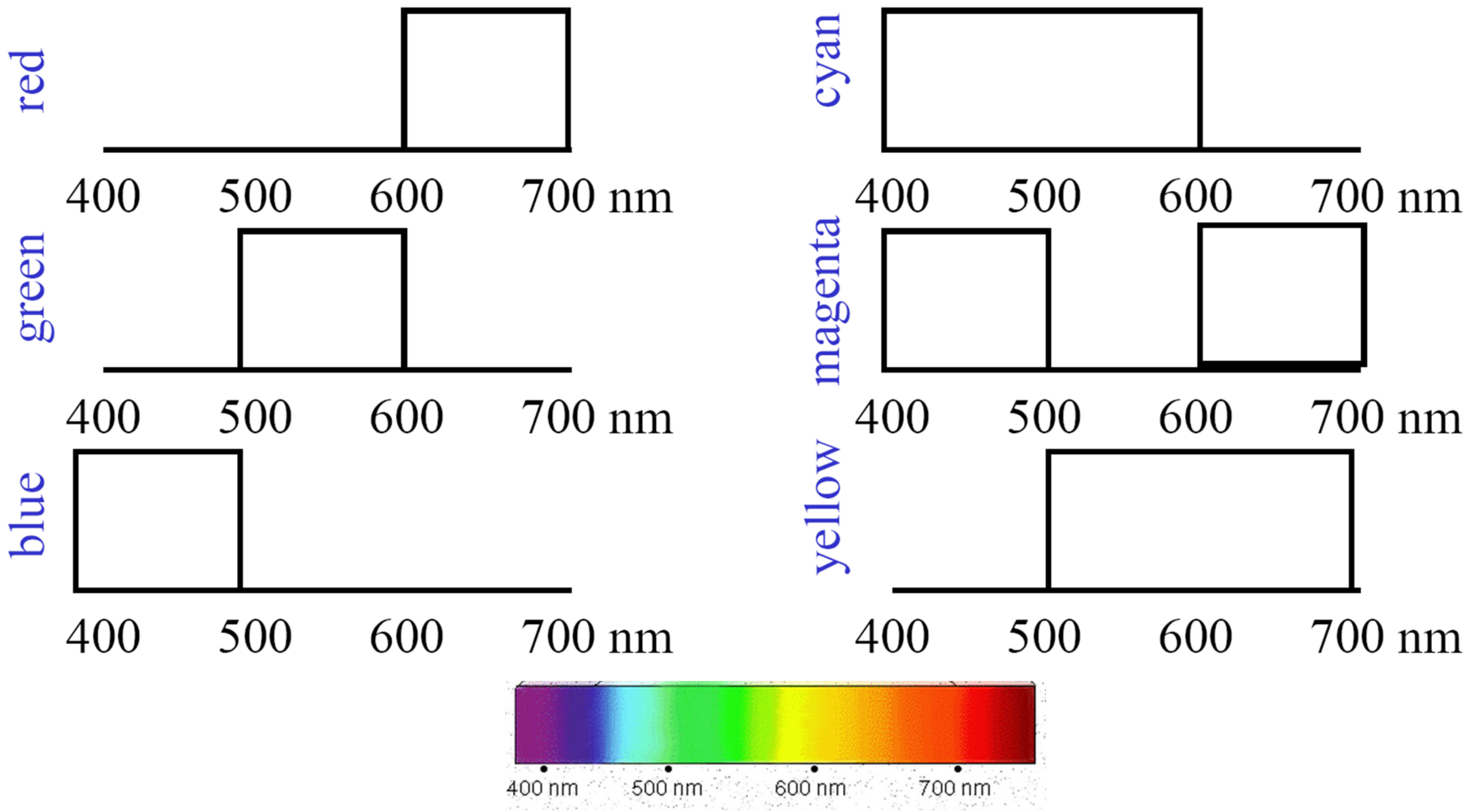


Surface reflectance spectra

Some examples of the reflectance spectra of surfaces

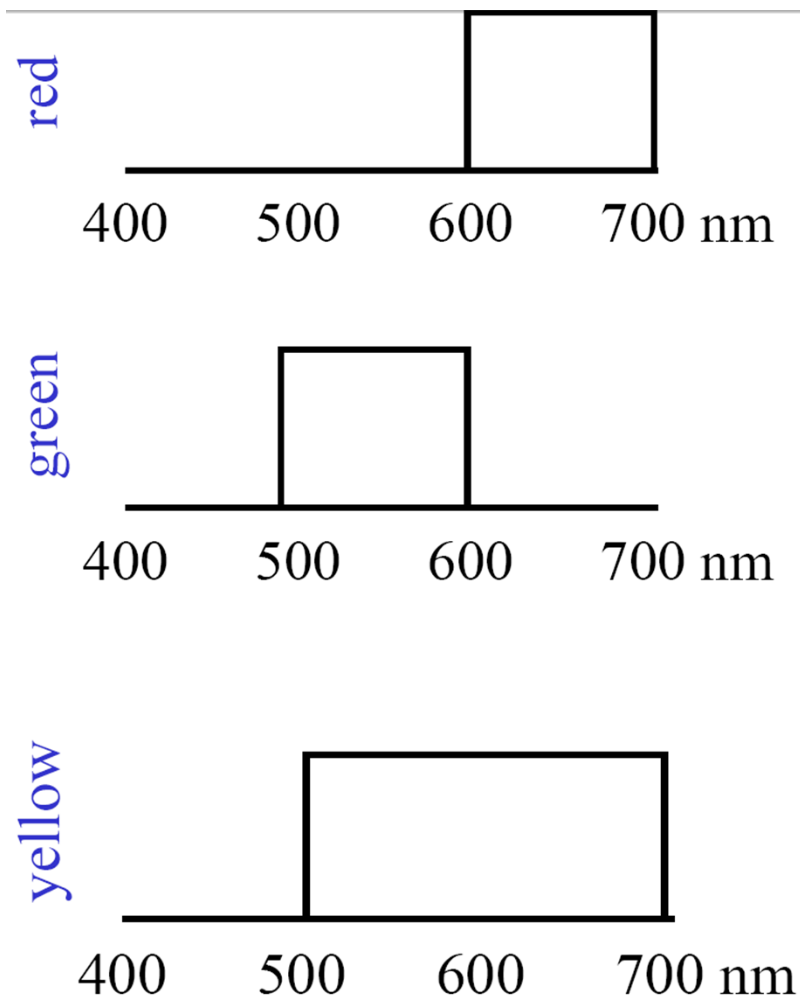


Color mixing

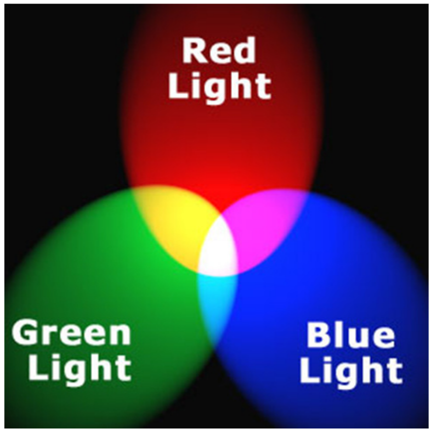


Source: W. Freeman

Additive color mixing



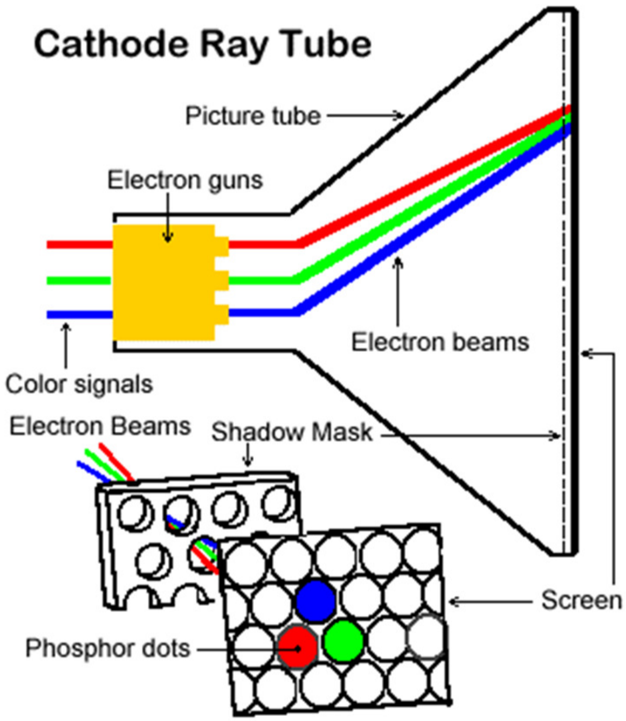
Colors combine by *adding* color spectra



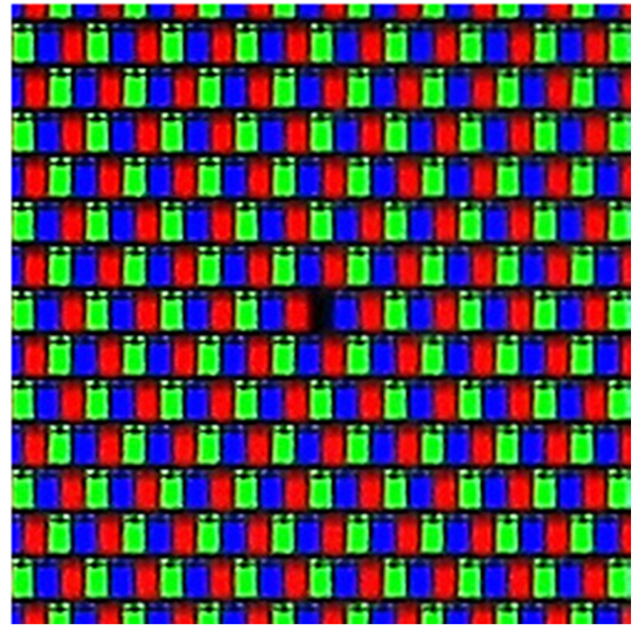
Light *adds* to existing black.

