UNIVERSITAT DE BARCELONA

>>> IMAGE PROCESSING AND COMPUTATIONAL PHOTOGRAPHY

SESSION 5: COLOR

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(c) inspired by D. Hoiem and A. Efros slides

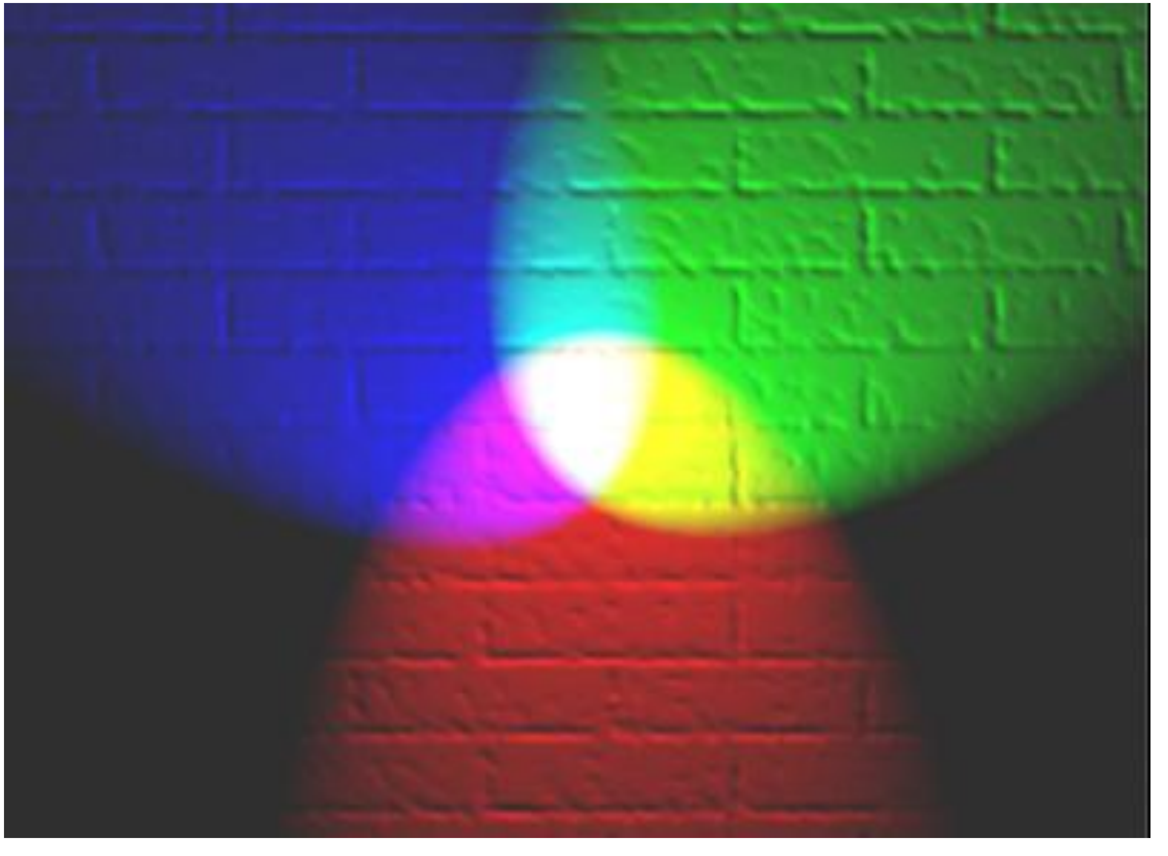
TODAY'S LECTURE

- More on human perception
- Physics of light and color
- Color spaces

- Tone transfer
- High-dynamic range

TODAY'S LECTURE

- How is incoming light measured by the eye or camera?
- How is light reflected from a surface?
- How can we represent color?



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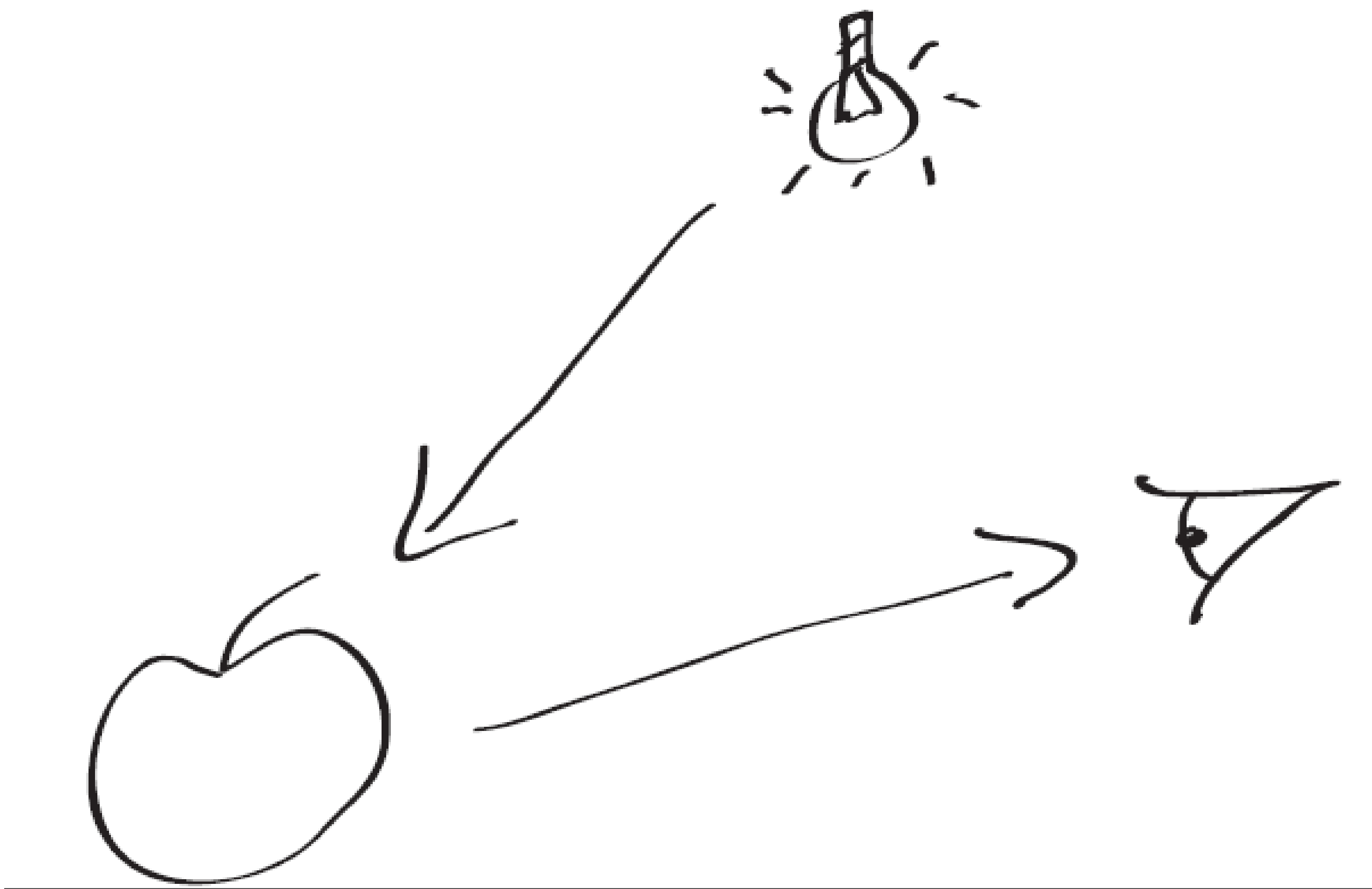
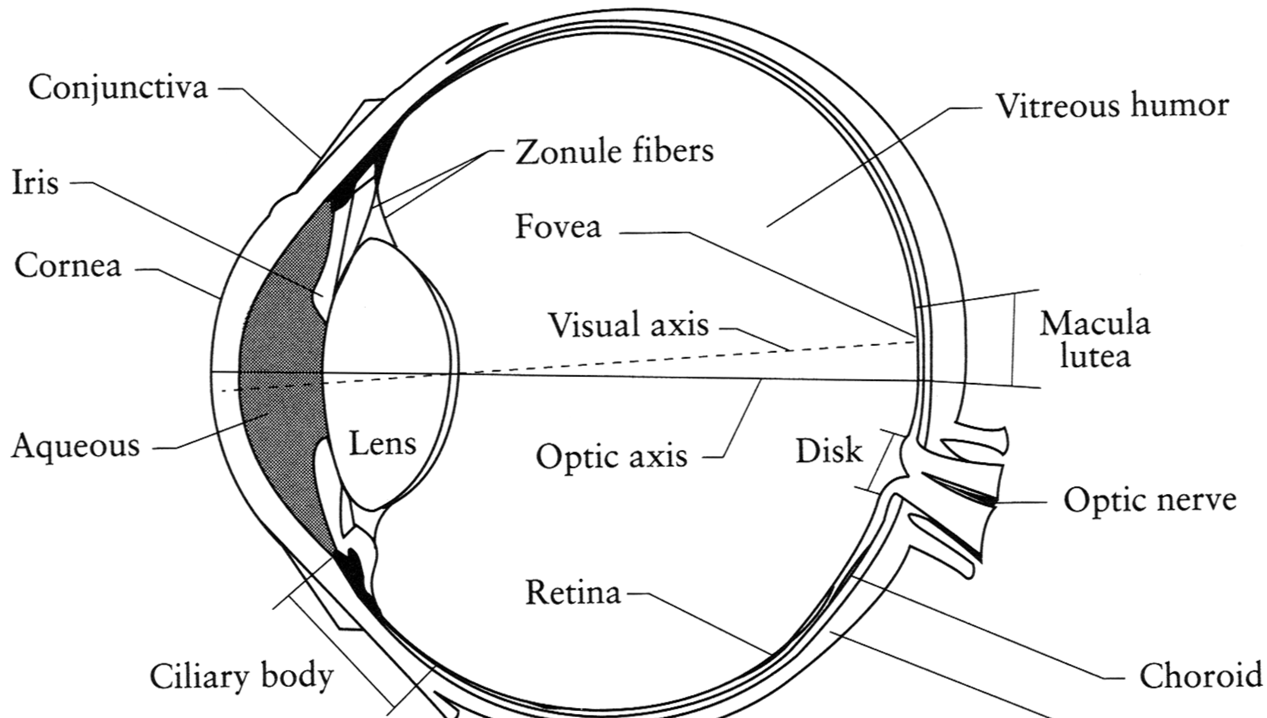


