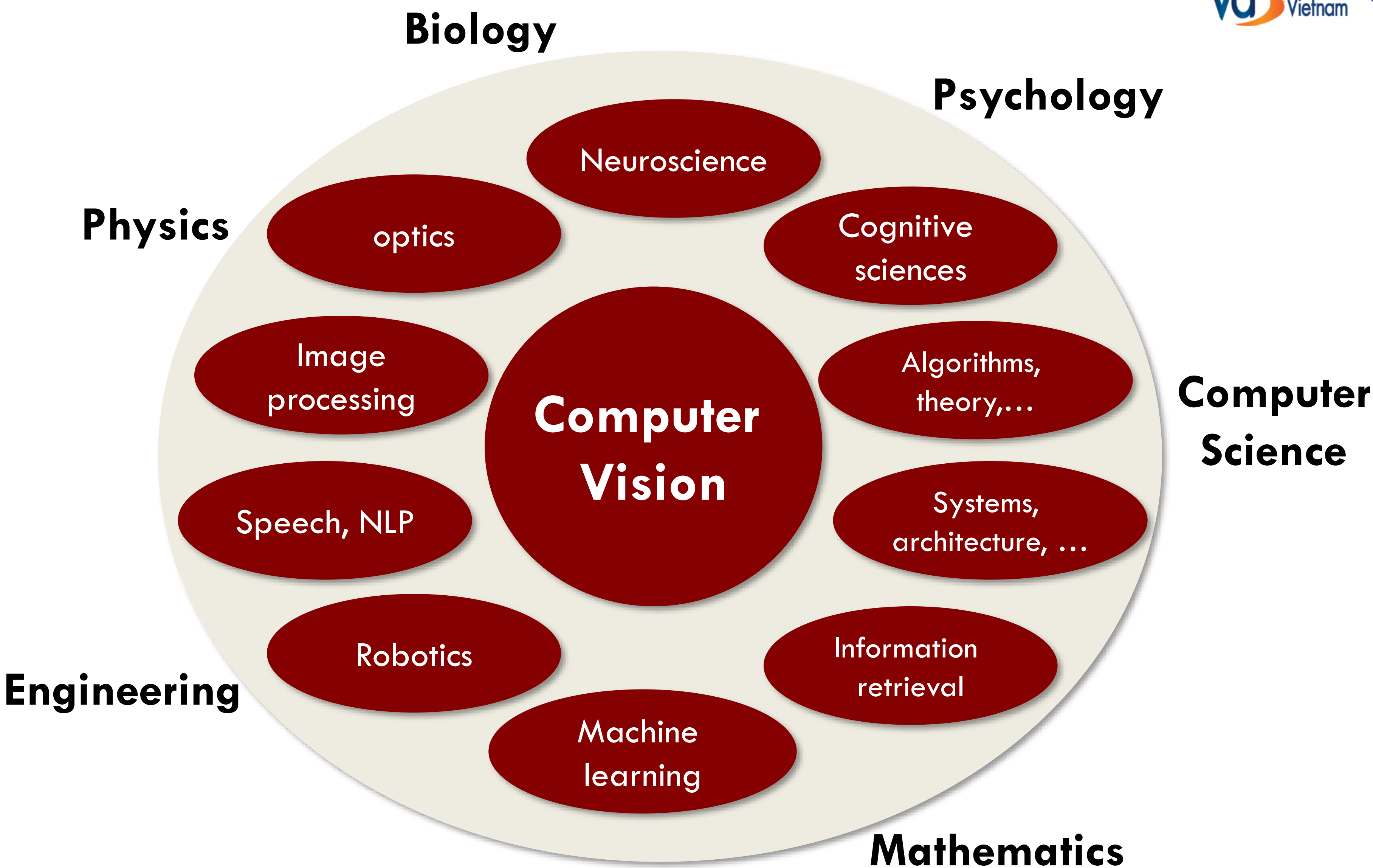
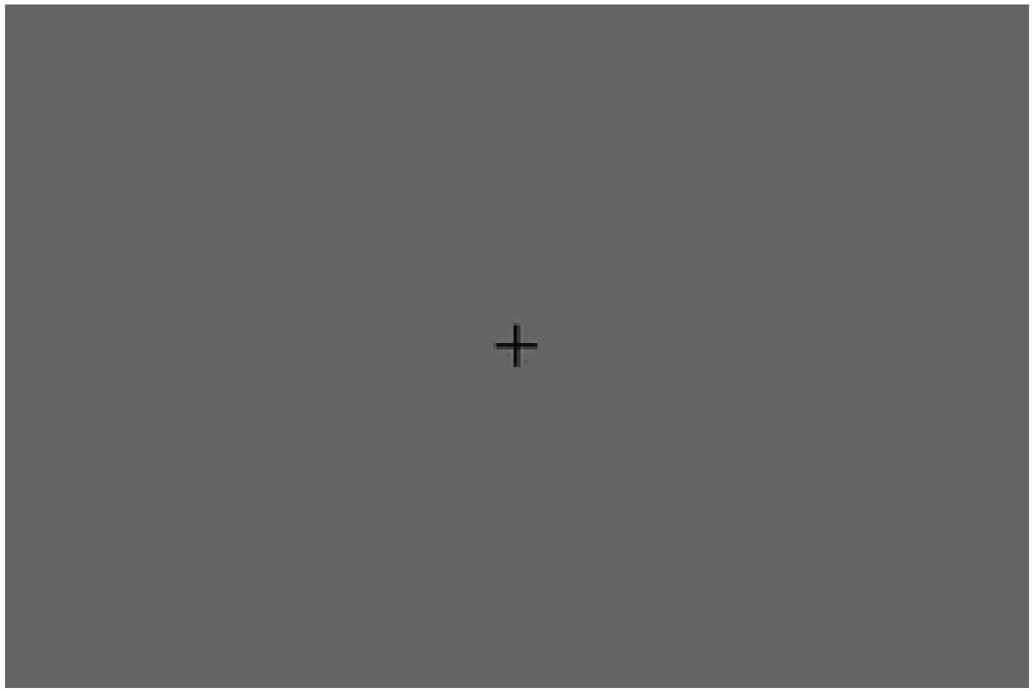
Lecture 1:
Introduction to Image Processing and Computer Vision


Biology
Psychology
Physics
Computer Science
Engineering
Mathematics
Neuroscience
optics
Cognitive sciences
Image processing
Computer Vision
Algorithms, theory,…
Speech, NLP
Systems, architecture, …
Robotics
Information retrieval
Machine learning

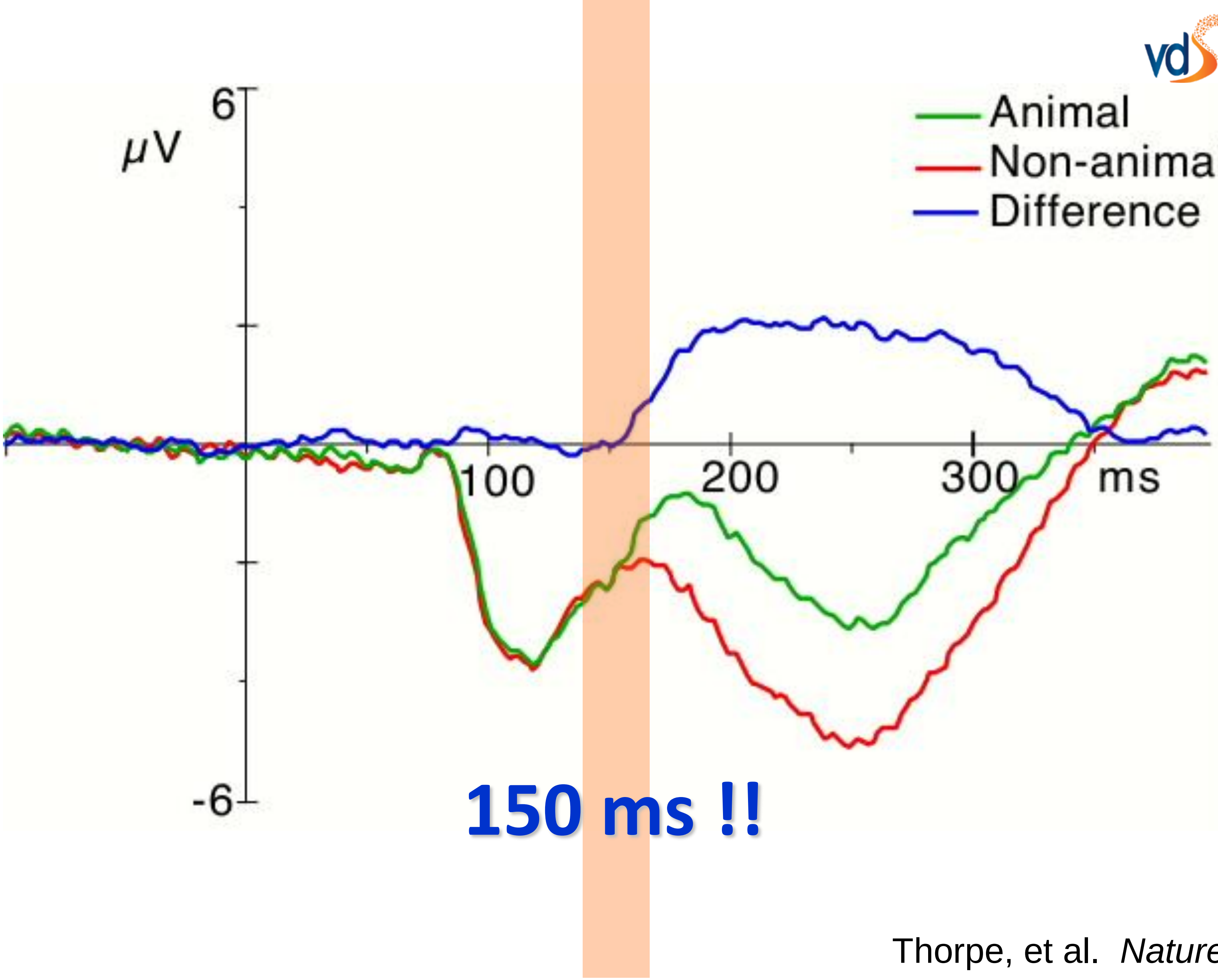
Quiz?

Human vision is superbly efficient



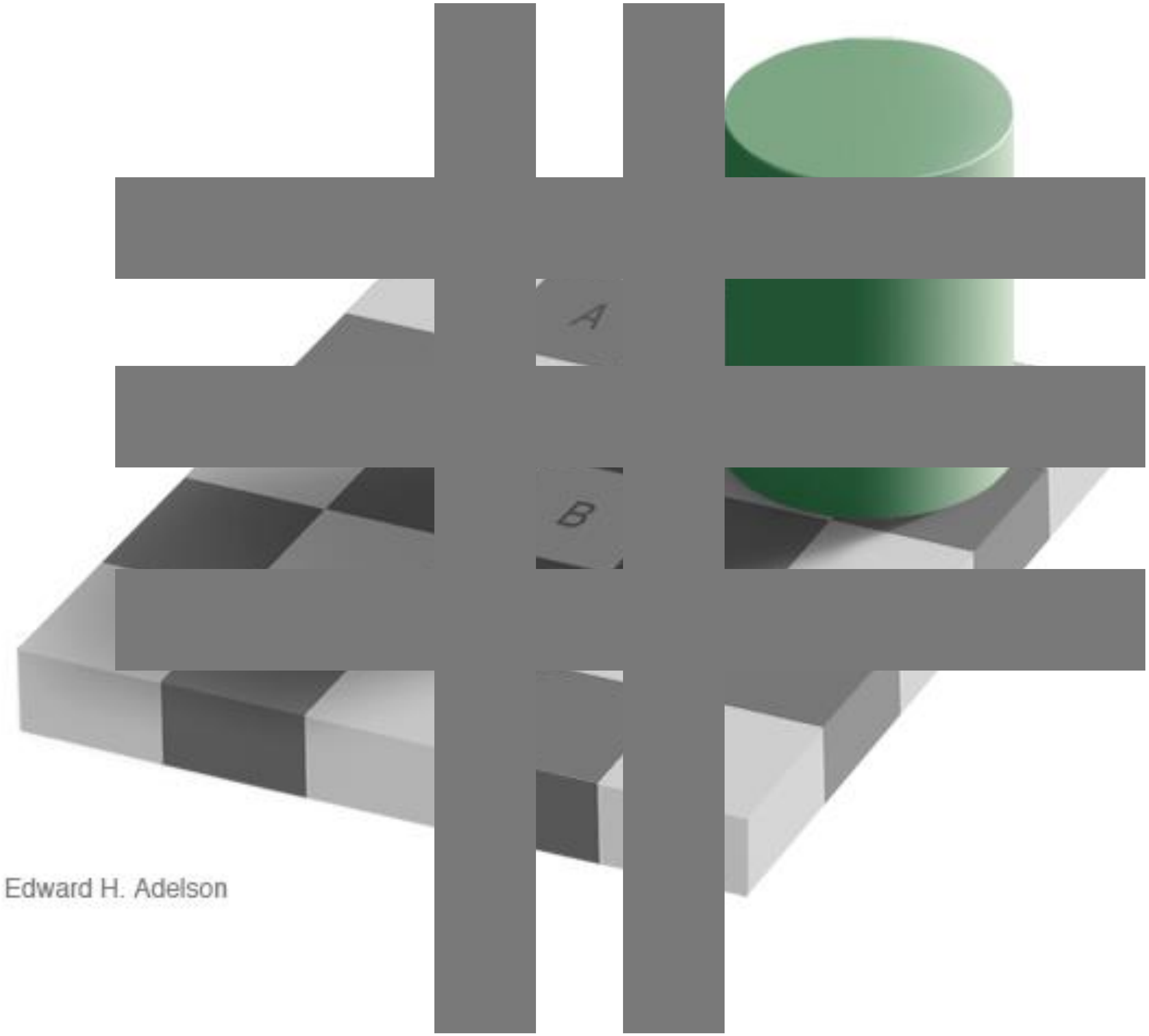
Potter, Biederman, etc. 1970s

Thorpe, et al. *Nature,* 1996

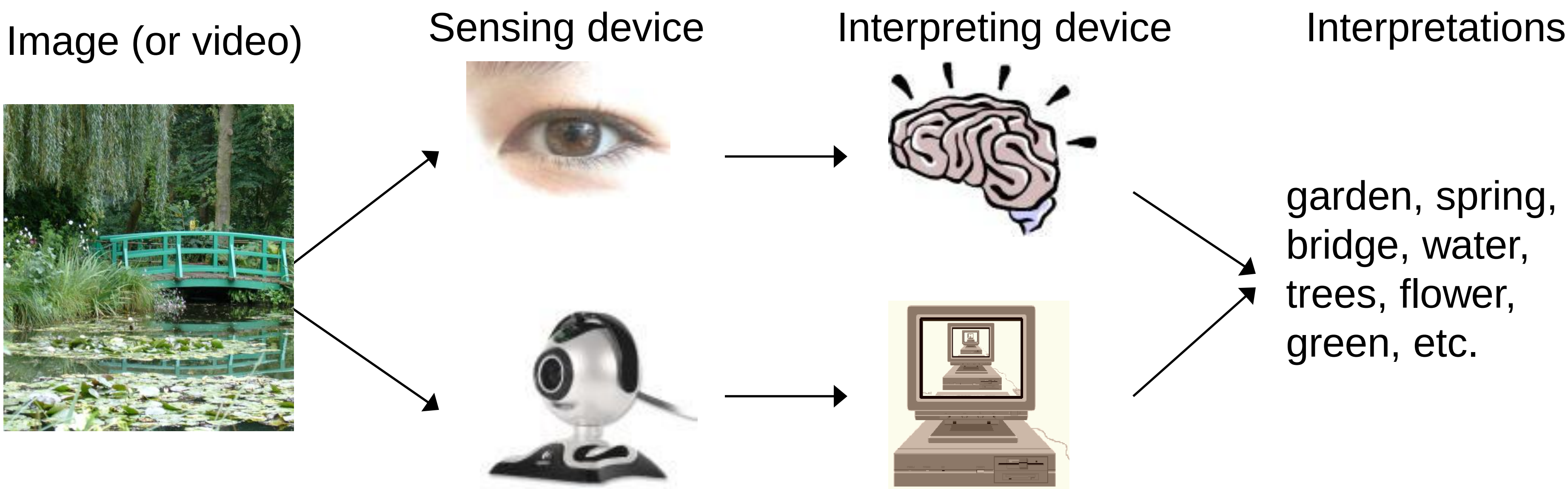


Thorpe, et al. *Nature,* 1996

Perception


A
B
Edward H. Adelson

What is (computer) vision?



The goal of computer vision

- To bridge the gap between pixels and “meaning”

What we see

0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

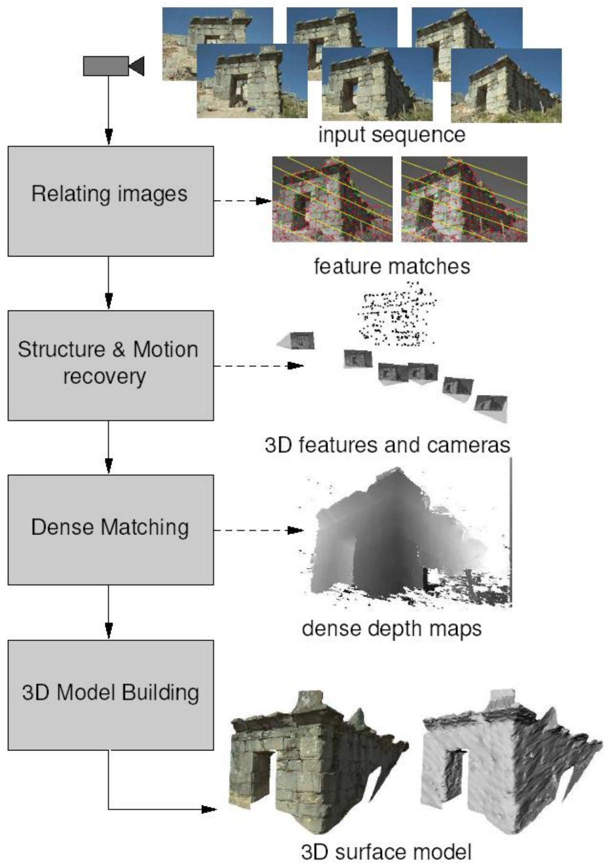
What a computer sees

Source: S. Narasimhan

What kind of information can we extract from an image?

