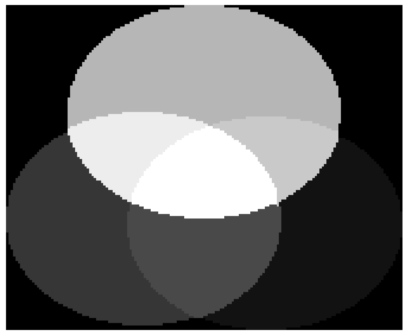
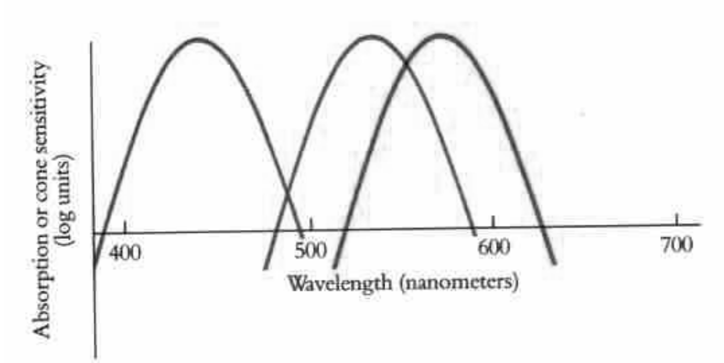
Color questions



9/25/2008 1

How do we see colors?

- Physiology:

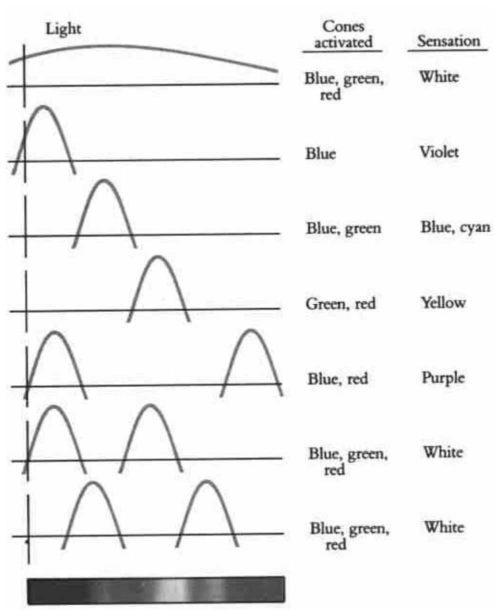


9/25/2008 2

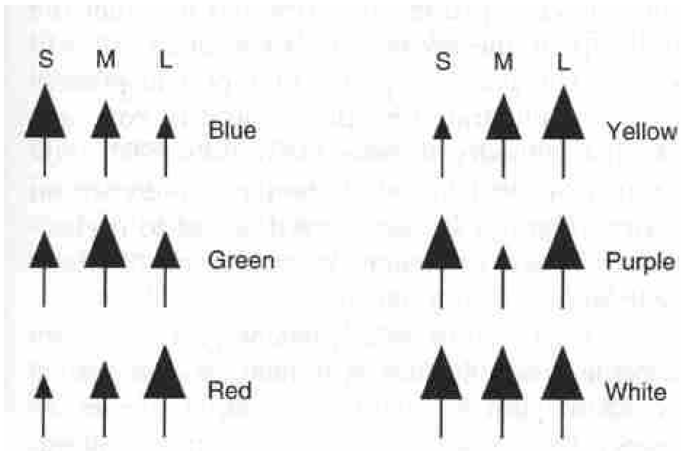
How do we see colors?

Trichromacy theory - Young and Helmholtz

- Psychological observations:
  - **Color Matching**
    - Thomas Young noticed that just by combining 3 primary colors of light (and adjusting their relative intensities), one could reproduce all colors of the spectrum (while two colors are too few)
    - Based on this observation, the design of color televisions included only 3 color channels: red, green, and blue (RGB)
    - Only these three colors are needed to be able to reproduce all the colors of the spectrum for the human eye



Our perception of color depends on the ratio of excitation in the three different cone classes