THE EYE

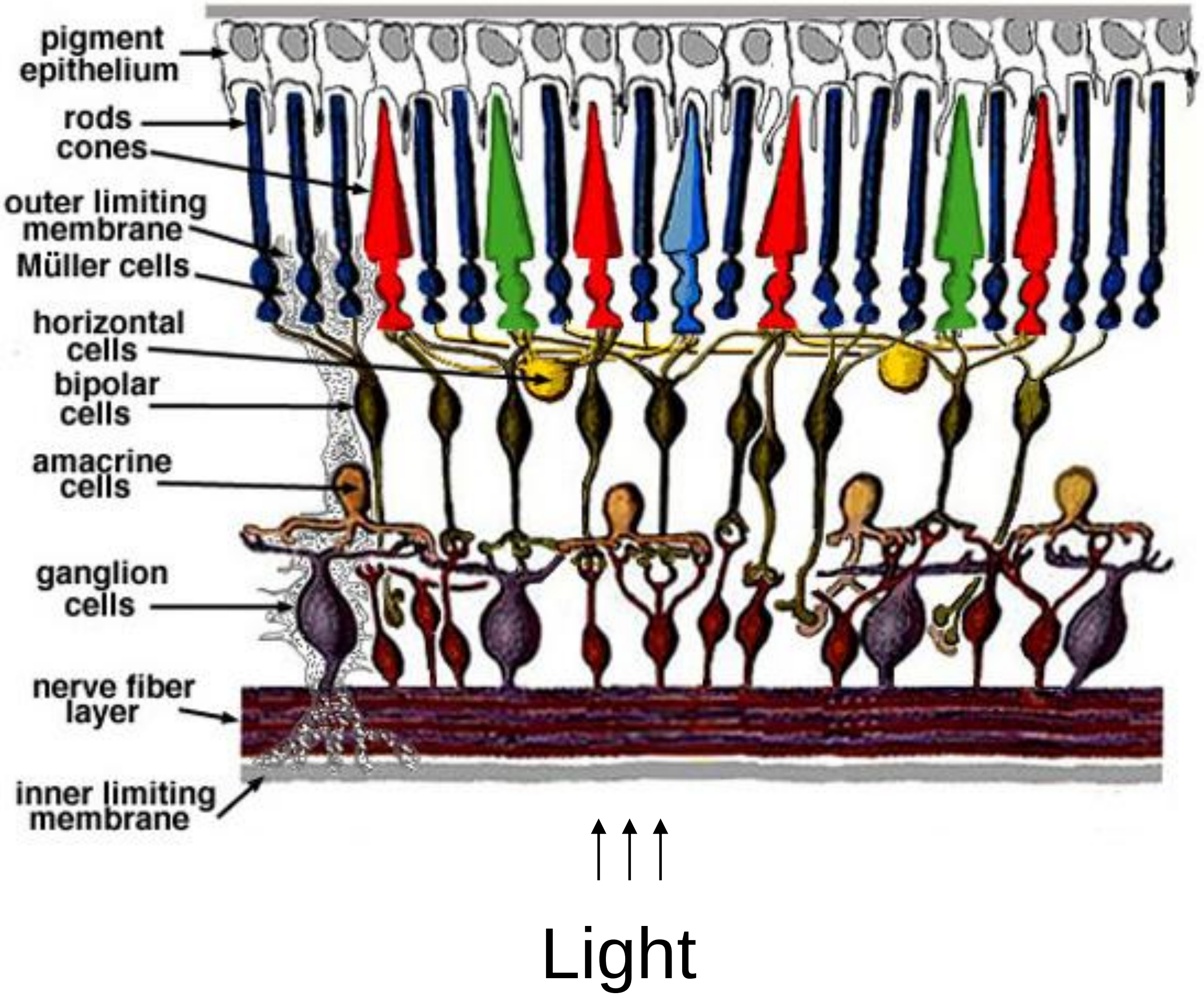


The human eye is a camera!

- **Iris** - colored annulus with radial muscles
- **Pupil** - the hole (aperture) whose size is controlled by the iris
- What’s the “film”?
- photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