- Metric 3D information
- Semantic information

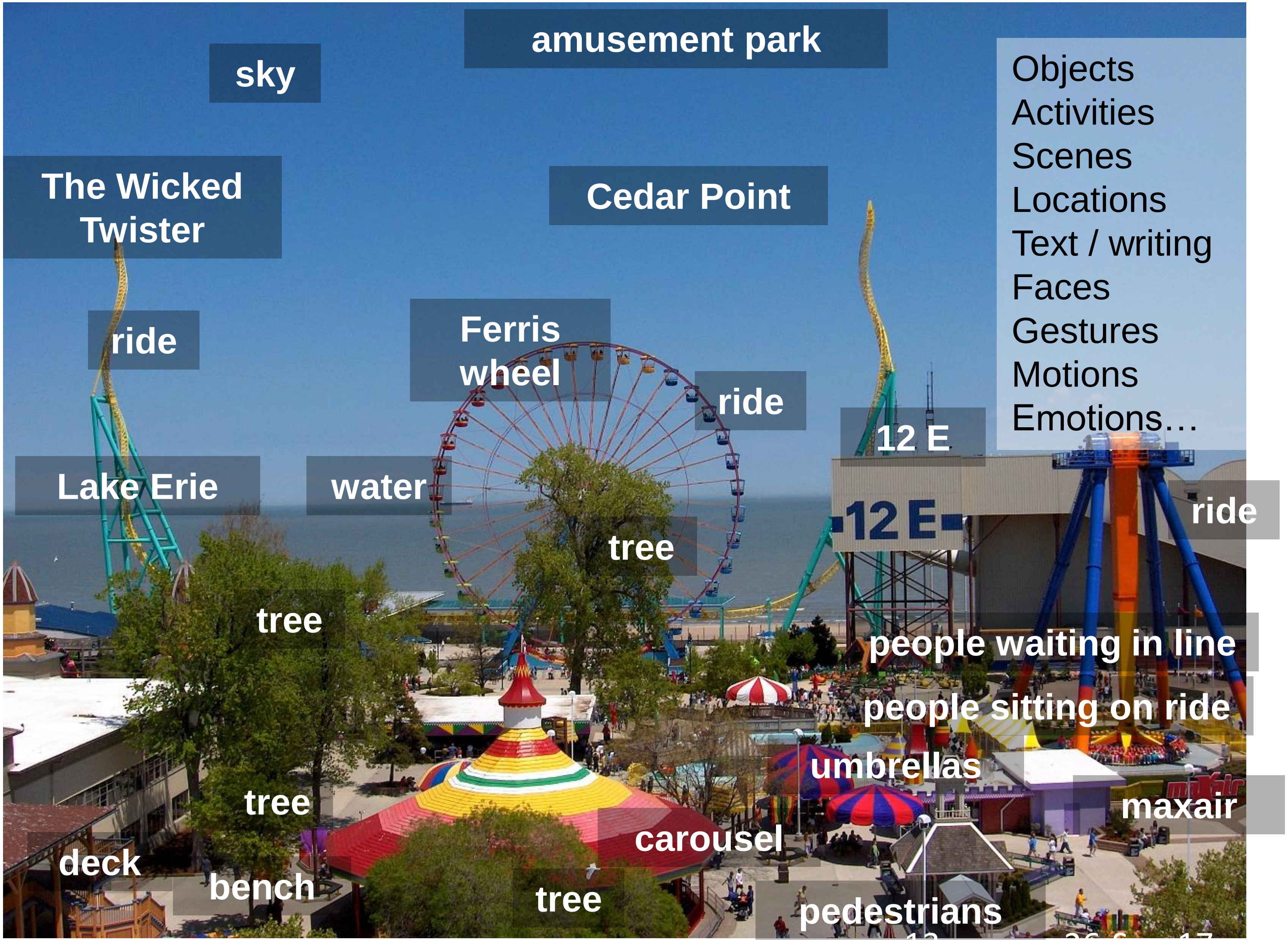
Vision as measurement device



Pollefeys et al.

Goesele et al.

Vision as a source of semantic information



Slide credit: Kristen Grauman

Why study computer vision?

AI Academy Vietnam

- Vision is useful: Images and video are everywhere!

Google Image Search

Google Photos

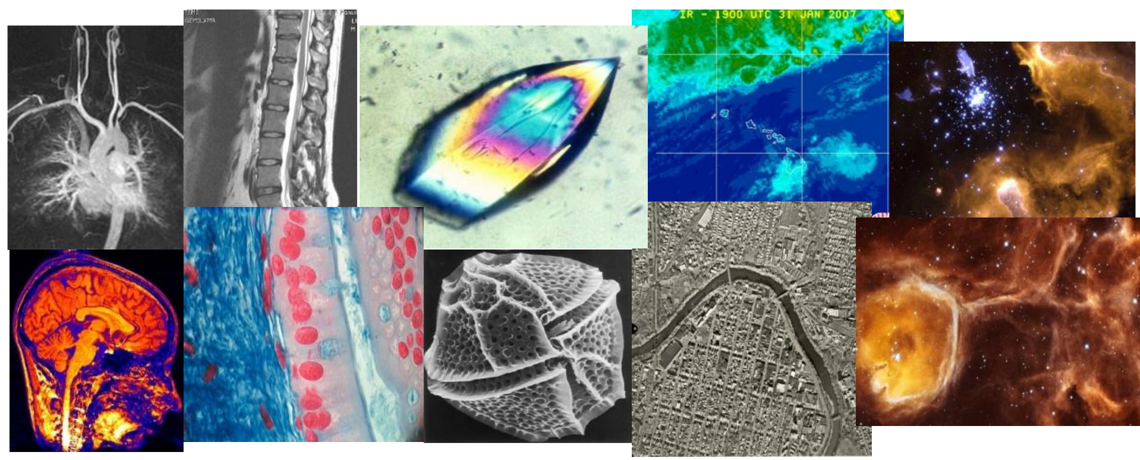
flickr

webshots beta

picsearch

YouTube Broadcast Yourself

Surveillance and security

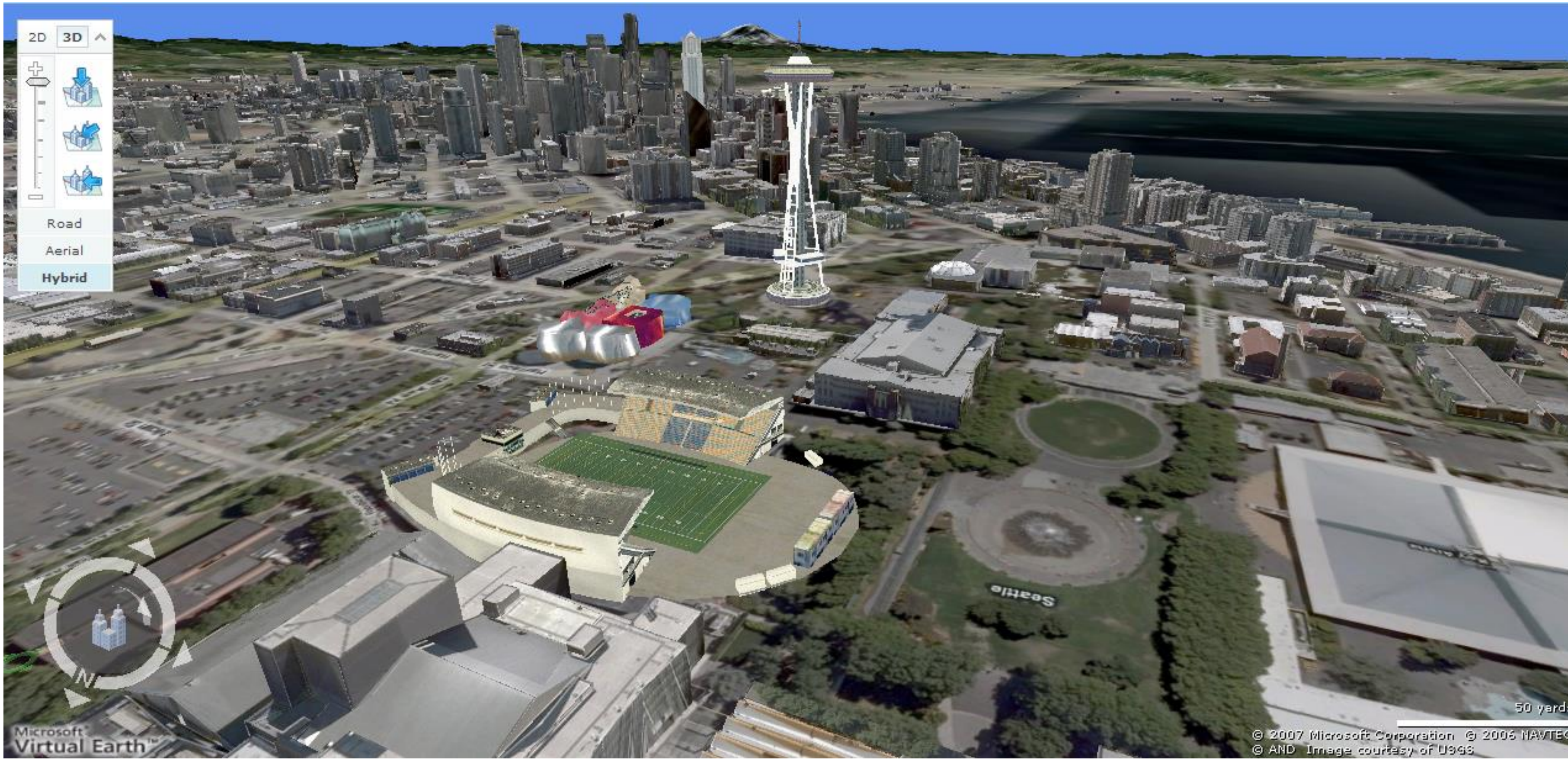


Medical and scientific images

Special effects: shape and motion capture

Source: S. Seitz

3D urban modeling



Bing maps, Google Streetview

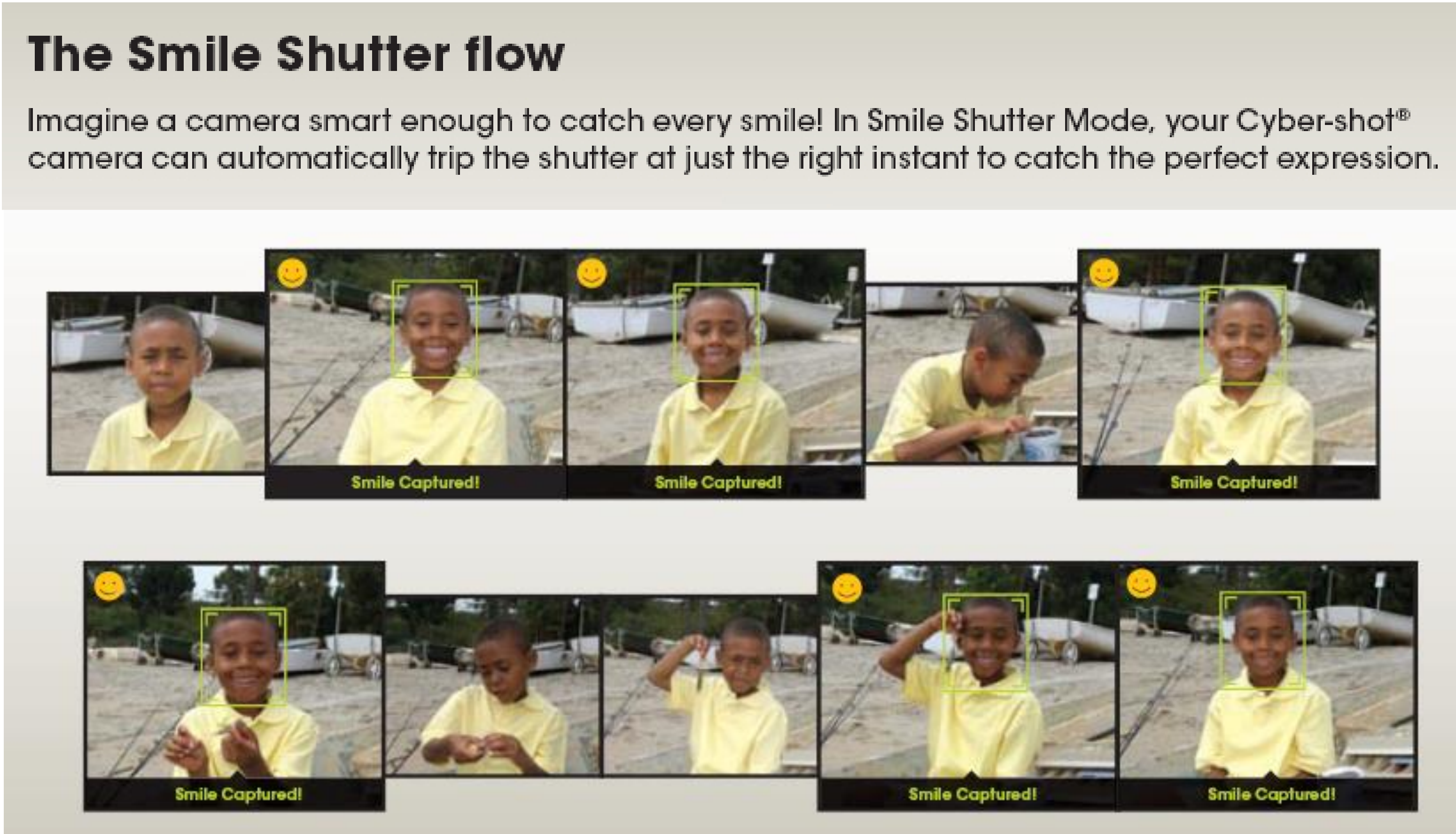
Source: S. Seitz

Face detection

- Many digital cameras now detect faces
  - Canon, Sony, Fuji, …

Source: S. Seitz

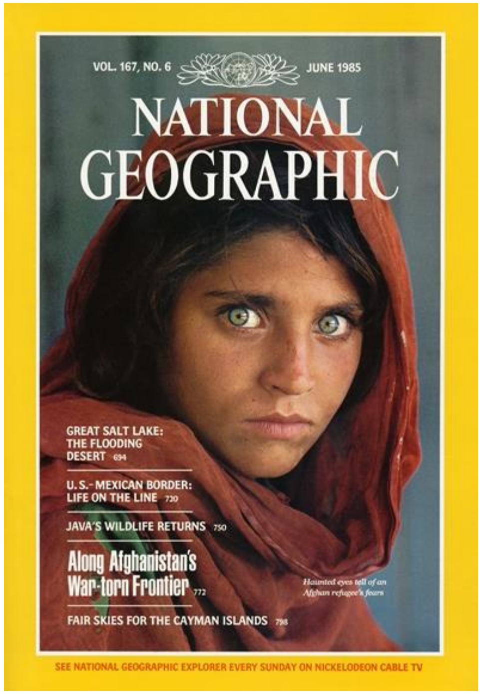
Smile detection



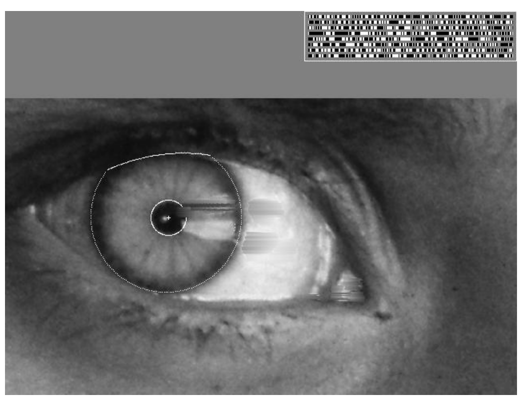
[Sony Cyber-shot® T70 Digital Still Camera](#)

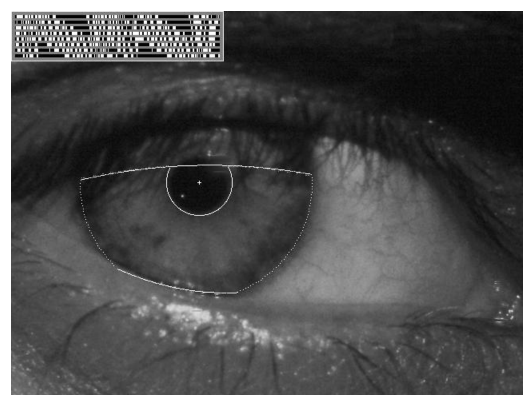
Source: S. Seitz

Biometrics



[How the Afghan Girl was Identified by Her Iris Patterns]





Source: S. Seitz

Biometrics

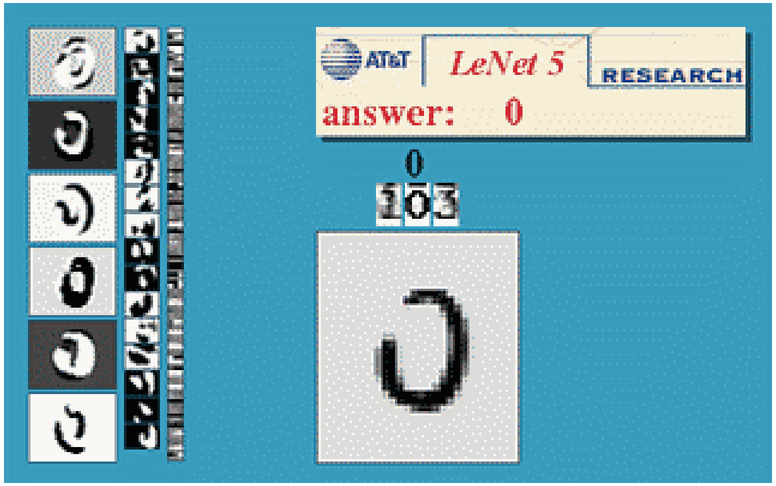
Fingerprint scanners on
many new laptops,
other devices

Face recognition systems now beginning
to appear more widely
iphone X just introduced face recognition

Optical character recognition (OCR)

Technology to convert scanned docs to text

- If you have a scanner, it probably came with OCR software



Digit recognition, AT&T labs

License plate readers
http://en.wikipedia.org/wiki/Automatic_number_plate_recognition

Source: S. Seitz

Automotive safety

- Mobileye: Vision systems in high-end BMW, GM, Volvo models
  - "In mid 2010 Mobileye will launch a world's first application of full emergency braking for collision mitigation for pedestrians where vision is the key technology for detecting pedestrians."

Source: A. Shashua, S. Seitz

Vision-based interaction (and games)

Sony EyeToy

Microsoft's Kinect

Assistive technologies

Source: S. Seitz

Augmented Reality

Virtual Reality

Vision for robotics, space exploration

NASA'S Mars Exploration Rover Spirit captured this westward view from atop a low plateau where Spirit spent the closing months of 2007.

Vision systems (JPL) used for several tasks

- Panorama stitching
- 3D terrain modeling
- Obstacle detection, position tracking
- For more, read "Computer Vision on Mars" by Matthies et al.

Source: S. Seitz

Color

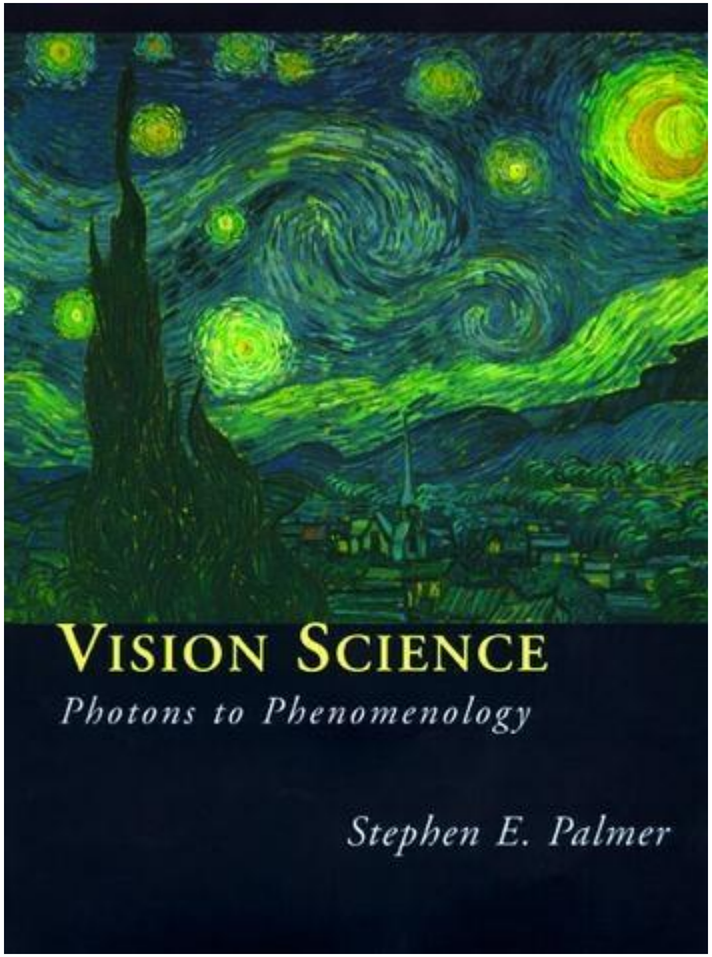
Overview of Color

- Physics of color
- Human encoding of color
- Color spaces
- White balancing

What is color?

- The result of interaction between physical light in the environment and our visual system.

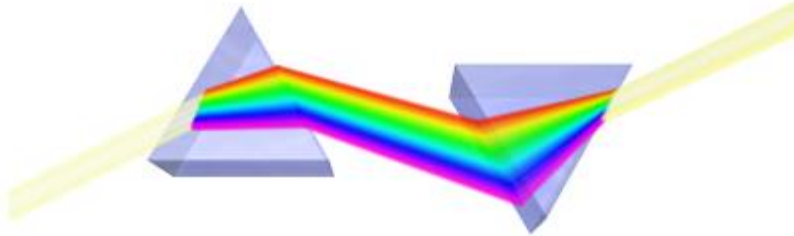
- A *psychological property* of our visual experiences when we look at objects and lights, *not a physical property* of those objects or lights.