9/25/2008 5

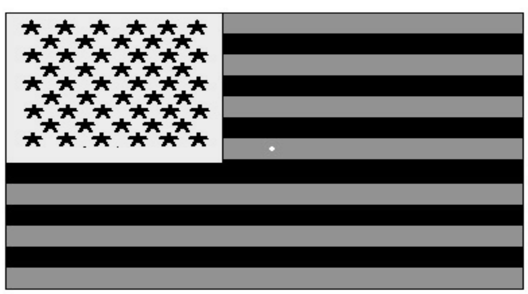
Summary so far…

- There are three cone types that differ in their photopigments
- The three photopigments are each selective for a different range of wavelengths
- If two lights evoke the same responses in the three cone types, then the two lights will look the same
- Trichromacy is basis of color technology in the print industry and color TV

9/25/2008 6

Trichromacy… is not the whole story

- Opponency Theory – Hering
- Psychological observations:
  - Ewald Hering noticed how even though we see colors that are both yellow and green, or red and yellow, or blue and green, it's really hard to imagine a color that is both red and green, or both yellow and blue
  - If you stare at green, you get a red after-image, if you stare at yellow, you get a blue after-image

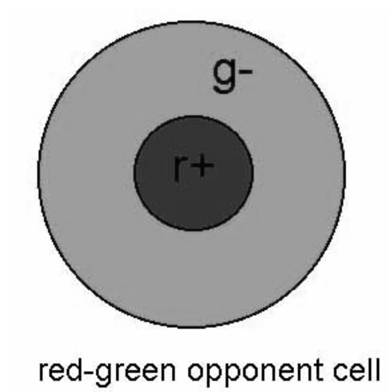


Opponency Theory

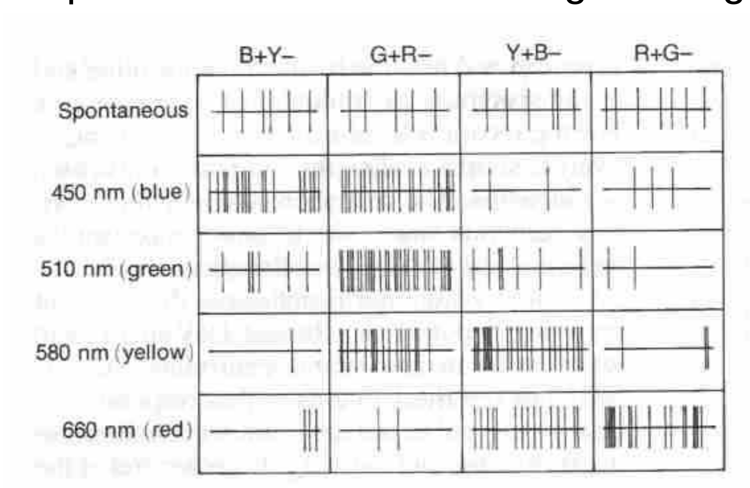
- Physiology:
  - Hering proposed that blue and yellow, and red and green are opponent colors that are processed in two independent channels (one for blue-yellow and one for red-green). And he was right!
  - In the LGN, there are color-opponent cells
  - There are both yellow-blue opponent cells and red-green opponent cells
  - These opponent cells have center/surround receptive fields (just like the many cells we've talked about already)

Opponency theory

(these red-green opponent cells respond best to a red spot of light surrounded by green)



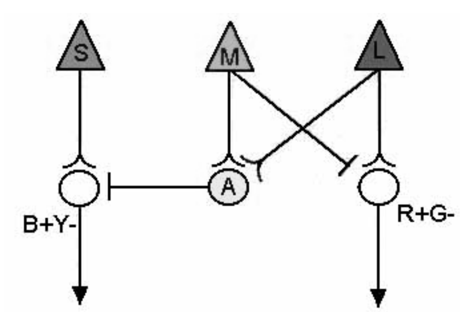
Firing patterns of opponent cells in response to different wavelengths of light