RETINA UP-CLOSE

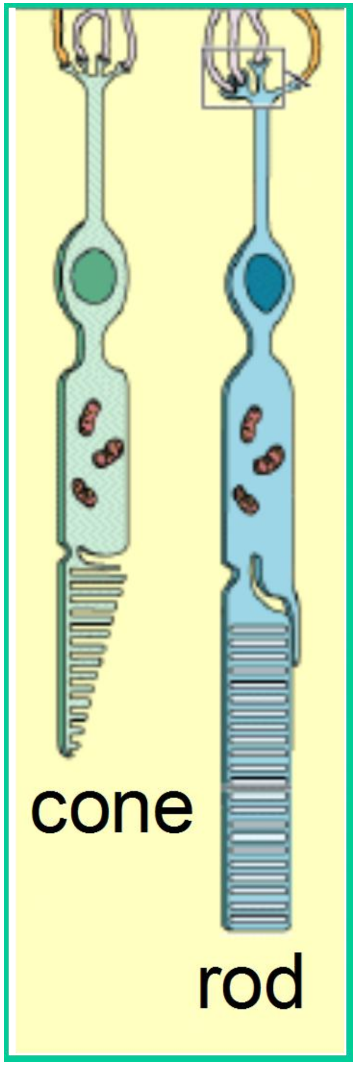


Slide Credit: Efros

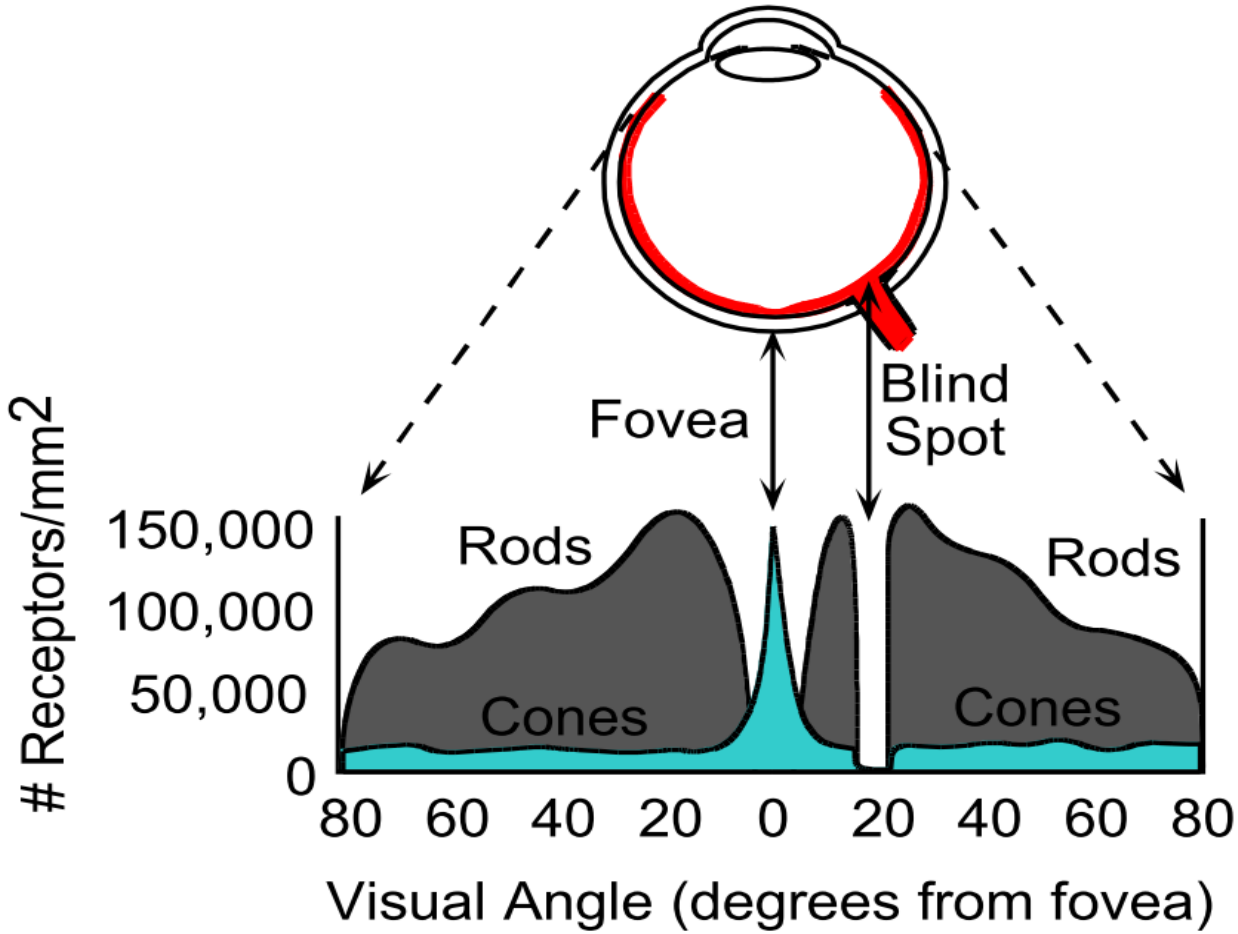
TWO TYPES OF LIGHT-SENSITIVE RECEPTORS

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

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



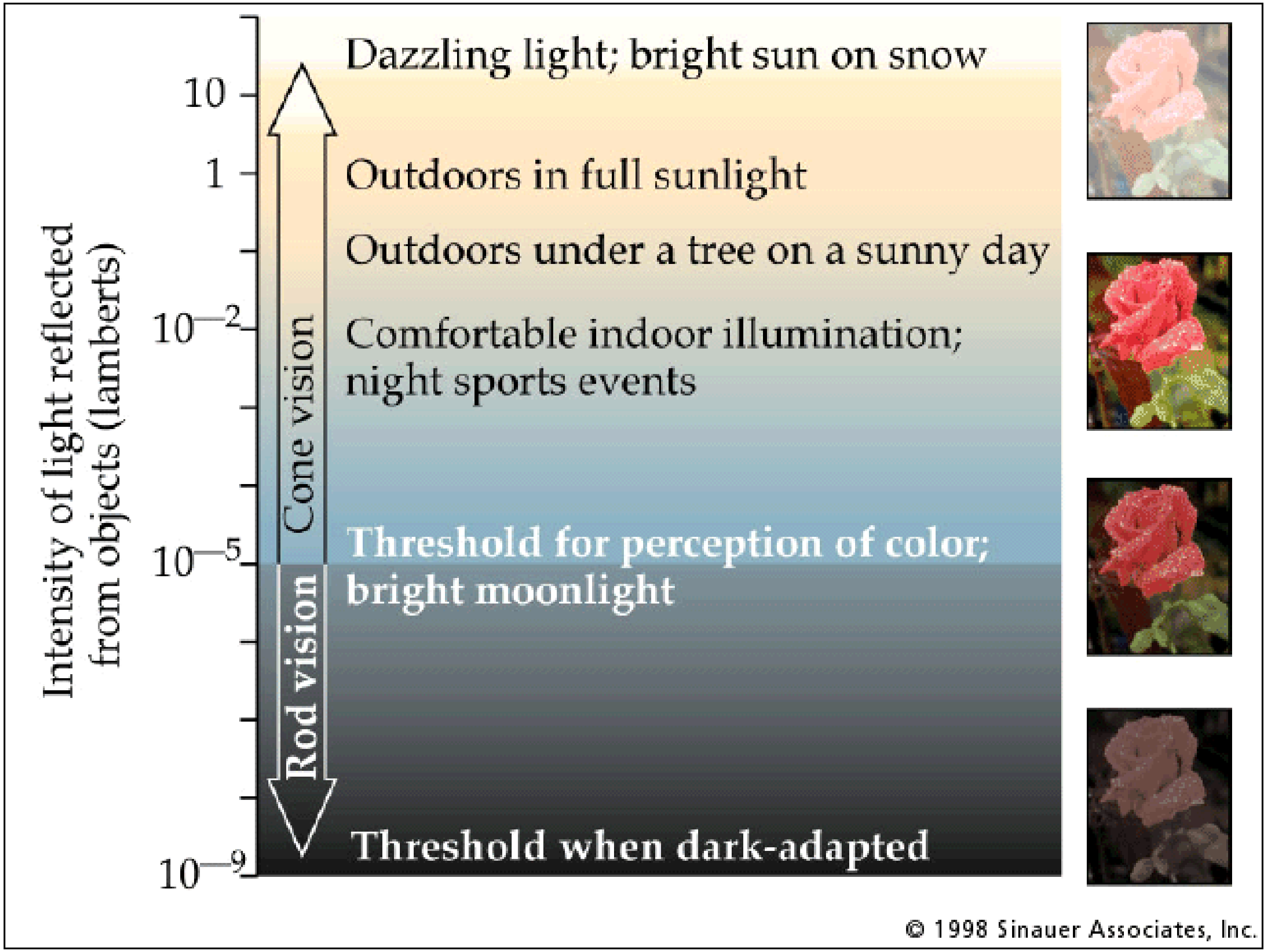
DISTRIBUTION OF RODS AND CONES



Night Sky: why are there more stars off-center?

