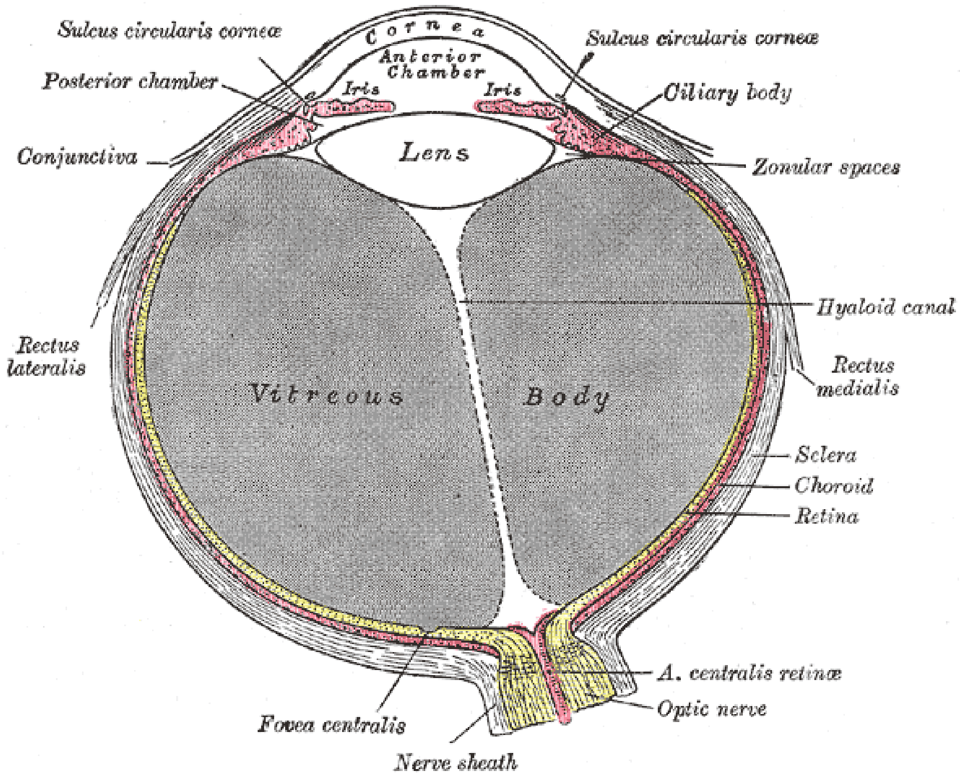


From *Grey's Anatomy*

Visual Anatomy & Transduction

10/13/14

Reminders

- Quiz 1 (on Ted) is due before midnight.
- Lab 1 is being done in section this week.
- Any iClicker opt-out requests need to be to me today.
- Keep up with the reading (chapter 2)!
  - We may not always get to all the relevant details in lecture.

Reminders

<u>Reality check</u>

Thus far, the <u>pace</u> of the lectures has been:

A. Very fast
B. Kind of fast
C. About right
D. Kind of slow
E. Very slow

Today

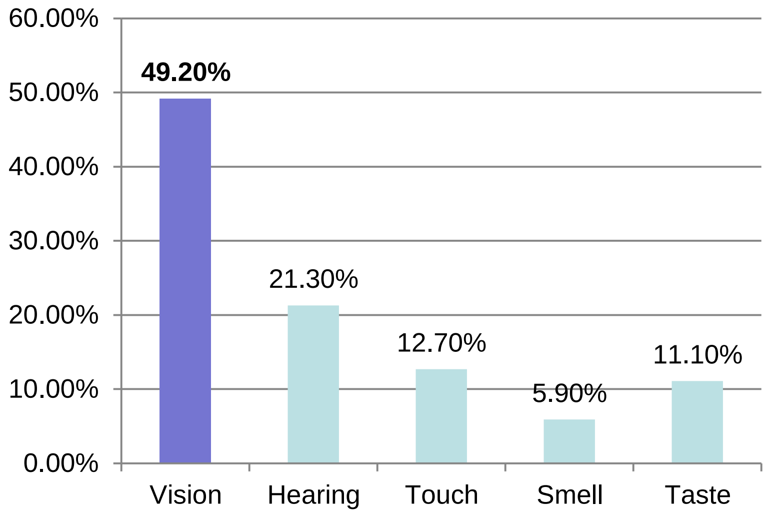
Functional eye anatomy

- ✓ Basic eye structure and function
- Photoreceptors and light transduction
  - Rods and cones

Vision

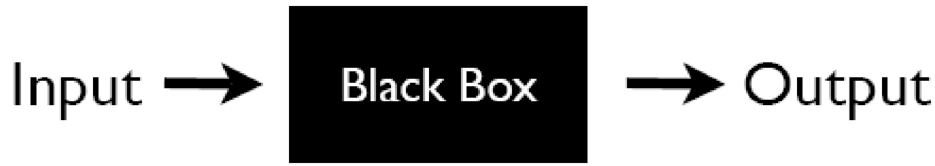
<u>Vision is the most popular sense</u>

- “I **use sight the most** and i'd have a lot of trouble doing daily tasks if i couldn't see. Also, it's nice to be able to see colors, art, movies, pictures, people's faces, etcetera.”
- “I am a **visual learner** and it's a sense that I don't think I can live without.”
- “As an amateur photographer and someone who has a keen attention to detail, I have a great appreciation for the **visual beauty of life**.“
- “So much of our **evolution and culture** as human beings is defined by what hits our retinas! When you take into account the most beautiful things that humans create - paintings, sculpture, literature, film, even most media - these things are primarily rooted in vision...”



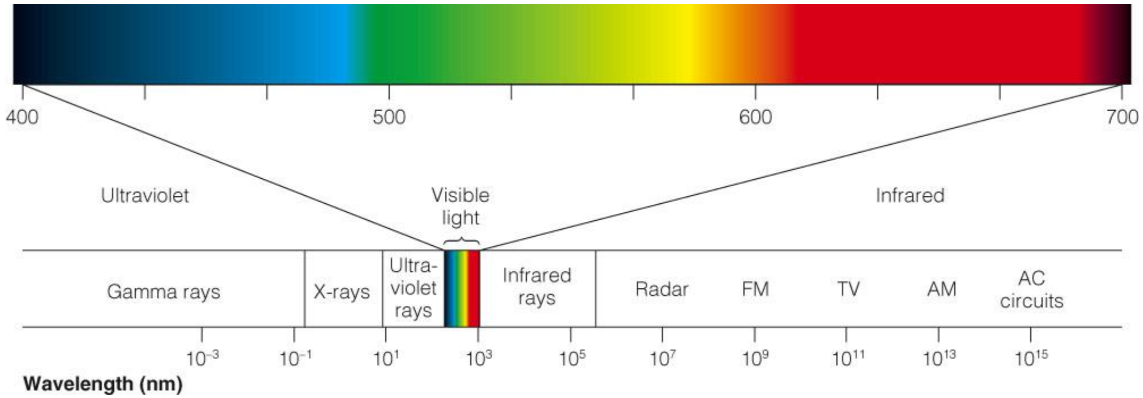
Functional eye anatomy

Using Marr’s first level of analysis (computational), how would we describe the eye’s function?



Basic function

The human eye is sensitive to a narrow portion of the electromagnetic spectrum. Our visual spectrum ranges from 400 to 700 nanometers.