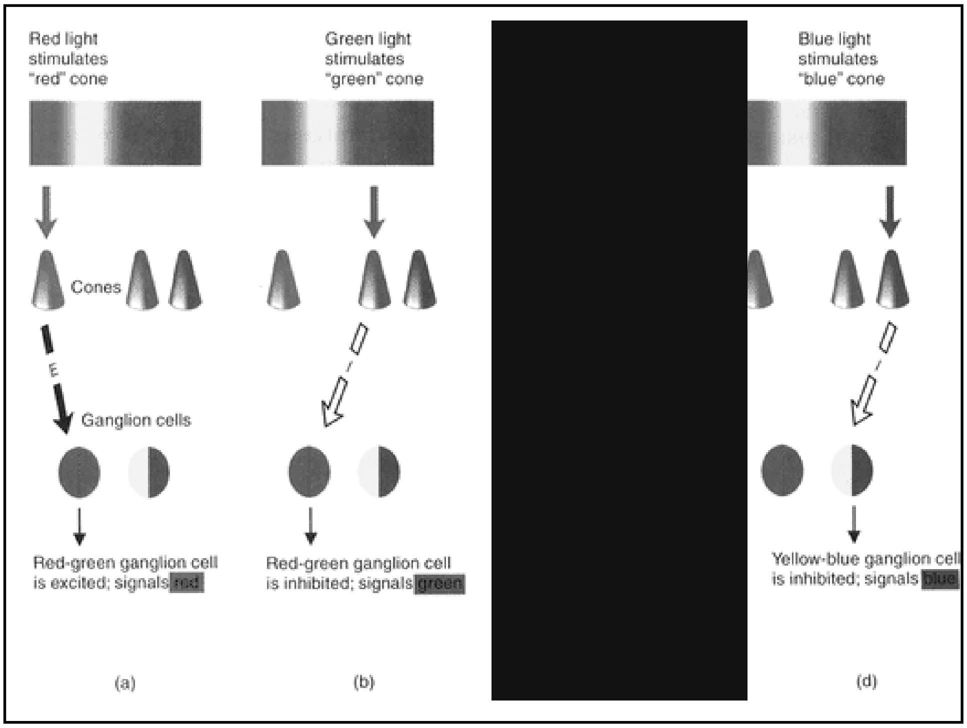


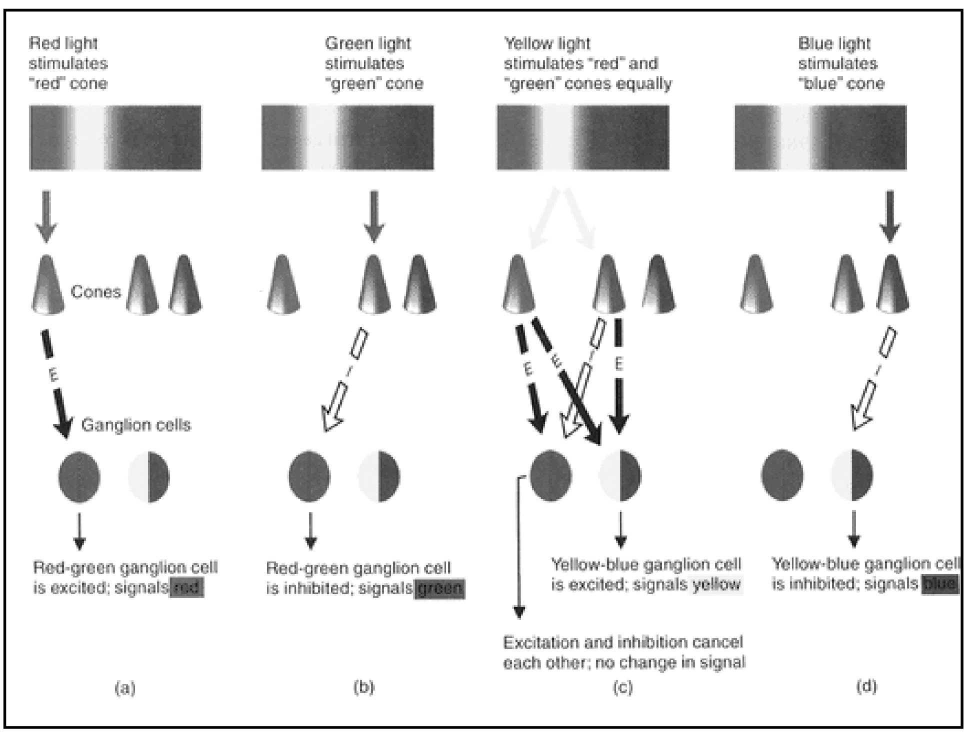
Puzzle: We don't have a yellow receptor. So how can we have a blue-yellow opponent pathway?