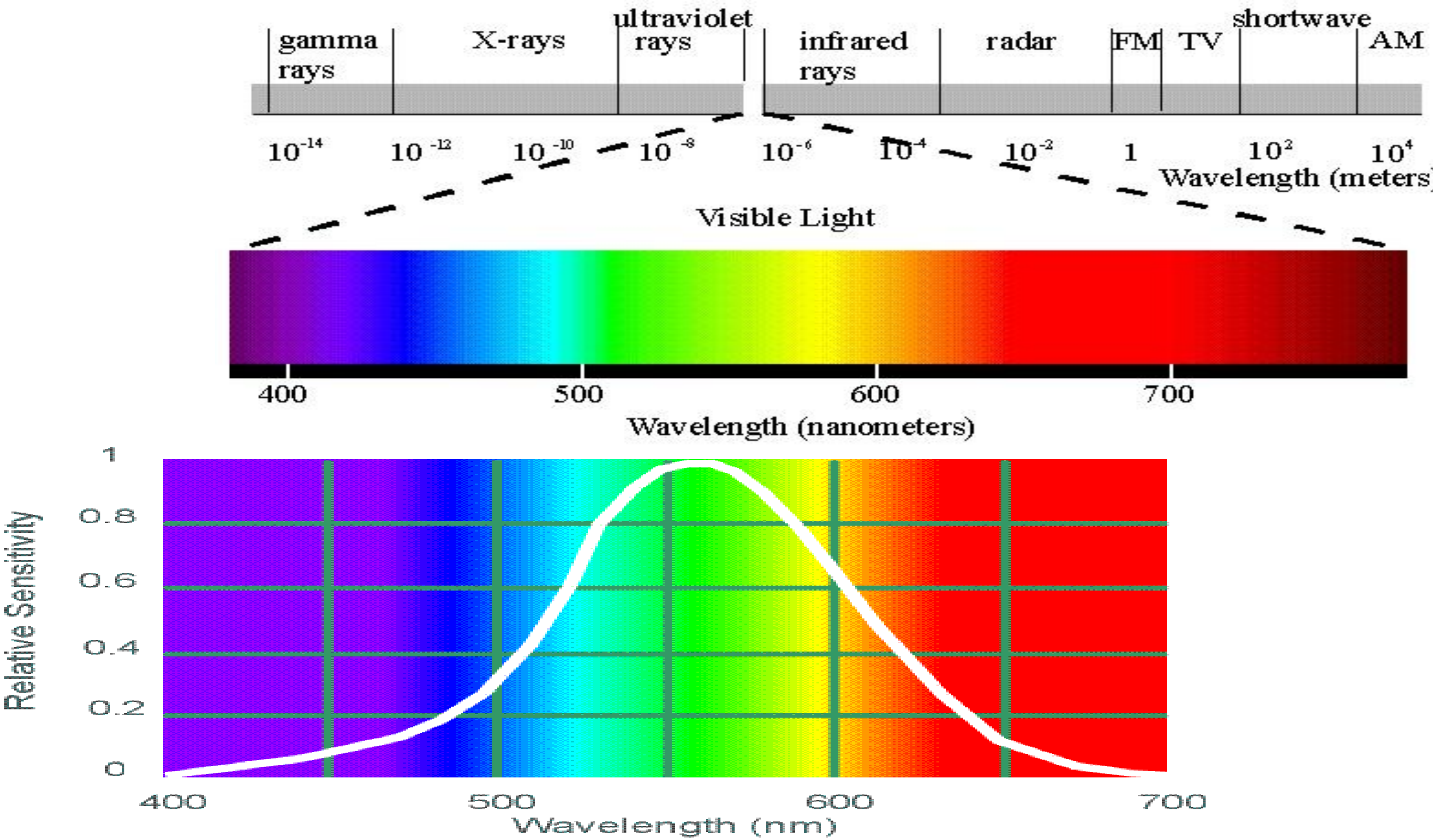
Slide Credit: Efros

ROD / CONE SENSITIVITY



Slide Credit: Efros

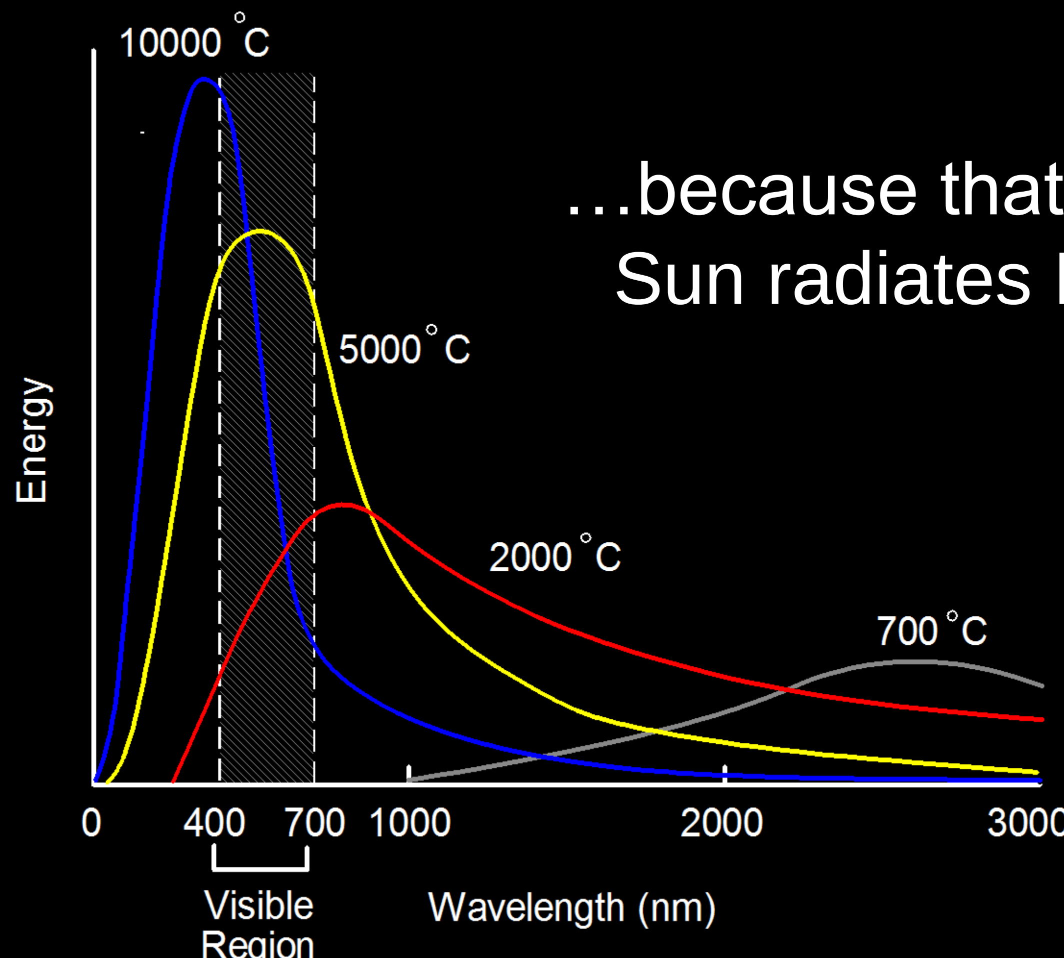
ELECTROMAGNETIC SPECTRUM



Human Luminance Sensitivity Function

VISIBLE LIGHT

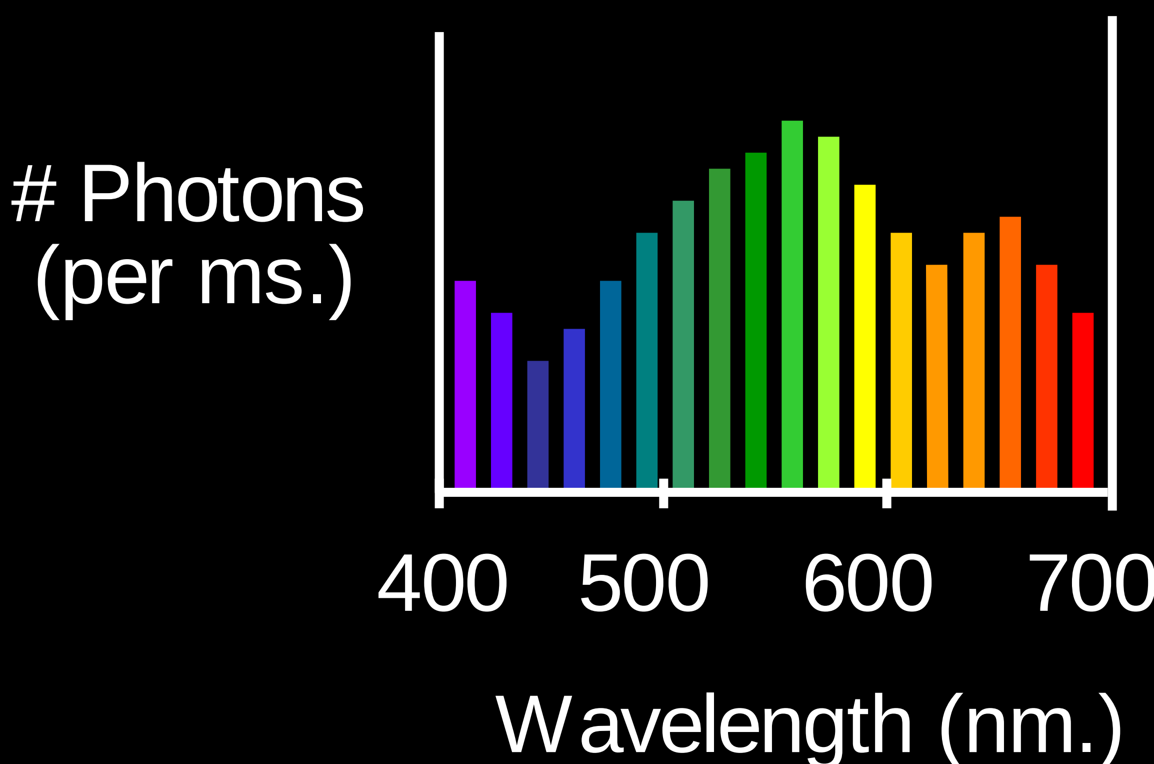
Why do we see light of these wavelengths?



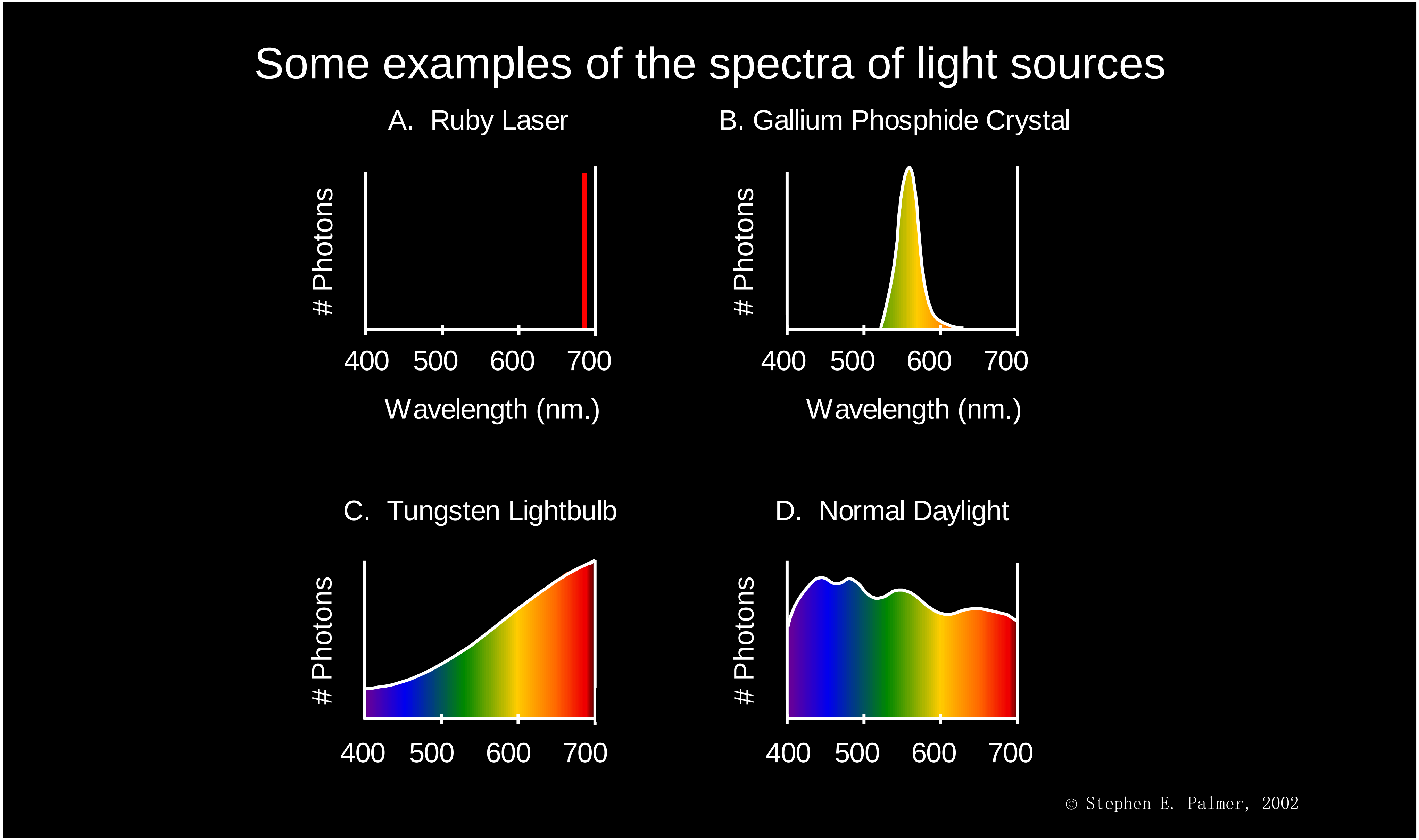
…because that's where the Sun radiates EM energy

VISIBLE 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.



PHYSICS OF LIGHT



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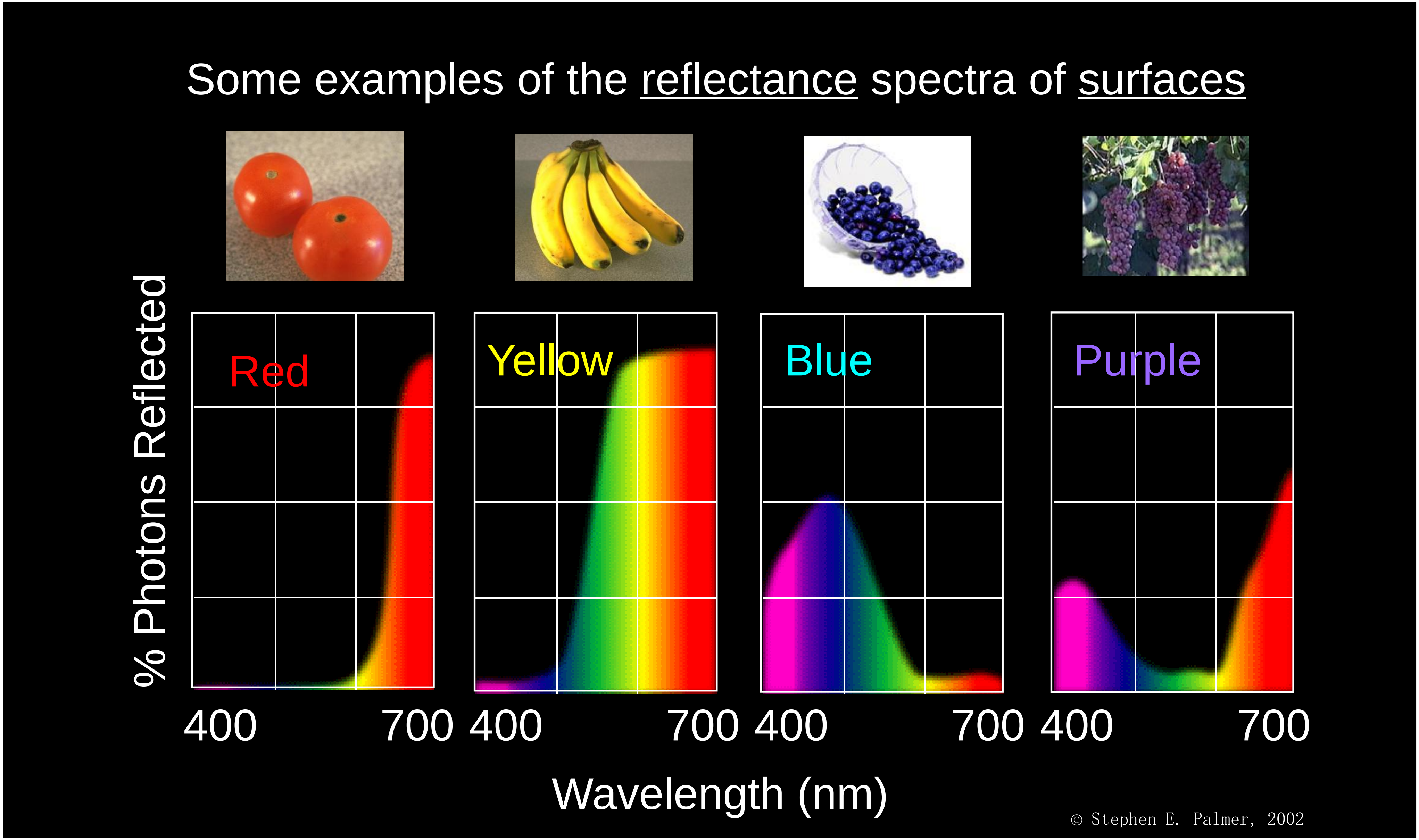
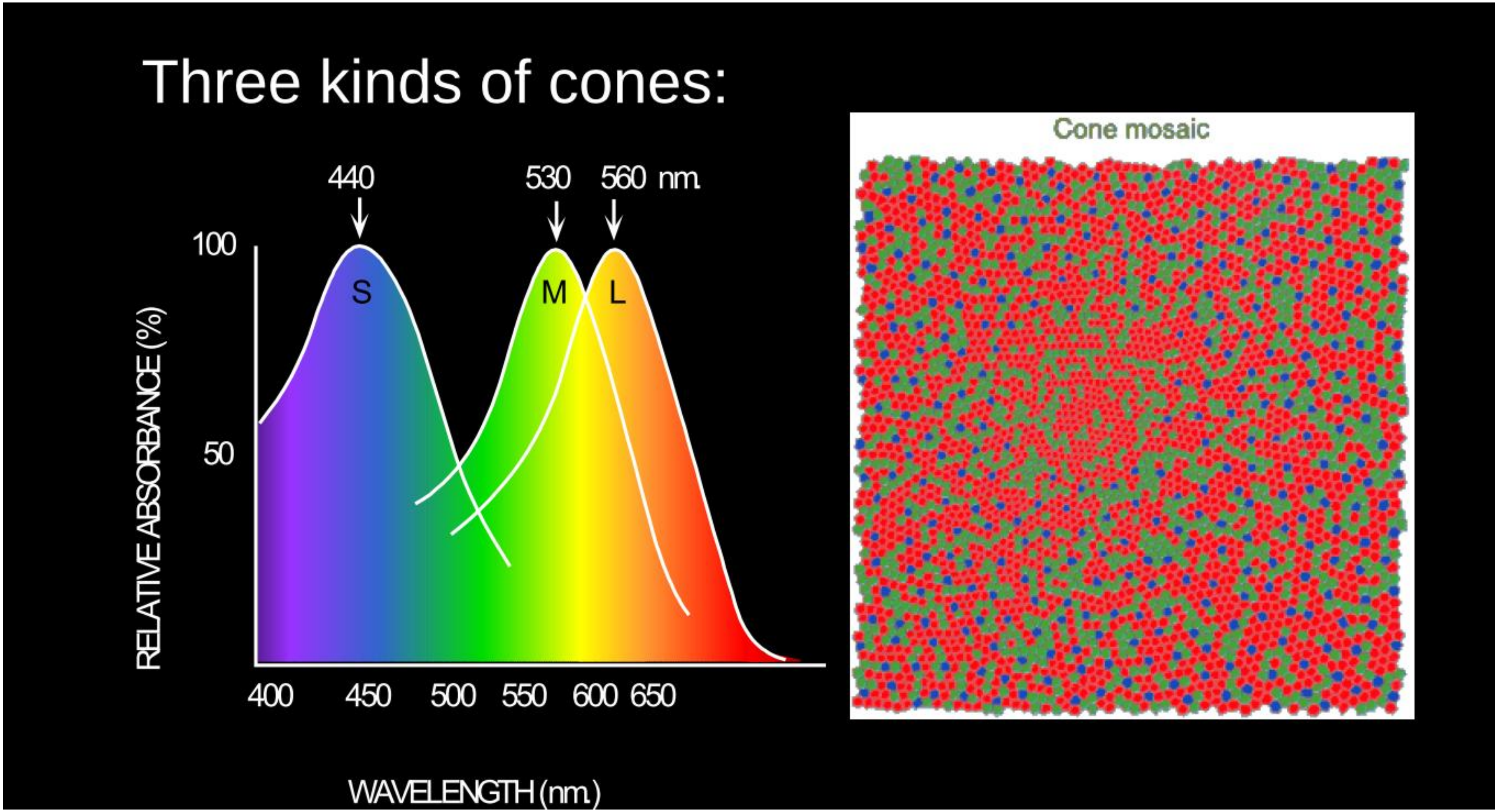