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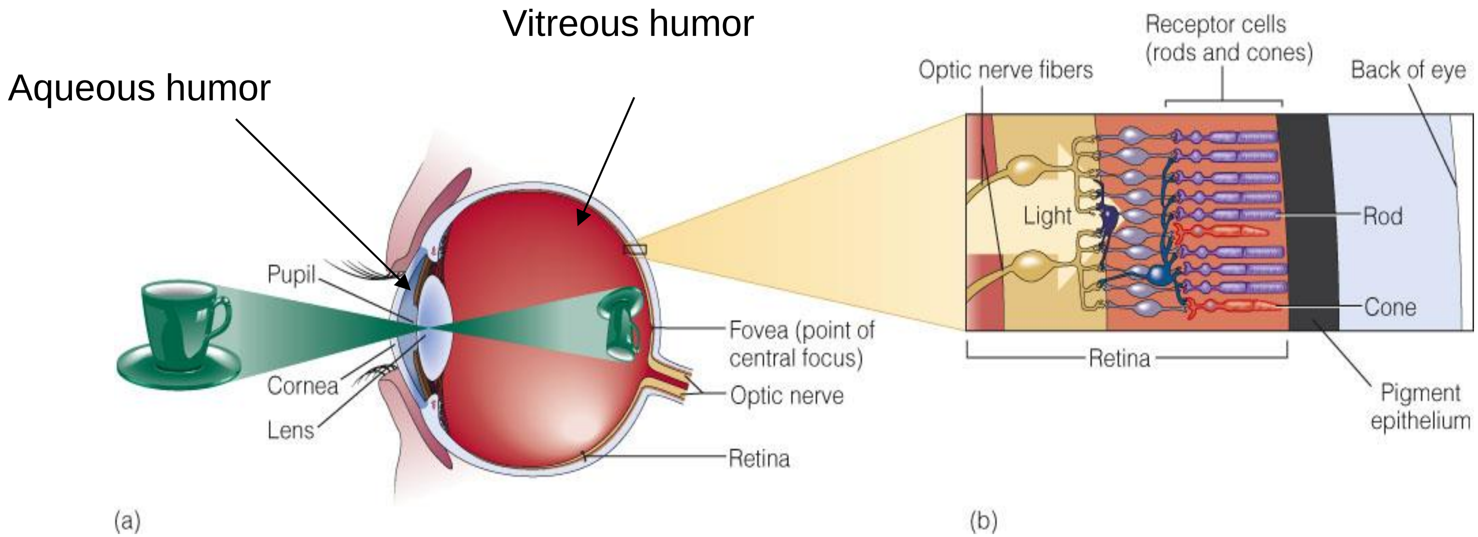
Functional eye anatomy

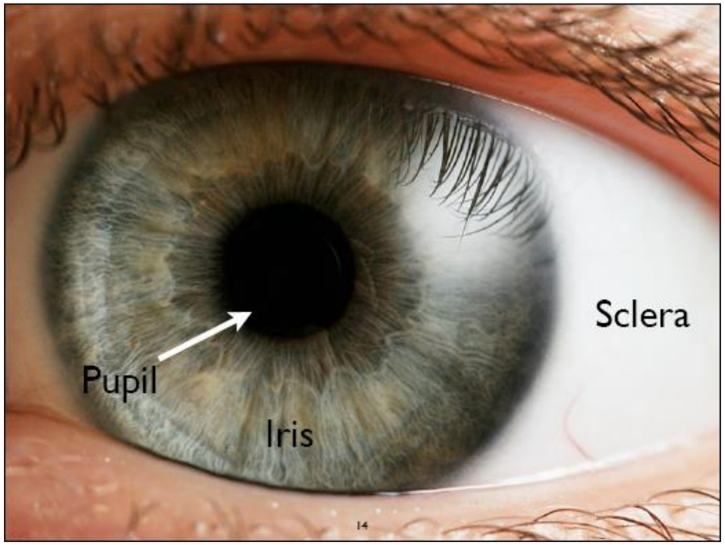
How does light get to the receptors in the eye?

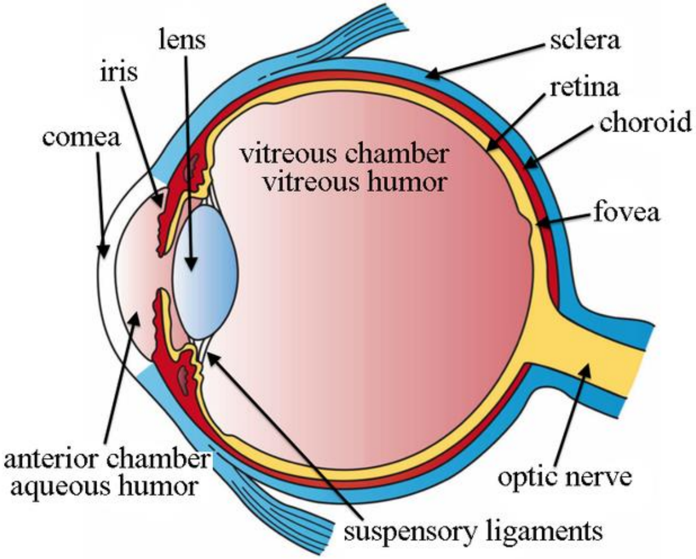


Functional eye anatomy: optics

Iris and pupil size

- The **iris** can either constrict or expand to regulate light input to the eye.
- This is an automatic response to environmental light intensity.
- Constriction in one eye, in response to light, causes the other pupil to constrict, even without direct light (**pupillary light reflex**).
- Less light (and states of emotional arousal) also dilate the pupil, making it larger.

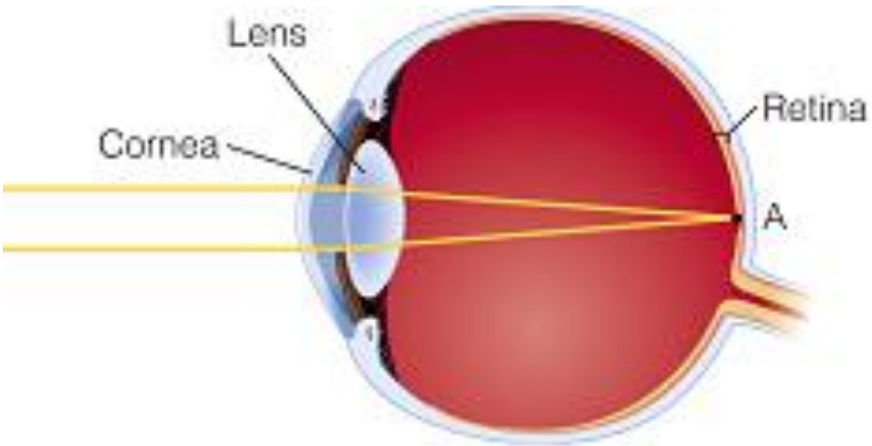




Functional eye anatomy: optics

Focusing light

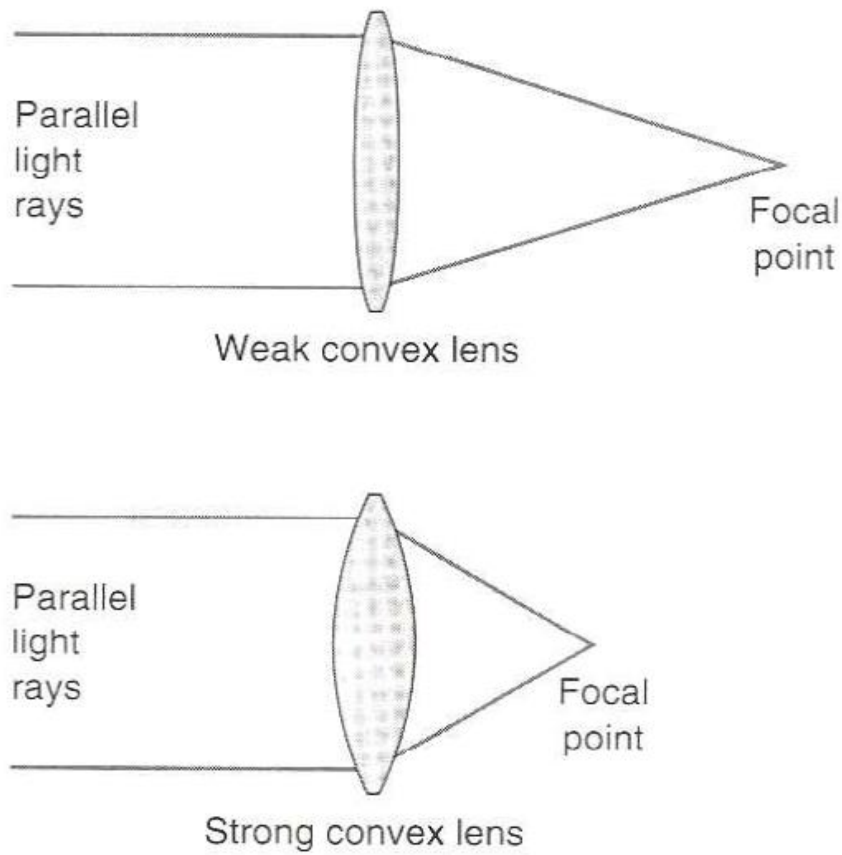
- The **cornea** is a transparent structure that provides about 80% of the eye's focal power.
- The **lens** is flexible and its curvature (thickness) can be adjusted to focus light on the retina. This is called **accommodation** and accounts for 20% of focusing power.
- The closest point at which a <u>relaxed</u> eye makes an object appear clear is the **far point**.
- The closest you can bring an object and <u>keep it in focus</u> is called the **near point**.