Source: W. Freeman

Examples of additive color systems



CRT phosphors

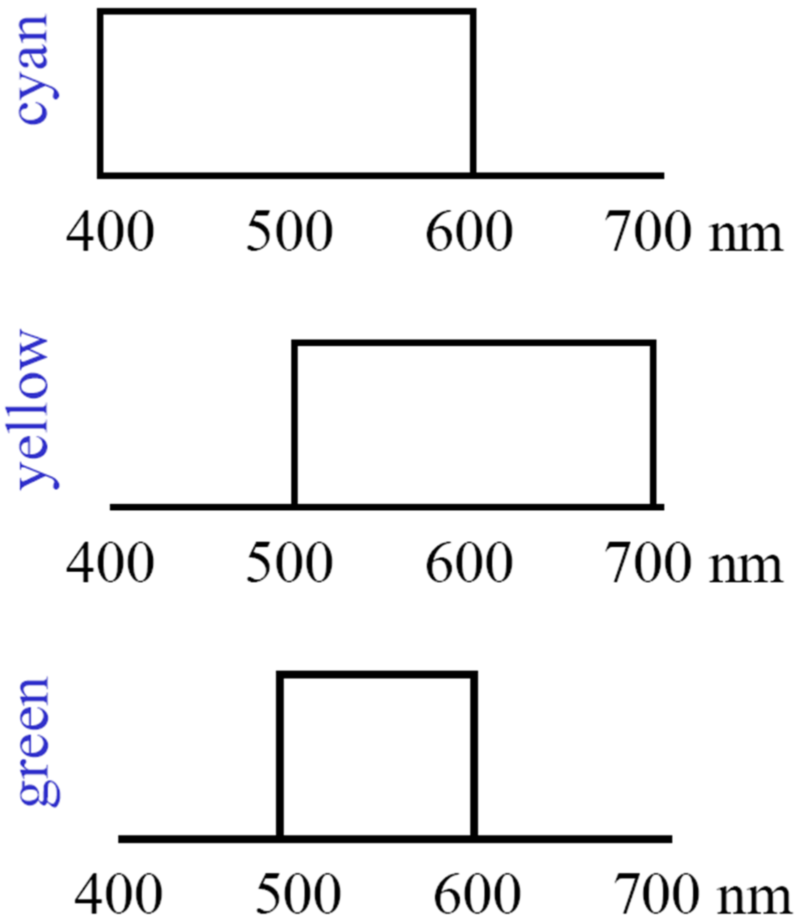


multiple projectors

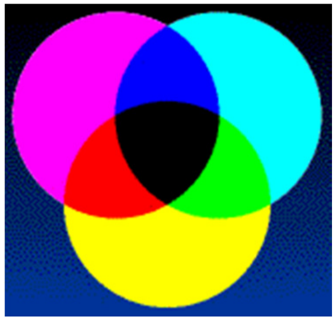
http://www.jegsworks.com

http://www.crtprojectors.co.uk/

Subtractive color mixing



Colors combine by *multiplying* color spectra.



Pigments *remove* color from incident light (white).

Source: W. Freeman

Examples of subtractive color systems

- Printing on paper
- Crayons
- Photographic film

STANDARD COLOR SPACES

Standard Color Spaces

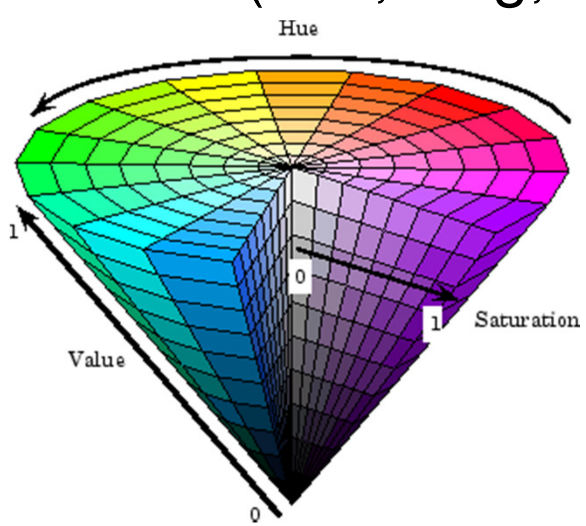
- Named Colors
  - Hundreds
  - About 800 on Wikipedia "List of Colors"
- Model or Color Space exists to handle the large number of colors possible

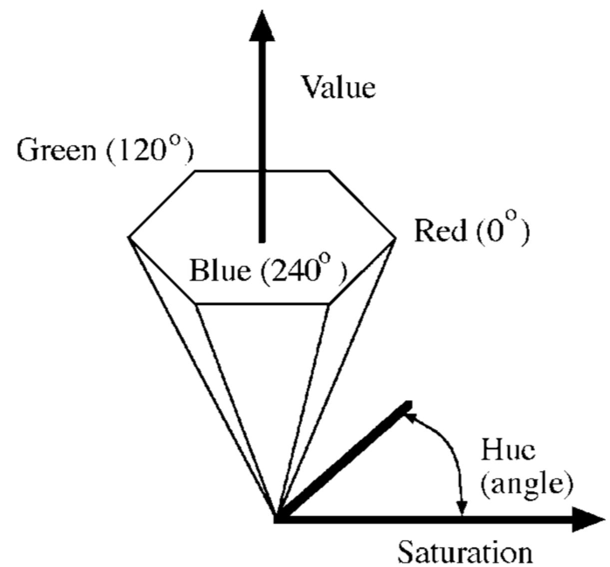
Standard color spaces

- Linear color space
  – RGB (RED - GREEN - BLUE)
- Non-linear color space
  – HSV (HUE - SATURATION - VALUE)

HSV color space

- **H**ue, **S**aturation, **V**alue
- Nonlinear – reflects topology of colors by coding **hue** as an angle
- Java:
  - public static Color getHSBColor(float h, float s, float b)
  - public static float[] RGBtoHSB(int r, int g, int b, float[] hsbvals)
  - public Color(int r, int g, int b)

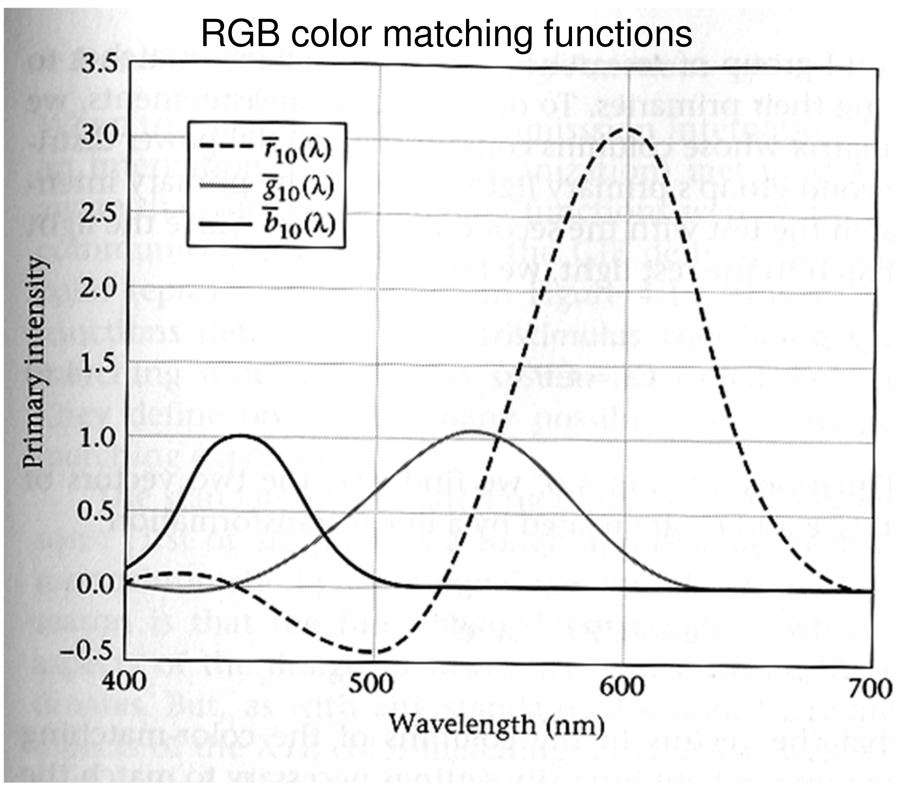


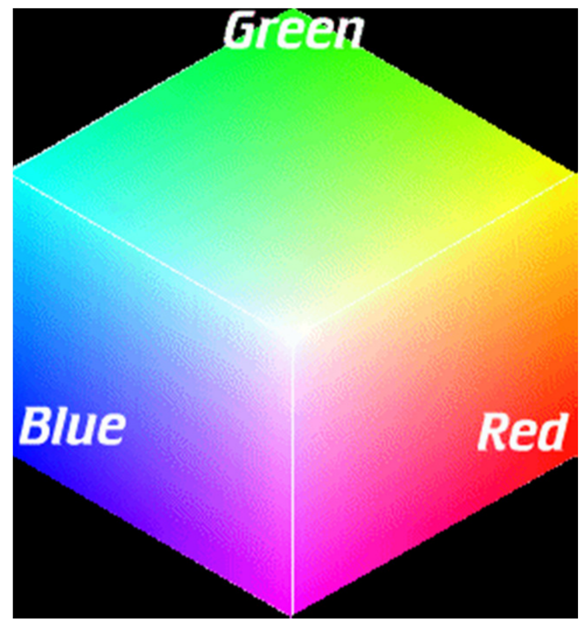


Kristen Grauman

RGB color space

- Single wavelength primaries
- Good for devices (e.g., phosphors for monitor)





Defining RGB Colors for Computing

- specify intensity of red, green, and blue components
- typical range of intensity 0 - 255
- 256 * 256 * 256 = 16,777,216 potential colors, 24 bit color
- Additive color
  - (0, 0, 0) = Black
  - (255, 255, 255) = White
  - (255, 0 , 255) = ? (255, 140, 0) = ?