PHYSOLOGY OF COLOR VISION

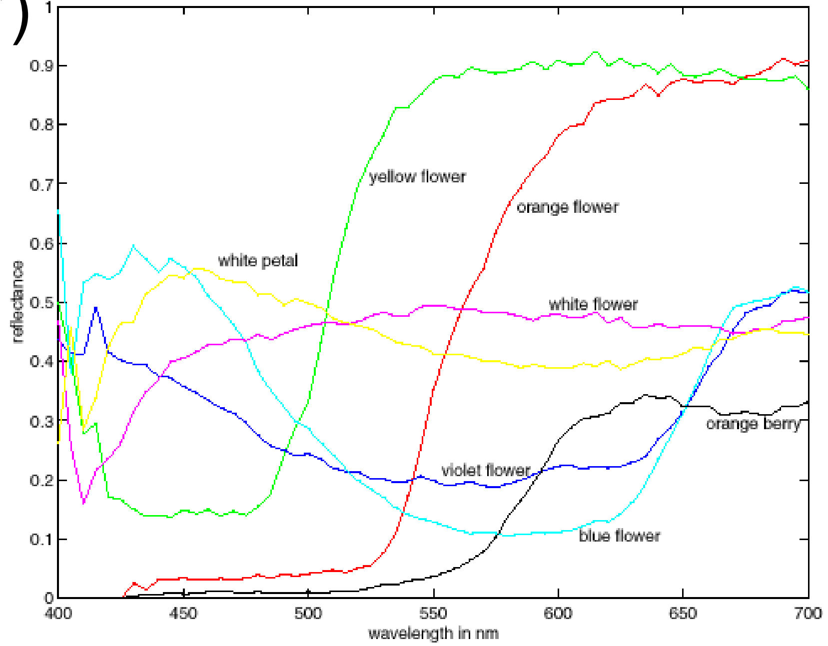


WE DO NOT PERCEIVE THE SPECTRUM

We perceive three values according to cones sensitivity.

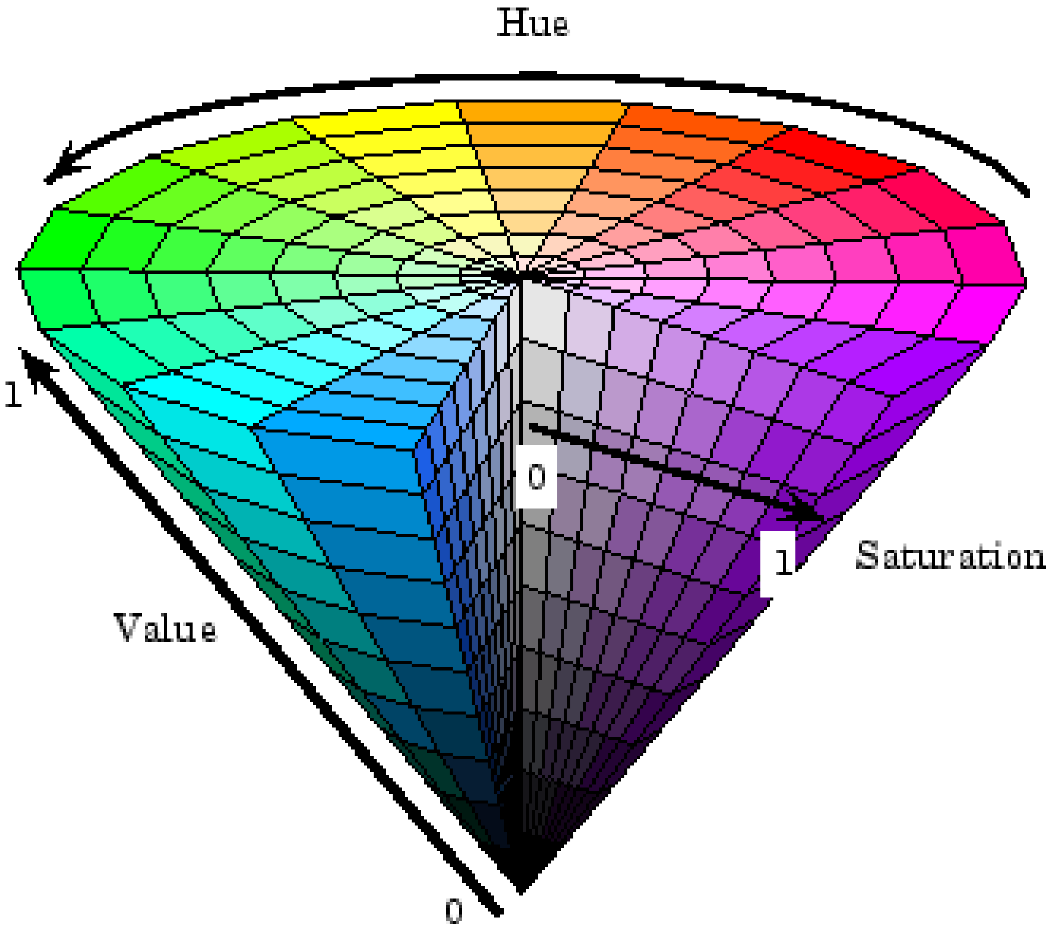
We describe this perception as
- Hue: mean wavelength, color
- Saturation: variance, vividness
- Intensity: total amount of light

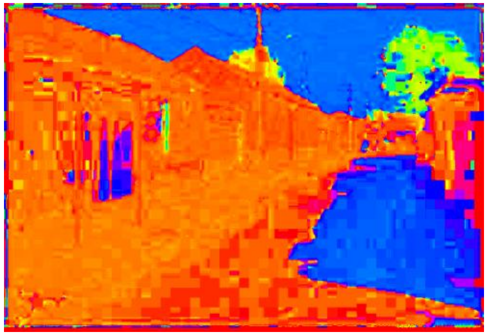
Same perceived color can be recreated with combinations of three primary colors ("trichromacy")



COLOR SPACES: HSV

Intuitive color space





H
(S=1,V=1)

S
(H=1,V=1)

V
(H=1,S=0)

TEST PICTURES USING http://www.phixr.com/photo/userindex#

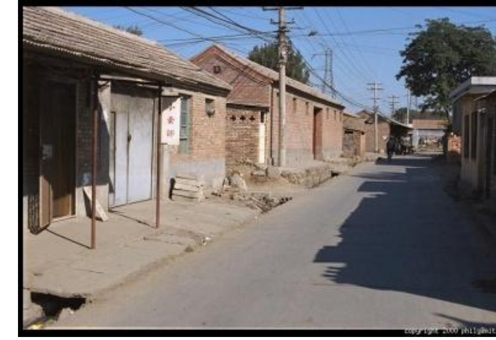
STANDARD COLOR SPACES

How do we represent colors?
We need a principled color space.