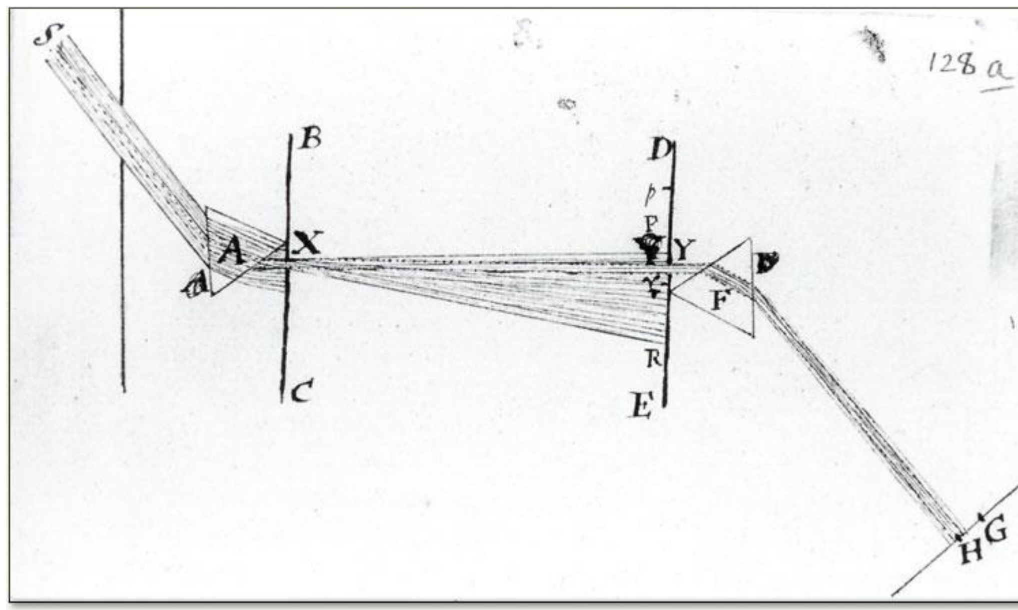


Slide credit: Lana Lazebnik

Color and light

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

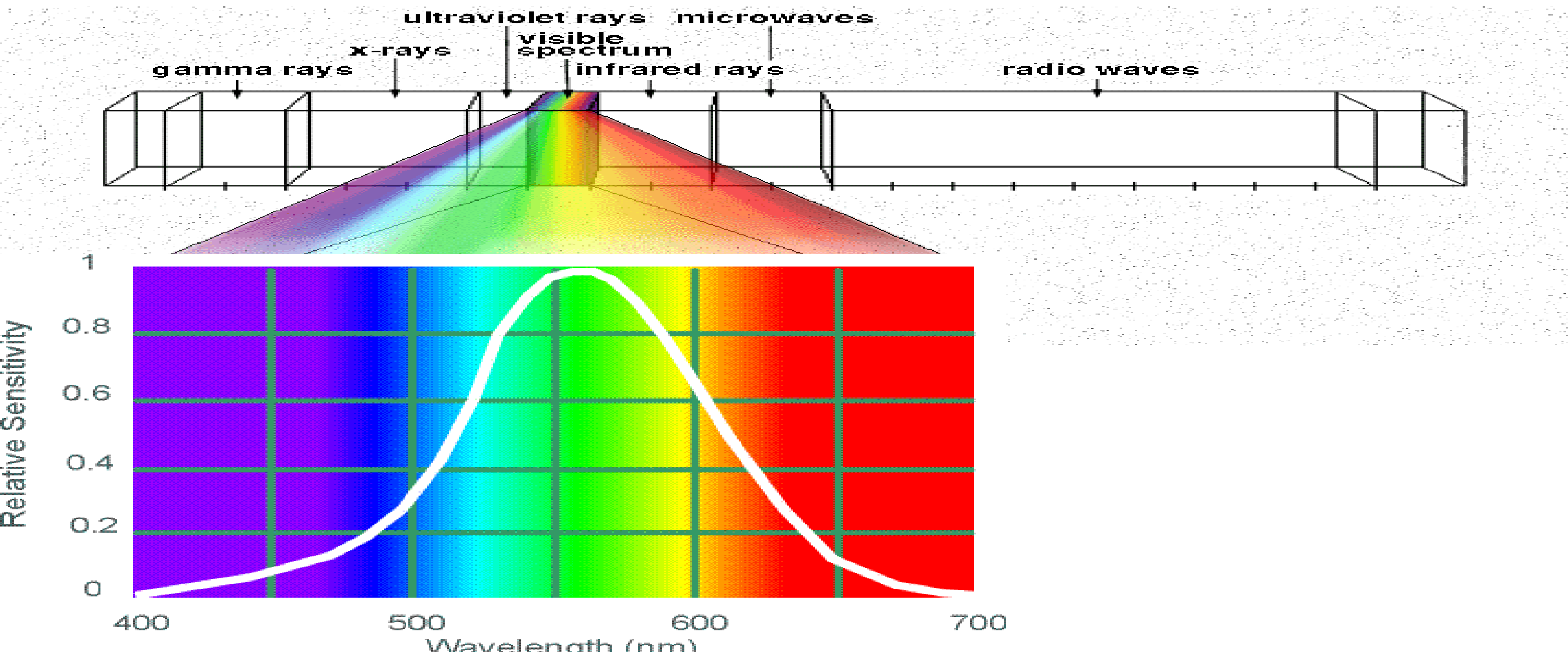




Newton 1665

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

Electromagnetic Spectrum



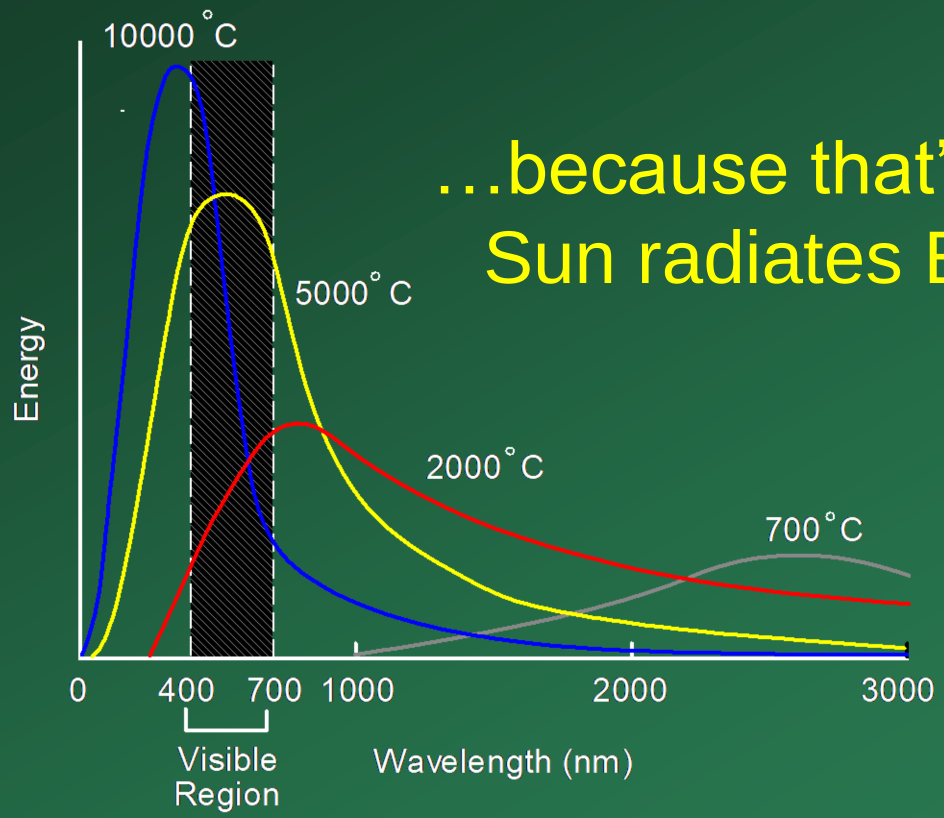
Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

Sun temperature makes it emit yellow light more than any other color.

Visible Light

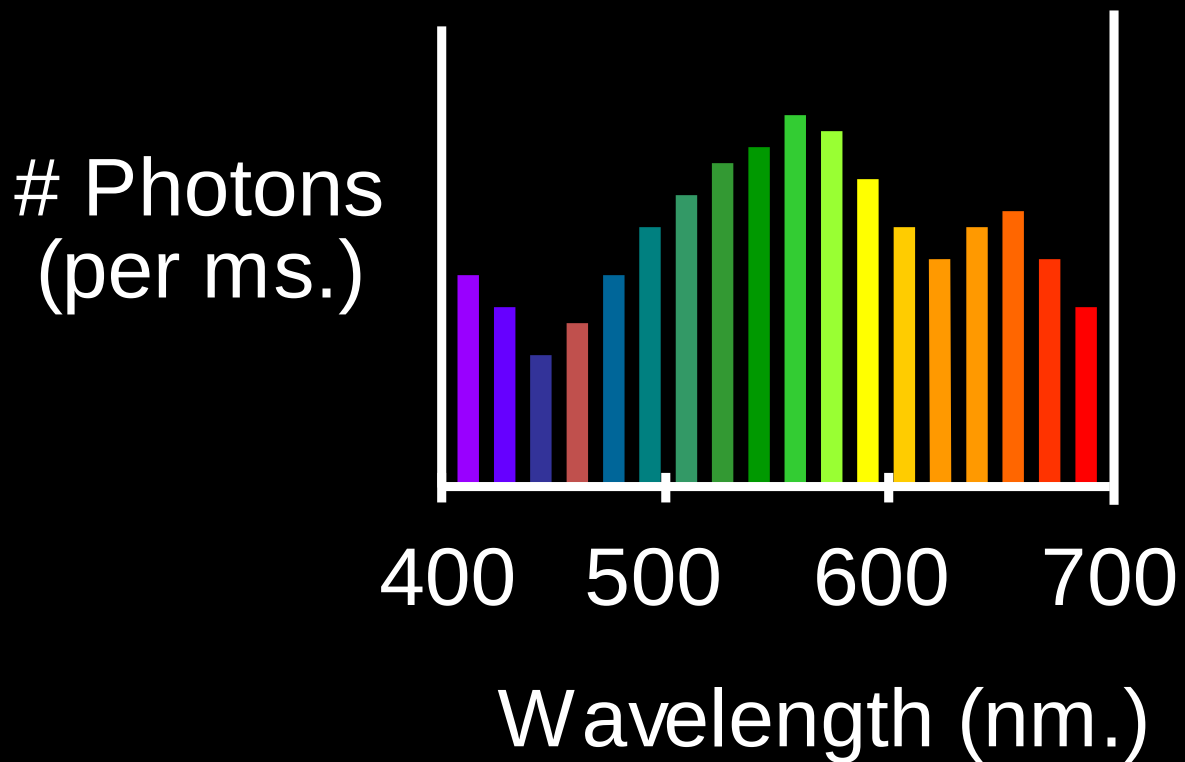
Why do we see light of these wavelengths?



…because that's where the Sun radiates EM energy

The Physics of Light

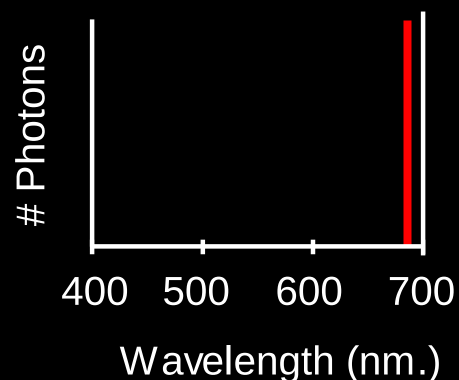
Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.



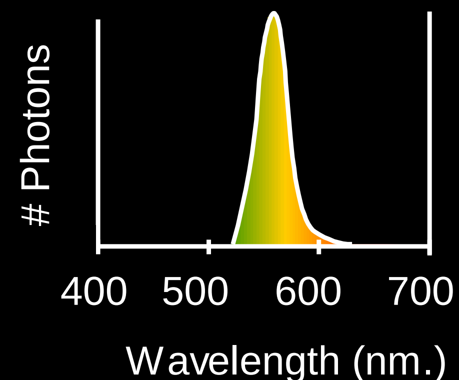
The Physics of Light

Some examples of the spectra of light sources

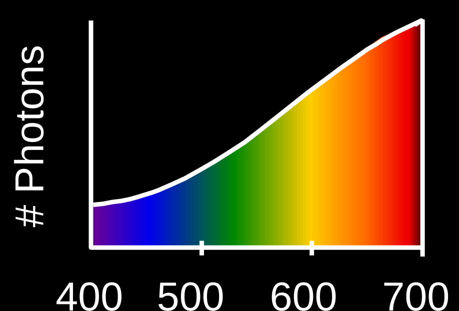
A. Ruby Laser



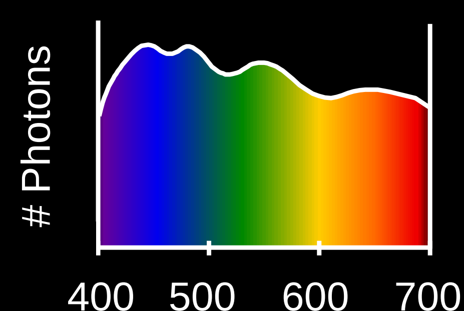
B. Gallium Phosphide Crystal



C. Tungsten Lightbulb

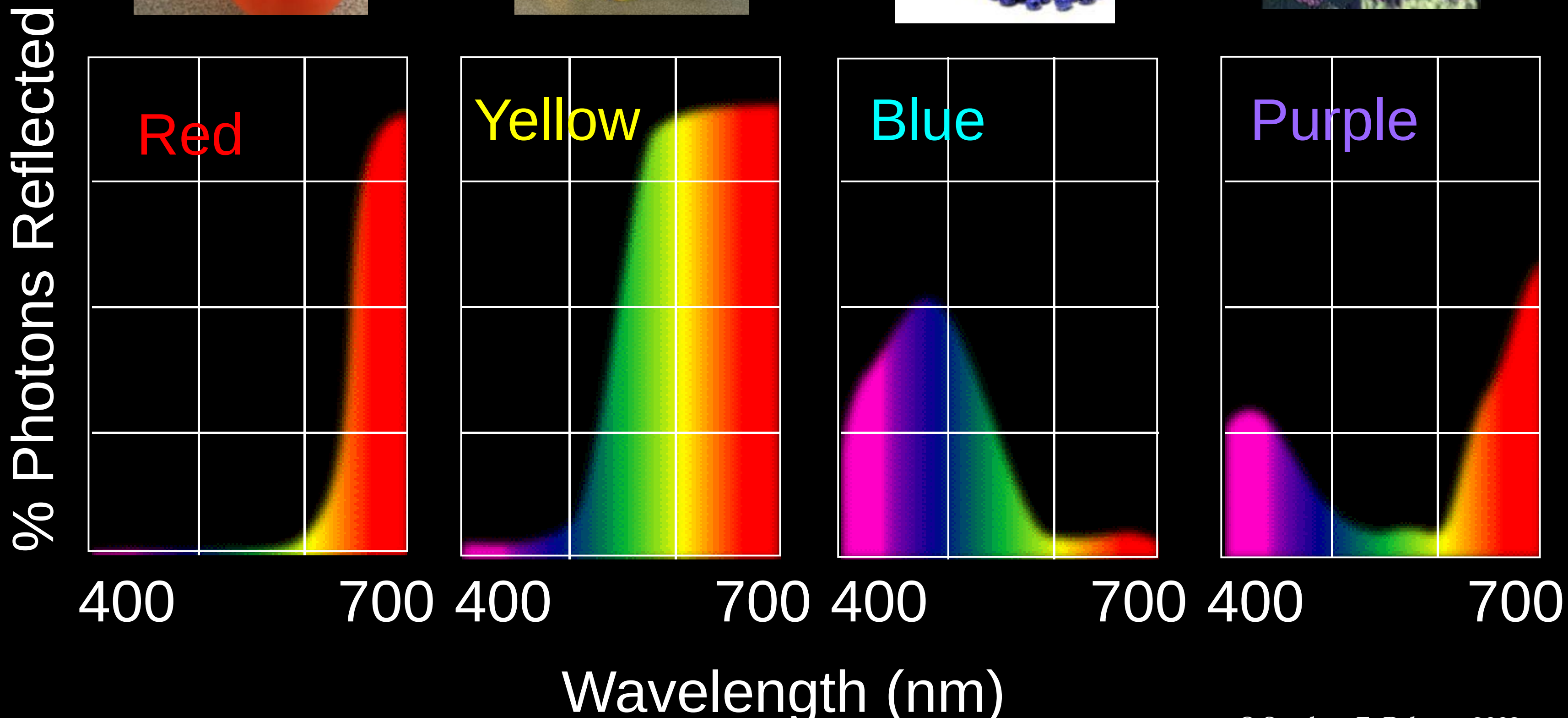


D. Normal Daylight



The Physics of Light

Some examples of the reflectance spectra of surfaces



Overview of Color

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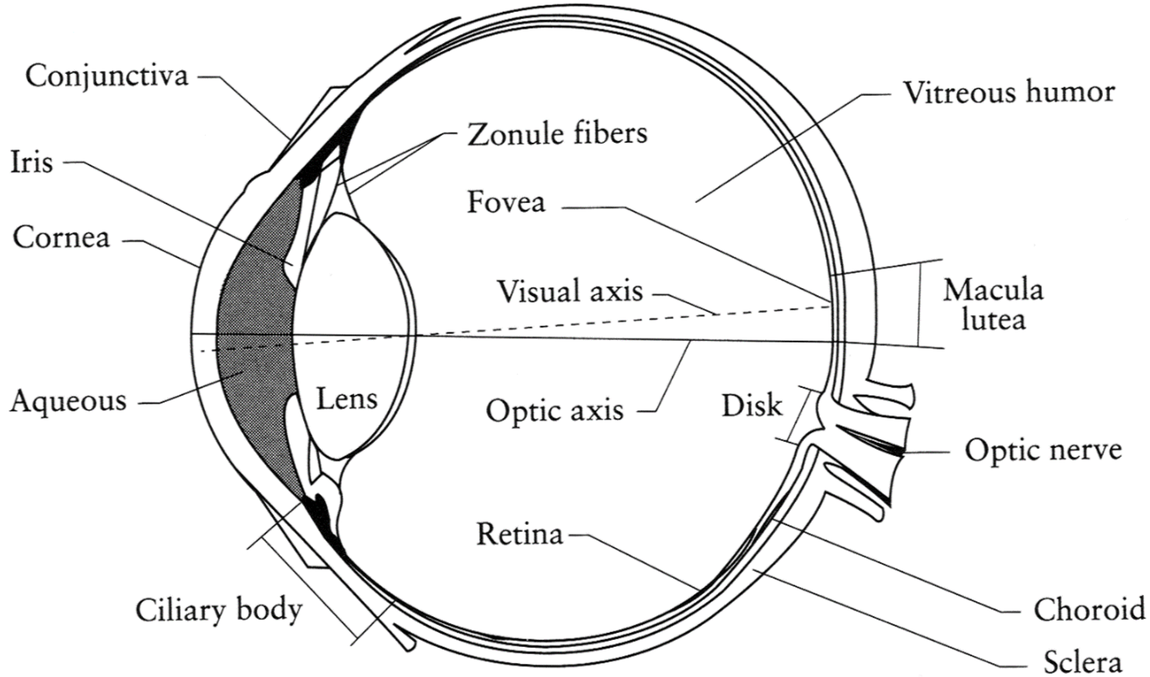
- Human encoding of color
- Color spaces
- White balancing

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
  - What's the sensor?
    - photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