RGB Colors

- RGB values in a Color Picker
- www.colorblender.com
- www.colorpicker.com
- Colors often expressed in hexadecimal
- base 16
  - digits, 0 - 9, A - F
  - 2 digits per color
  - Cardinal = C41E3A = (196, 30, 58)

```
text-align: center; background-color: #C41E3A;
```

Color In Java

- java.awt.Color
- RGBa color model
- 13 named constants
- Multiple constructors
- Also an *alpha* value
  - Introduced by Alvy Ray Smith (member of LucasArts computer group)
  - express level of transparency / opacity
  - 0 = transparent, 255 = fully opaque

Color in Java

- 0 - 255 for intensity of RGB and Alpha
- additive color model
- bit packing, bitwise operators

Color

```
public Color(int rgb)
```

Creates an opaque sRGB color with the specified combined RGB value consisting of the red component in bits 16-23, the green component in bits 8-15, and the blue component in bits 0-7. The actual color used in rendering depends on finding the best match given the color space available for a particular output device. Alpha is defaulted to 255.

Parameters:

`rgb` - the combined RGB components

Sample Programs

- ColorExample
  - ColorPanel
  - AlphaColorPanel
- ColorChooserMain
  - Main - Frame - 2 Panels
  - JColorChooser class built in to Java
  - http://docs.oracle.com/javase/tutorial/uiswing/components/colorchooser.html

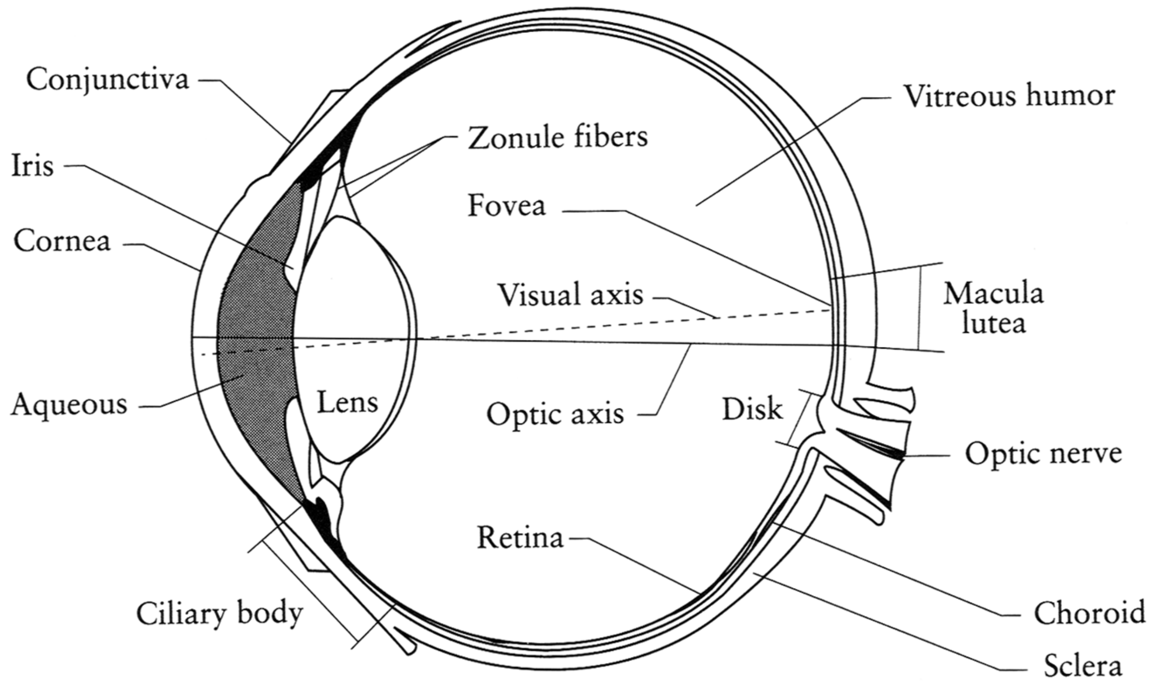
COLOR PERCEPTION

Color and light

- **Color of light** arriving at camera depends on
  - Spectral reflectance of the surface light is leaving
  - Spectral radiance of light falling on that patch

- **Color perceived** depends on
  - Physics of light
  - Visual system receptors
  - Brain processing, environment

The Eye



The human eye is a camera!

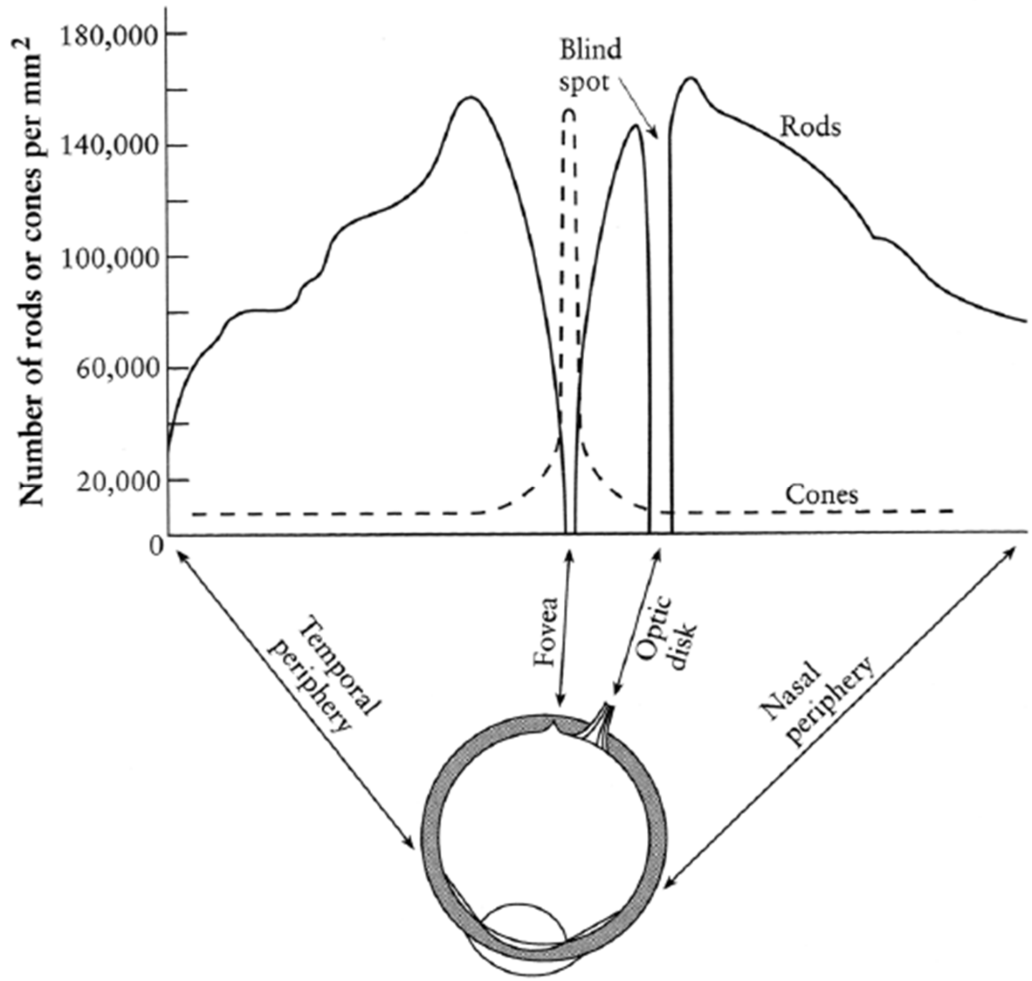
- **Iris** - colored annulus with radial muscles
- **Pupil** - the hole (aperture) whose size is controlled by the iris
- **Lens** - changes shape by using ciliary muscles (to focus on objects at different distances)
- **Retina** - photoreceptor cells

Slide by Steve Seitz

Types of light-sensitive receptors

Cones
- cone-shaped
- less sensitive
- operate in high light
- color vision

Rods
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision

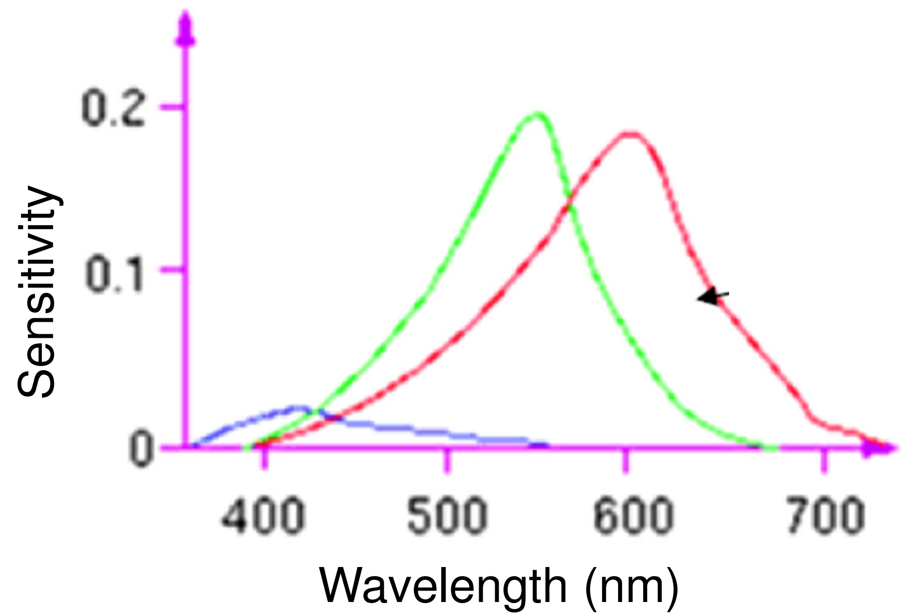


Slide credit: Alyosha Efros

Types of cones

- React only to some wavelengths, with different sensitivity (light fraction absorbed)
- Brain fuses responses from local neighborhood of several cones for perceived color
- Sensitivities vary per person, and with age
- Color blindness: deficiency in at least one type of cone