Many possible definitions:
- We could use cone response (LMS)
- Unfortunately, it was not known when colorimetry was invented

The good news is that color vision is “linear” and 3-dimensional, so any new color space can be obtained using a 3x3 matrix.
- But not all spaces are linear (e.g. HSV, Lab)

COLOR SPACES: sRGB



Some drawbacks

- Strongly correlated channels
- Non-perceptual

R
(G=0,B=0)

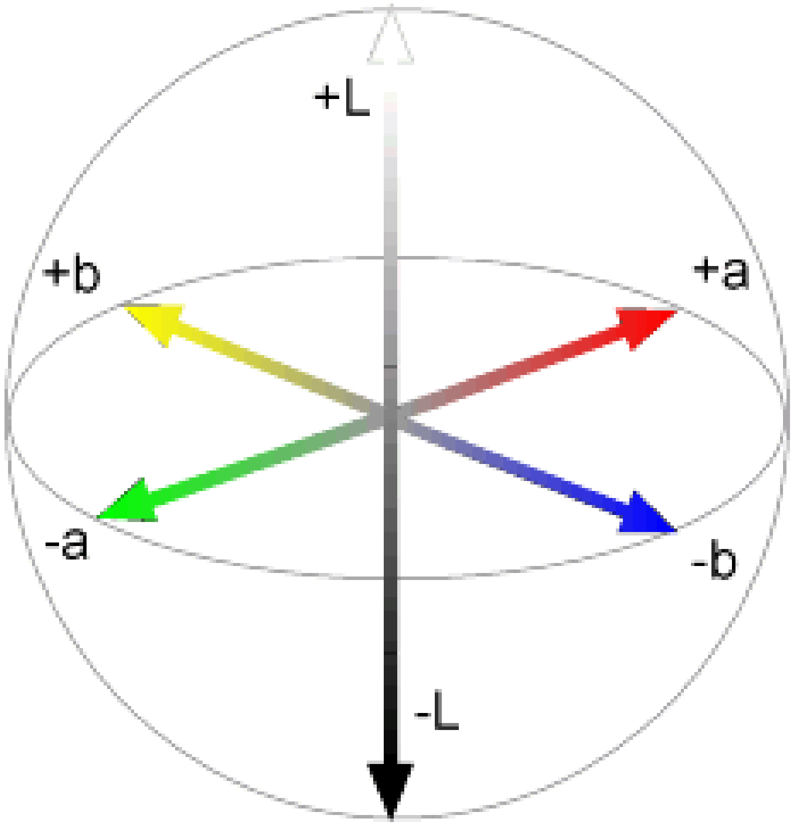
G
(R=0,B=0)

B
(R=0,G=0)

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

COLOR SPACES: CIE Lab

“Perceptually uniform” color space



Luminance = brightness
Chrominance = color

L
(a=0,b=0)

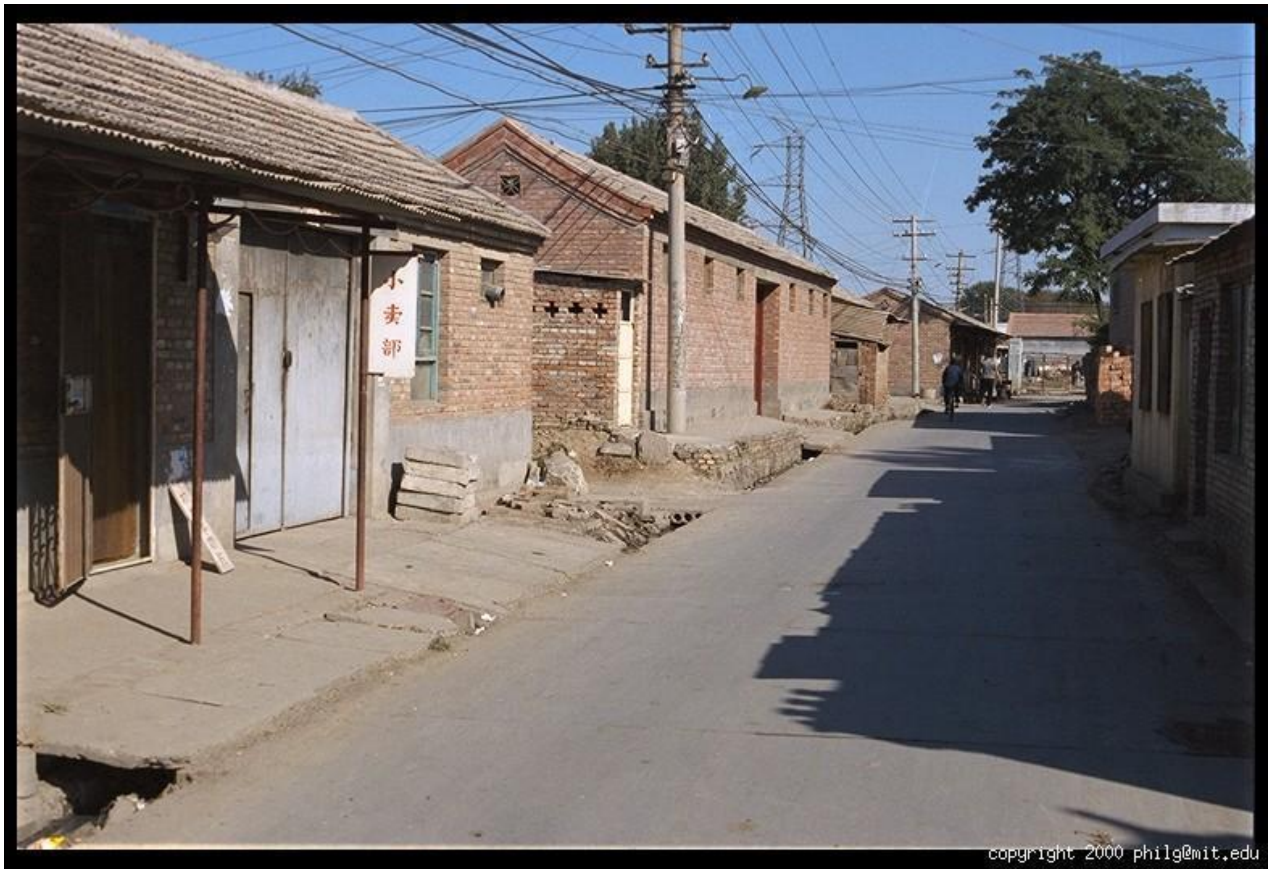
a
(L=65,b=0)

b
(L=65,a=0)

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

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

MOST INFORMATION IN INTENSITY



Original image

MOST INFORMATION IN INTENSITY

Only intensity shown – constant color

MOST INFORMATION IN INTENSITY

Only color shown – constant intensity

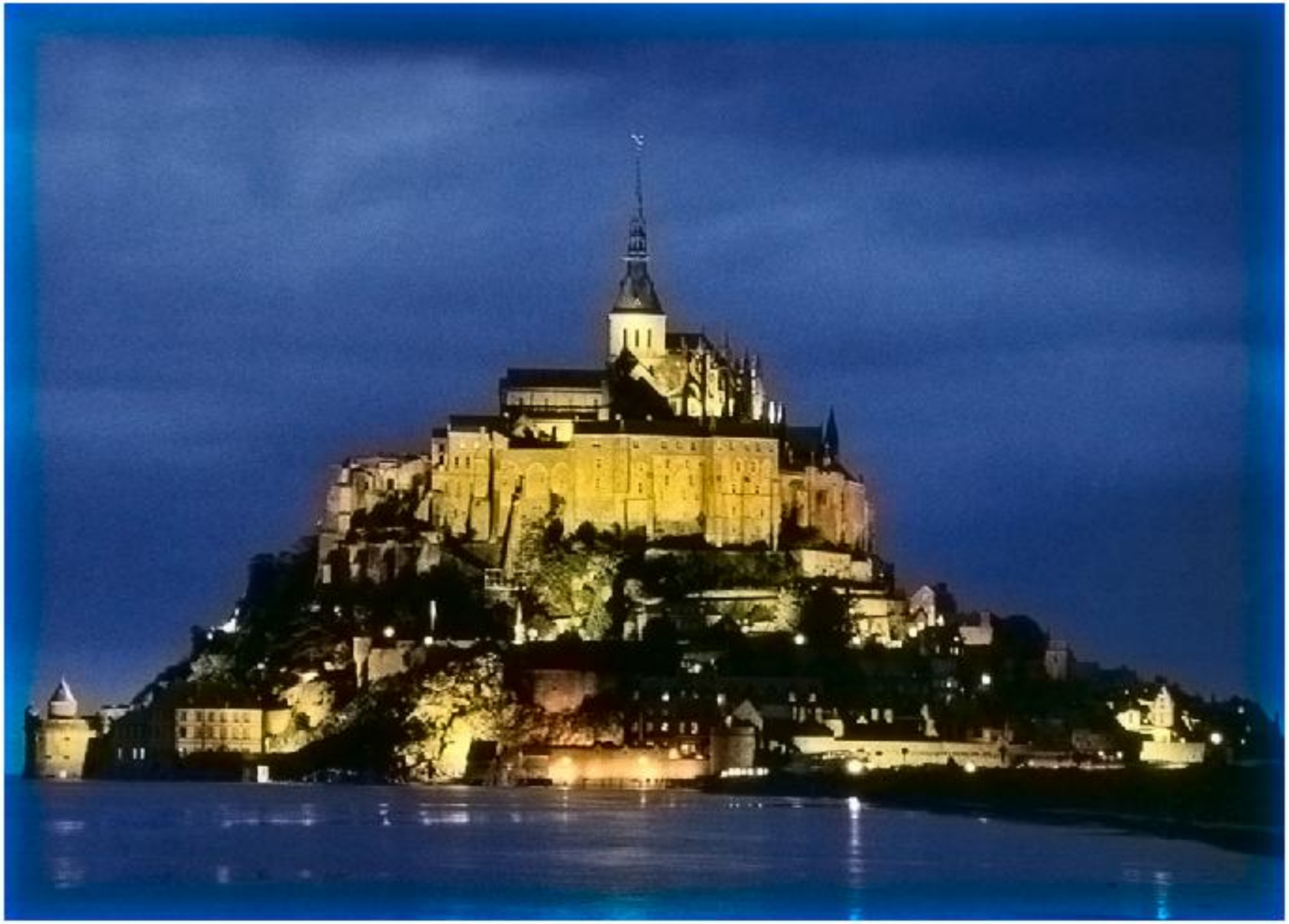
MOST INFORMATION IN INTENSITY

Original image

MOST INFORMATION IN INTENSITY

Color (r,g,b) filtered using a Gaussian filter of size 100 and std = 15

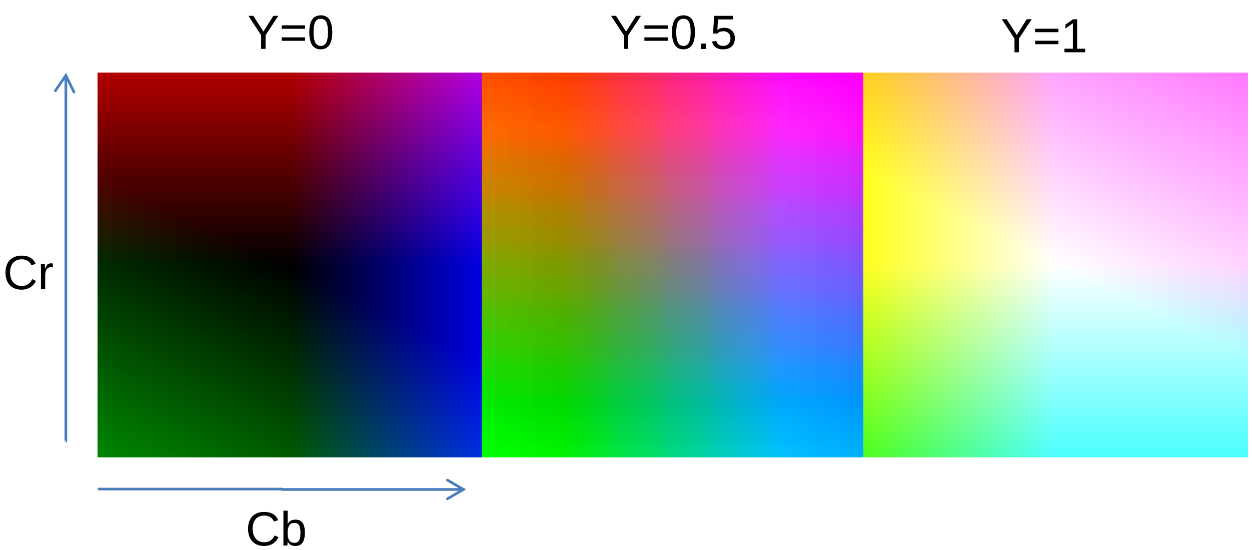
MOST INFORMATION IN INTENSITY



Color (a,b) filtered using a Gaussian filter of size 100 and std = 15

COLOR SPACES: YCbCr

Fast to compute, good for compression, used by TV



$$Y' = 16 + \frac{65.738 \cdot R'_D}{256} + \frac{129.057 \cdot G'_D}{256} + \frac{25.064 \cdot B'_D}{256}$$

$$C_B = 128 + \frac{-37.945 \cdot R'_D}{256} - \frac{74.494 \cdot G'_D}{256} + \frac{112.439 \cdot B'_D}{256}$$

$$C_R = 128 + \frac{112.439 \cdot R'_D}{256} - \frac{94.154 \cdot G'_D}{256} - \frac{18.285 \cdot B'_D}{256}$$