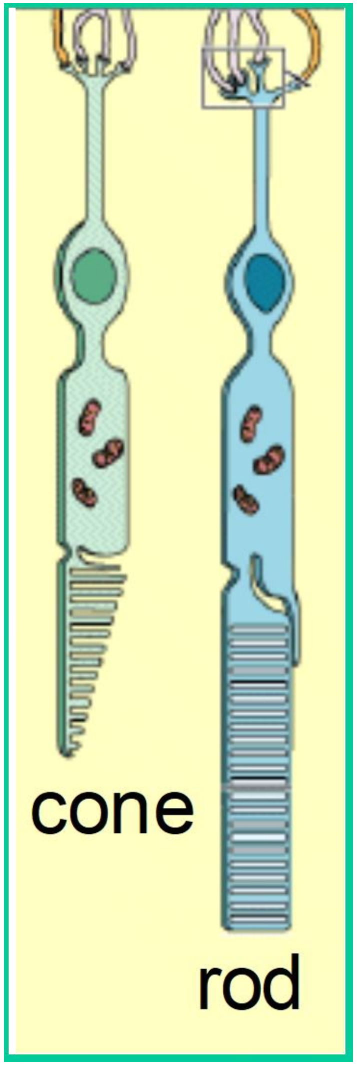
Two types of light-sensitive receptors

Cones

cone-shaped
less sensitive
operate in high light
color vision

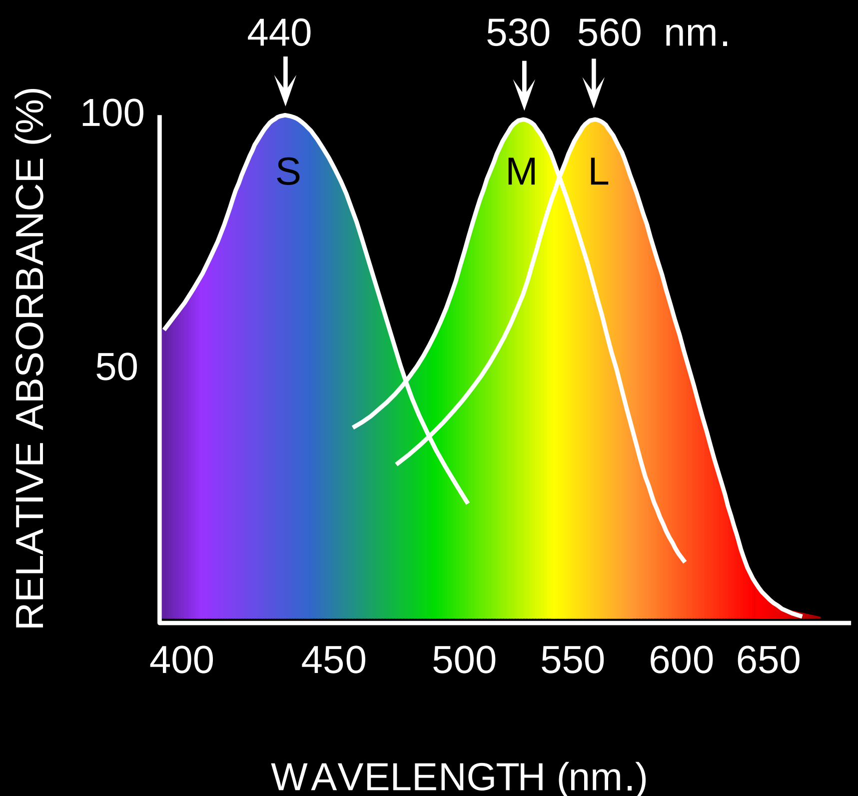
Rods

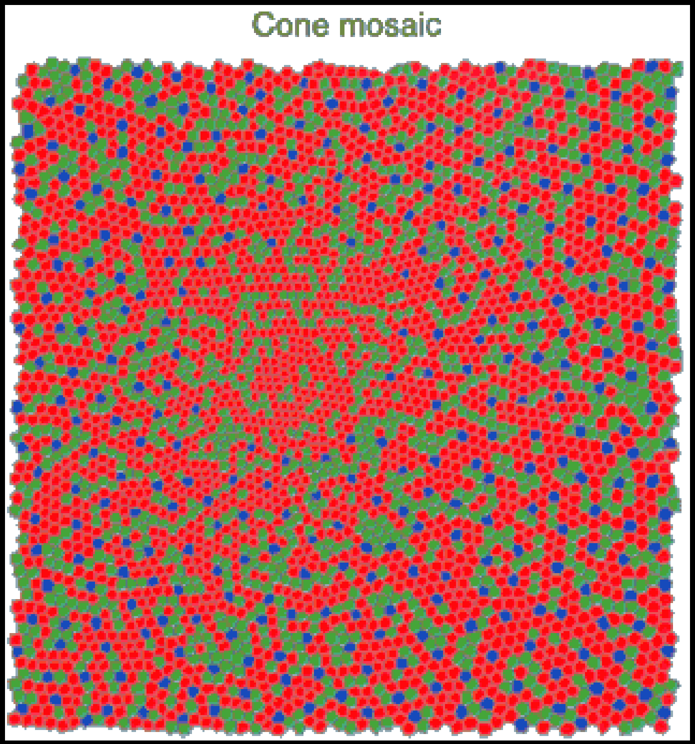
rod-shaped
highly sensitive
operate at night
gray-scale vision



Physiology of Color Vision

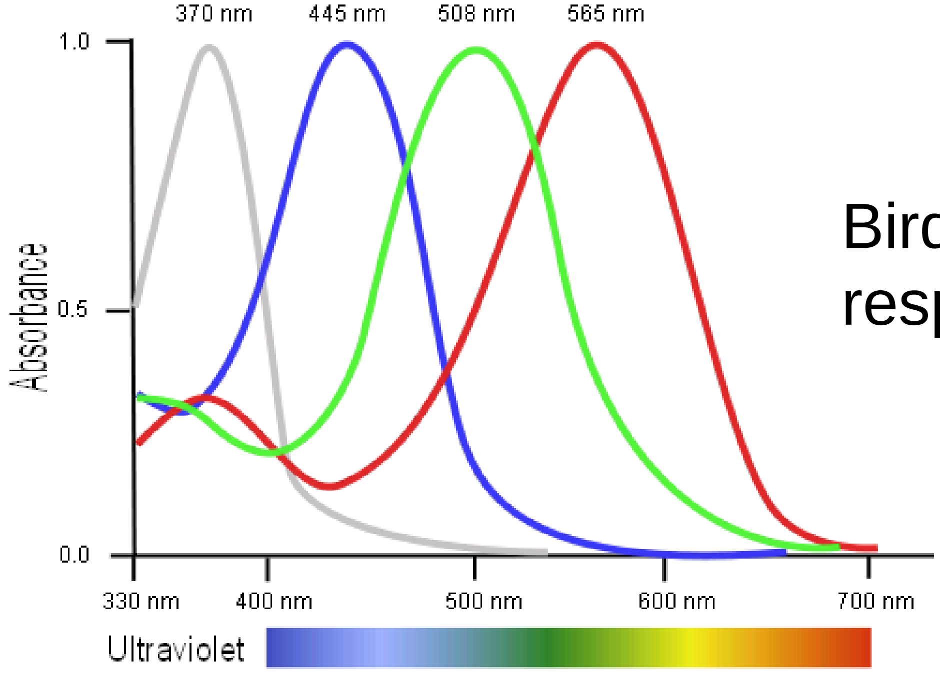
Three kinds of cones:





- Why are M and L cones so close?
- Why are there 3?

Tetrachromatism

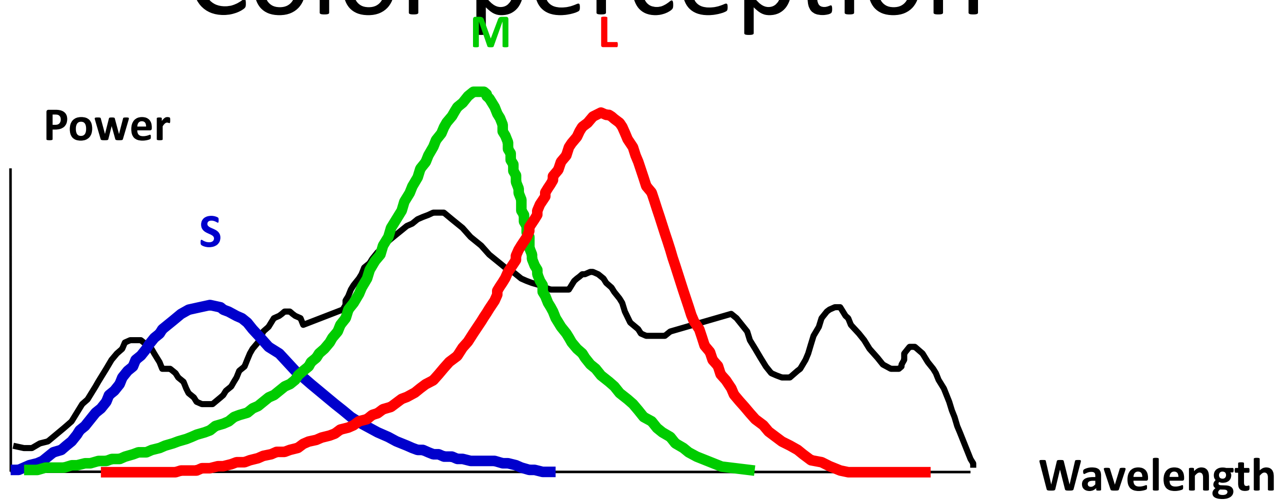


Bird cone responses

- Most birds, and many other animals, have cones for ultraviolet light.
- Some humans seem to have four cones (12% of females).
- True tetrachromatism is _rare_; requires learning.

James Hays

Color perception

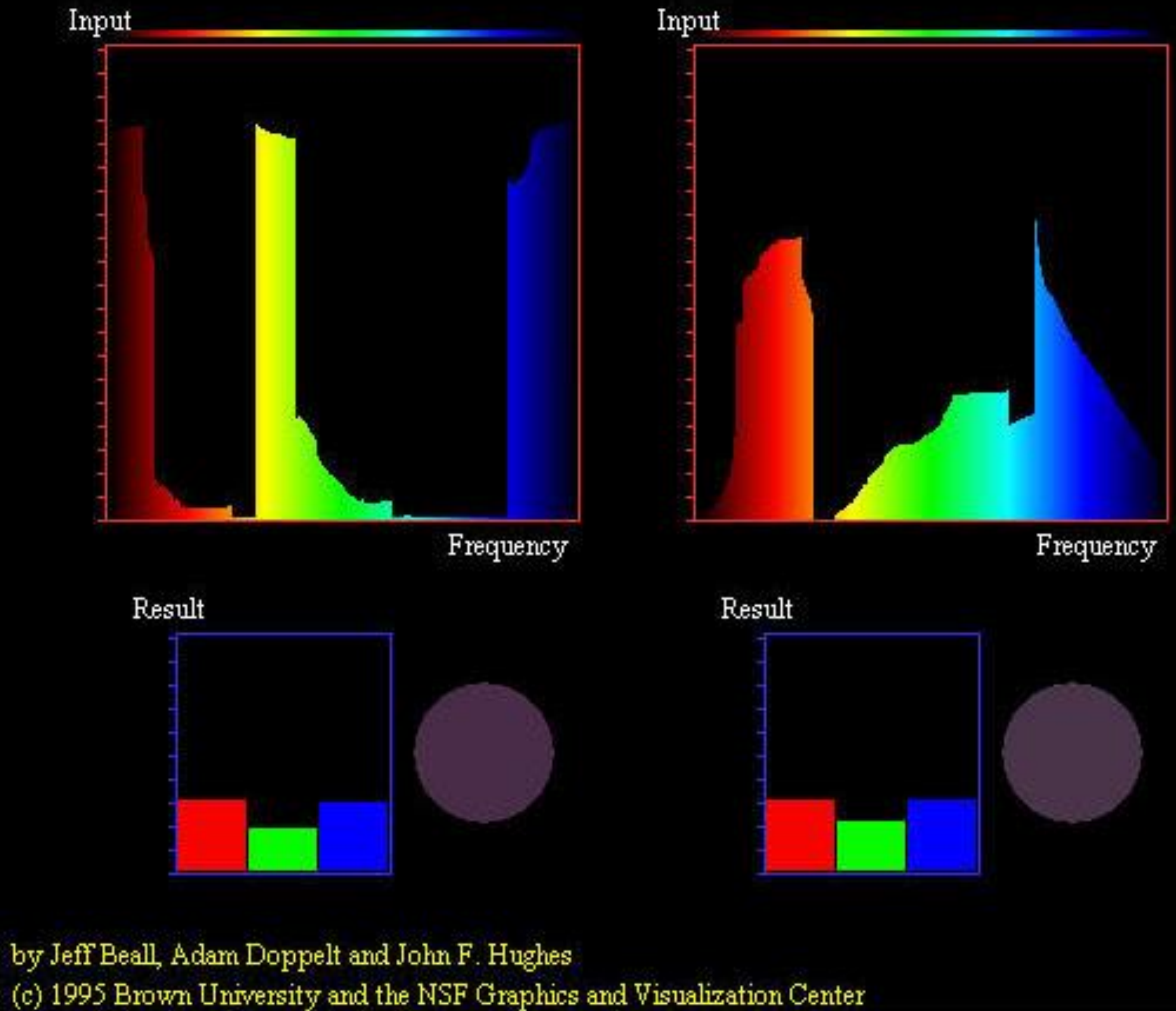


Rods and cones act as filters on the spectrum

- To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths
  - Each cone yields one number
- Q: How can we represent an entire spectrum with 3 numbers?
- A: We can't! Most of the information is lost.
  - As a result, two different spectra may appear indistinguishable
    - » such spectra are known as **metamers**

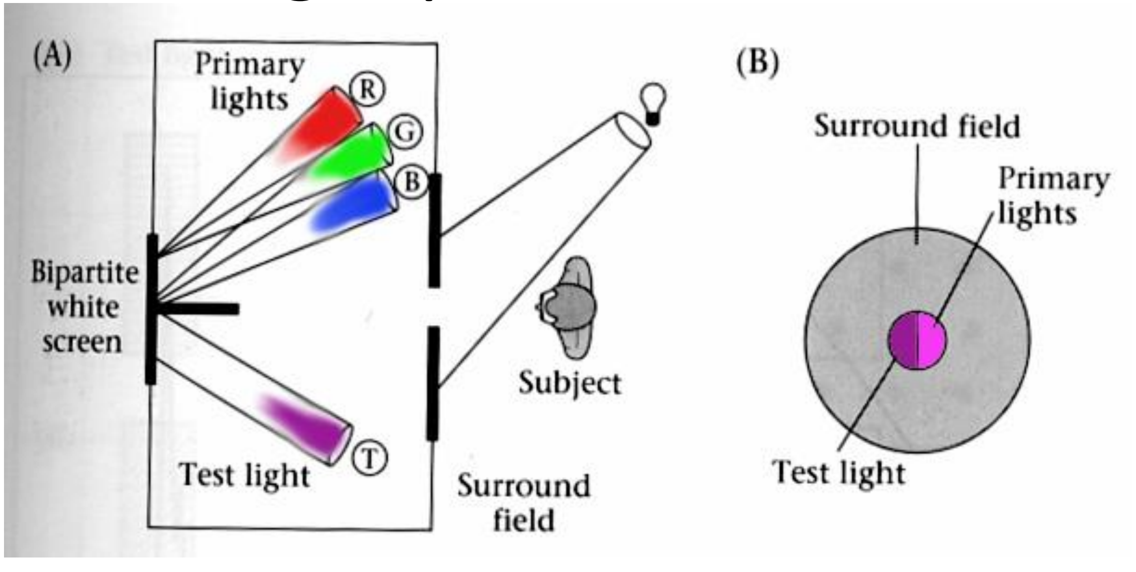
Slide by Steve Seitz

Metamers


Input
Frequency
Result
Input
Frequency
Result
by Jeff Beall, Adam Doppelt and John F. Hughes
(c) 1995 Brown University and the NSF Graphics and Visualization Center

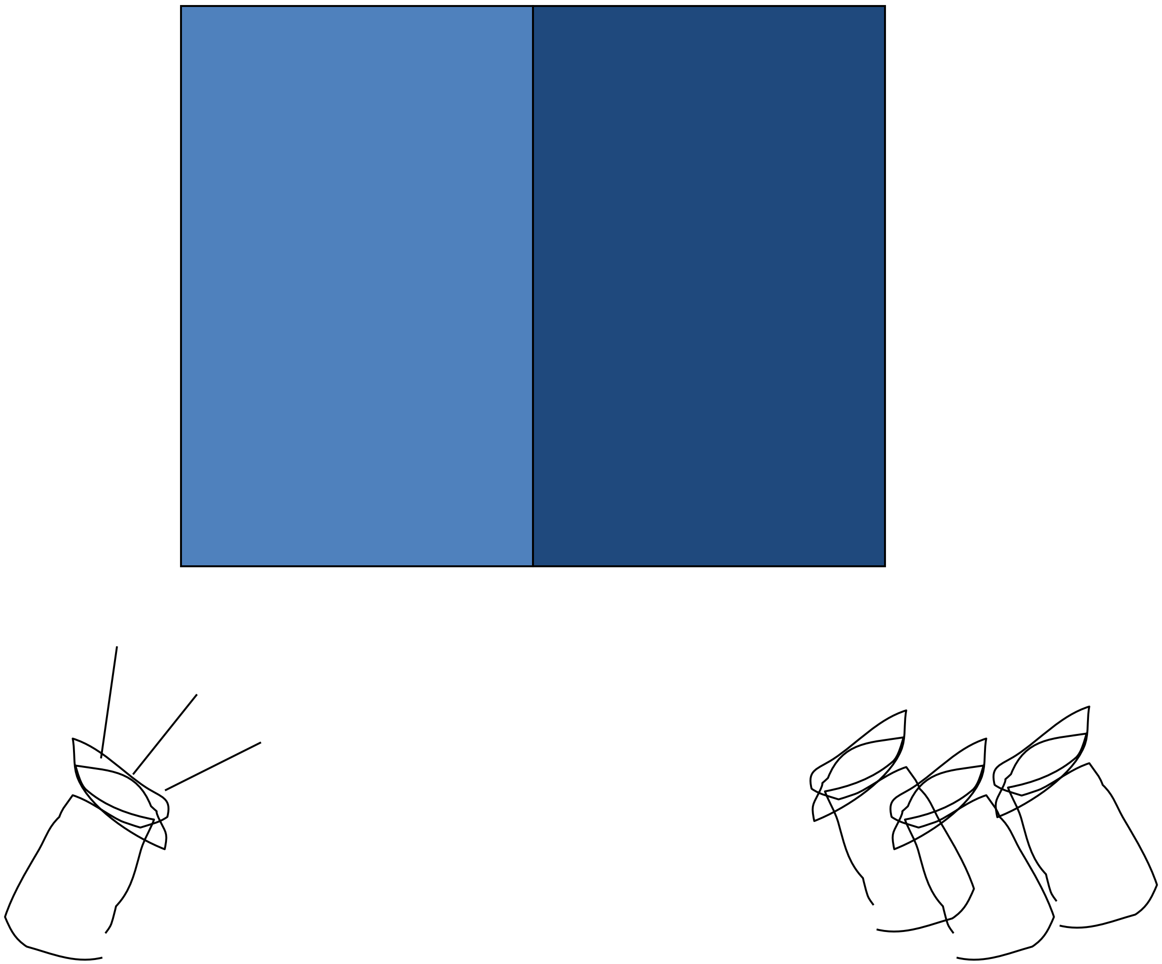
Standardizing color experience

- We would like to understand which spectra produce the same color sensation in people under similar viewing conditions
- Color matching experiments