Three kinds of cones



Types of cones

Possible evolutionary pressure for developing receptors for different wavelengths in primates

Osorio & Vorobyev, 1996

Trichromacy

- Experimental facts:
  - Three primaries will work for most people if we allow subtractive matching; “trichromatic” nature of the human visual system
  - Most people make the *same* matches for a given set of primaries (i.e., select the same mixtures)

Environmental effects & adaptation

- **Chromatic adaptation**:
  - We adapt to a particular illuminant
- **Assimilation, contrast effects, chromatic induction:**
  - Nearby colors affect what is perceived; receptor excitations interact across image and time
- **Afterimages**

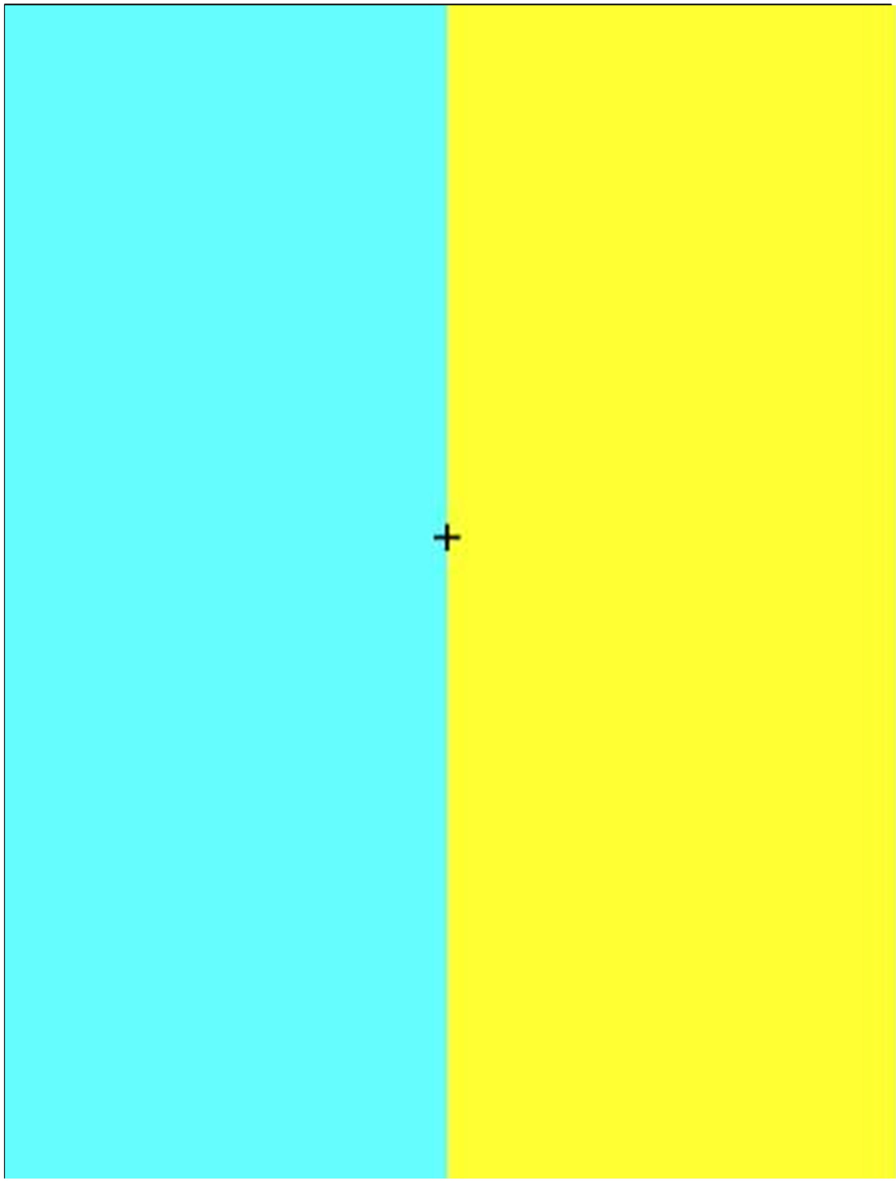
Color matching != color appearance

Physics of light != perception of light

Chromatic adaptation

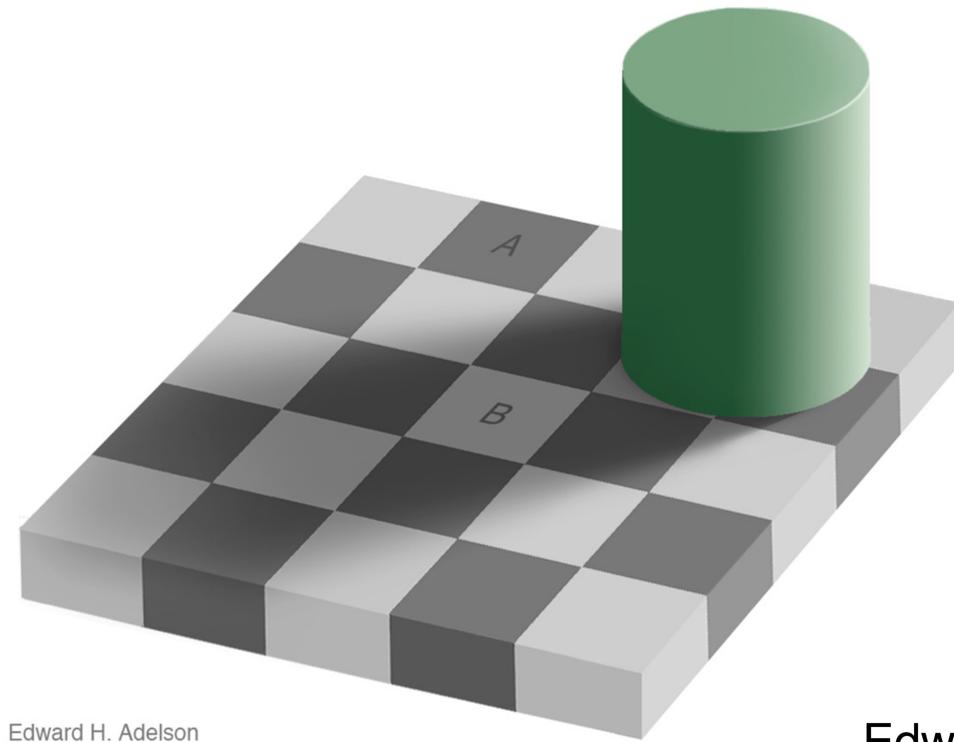
- If the visual system is exposed to a certain illuminant for a while, color system starts to adapt / skew.

Chromatic adaptation



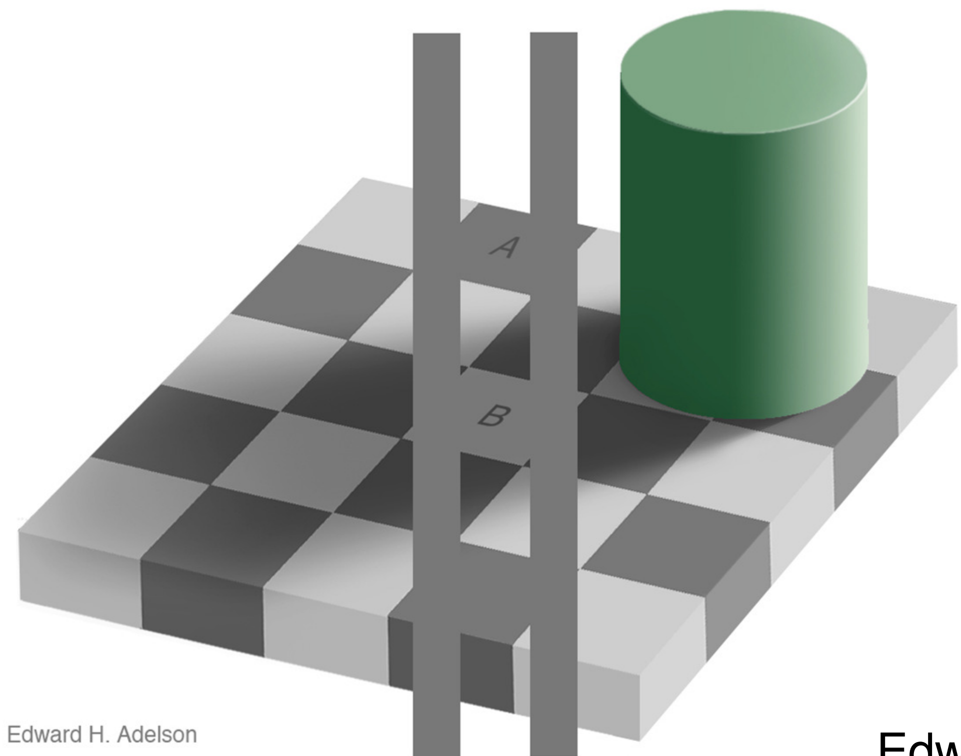
http://www.planetperplex.com/en/color_illusions.html