Y
(Cb=0.5,Cr=0.5)

Cb
(Y=0.5,Cr=0.5)

Cr
(Y=0.5,Cb=05)

Outline

- Linear adjustment
- Tone mapping
- Global histogram equalization
- Local histogram equalization
- Examples: vivid, improve overall contrast, correct for off-white illumination, film noir

ILLUMINANTS

Different illuminants have different color temperature

Our eyes adapt to this: Chromatic adaptation

Color temperature describes the spectrum of light which is radiated from a "blackbody" with that surface temperature.
A blackbody is an object which absorbs all incident light — neither reflecting it nor allowing it to pass through. A rough analogue of blackbody radiation in our day to day experience might be in heating a metal or stone: these are said to become "red hot" when they attain one temperature, and then "white hot" for even higher temperatures.

WHITE BALANCE PROBLEM

When watching a picture on screen or print, we adapt to the illuminant of the room, not that of the scene in the picture
The eye cares more about objects' intrinsic color, not the color of the light leaving the objects
We need to discount the color of the light source

White balance

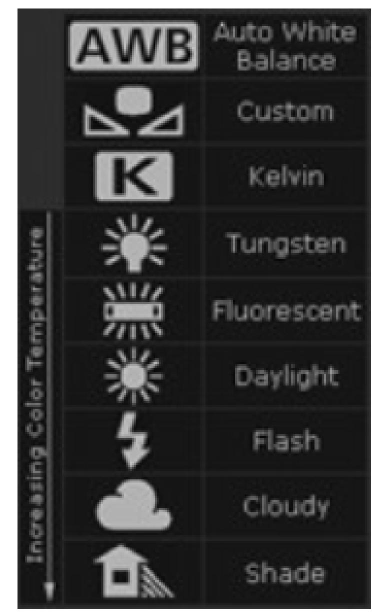
- When looking at a picture on screen or print, we adapt to the illuminant of the room, not to that of the scene in the picture
- When the white balance is not correct, the picture will have an unnatural color “cast”

incorrect white balance

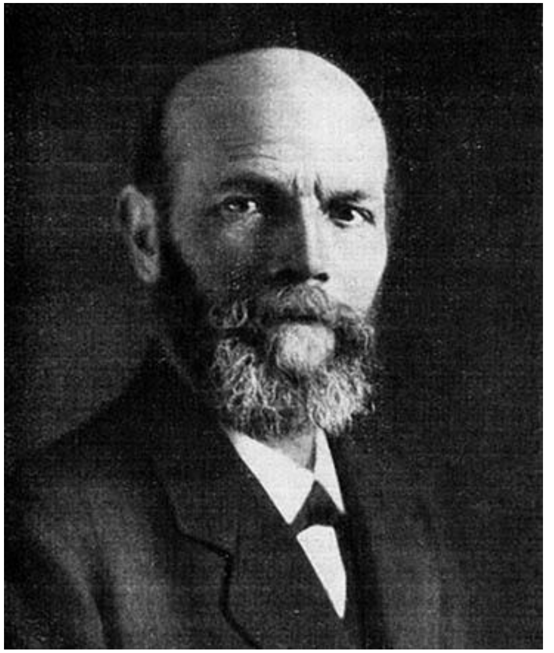
correct white balance

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



VON KRIES ADAPTATION



Multiply each channel by a gain factor

$$R' = R \cdot k_r$$
$$G' = G \cdot k_g$$
$$B' = B \cdot k_b$$

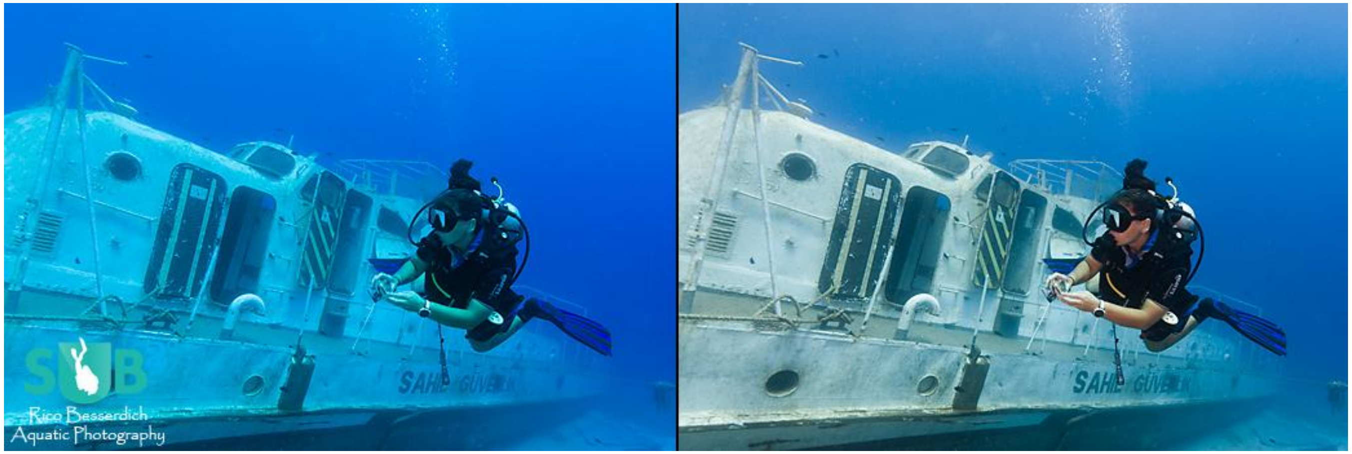
How do we find the factors?

Use grey cards:
Take a picture of a neutral object (white or grey)
Deduce a factor for each channel
Use weights:

$$k_r = \frac{k}{r_w} \quad k_g = \frac{k}{g_w} \quad k_b = \frac{k}{b_w}$$

k is a constant value depending on the exposure and the denominators are the values measured on the neutral object

Examples of images requiring White Balance



COLOR BALANCING

Without grey cards:

Grey world assumption: The average value of an image is grey. This can be used to detect distorsions.

Guess pixels corresponding to white objects

Brightest pixel is white

PLAYING WITH COLOR SPACES: COLOR TRANSFER

Source

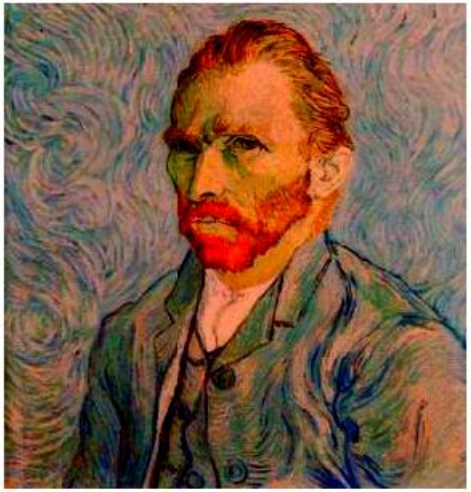
Targe
t

Result

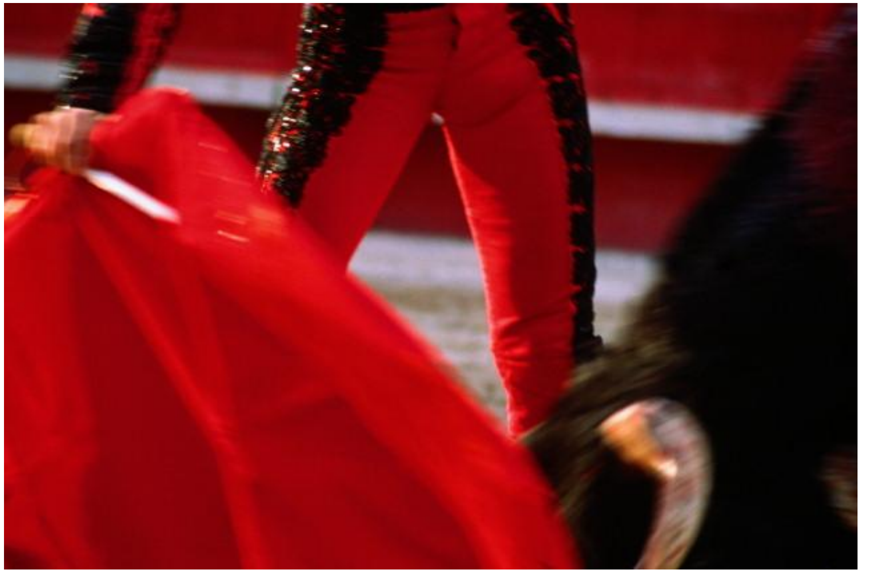
PLAYING WITH COLOR SPACES: COLOR TRANSFER

Originals

Transferences



Color Blindness

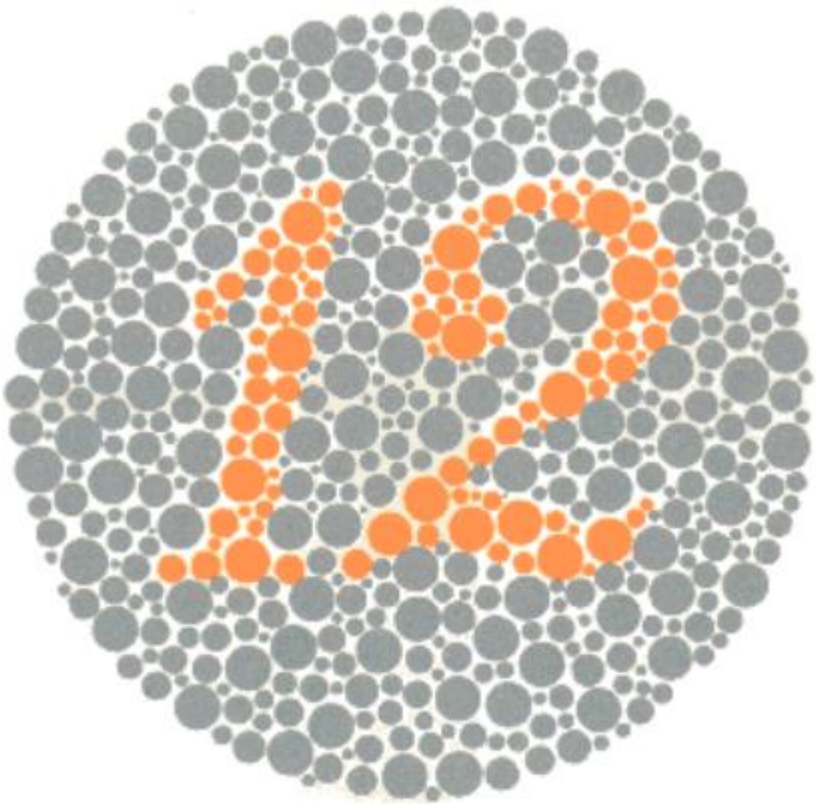


Are Bulls Angered by the Color Red?