Functional eye anatomy: optics

Focusing light

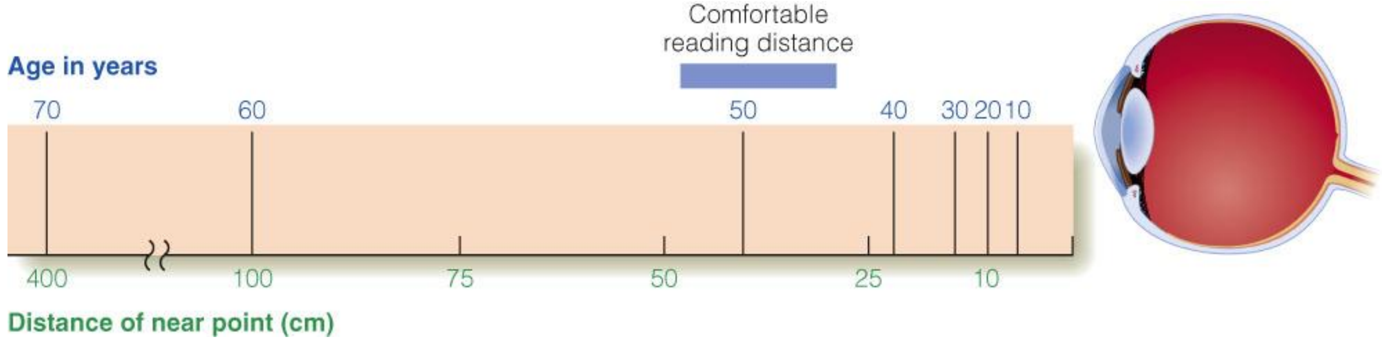
- The goal is to focus light on the back of the retina.
- A flattened lens (**ciliary muscle** *relaxed*) will bend the incoming light less, resulting in a more distant focal point.
- A fatter, more convex lens (ciliary muscle *constricted*) will bend the light more. This brings the focal length closer to the lens.
- Accommodation is just the process of changing the lens shape in the eye.



Functional eye anatomy: optics

Age related changes in the lens

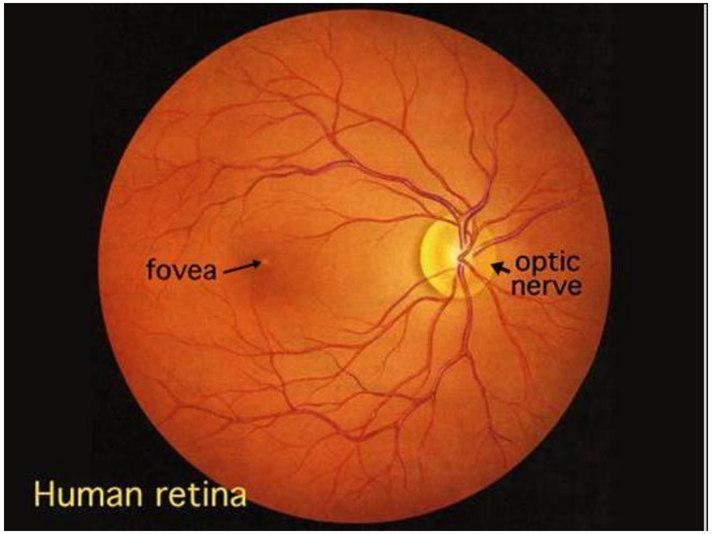
- The lens gets harder and less flexible as you get older.
- The ciliary muscles controlling the lens can also weaken.
- The distance of the near point will then increase. This is called **presbyopia** ("old eye").
- Also a greater chance of cataracts – clouding of the lens – as you get older.

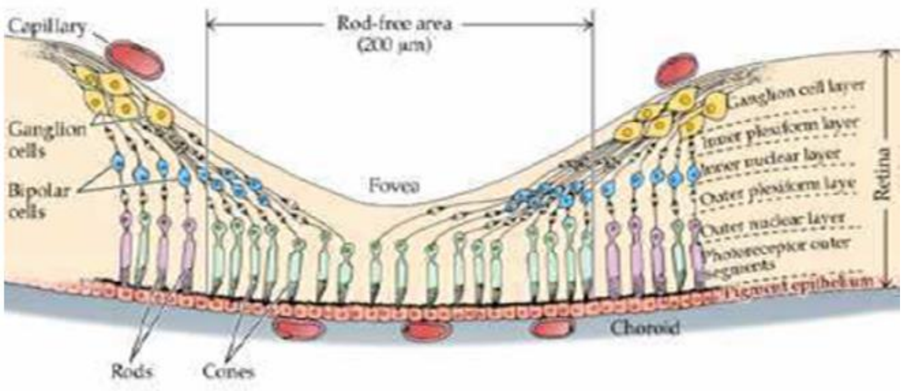


Functional eye anatomy: optics

Detail vision

- Incoming light is focused on the **macula**, a cone-rich area that allows high-resolution vision. It has a yellow pigment that absorbs blue and ultraviolet light.
- The **fovea** is in the center of the macula. It has the densest concentration of cones that provides fine detail vision.
- It is also largely free of ganglion cells and capillaries, allowing more light through.
- Optimal vision occurs when cornea and lens focus light directly into the center of the fovea's surface.

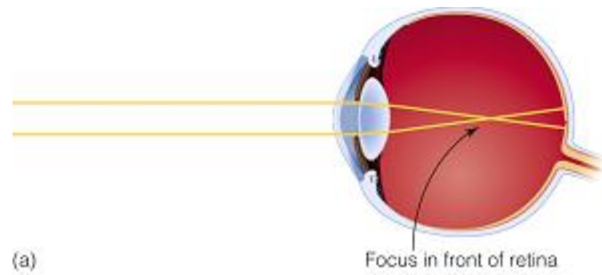


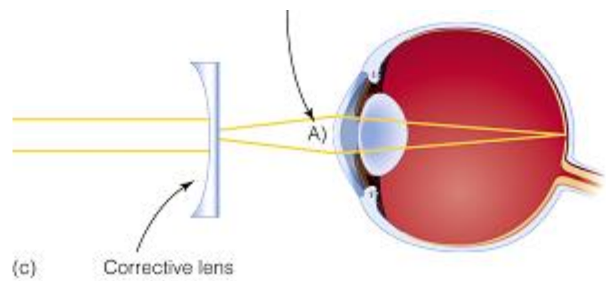


Functional eye anatomy: optics

Myopia (nearsightedness)

- An inability to clearly see objects at a distance.
- Distant images are focused in front of the retina.
- There are two types:
  1. Refractive myopia – the cornea or lens converges (focuses) light too much.
  2. Axial mypoia – the eye is too long.
- The treatments are to use a corrective lens or to reshape (flatten) the cornea.

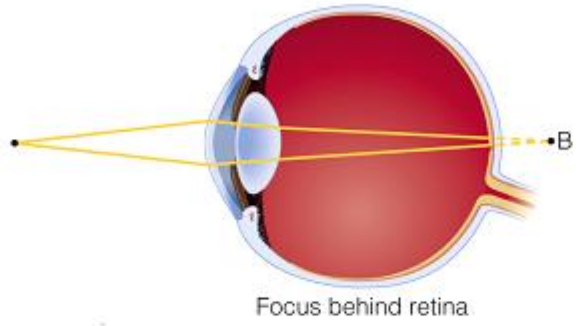




Functional eye anatomy: optics

Hyperopia (farsightedness)

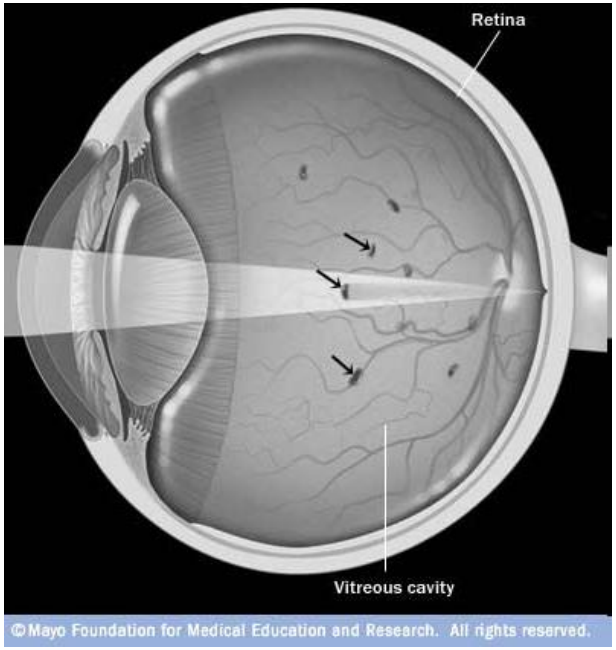
- An inability to clearly see close objects.
- Distant images are focused beyond the retina.
- As before, cause can be due to cornea or lens shape, or length of eye (too short).
- The treatment is usually a corrective lens or surgery.