Brightness perception



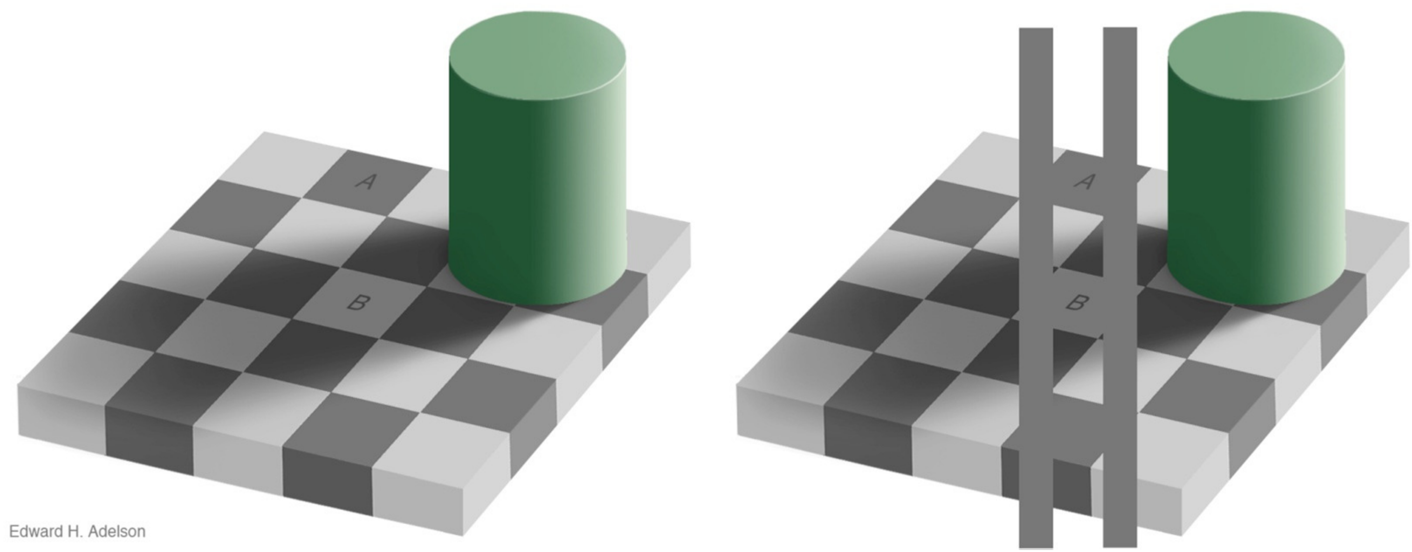
Edward Adelson

http://web.mit.edu/persci/people/adelson/illusions_demos.html



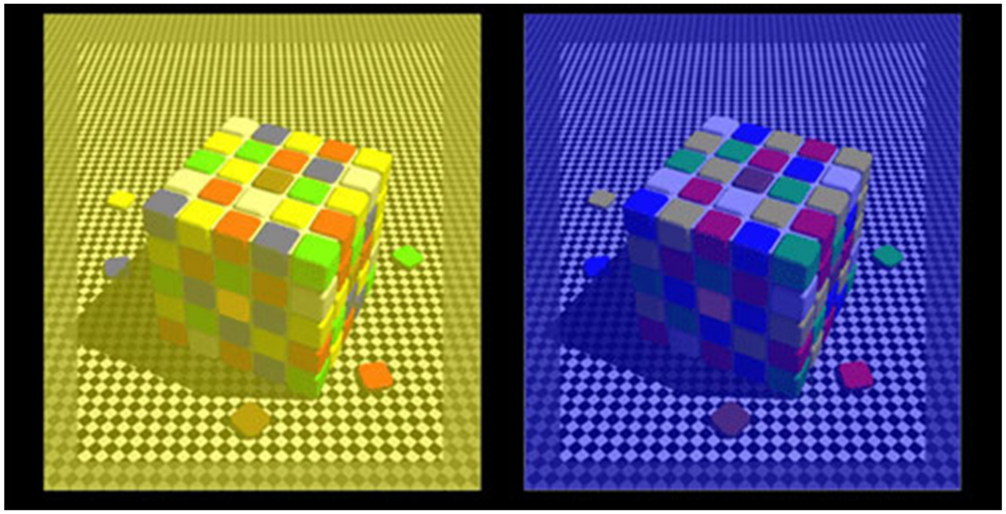
Edward Adelson

http://web.mit.edu/persci/people/adelson/illusions_demos.html



Edward Adelson

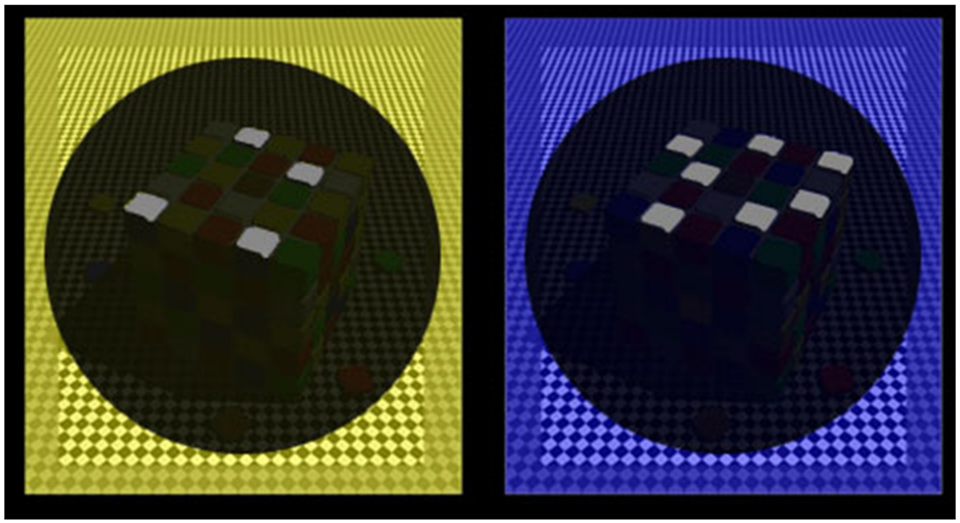
http://web.mit.edu/persci/people/adelson/illusions_demos.html



Look at blue squares

Look at yellow squares

- Content © 2008 R.Beau Lotto
- http://www.lottolab.org/articles/illusionsoflight.asp



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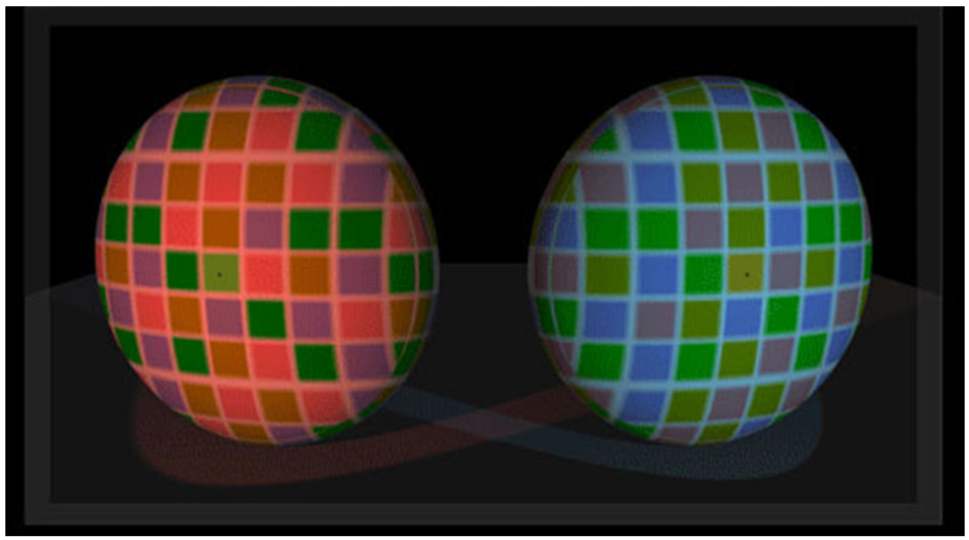
- http://www.lottolab.org/articles/illusionsoflight.asp



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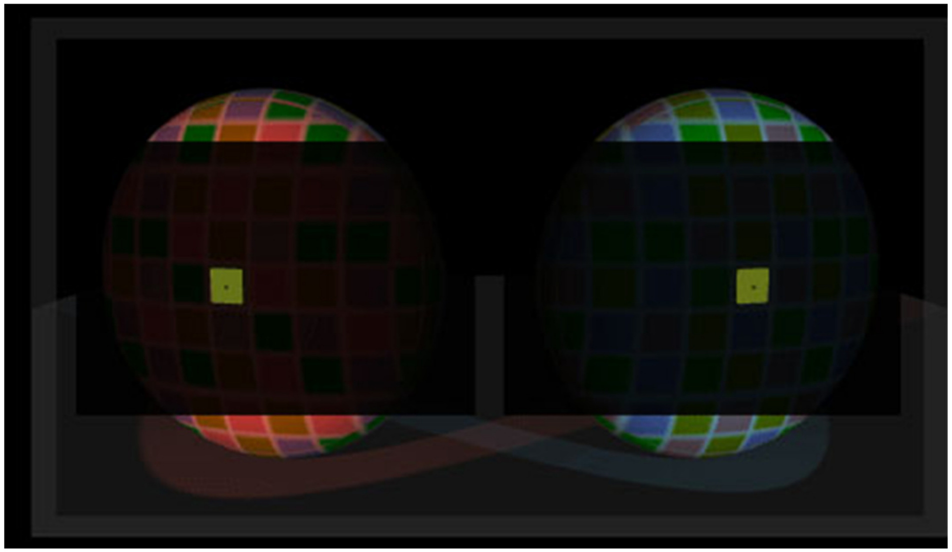
- http://www.lottolab.org/articles/illusionsoflight.asp