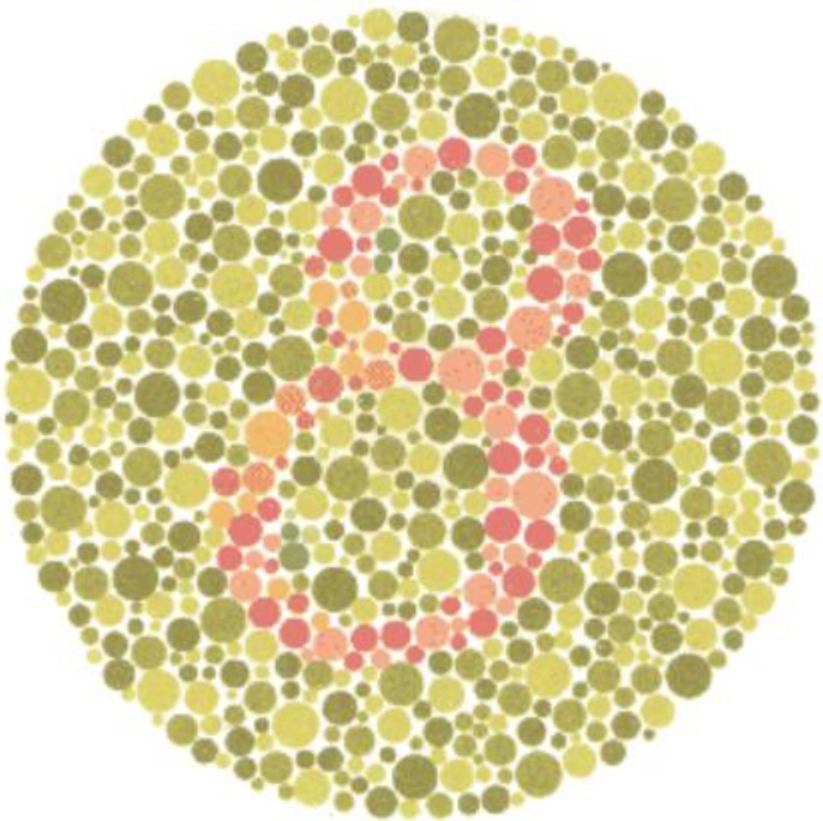
Are Cats, Dogs & Bulls Color Blind?

Cats, dogs, bulls, and many other mammals can see in color. Comparative to the human eye, other mammals do however see color in a different and more limited fashion. Scientifically speaking, dogs do not have L-Cones which means they cannot see red, but can see blue and green –

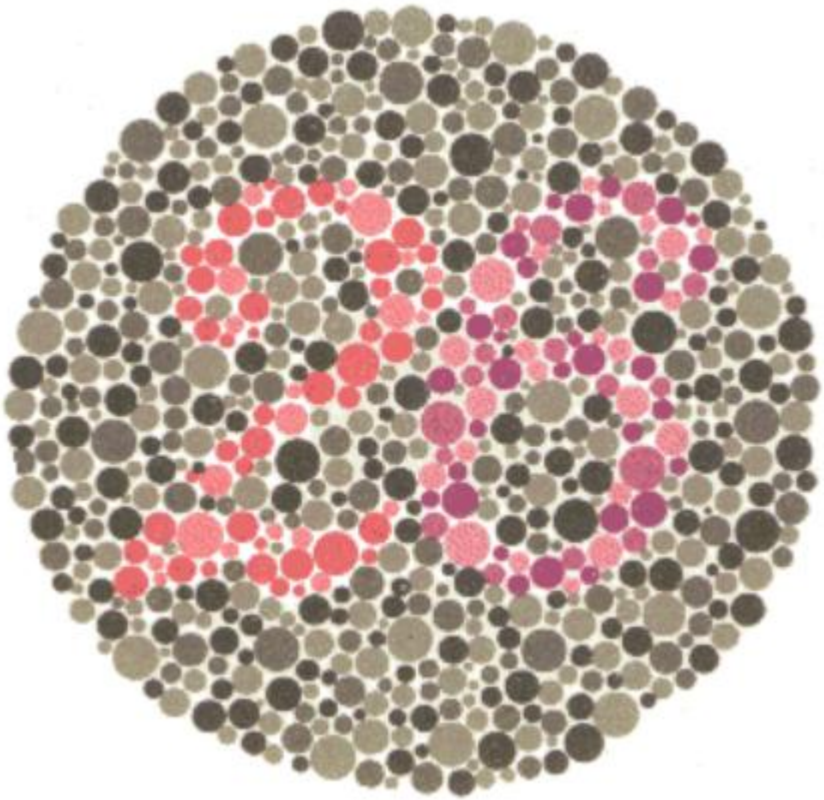
Color Blindness



Color Blindness



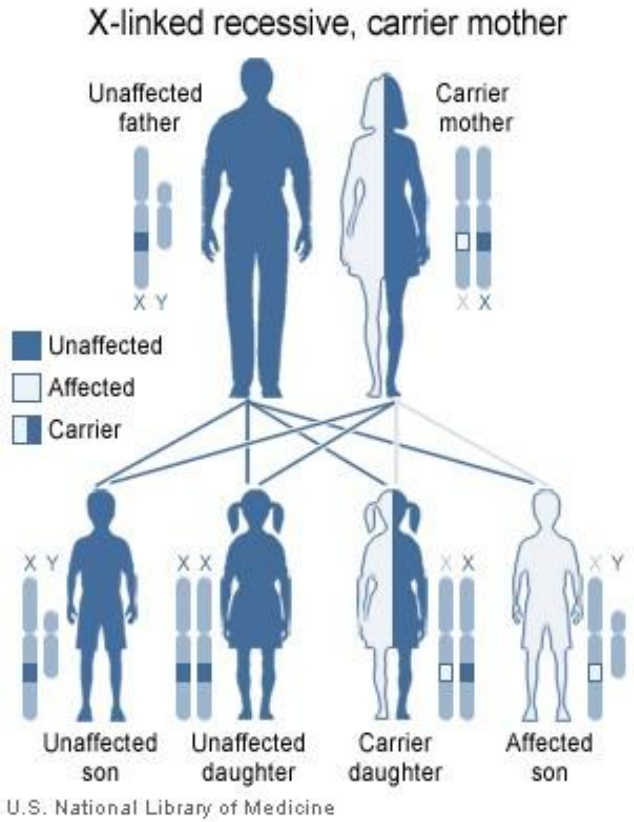
Color Blindness



Color Blindness

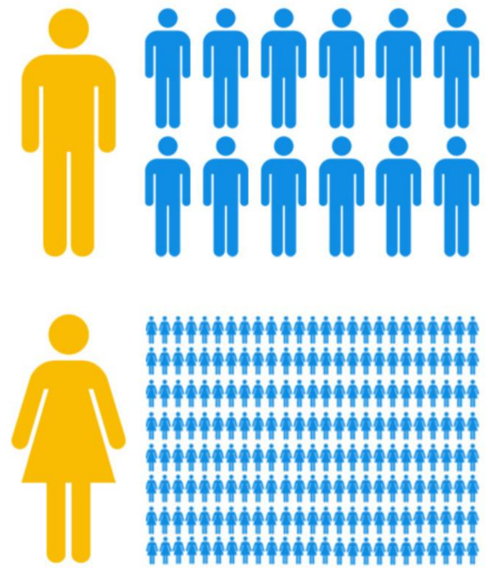
Causes

1. Non Hereditary Color Blindness
    1. Shaken Baby Syndrome:
    2. Trauma:
    3. UV Damage



2. Color Blindness from Gene Mutations

3. Color Blindness from Diseases



Color Blindness

Cone Cells and Color Blindness

The (normal) eye contains 3 types of cone cells, each containing a different pigment:

The L-cone detecting long wavelength light (peaking in the yellows – but also responsible for reds).

The M-cone detecting medium wavelength light (peaking in the greens).

The S-cone which detects short wavelength light (peaking with blue).

Your brain determines what color it is seeing by observing the ratio between the signals it receives from each of the three types of cones. Color blindness occurs when one or more types of cones are either totally absent, or has a limited spectral sensitivity.

Color Blindness

Anomalous Trichromacy
Anomalous trichromacy is most the common color vision deficiency “Deuteranomaly” , found in approximately 5% of all males. Anomoalous trichromacy occurs when one of the three cone pigments is altered, Sub-classifications of anomalous trichromacy:

1. **Protanomaly** is caused by defective L-cones, lowering sensitivity to red hues. weakened ability to distinguish between some hues of red and green.
2. **Deuteranomaly** is similarly caused by defective M-cones and is by far the most common form of color blindness, weakening the ability to differentiate red and green hues in as much as 5% of all males. Known as red green color blindness.
3. **Tritanomaly** is a rare form of color blindness, resulting from weakened S-cones. affects the ability to discriminate between blue and yellow

Dichromacy
In this case, the cone is either absent or non functional.
(Protanopia-Deuteranopia – Tritanopia)

Monochromacy
Monochromacy, more commonly referred to as “total color blindness”, is caused by the total absence of either 2 or 3 of the pigmented retinal cones, reducing vision to one dimension. It comes in two forms:

Rod monochromacy associated with sensitivity to light (Photophobia) and poor vision.

Cone monochromacy color blindness, accompanied by relatively normal vision.

How a color blind sees?