Functional eye anatomy: optics

Vitreous humor

- After passing through the lens, light must travel through the **vitreous humor**, a gelatinous substance that helps maintain the shape of the eye.
- **Floaters** can sometimes be seen in the vitreous as debris (blood cells, clotted vitreous, etc.) casts a shadow on the retina.
- Most people experience floaters, though an abrupt increase can signal a detached retina, retinal tear, or other injury.



Functional eye anatomy: optics

Progress check

If your cornea refracts (bends) light too much, you are most likely to have which of the following vision problems?

A. Presbyopia

B. Myopia (nearsightedness)

C. Hyperopia (farsightedness)

D. Floaters

Functional eye anatomy: design considerations

Since you know that detail vision involves focusing light and images onto the fovea, how does this affect the design of cognitive artifacts?

In one example, consider the size and placement of icons on typical smart phones and tablets. They typically fall within foveal vision (roughly 2°) and are separated by white (blank) space.

uxmatters.com

Functional eye anatomy: design considerations

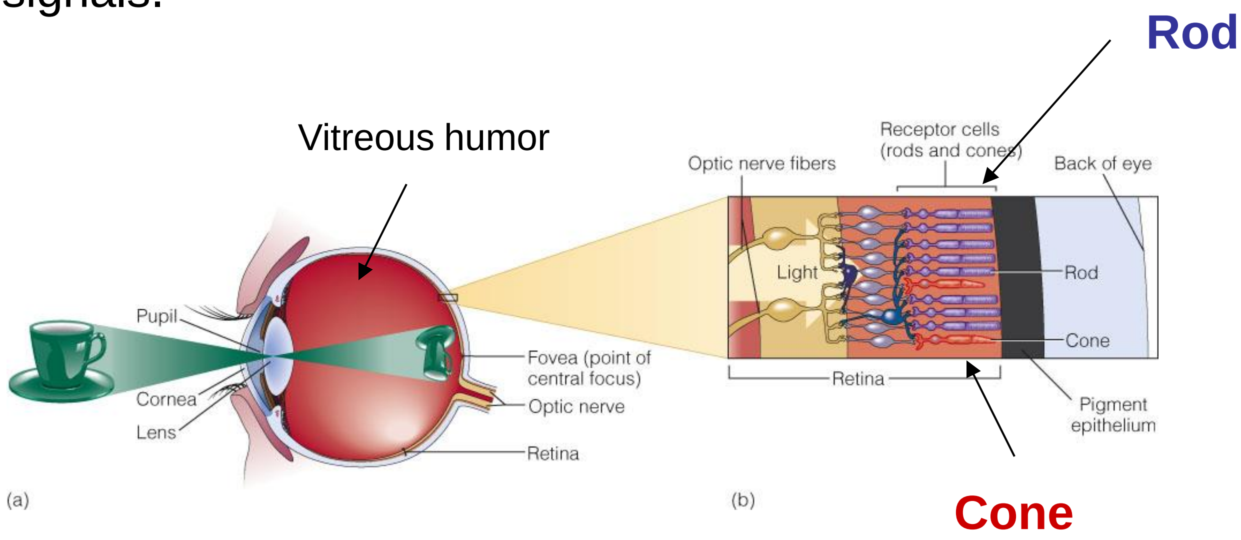
How can developmental differences affect how you design visual images for specific groups?

<u>For young users</u>:

- Make visual images colorful, but simple.
- Text can be very small – even to exclude older users.

Functional eye anatomy: transduction

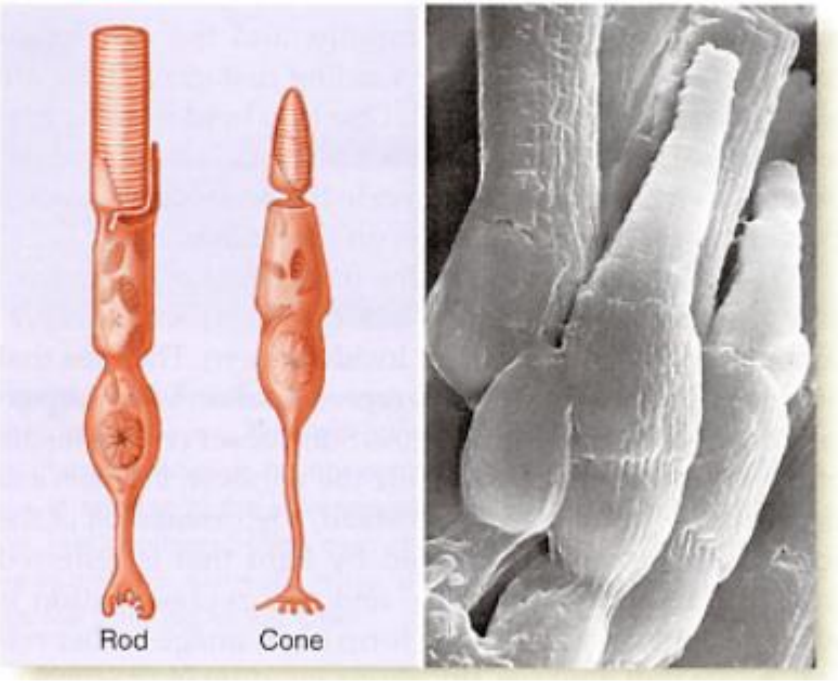
Once you get through to the retina, you can begin the process of transduction – changing light energy into neural signals.



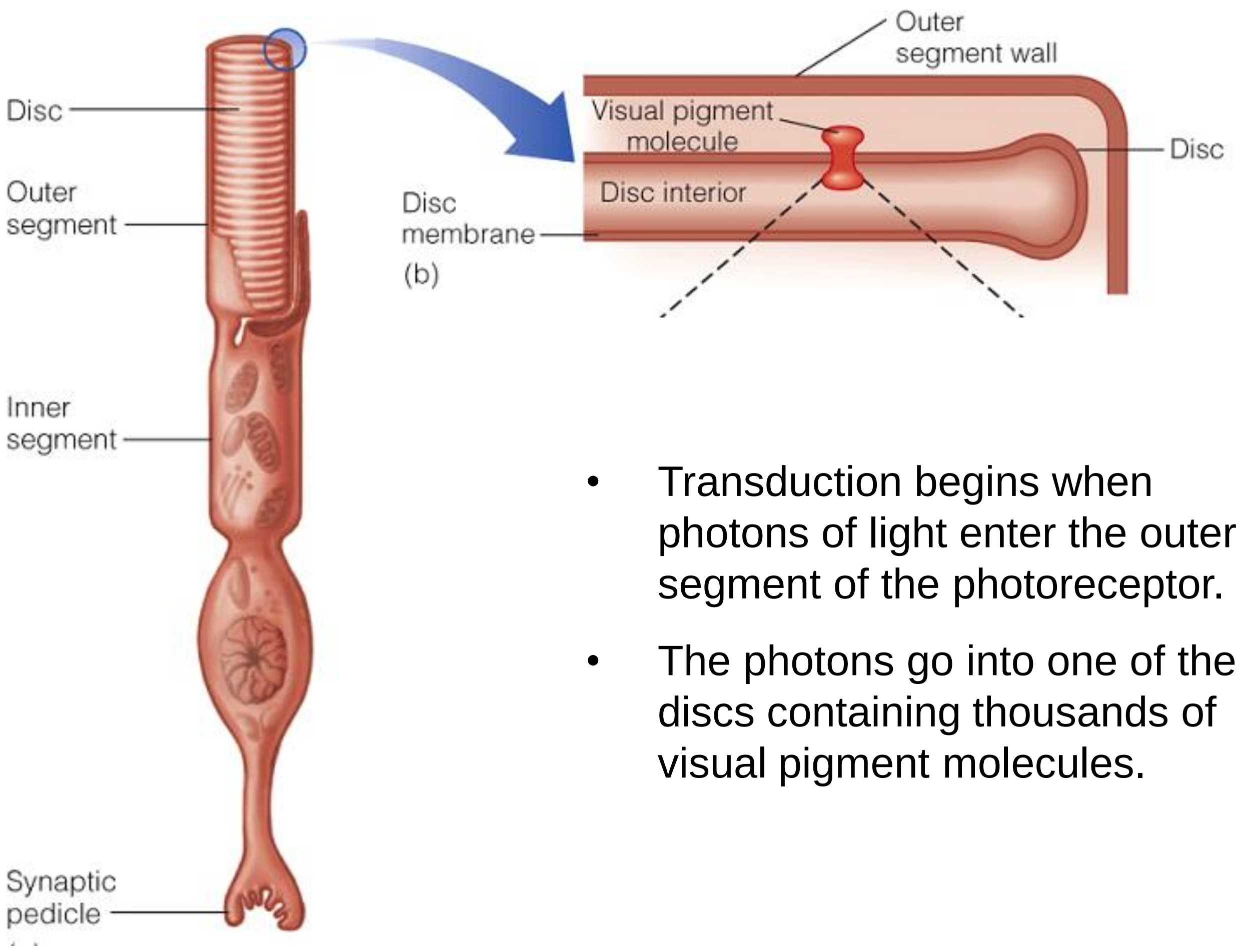
Functional eye anatomy: transduction

Rods and cones have different properties, but function similarly during transduction of visible light.