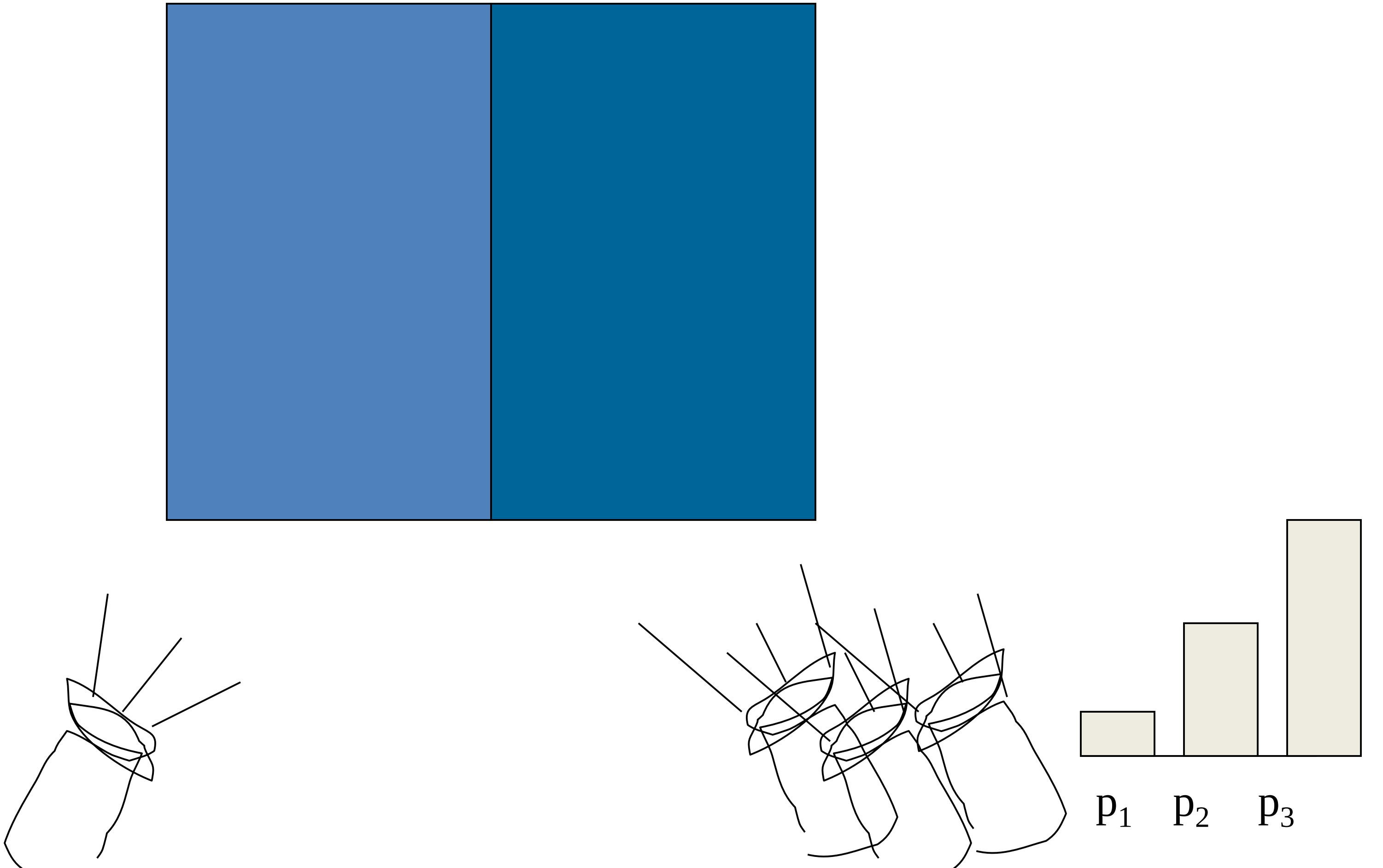
Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Color matching experiment 1



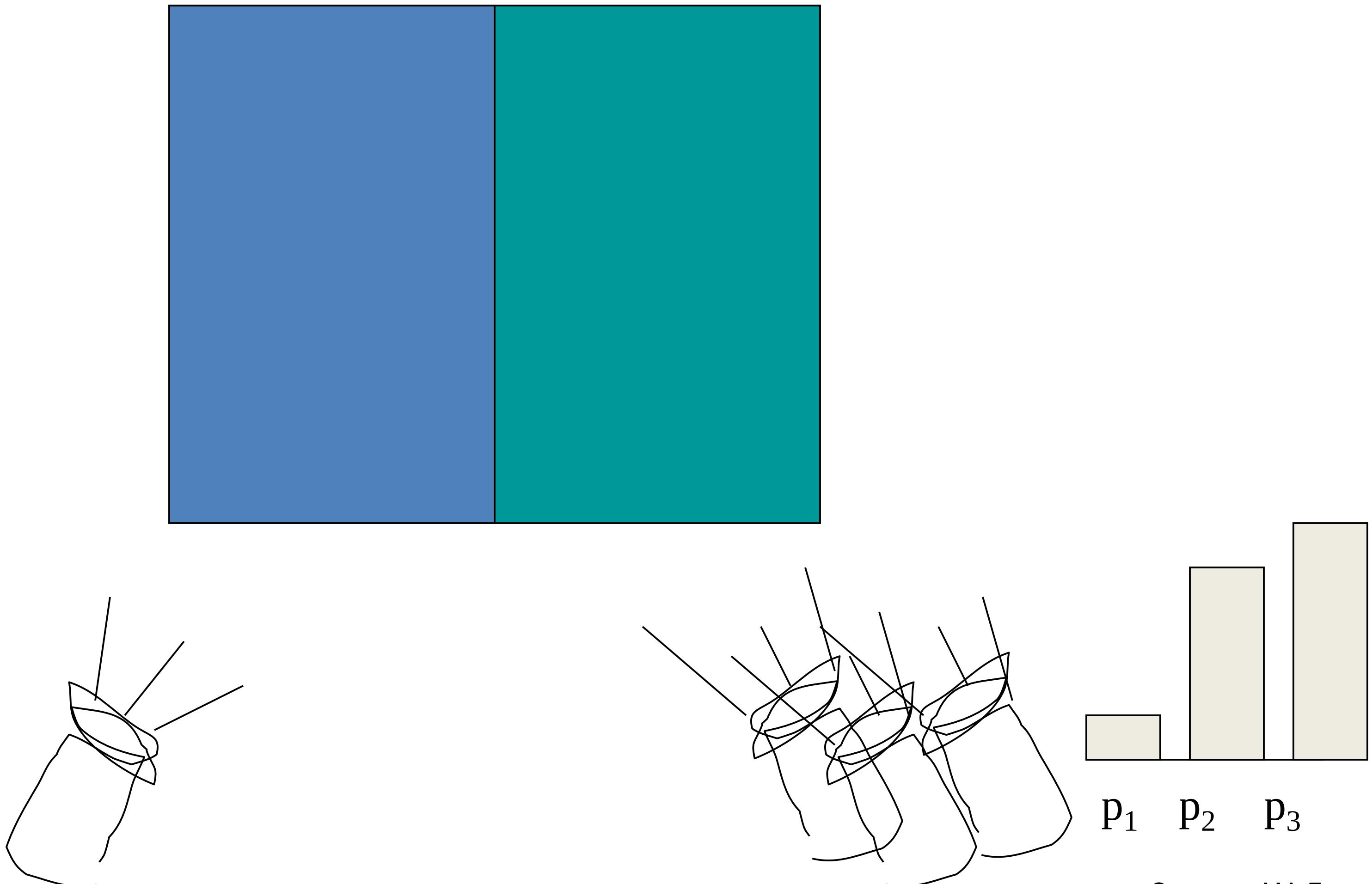
Source: W. Freeman

Color matching experiment 1



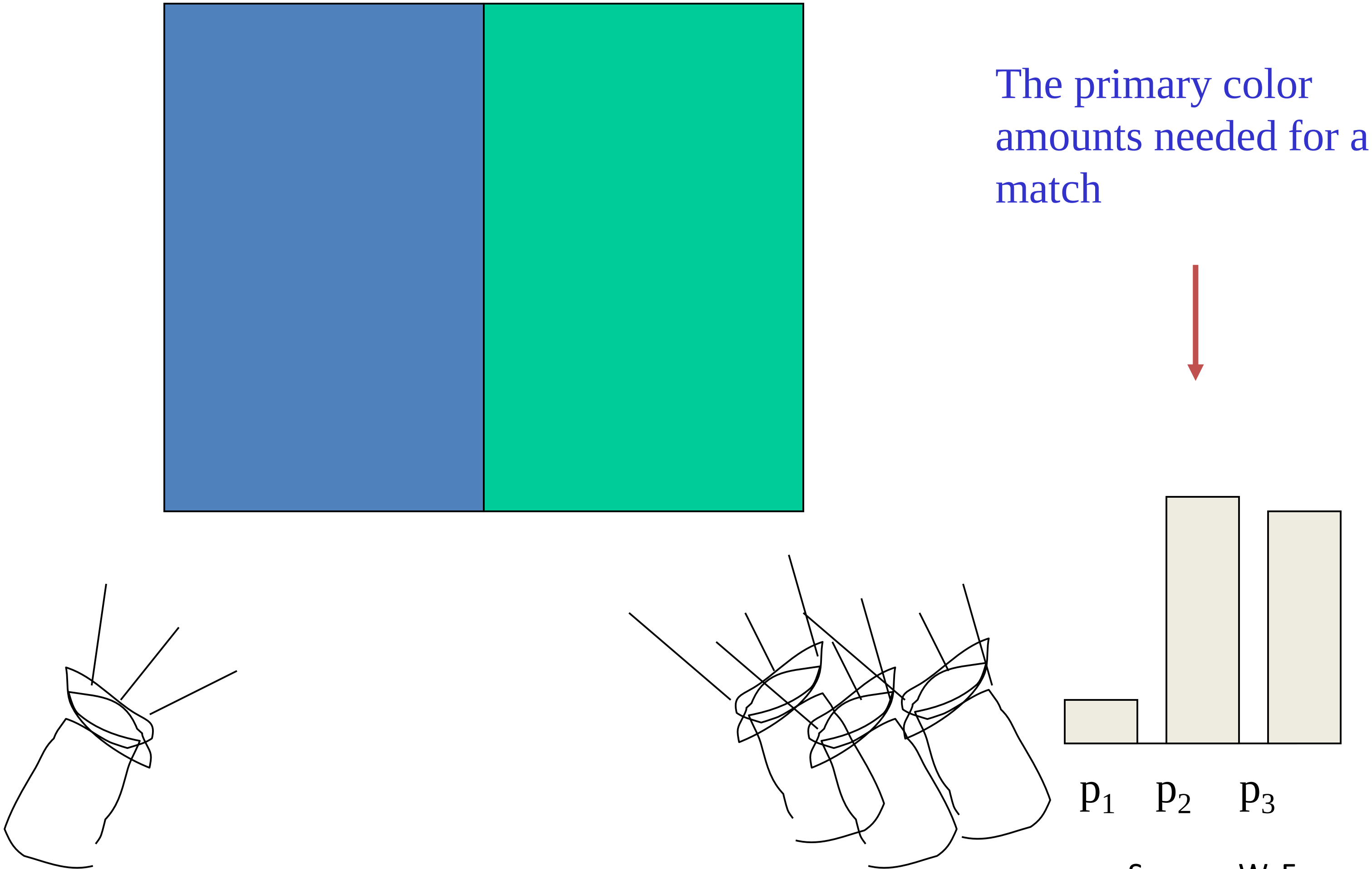
Source: W. Freeman

Color matching experiment 1



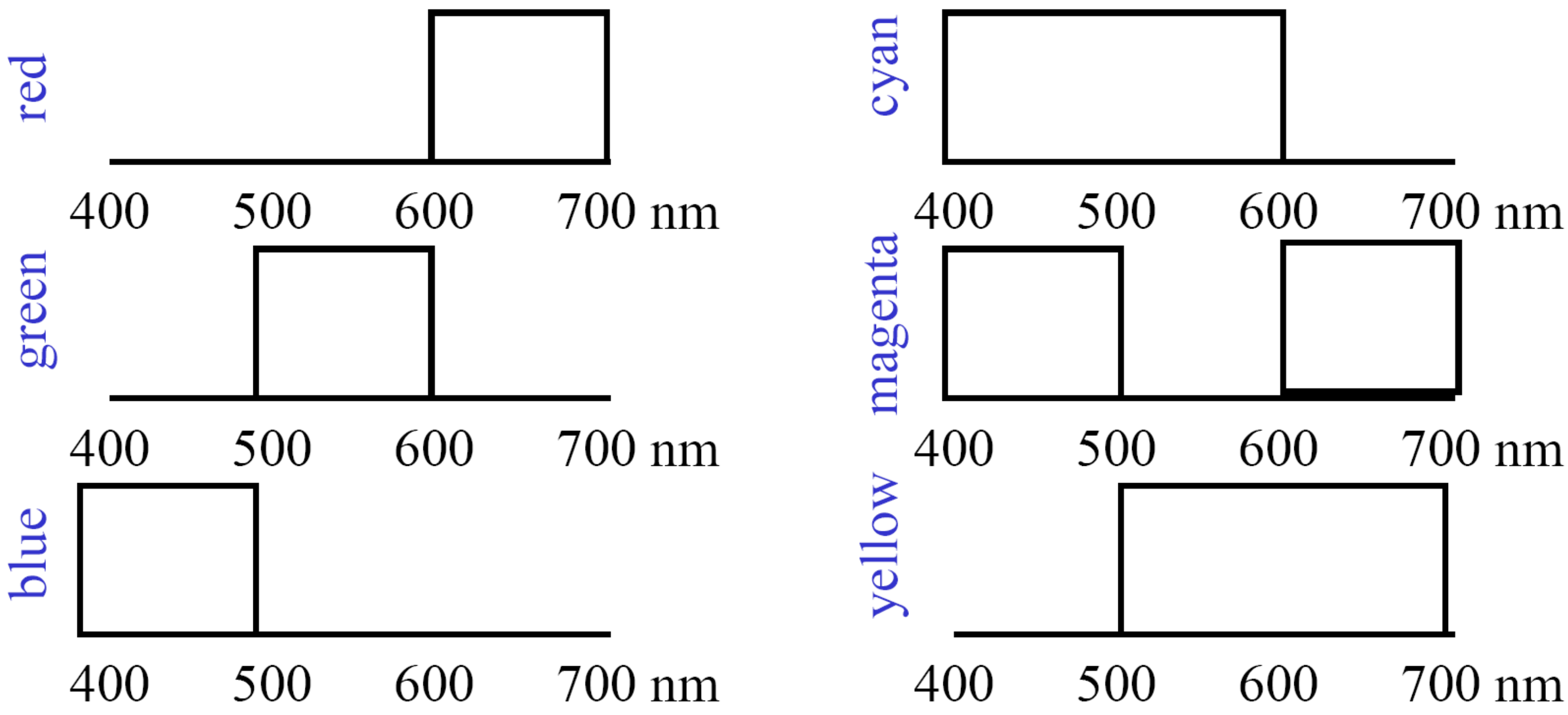
Source: W. Freeman

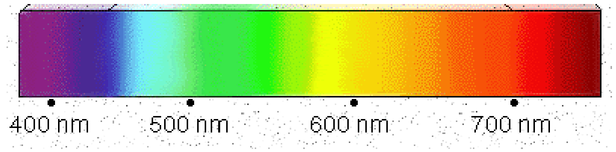
Color matching experiment 1



Source: W. Freeman

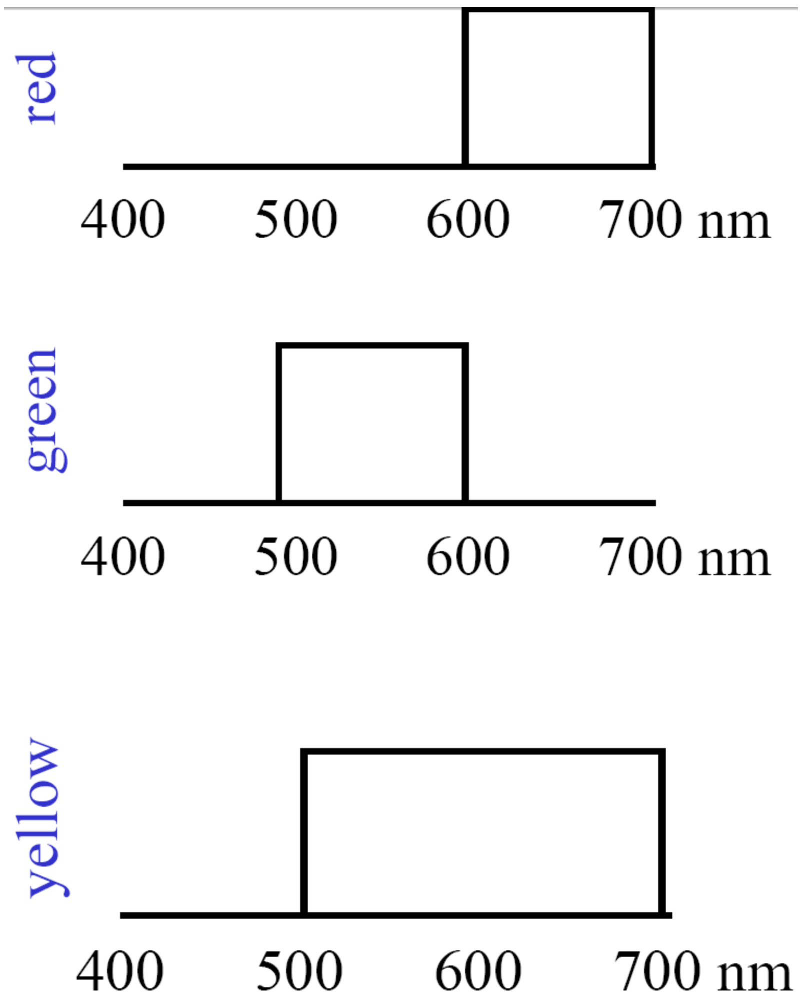
Color mixing



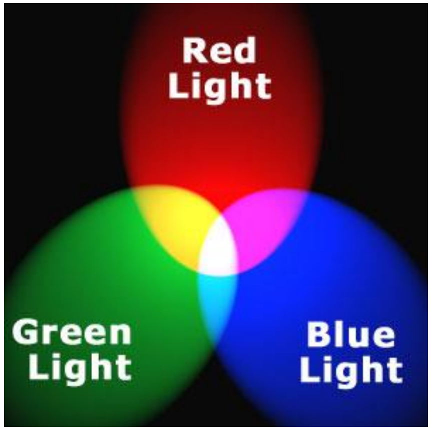


Source: W. Freeman

Additive color mixing



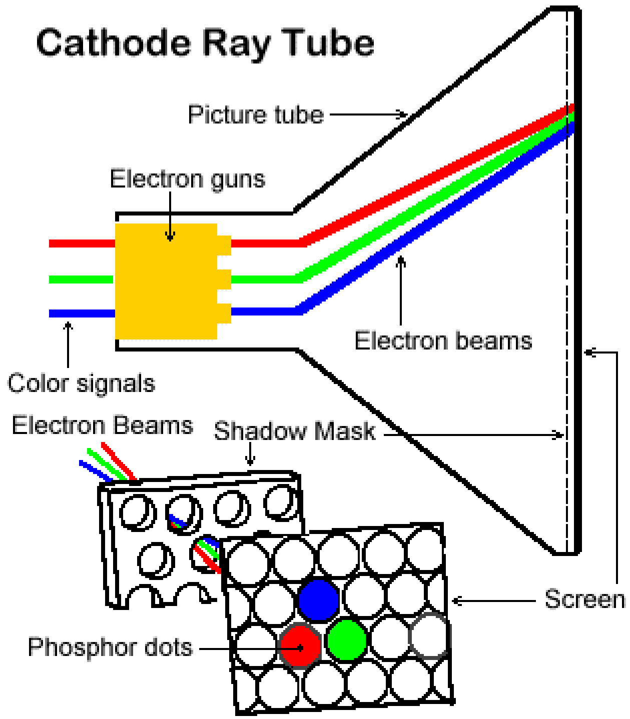
Colors combine by *adding* color spectra



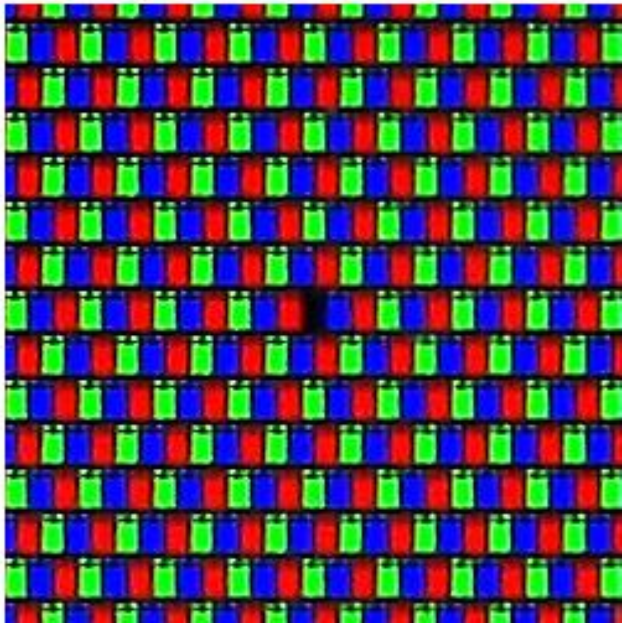
Light *adds* to existing black.