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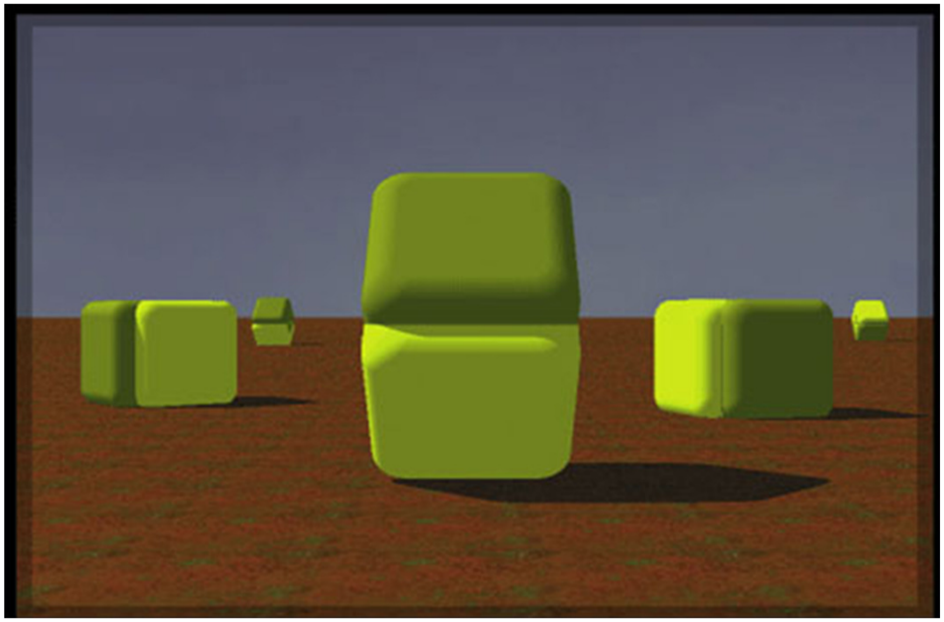
- http://www.lottolab.org/articles/illusionsoflight.asp



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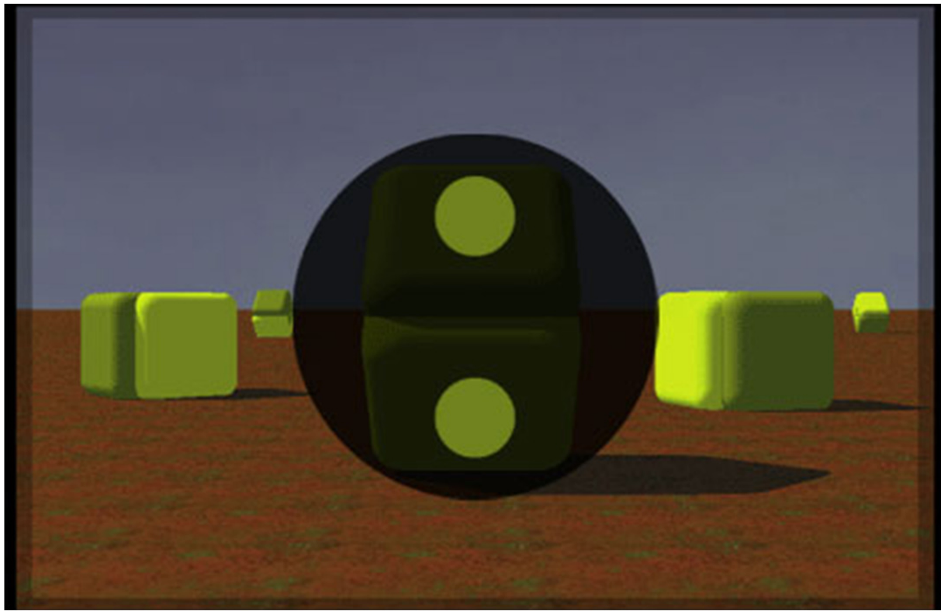


- Content © 2008 R.Beau Lotto
- http://www.lottolab.org/articles/illusionsoflight.asp

After images

- Tired photoreceptors send out negative response after a strong stimulus

http://www.sandlotscience.com/Aftereffects/Andrus_Spiral.htm

http://www.michaelbach.de/ot/mot_adaptSpiral/index.html

Source: Steve Seitz

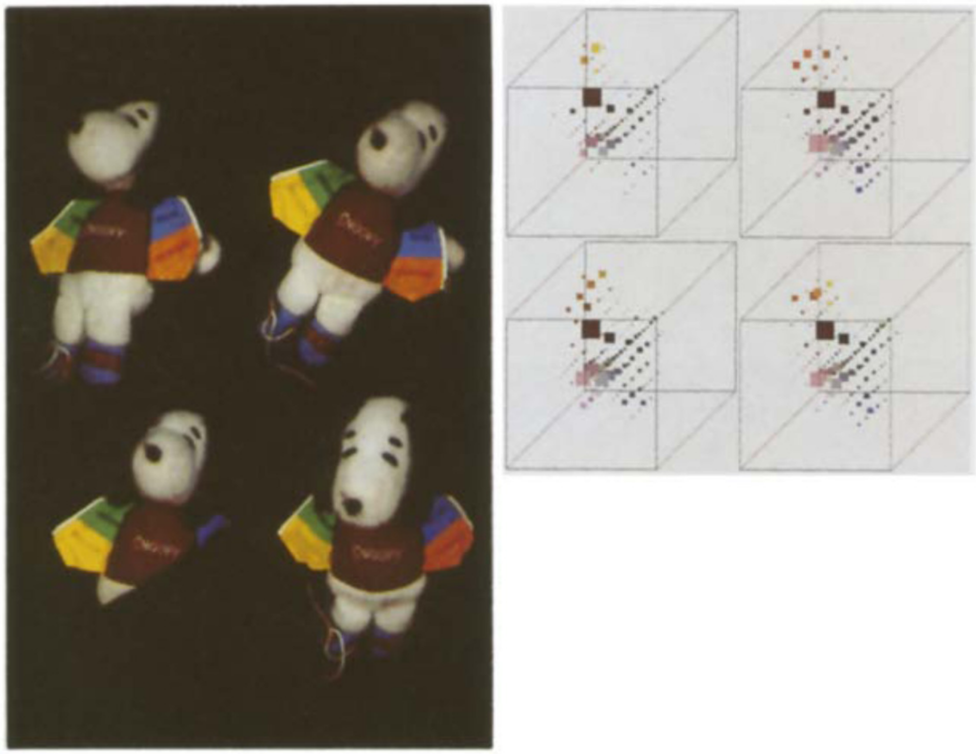
Name that color

Blue Red Green Cyan
Magenta Black Pink
Yellow Orange Violet
Brown Purple Cyan
Indigo Red Green Blue

High level interactions affect perception and processing.

COLOR IN COMPUTER VISION

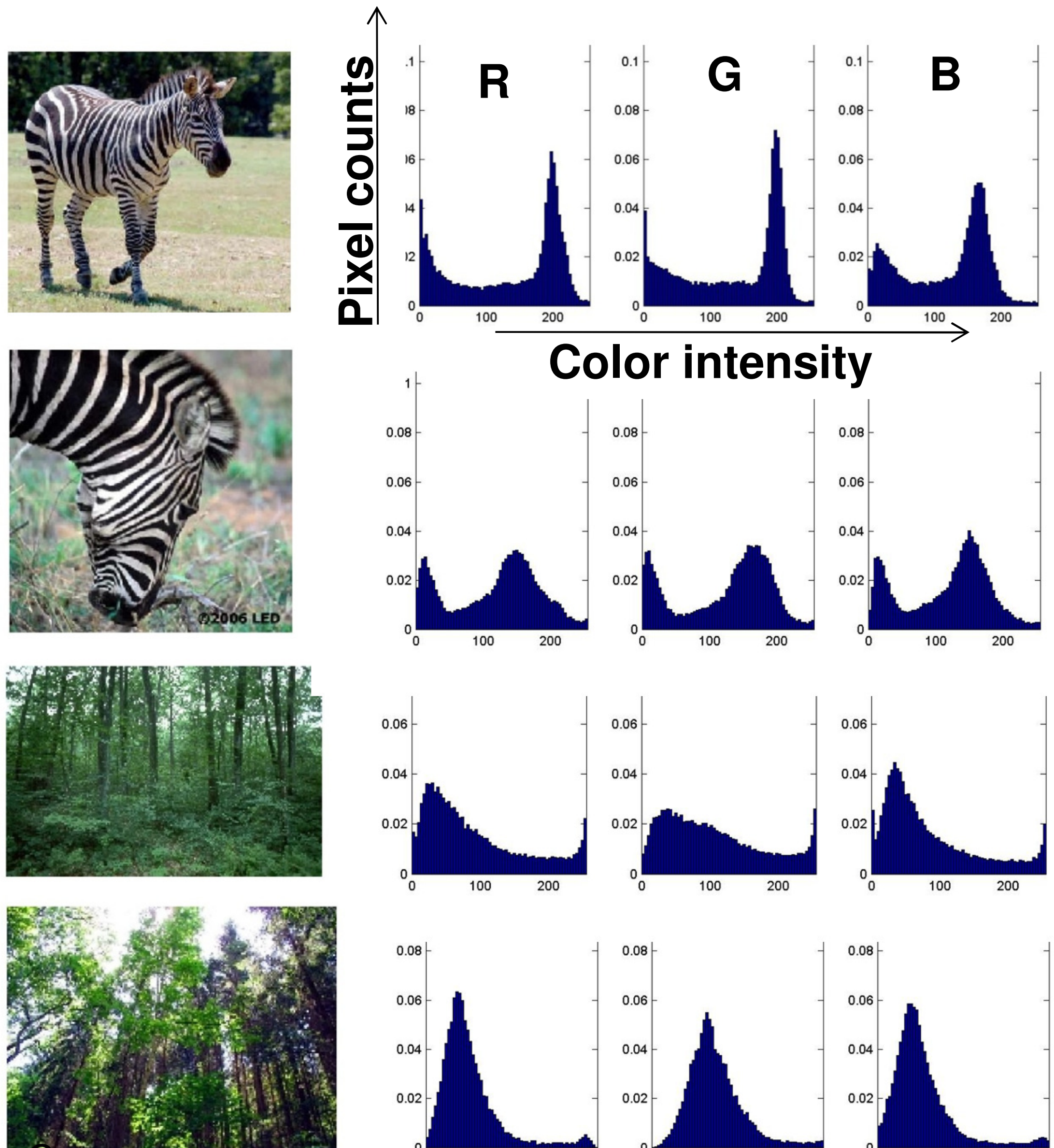
Color as a low-level cue for CBIR



Swain and Ballard, Color Indexing, IJCV 1991

Blobworld system
Carson et al, 1999

Color as a low-level cue for CBIR



- Color histograms: Use distribution of colors to describe image
- No spatial info – invariant to translation, rotation, scale