A third type of visual receptor, the **intrinsically photosensitive retinal ganglion cell (ipRGC)**, helps regulate circadian rhythms and the pupillary reflex.



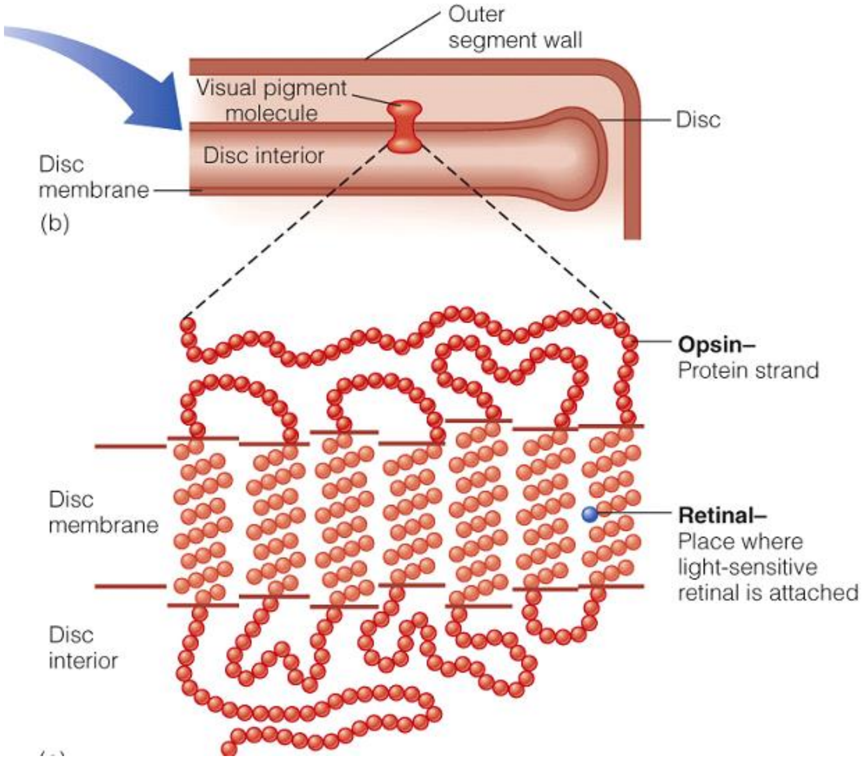
Functional eye anatomy: transduction



- Transduction begins when photons of light enter the outer segment of the photoreceptor.
- The photons go into one of the discs containing thousands of visual pigment molecules.

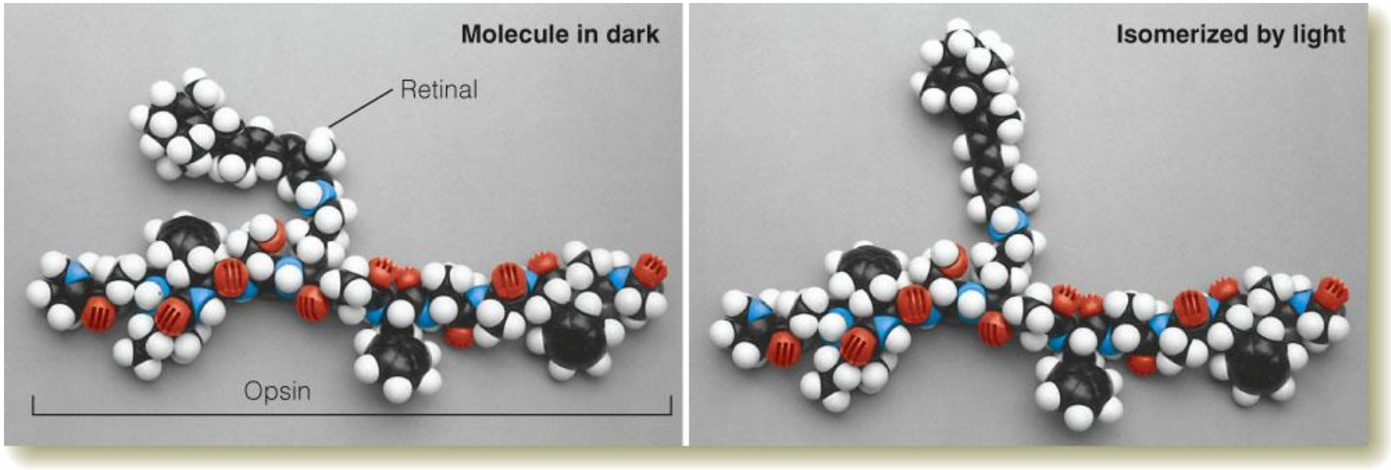
Functional eye anatomy: transduction

- The visual pigment molecule is a long protein strand called **opsin**.
- Only one location on the protein strand is reactive to light – the **retinal**.
- Each visual pigment molecule has only one retinal.



Functional eye anatomy: transduction

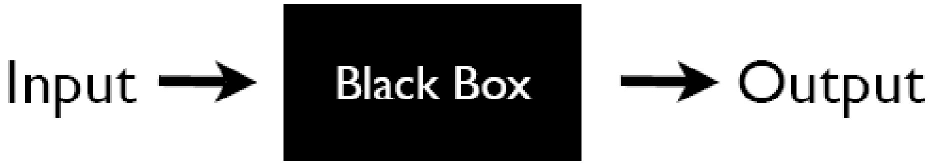
If a single photon of light is absorbed by a retinal molecule, the molecule changes shape (and later separates), a process called **isomerization**. This one triggering event leads to an enzyme cascade – thousands of chemical reactions leading to a change in receptor activity.



Functional eye anatomy: transduction

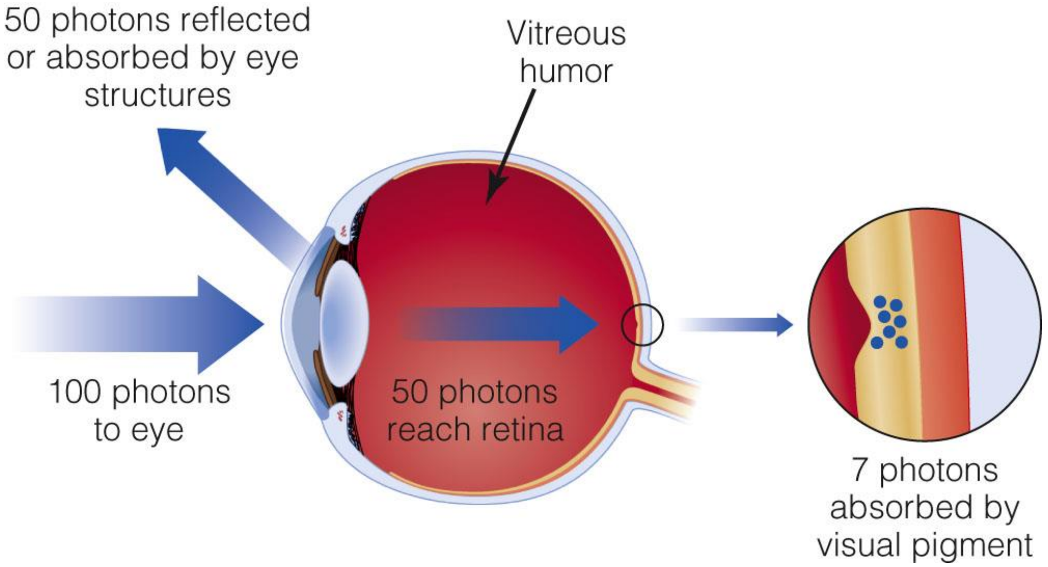
How many visual pigment molecules need to go through isomerization to be detectable by a person?