Source: W. Freeman

Examples of additive color systems



CRT phosphors

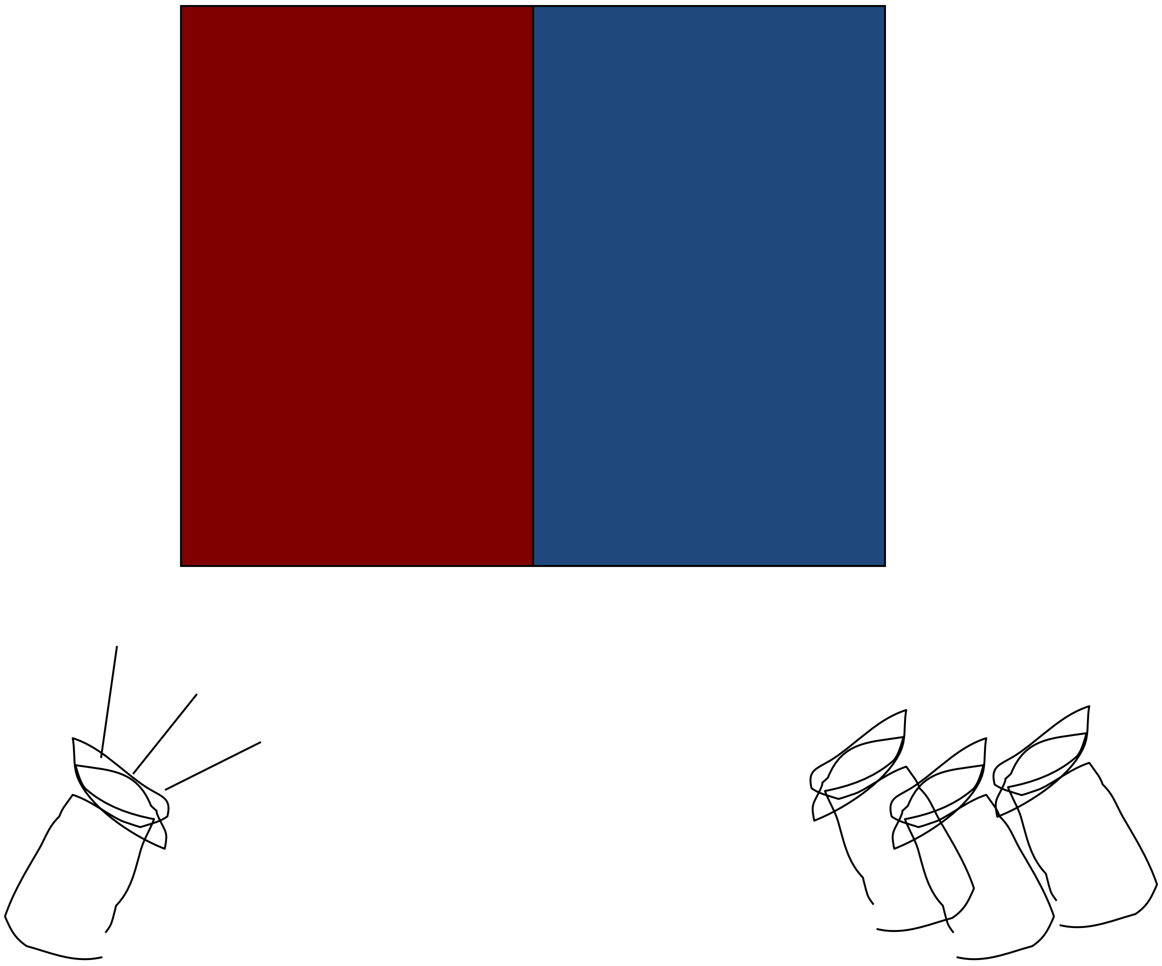


multiple projectors

http://www.jegsworks.com

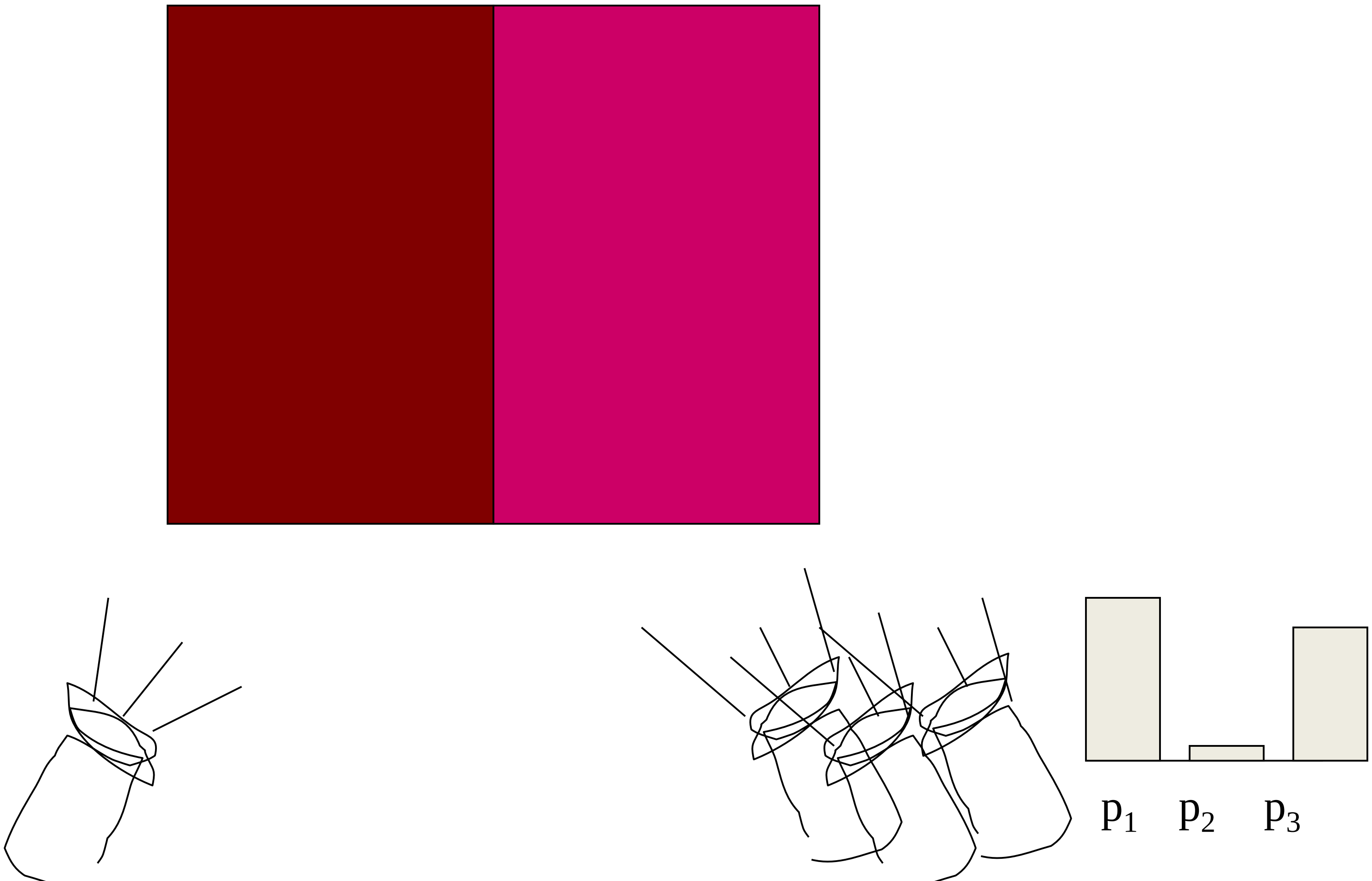
http://www.crtprojectors.co.uk/

Color matching experiment 2



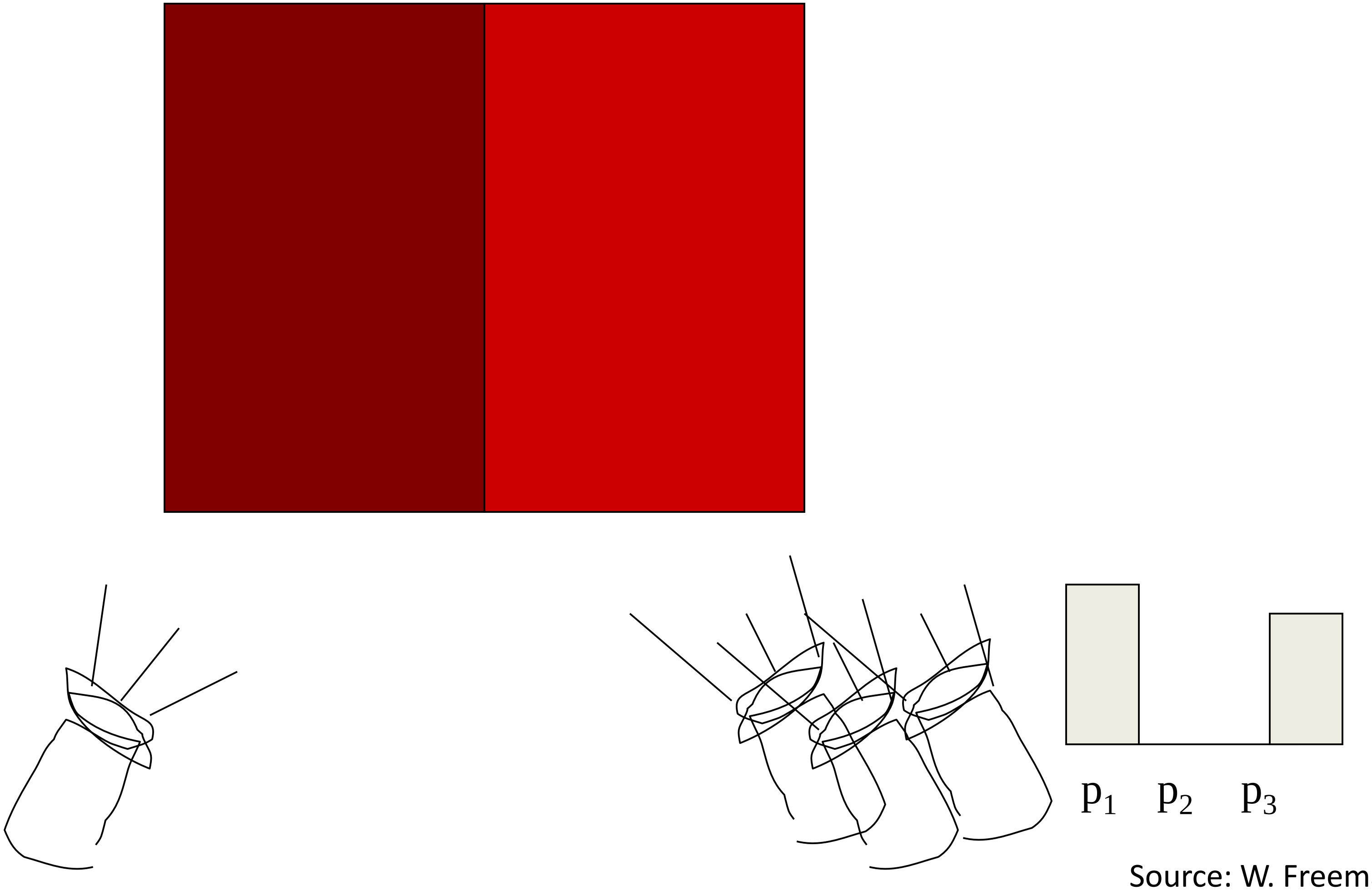
Source: W. Freeman

Color matching experiment 2



Source: W. Freeman

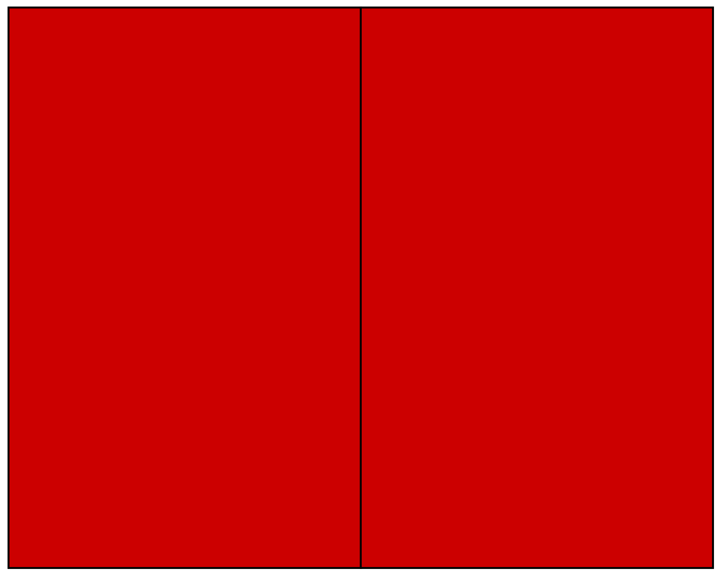
Color matching experiment 2



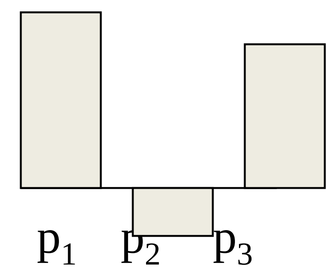
Source: W. Freeman

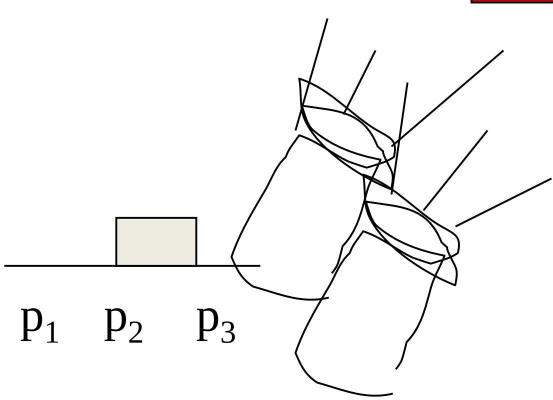
Color matching experiment 2

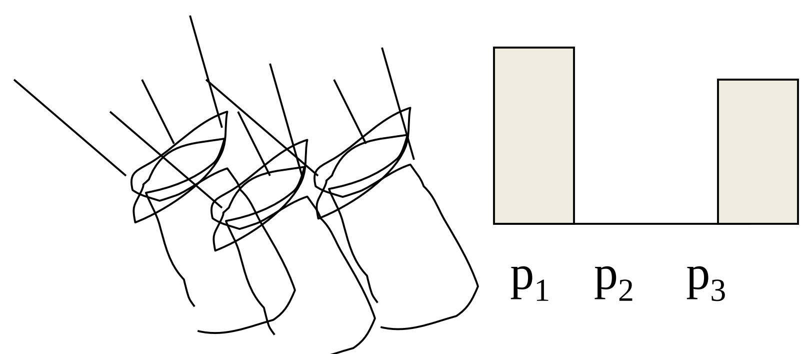
We say a “negative” amount of p_2 was needed to make the match, because we added it to the test color’s side.



The primary color amounts needed for a match:

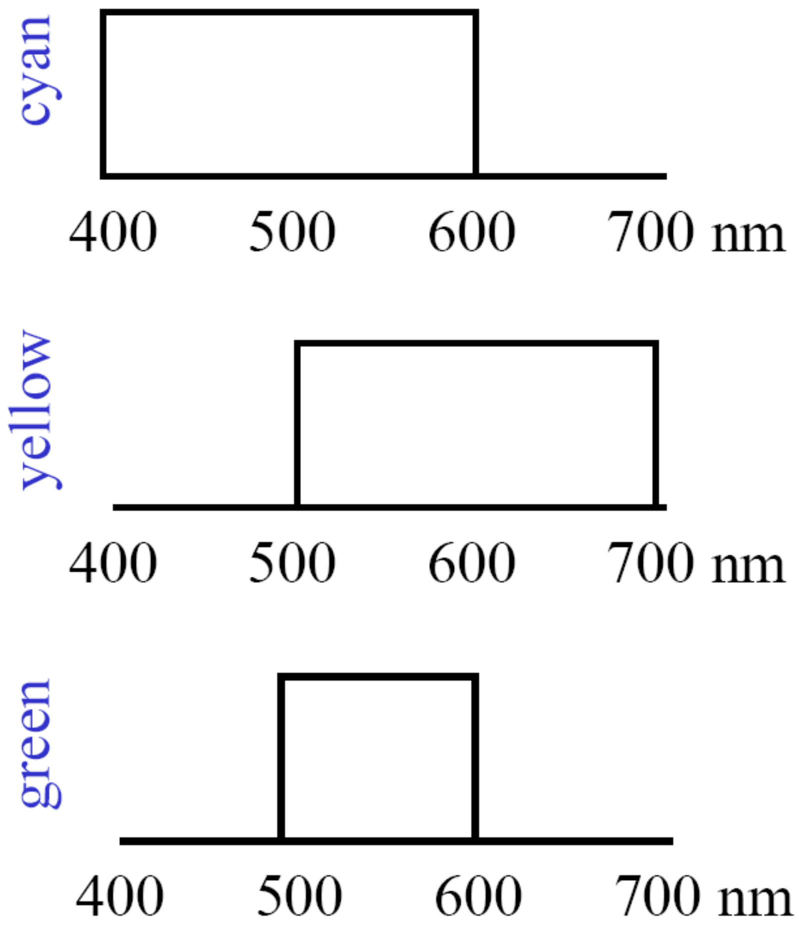




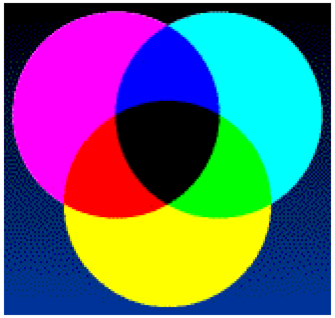


Source: W. Freeman

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

Trichromacy

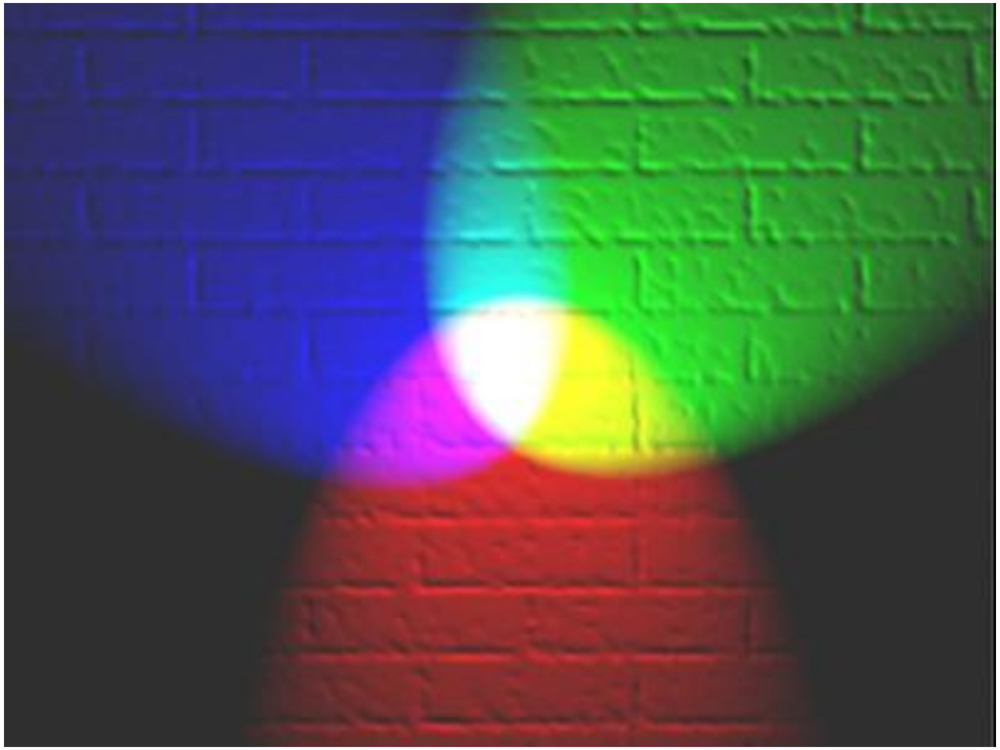
- In color matching experiments, most people can match any given light with three primaries
  - Primaries must be *independent*
- For the same light and same primaries, most people select the same weights
  - Exception: color blindness
- Trichromatic color theory
  - Three numbers seem to be sufficient for encoding color
  - Dates back to 18th century (Thomas Young)

Overview of Color

- Physics of color
- Human encoding of color
- Color spaces
- White balancing

Color spaces

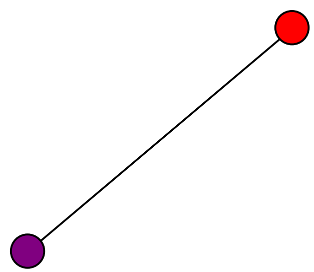
- How can we represent color?