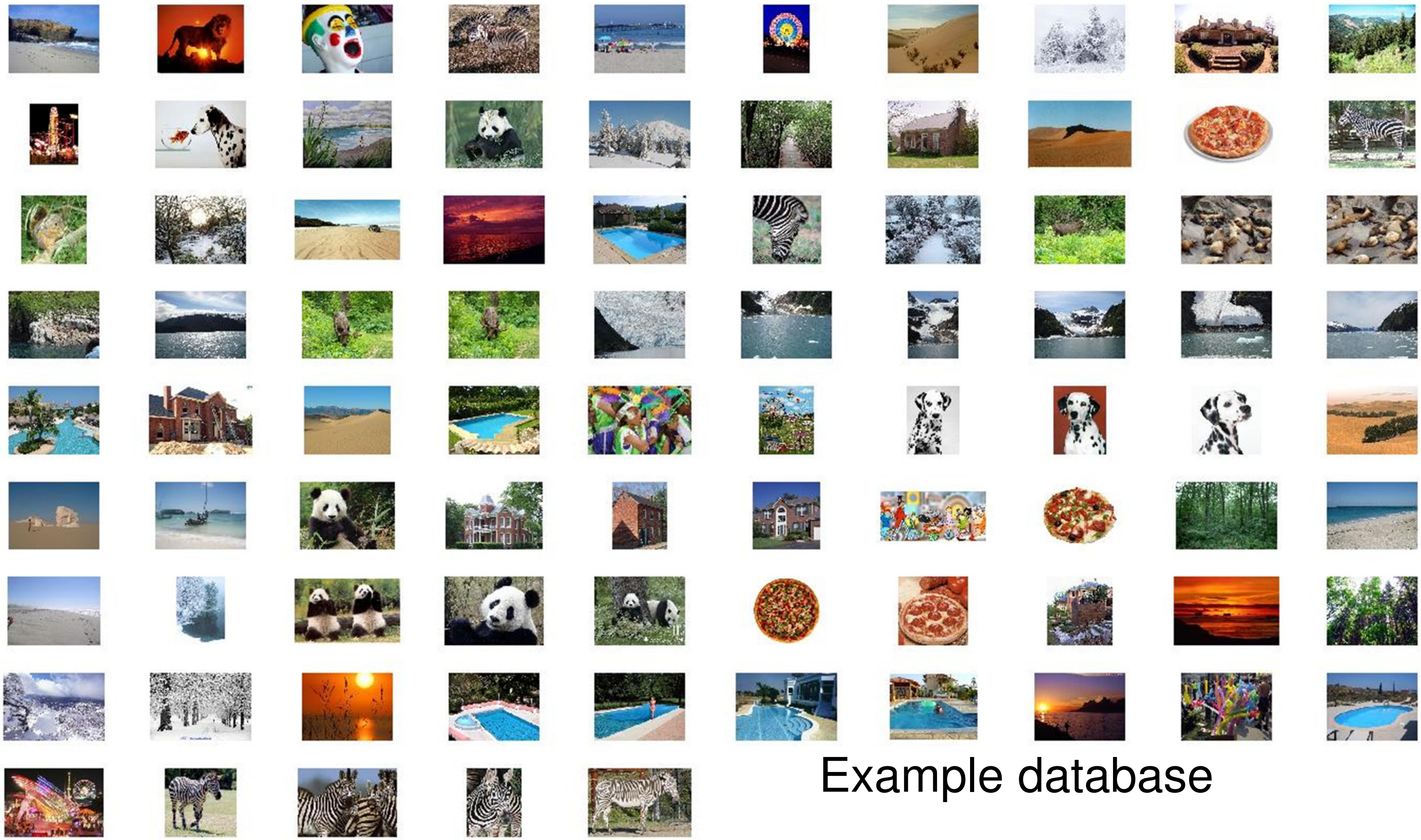
Kristen Grauman

Color-based image retrieval

- Given collection (database) of images:
  - Extract and store one color histogram per image
- Given new query image:
  - Extract its color histogram
  - For each database image:
    - Compute intersection between query histogram and database histogram
  - Sort intersection values (highest score = most similar)
  - Rank database items relative to query based on this sorted order

Kristen Grauman

Color-based image retrieval



Example database

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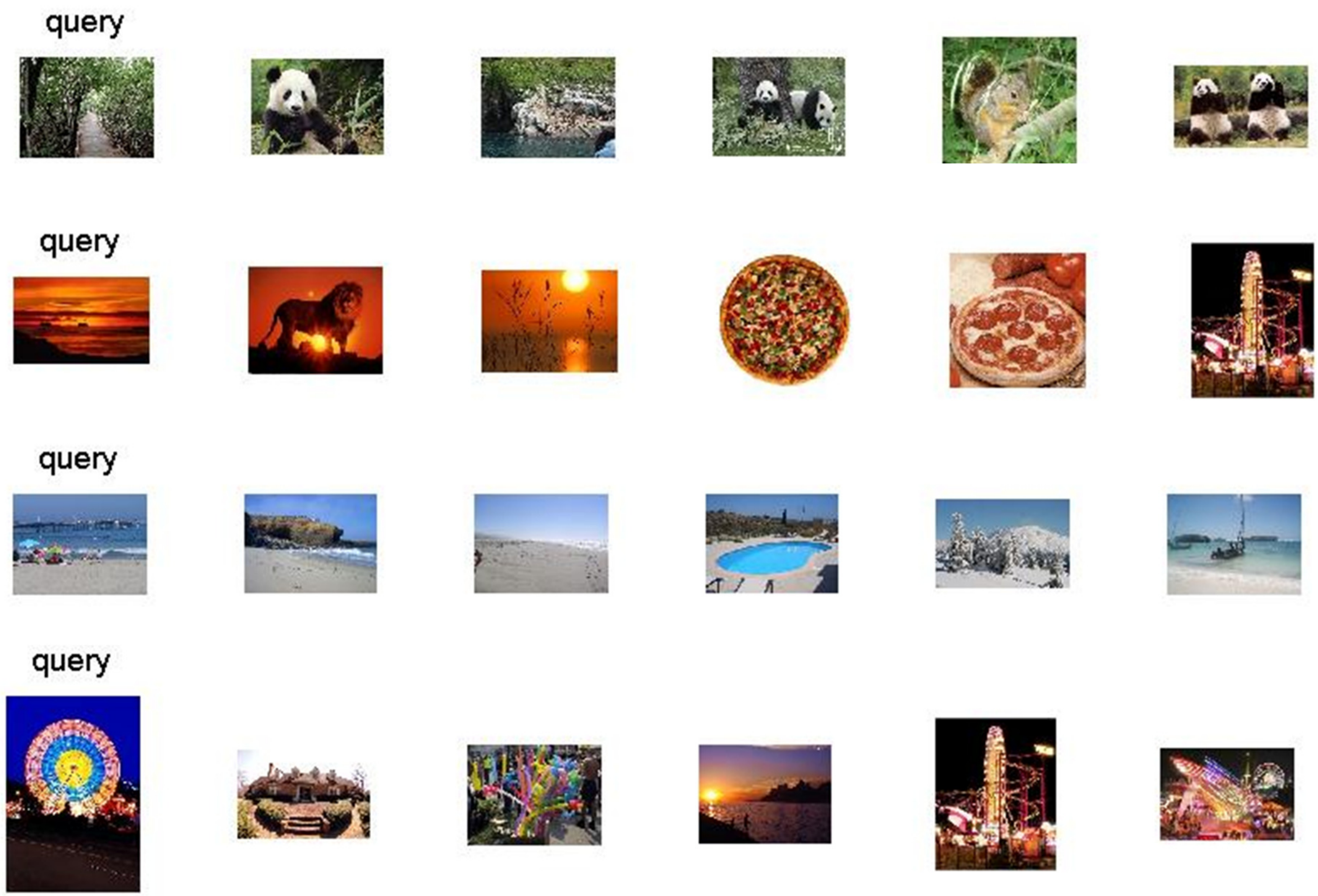
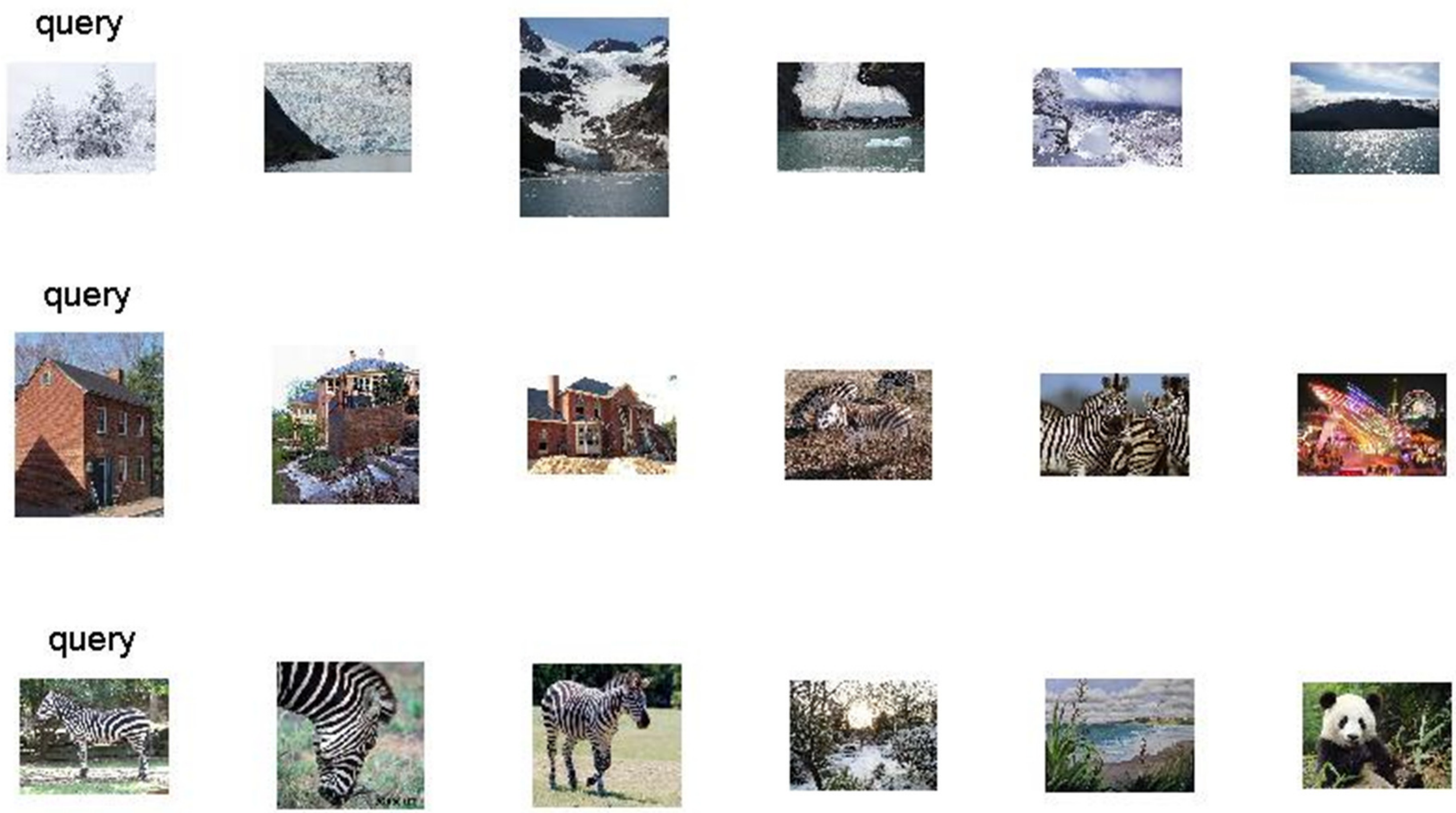
Color-based image retrieval