- Selig Hecht and colleagues (1942) attempted to answer this question with a very clever *psychophysics* experiment.
- Asked: How much light is needed for detection?
- Using a precisely calibrated light source, he determined that a person could detect a flash of light containing just 100 photons (using the method of constant stimuli).



Functional eye anatomy: transduction

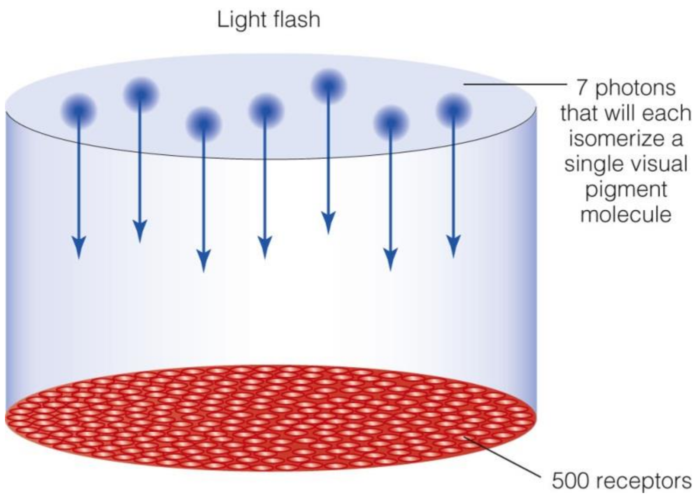
Hecht then calculated the number of photons lost before reaching the retina and determined that 7 of the 100 photons was absorbed by the light-sensitive *retinal* molecule on the visual pigment.



Functional eye anatomy: transduction

Hecht then went further to ask how many visual pigment molecules must be isomerized to activate a single rod receptor.

- The small size of the test light suggested that the photons would encounter about 500 receptors.
- He concluded that it was *unlikely* for more than one photon to reach a single receptor.
- Therefore, activation of 7 rod receptors must make a test signal perceptible.



Functional eye anatomy: transduction

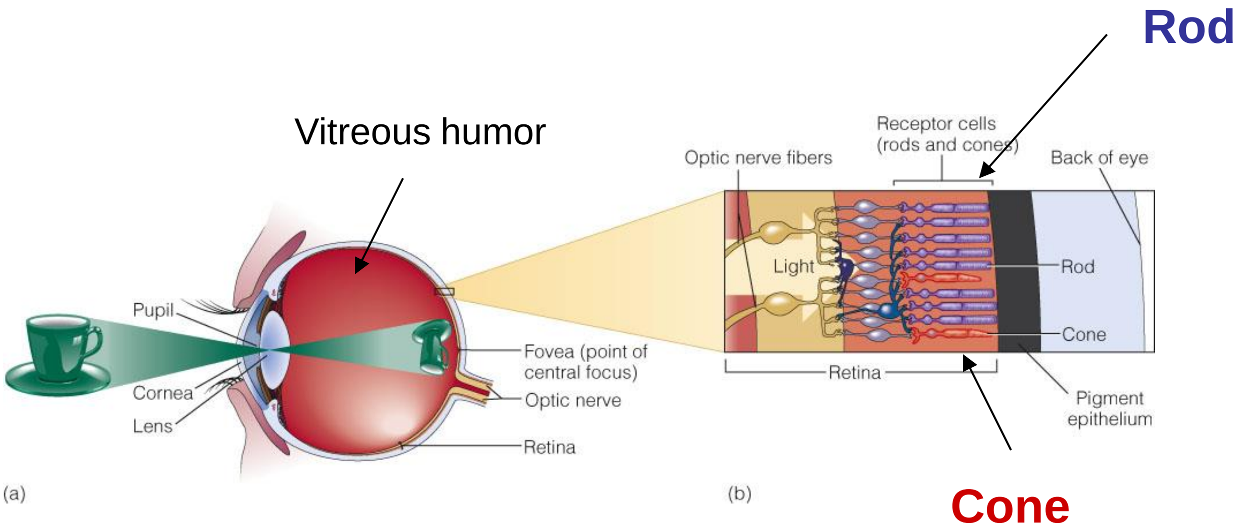
Progress check

The specific part of the visual pigment that reacts to light, triggering the enzyme cascade, is the:

A. Opsin
B. Retinal
C. Disc
D. Outer segment
E. Inner segment

Functional eye anatomy: transduction

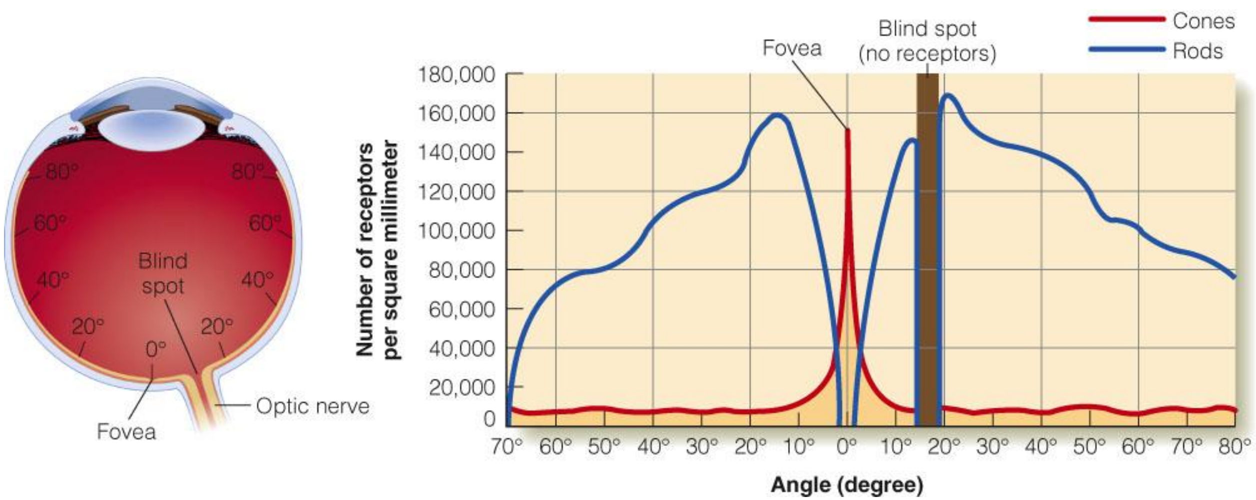
We know how light comes in, is focused on the retina and is transduced into a neural signal. Now we will look at the different characteristics of the receptors that respond to the light.



Functional eye anatomy: rods & cones

Differences between rods and cones

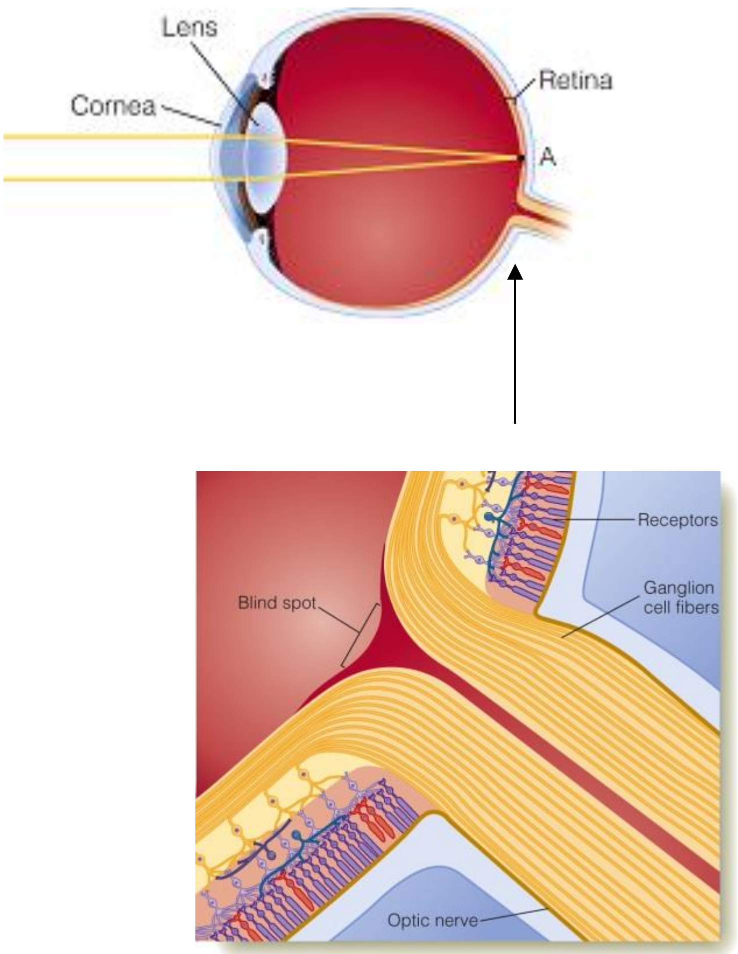
- Distribution on retina
  - **Fovea** consists solely of cones (about 50,000 – 110,000).
  - Peripheral retina has both rods and cones.
  - More rods than cones in periphery.
- There are about 120 million rods and 6 million cones (though, this may be a high estimate).