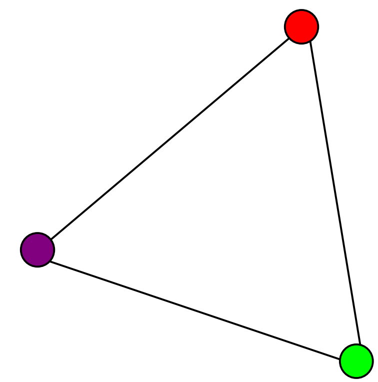
http://en.wikipedia.org/wiki/File:RGB_illumination.jpg

Linear color spaces

- Defined by a choice of three *primaries*
- The coordinates of a color are given by the weights of the primaries used to match it

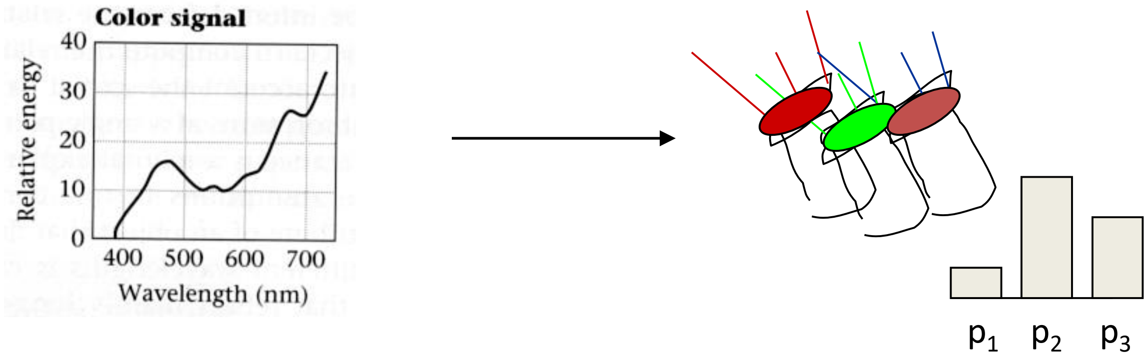


mixing two lights produces colors that lie along a straight line in color space



mixing three lights produces colors that lie within the triangle they define in color space

How to compute the weights of the primaries to match any spectral signal

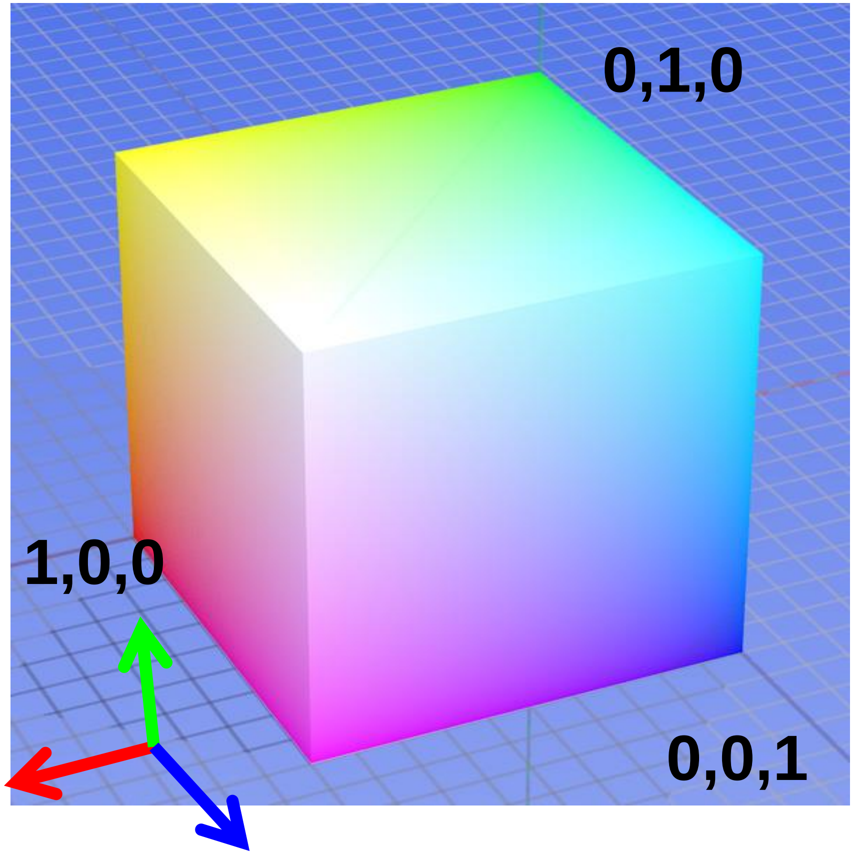


- **Matching functions:** the amount of each primary needed to match a monochromatic light source at each wavelength

Source: W. Freeman

Color spaces: RGB

Default color space



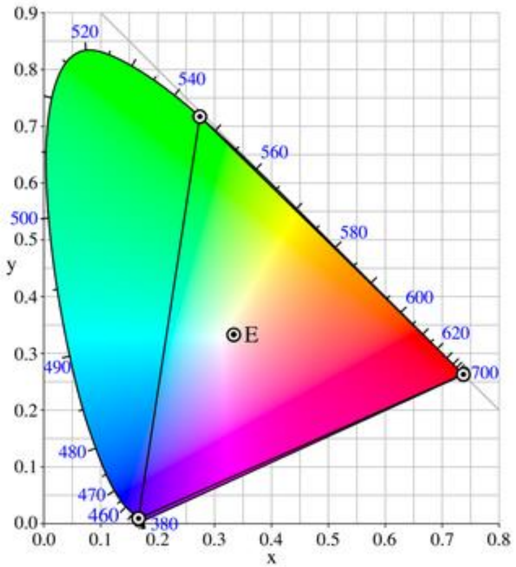
Any color = r*R + g*G + b*B

- Strongly correlated channels
- Non-perceptual

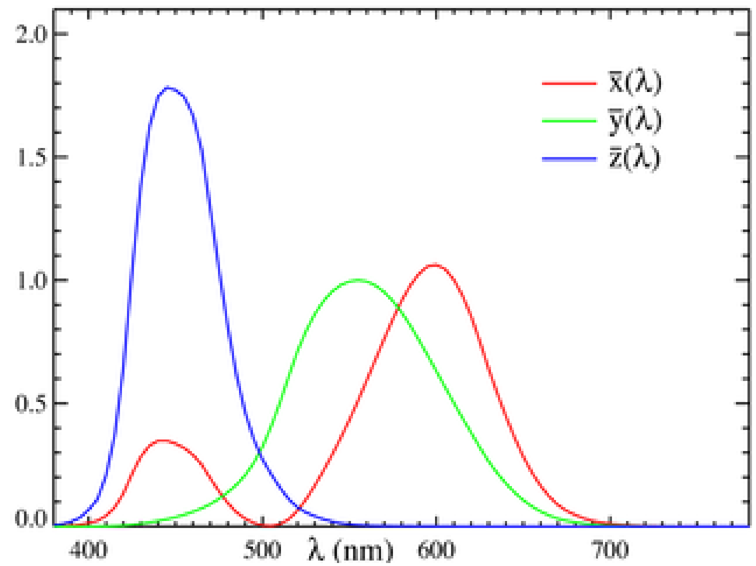
Image from: http://en.wikipedia.org/wiki/File:RGB_color_solid_cube.png

Linear color spaces: CIE XYZ

- Primaries are imaginary, but matching functions are everywhere positive
- The Y parameter corresponds to brightness or *luminance* of a color
- 2D visualization: draw (x,y), where $x = X/(X+Y+Z)$, $y = Y/(X+Y+Z)$



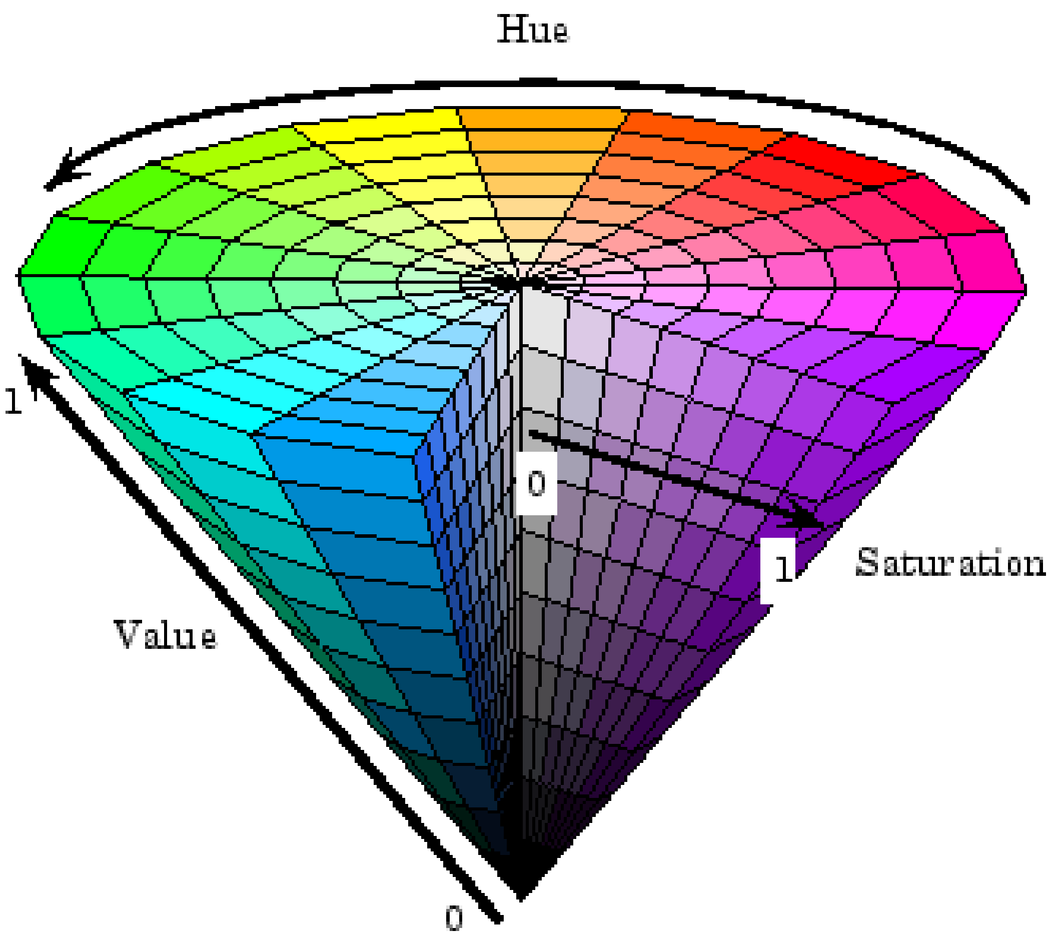
Matching functions



http://en.wikipedia.org/wiki/CIE_1931_color_space

Color spaces: HSV

Intuitive color space



If you had to choose, would you rather go without:

- intensity (‘value’), or
- hue + saturation (‘chroma’)?

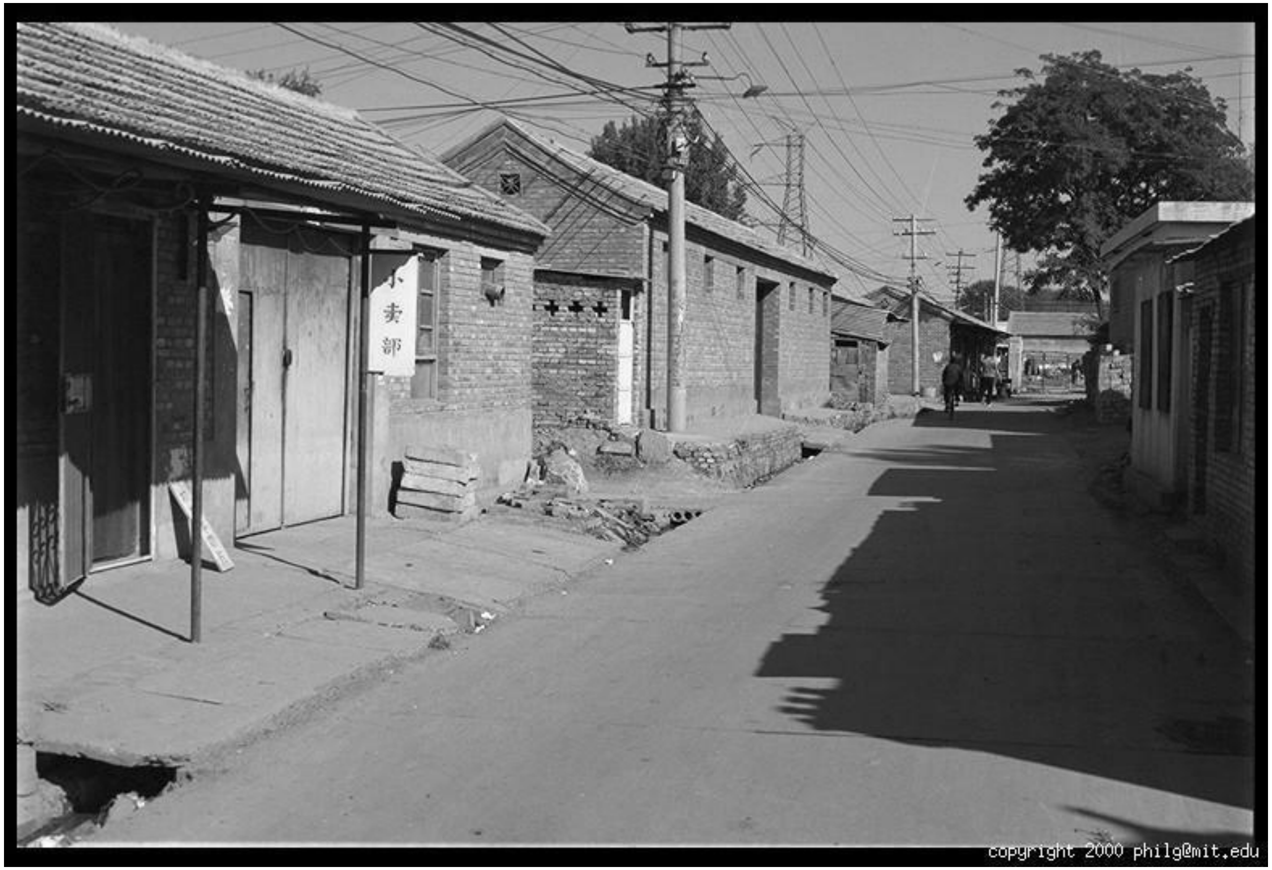
If you had to choose, would you rather go without luminance or chrominance?

Most information in intensity

Only color shown – constant intensity

James Hays

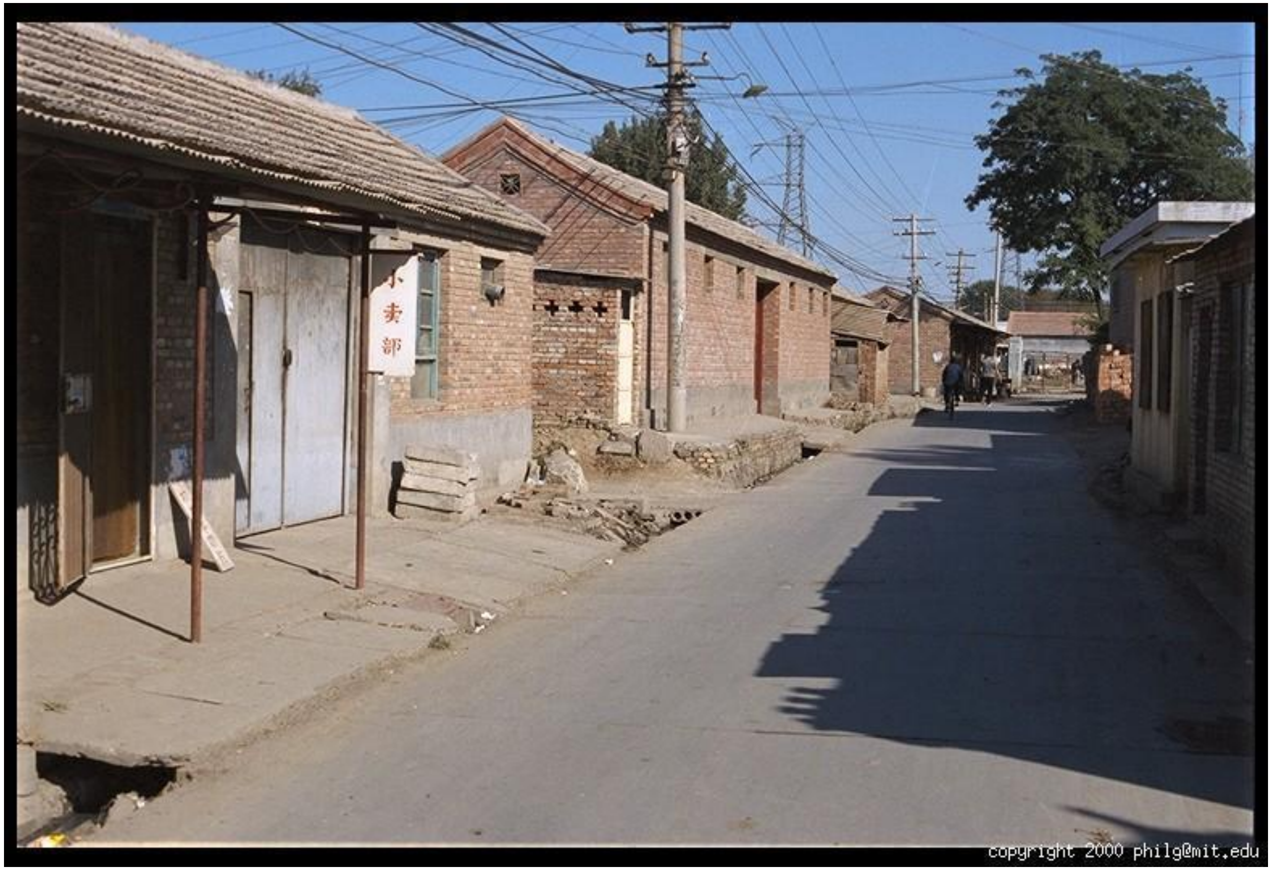
Most information in intensity



Only intensity shown – constant color

James Hays

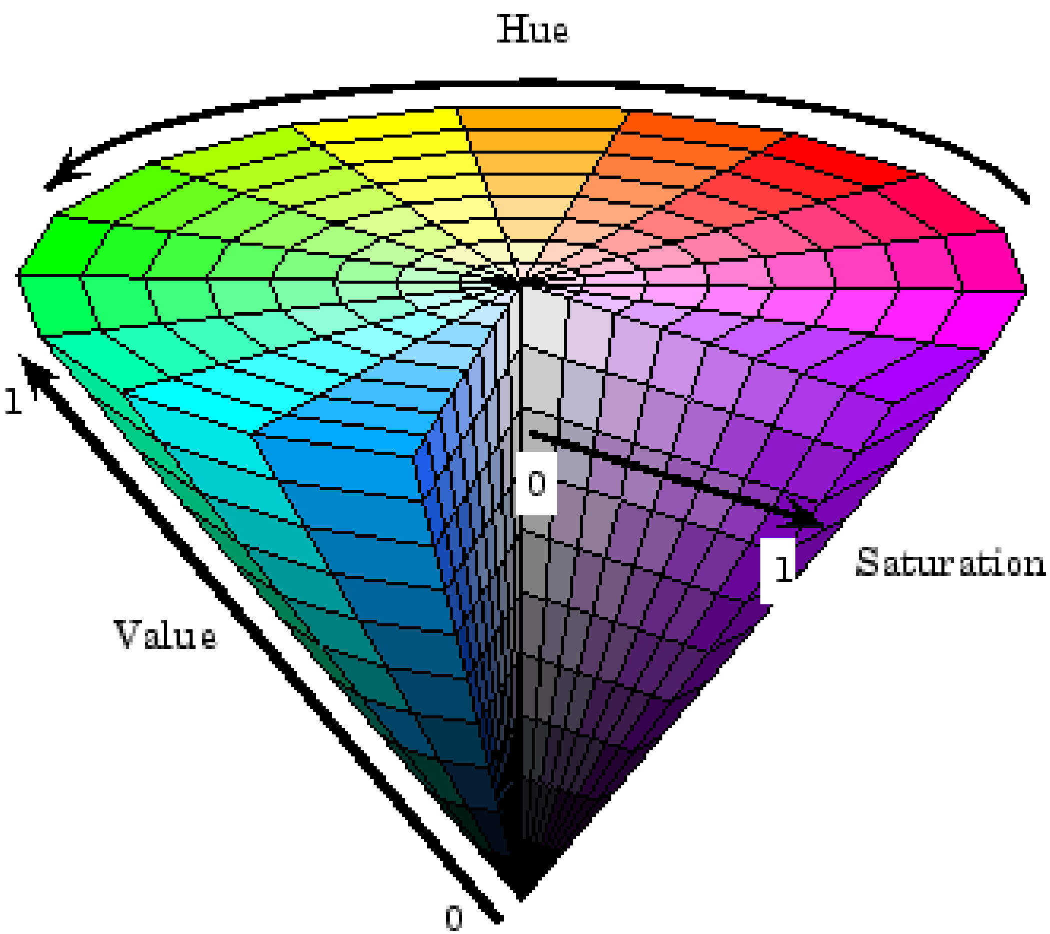
Most information in intensity

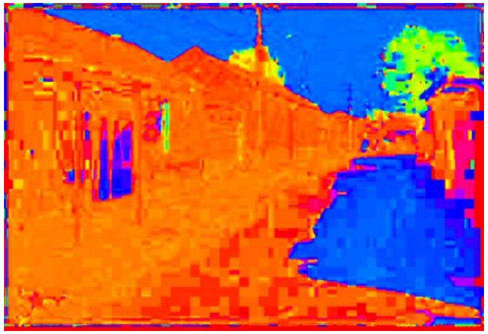


Original image

Color spaces: HSV

Intuitive color space





H
(S=1,V=1)