One solution: Since we know that green and red light together can make yellow, we can make a yellow receptor by making a cell that gets excitatory input from both red and green cones.

The cell marked (A) in this figure acts as a yellow detector:




Red light
stimulates
"red" cone
Green light
stimulates
"green" cone
[redacted]
Blue light
stimulates
"blue" cone
Cones
E
Ganglion cells
Red-green ganglion cell
is excited; signals red
Red-green ganglion cell
is inhibited; signals green
Yellow-blue ganglion cell
is inhibited; signals blue
(a)
(b)
(d)


Red light
stimulates
"red" cone
Green light
stimulates
"green" cone
Yellow light
stimulates "red" and
"green" cones equally
Blue light
stimulates
"blue" cone
Cones
E
Ganglion cells
E
E
E
Red-green ganglion cell
is excited; signals red
Red-green ganglion cell
is inhibited; signals green
Yellow-blue ganglion cell
is excited; signals yellow
Yellow-blue ganglion cell
is inhibited; signals blue
Excitation and inhibition cancel
each other; no change in signal
(a)
(b)
(c)
(d)

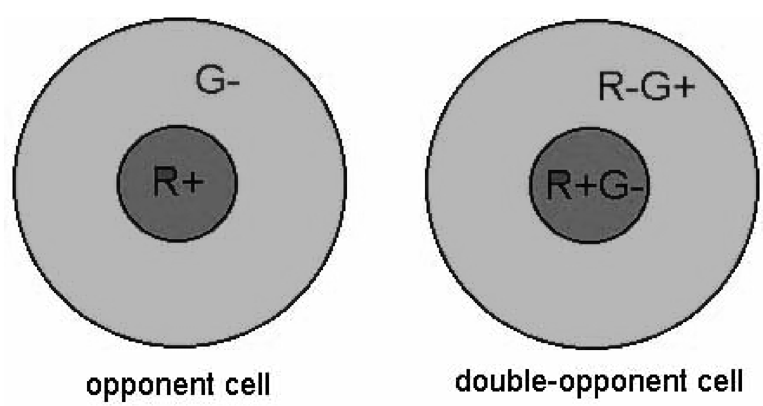
Double-Opponent Cells

- Sometimes lights of different wavelengths are perceived to be the same.
- Our perception of colors doesn't change too much depending on the illumination.
- A sweater might look the same sort of red to you both in daylight and in tungsten light even though its SPD is completely different

Why does this happen?

- The visual system must be doing something to account for the ambient illumination.

It turns out that in addition to simple opponent cells, we have **double-opponent cells (DO)**



- **Double-opponent cells reside in collections called blobs (no, really!) in layer 4 of V1**
- Double-opponent cells have larger receptive fields than simple opponent cells, so they can "see" more of the ambient illumination.
- Most importantly, double-opponent cells are responsive most to the difference in wavelength between light in the center and light in the surround of its receptive field.

- This means that a DO cell would signal the same level of activity whether the center is illuminated by red and surround by gray, or the center by gray and surround by green.
- All the DO cell cares about is the difference between red and green (not the absolute amount of either).
- The double-opponent mechanism allows us to account for differences in ambient illumination.

Metamaric and nonmetamaric lights

- **Metamers** are lights that are physically different (*have different spectral compositions*) but appear identical

- The underlying notion is that color is due the **ratio** of activity in the three cone classes

Physically different lights creating the same ratio…should look the same

- For example, in matching yellow with red+green, the cones couldn't tell whether they were being stimulated by a monochromatic yellow (say 580 nm) or the red and green lights (a 530 nm and 630 nm)

- This is due to the **"principle of univariance"**…once a cone captures light, it can't tell what the light's wavelength was

- Some lights that normals can distinguish are metamers for colorblind people

Principle of Univariance

- The result is that **a single type of cone cannot distinguish color from luminance**
- Alternating between equally bright "red" and "green" wavelengths, or flickering a single wavelength of light between bright and dim, will produce identical cone outputs
- The L, M or S cones by themselves are completely colorblind