Functional eye anatomy

Blind spot

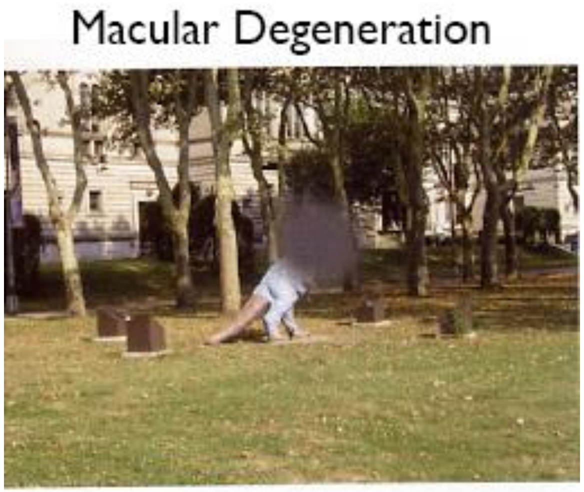
- The place where optic nerve leaves the eye.
- We don’t notice it because:
  - One eye covers the blind spot of the other.
  - It is located outside of the macula (away from detail vision).
  - The brain “fills in” the spot.

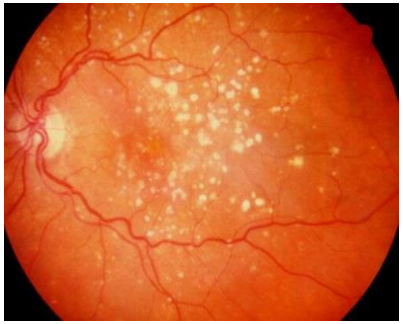


Functional eye anatomy

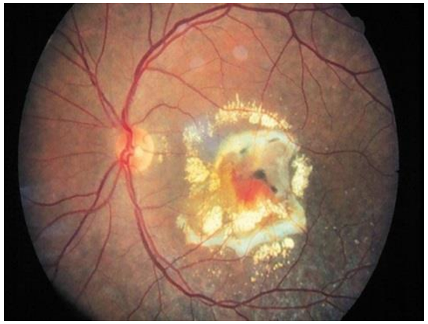
Age-related macular degeneration

- Fovea and surrounding area (**macula**) are destroyed.
- Caused by interrupted supply of blood to the macula.
- Creates a central “blind spot” on retina.
- Most common in older individuals.





Dry AMD



Wet AMD

Functional eye anatomy

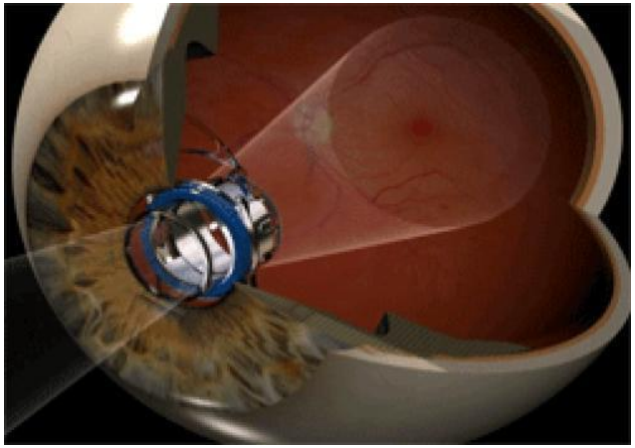
Macular degeneration treatments

If the macula is destroyed, perhaps a healthy portion of the retina can take over its function?

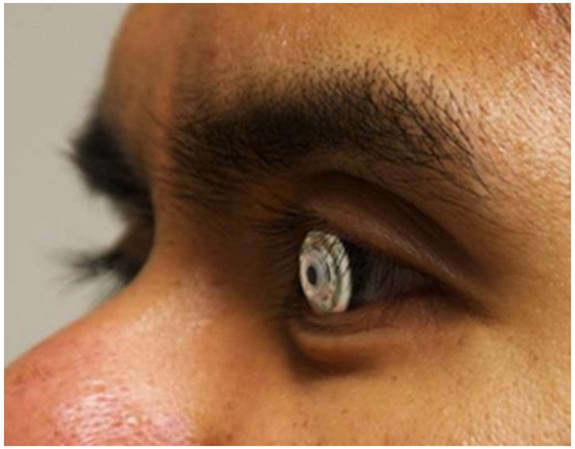
Possibly – but you would have to magnify the image for lower resolution outside the fovea.

- Implantable Miniature Telescopic lens

- Telescopic contact lens



VisionCare Ophthalmic Technologies



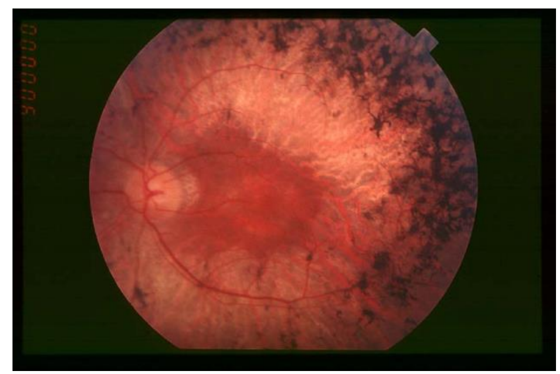
Jacobs School of Engineering

Functional eye anatomy

Retinitis pigmentosa

- Genetic disease affecting receptors in the retina.
- Rods are destroyed first.
- Foveal cones can also be attacked.
- Severe cases result in complete blindness.
- No effective treatment, but onset may be delayed with vitamin A supplements.

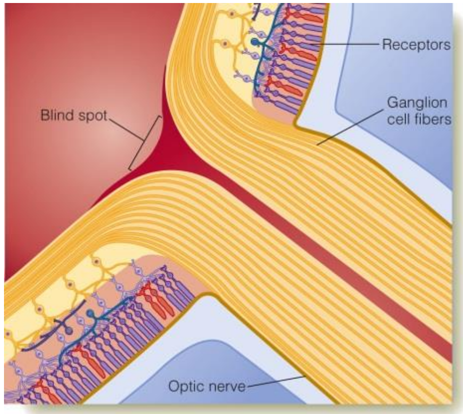
Retinitis Pigmentosa



Functional eye anatomy

Glaucoma

- Damage to the optic nerve (retinal ganglion cells).
- Most often caused by increased pressure in the eye, inhibiting blood flow to the optic nerve.
- Onset can be gradual and hard to detect.
- Damage is permanent.

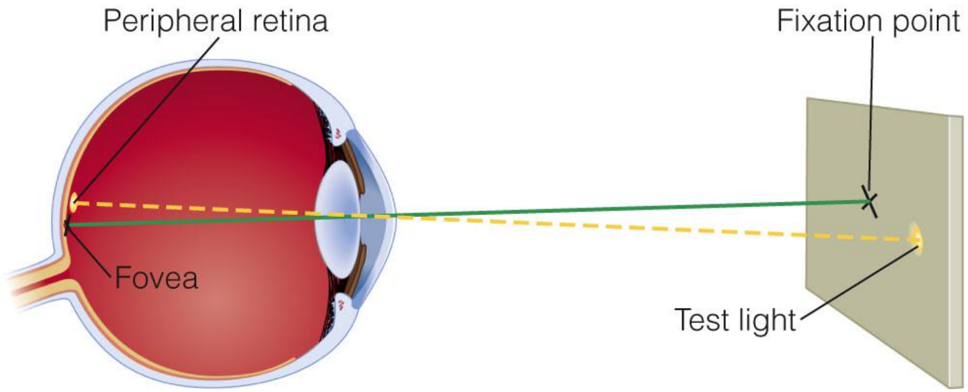


Functional eye anatomy: rods & cones

Comparing rod and cone sensitivity using dark adaptation

1. Using the method of adjustment, determine the subject's sensitivity to a test light while the room light are still on. This is the **light-adapted sensitivity**.