S
(H=1,V=1)

V
(H=1,S=0)

James Hays

Overview of Color

- Physics of color
- Human encoding of color
- Color spaces
- White balancing

White balance

- When looking at a picture on screen or print, we adapt to the illuminant of the room, not to that of the scene in the picture
- When the white balance is not correct, the picture will have an unnatural color "cast"

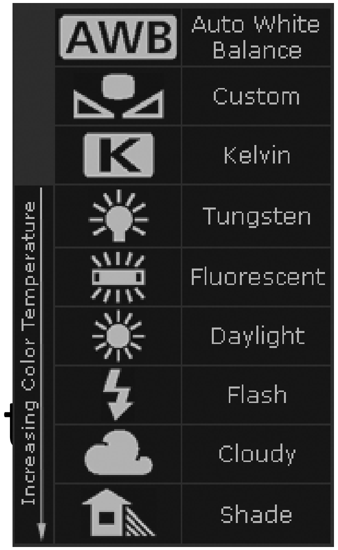
incorrect white balance

correct white balance

http://www.cambridgeincolour.com/tutorials/white-balance.htm

White balance

- Film cameras:
  - Different types of film or different filters for different illumination conditions
- Digital cameras:
  - Automatic white balance
  - White balance settings corresponding to several common illuminants
  - Custom white balance using a reference object



http://www.cambridgeincolour.com/tutorials/white-balance.htm

Slide: F. Durand

White balance

- Von Kries adaptation
  - Multiply each channel by a gain factor
  - A more general transformation would correspond to an arbitrary 3x3 matrix

Slide: F. Durand

White balance

- Von Kries adaptation
  - Multiply each channel by a gain factor
  - A more general transformation would correspond to an arbitrary 3x3 matrix
- Best way: gray card
  - Take a picture of a neutral object (white or gray)
  - Deduce the weight of each channel
    - If the object is recoded as r_w, g_w, b_w use weights $1/r_w$, $1/g_w$, $1/b_w$

Slide: F. Durand

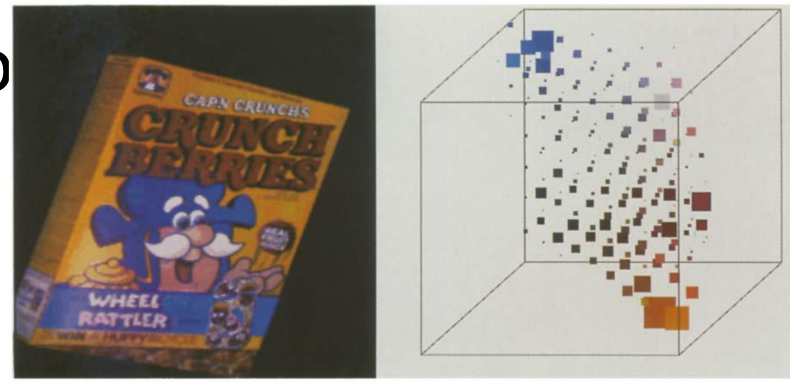
White balance

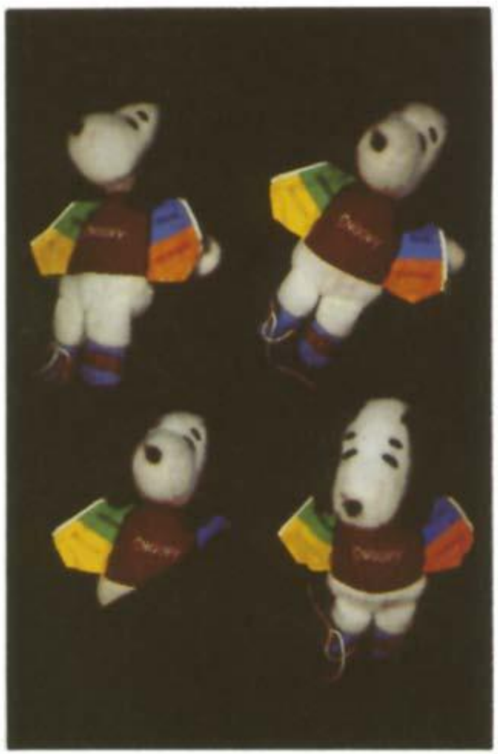
- Without gray cards: we need to "guess" which pixels correspond to white objects
- Gray world assumption
  - The image average r_{ave}, g_{ave}, b_{ave} is gray
  - Use weights $1/r_{ave}$, $1/g_{ave}$, $1/b_{ave}$
- Gamut mapping
  - Gamut: convex hull of all pixel colors in an image
  - Find the transformation that matches the gamut of the image to the gamut of a "typical" image under white light
- Use image statistics, learning techniques

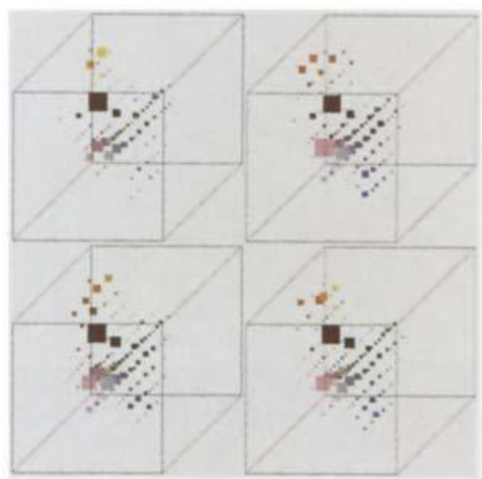
Slide: F. Durand

Uses of color in computer vision

Color histograms fo



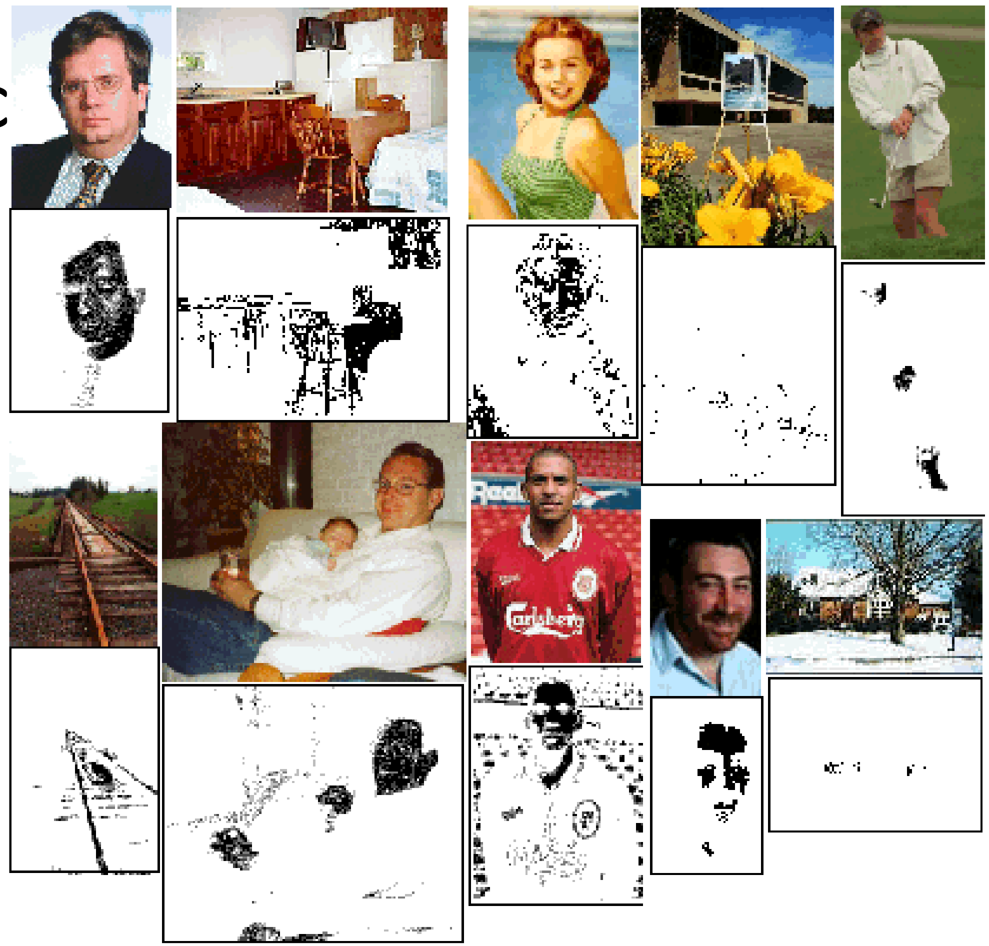




Swain and Ballard, [Color Indexing](), IJCV 1991.

Uses of color in computer vision

Skin detec

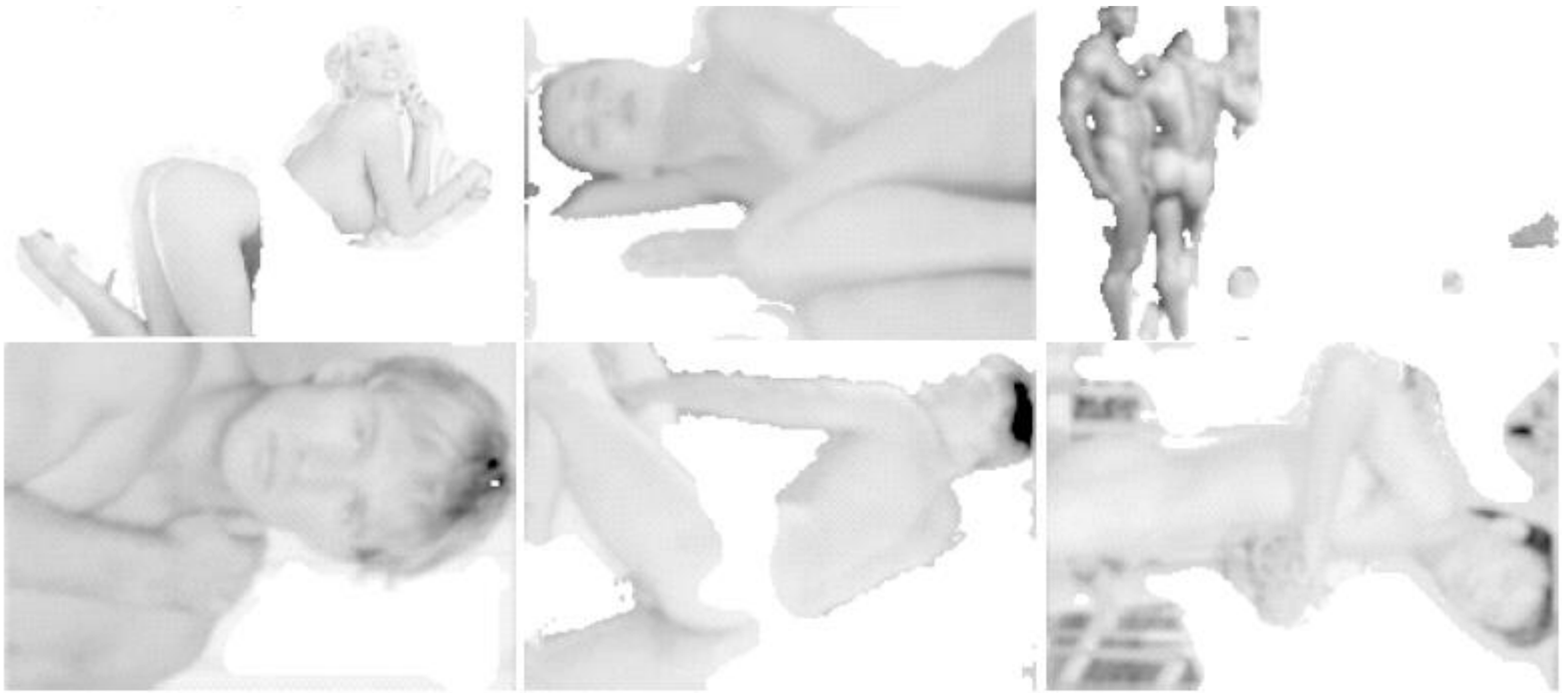


M. Jones and J. Rehg, [Statistical Color Models with Application to Skin Detection](), IJCV 2002.

Source: S. Lazebnik

Uses of color in computer vision

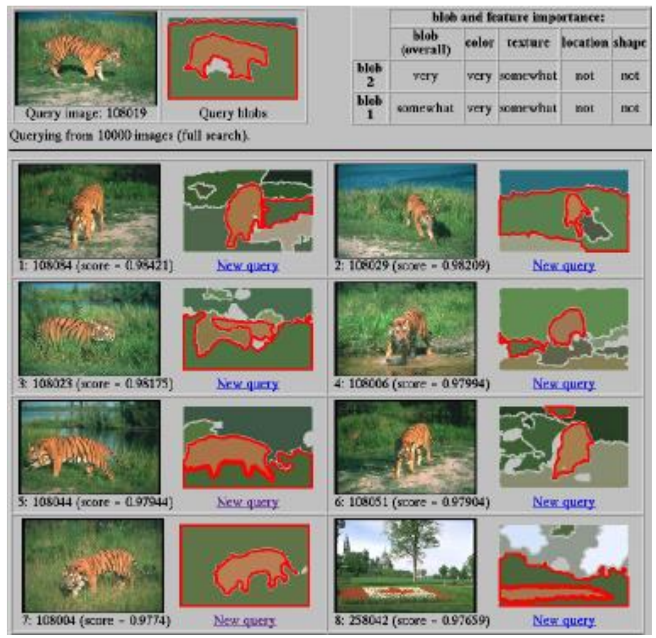
Nude people detection



Forsyth, D.A. and Fleck, M. M., ``Automatic Detection of Human Nudes,'' *International Journal of Computer Vision* , **32** , 1, 63-77, August, 1999

Uses of color in computer vision

Image segmentation and retrieval



C. Carson, S. Belongie, H. Greenspan, and Ji. Malik, Blobworld: Image segmentation using Expectation-Maximization and its application to image querying, ICVIS 1999.

Source: S. Lazebnik

Uses of color in computer vision

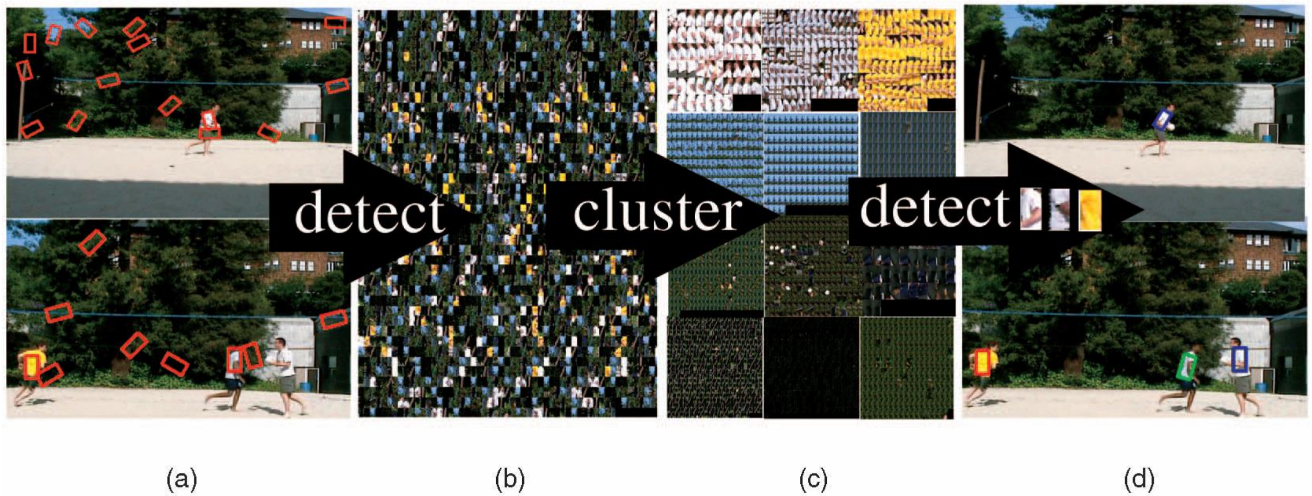
Robot soccer

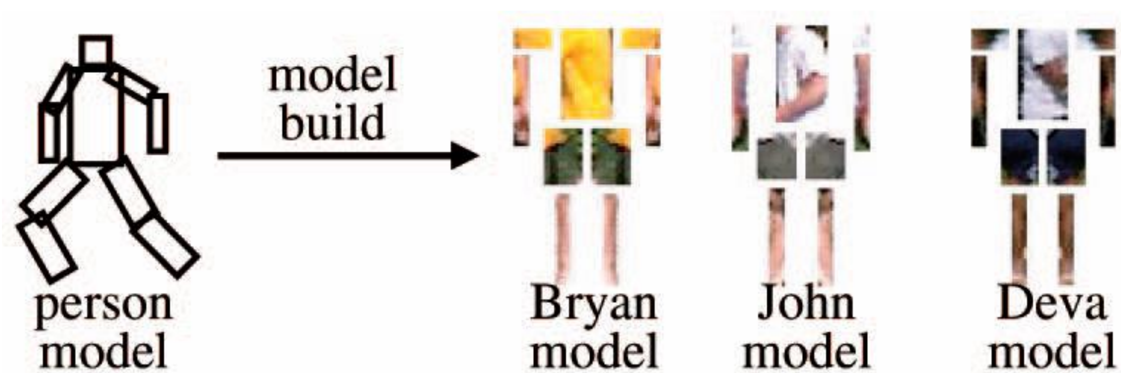
M. Sridharan and P. Stone, Towards Eliminating Manual Color Calibration at RoboCup. RoboCup-2005: Robot Soccer World Cup IX, Springer Verlag, 2006

Source: K. Grauman

Uses of color in computer vision

Building appearance models for tracking





D. Ramanan, D. Forsyth, and A. Zisserman. Tracking People by Learning their Appearance. PAMI 2007.

Source: S. Lazebnik