Example retrievals

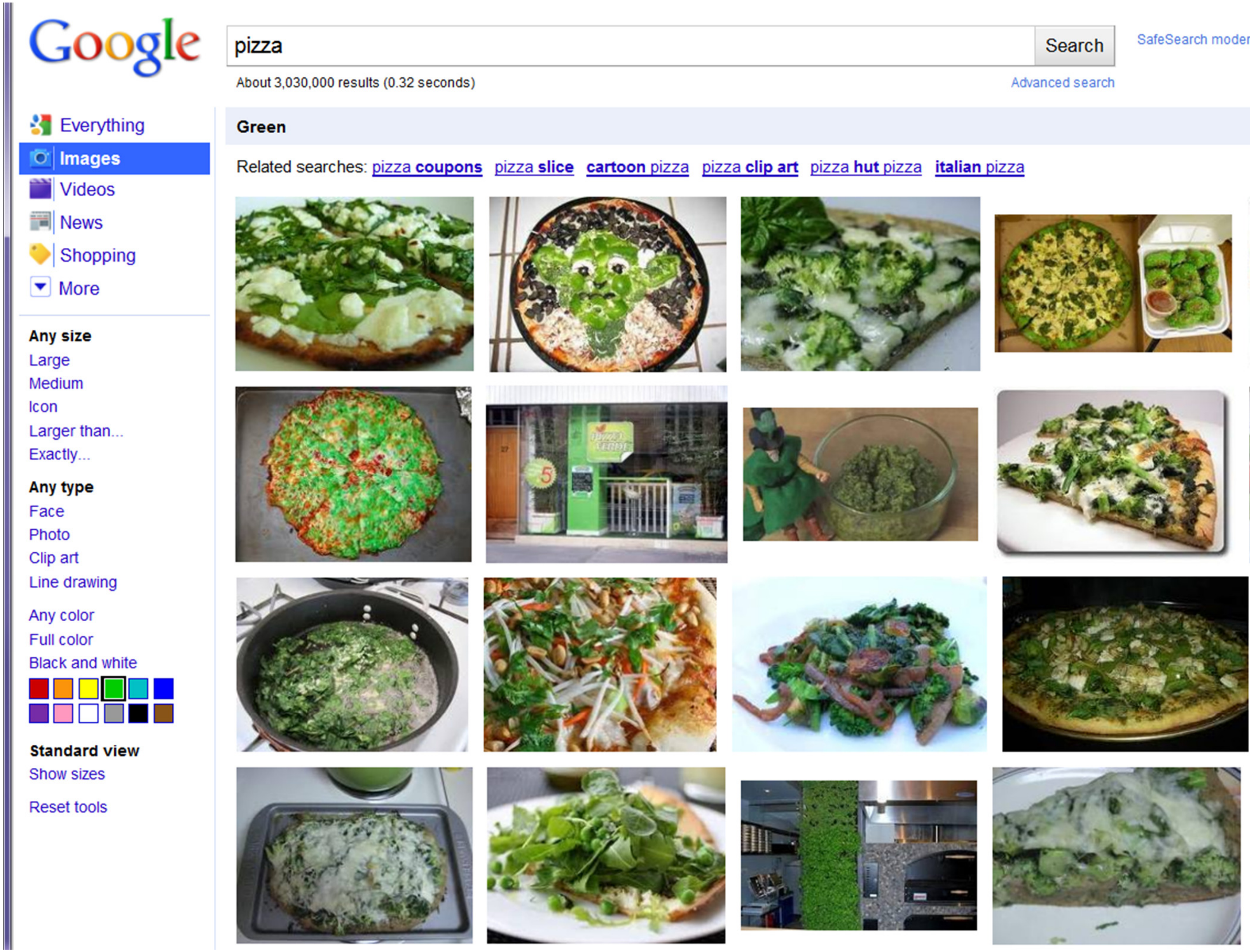
Kristen Grauman

Color-based image retrieval



Example retrievals

Kristen Grauman


Google
pizza
Search
SafeSearch moder
About 3,030,000 results (0.32 seconds)
Advanced search
Everything
Images
Videos
News
Shopping
More
Any size
Large
Medium
Icon
Larger than...
Exactly...
Any type
Face
Photo
Clip art
Line drawing
Any color
Full color
Black and white
Standard view
Show sizes
Reset tools
Green
Related searches: pizza coupons pizza slice cartoon pizza pizza clip art pizza hut pizza italian pizza

Color-based skin detection

M. Jones and J. Rehg, Statistical Color Models with Application to Skin Detection, IJCV 2002.

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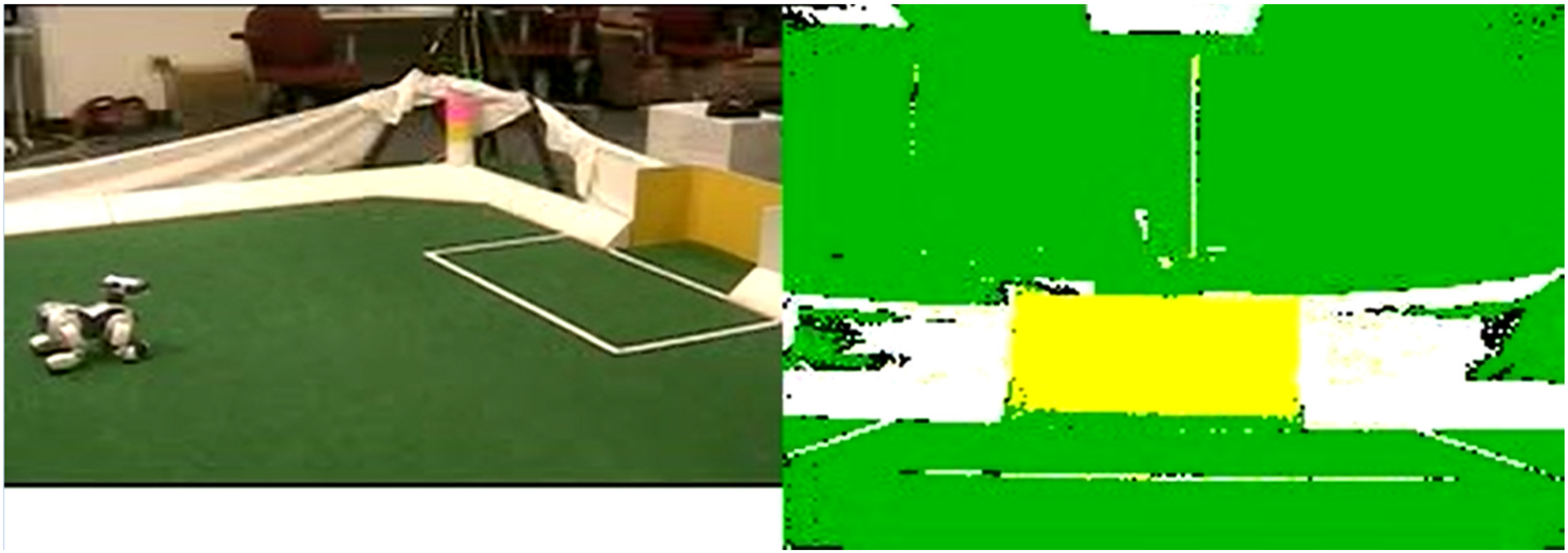
Color-based segmentation for robot soccer



Towards Eliminating Manual Color Calibration at RoboCup. Mohan Sridharan and Peter Stone. RoboCup-2005: Robot Soccer World Cup IX, Springer Verlag, 2006

http://www.cs.utexas.edu/users/AustinVilla/?p=research/auto_vis

Kristen Grauman