Principle of Univariance

- A cone responds to light anywhere within its span of sensitivity, but it can only respond through a change in its baseline activity — signaling *more* or *less*
- The cone output will signal "more" as the light becomes more intense, or as the light wavelengths move closer to its peak sensitivity, but all wavelengths, and all changes in light intensity, can produce the same "more" or "less" response.
- This is the **principle of univariance**

Deficits of color perception

- About 4% of males have some sort of color deficiency
- Color-deficiency often goes unnoticed until late in life
- In fact, one of the earliest reports of color-deficiency was in the 1800's by English chemist John Dalton
  - He was a Quaker and caused quite a stir by wearing a scarlet robe to his Ph.D. graduation. Later it became clear that scarlet, gray and dark green-blue appeared exactly the same to him.

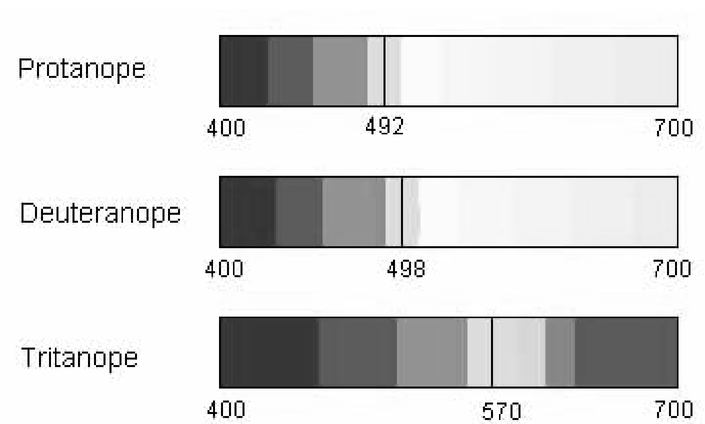
Types of color deficiency

- **Monochromats** are missing all 3 cone types:
  - very rare
  - only have rods
  - don't see color at all, only different shades of gray
  - have to wear dark sunglasses during the daytime, otherwise their photoreceptors are fully bleached and they are effectively blind

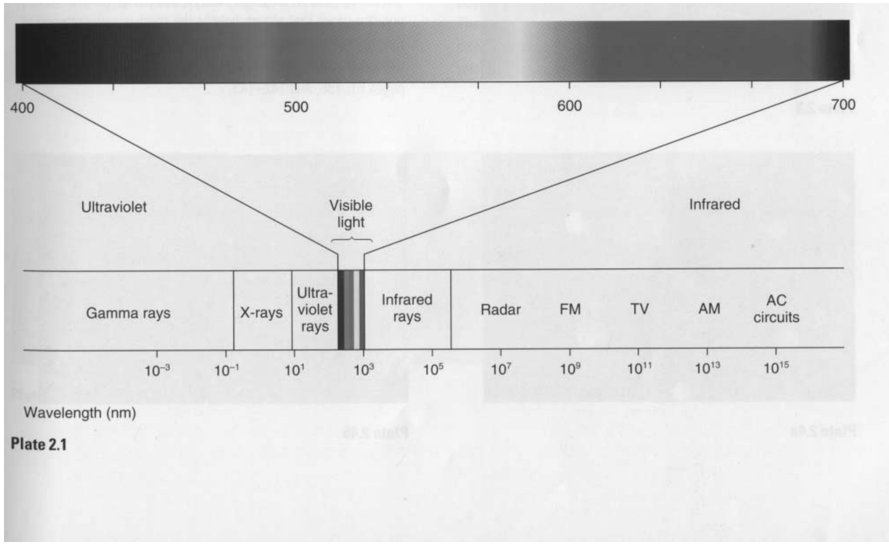
Dichromats

- **Protanopes**: missing the long-wavelength visual pigment, only see blue and yellow, hereditary & sex-linked
- **Deuteronopes**: missing the middle-wavelength visual pigment, only see blue and yellow, hereditary & sex-linked
- **Tritanopes**: only see blue and red, very rare

Dichromats can see some color, but not as big a range as trichromats



Visual Spectrum



9/25/2008 29