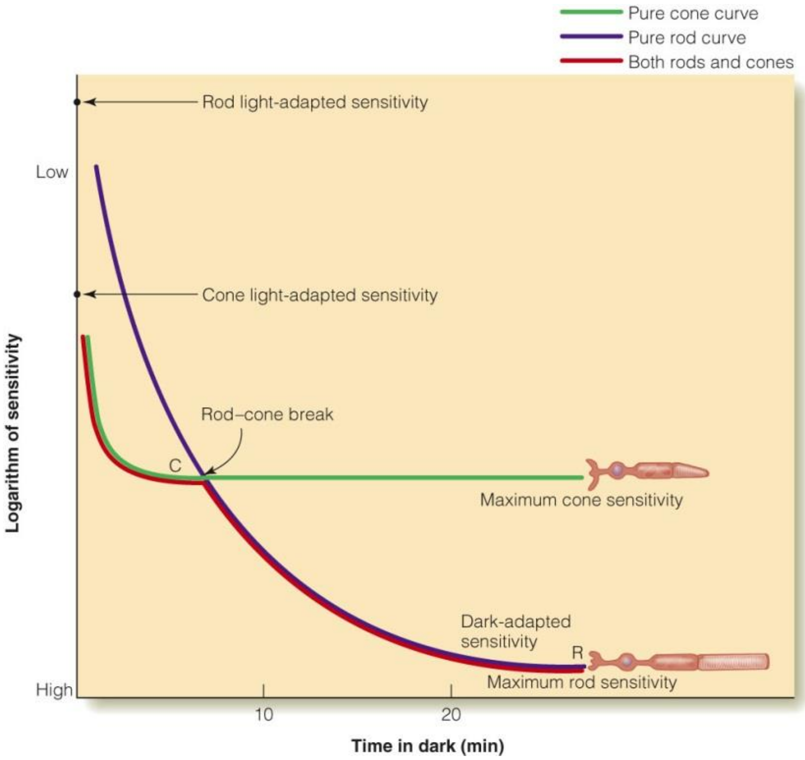
2. Next, turn off the lights and have the subject continue to adjust the test light until you they no longer improve. This is the **dark-adapted sensitivity**.



Functional eye anatomy: rods & cones

Experiment for rods and cones:

- Observer looks at fixation point, but pays attention to a test light to the side.
- We find a two stage dark adaptation curve:
  - Stage one begins with a rapid increase in sensitivity (3-4 minutes).
  - Then sensitivity levels off for seven to ten minutes – the **rod-cone break.**
  - Stage two shows increased sensitivity for another 20 to 30 minutes.



Functional eye anatomy: rods & cones

Testing cones and rods separately

- Experiment for <u>cone</u> adaptation
  - Test light falls directly on fovea – only stimulates cones.
  - Results show that sensitivity increases for three to four minutes and then levels off.

Functional eye anatomy: rods & cones

Progress check

You test cone adaptation to the dark by shining a light only in the fovea, which we know only has cones. Can you test rod dark adaption by shining a light only in the periphery? Why or why not?

A. Yes

B. No

Functional eye anatomy: rods & cones

Testing cones and rods separately

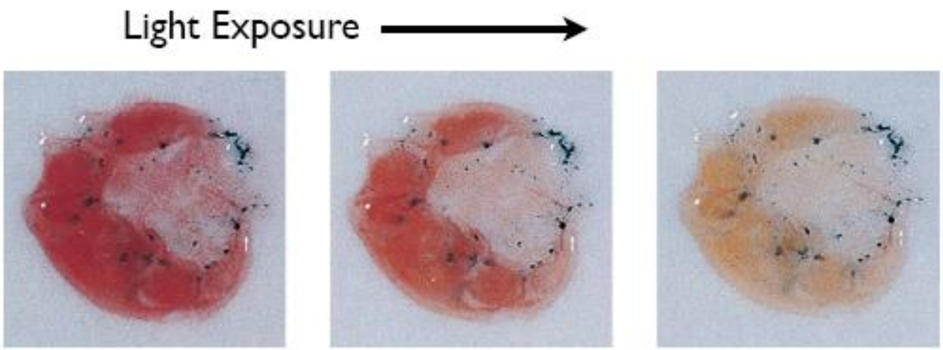
- Experiment for <u>cone</u> adaptation
  - Test light falls directly on fovea – only stimulates cones.
  - Results show that sensitivity increases for three to four minutes and then levels off.

- Experiment for <u>rod</u> adaptation
  - Must use a **rod monochromat** – someone born with no cone receptors.
  - Results show that sensitivity increases for about 20-30 minutes and then levels off.

Functional eye anatomy: rods & cones

Why do rods and cones become more sensitive in the dark?

- After a retinal is isomerized, it separates from the visual pigment.
- This is **visual pigment bleaching**: the loss of retinal pigment and color.
- Darkness provides the opportunity to regenerate.



Functional eye anatomy: rods & cones

Visual pigment regeneration

- Retinal and opsin must recombine to respond to light
- Cone pigment regenerates in about 7-10 minutes.
- Rod pigment takes more than 30 minutes.
- Enzymes necessary for pigment regeneration are found in the **pigment epithelium**.*
- If your retina separates from the pigment epithelium (**detached retina**), you lose the ability to regenerate visual pigment.

Functional eye anatomy : rods & cones

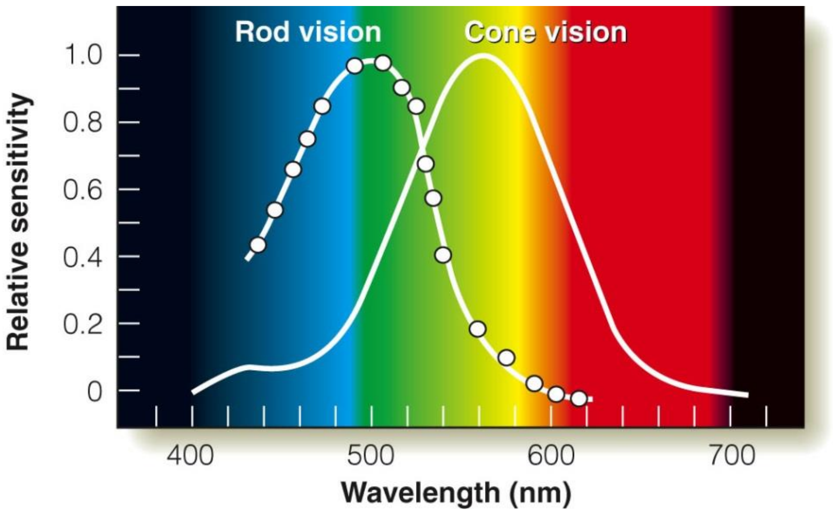
Rod spectral sensitivity:

- most sensitivity at 500 nm.

Cone spectral sensitivity:

- most sensitivity at 560 nm.

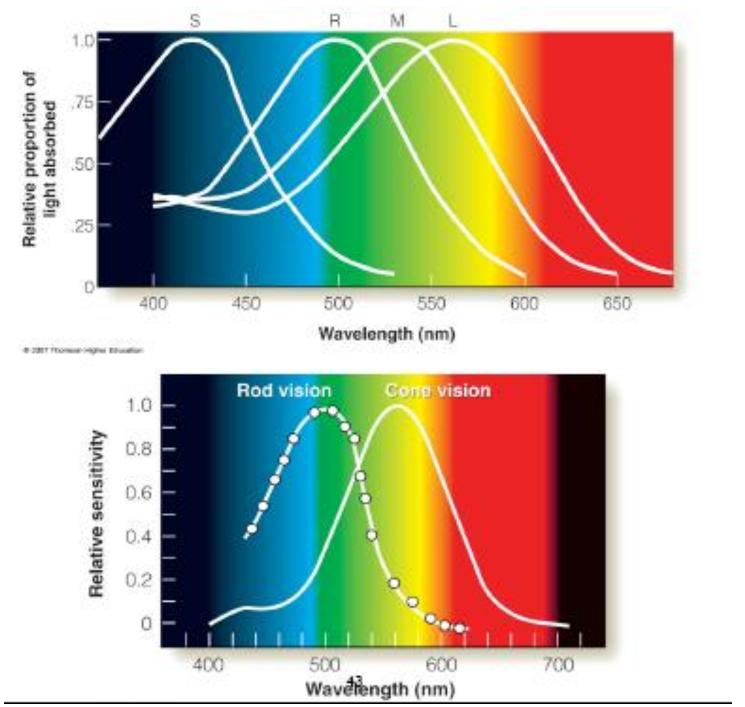
This difference results in the **Purkinje shift**, an enhanced sensitivity to shorter wavelengths during dark adaptation when the shift from cone to rod vision occurs.



Functional eye anatomy: rods & cones

Difference in spectral sensitivity is due to absorption spectra of visual pigments

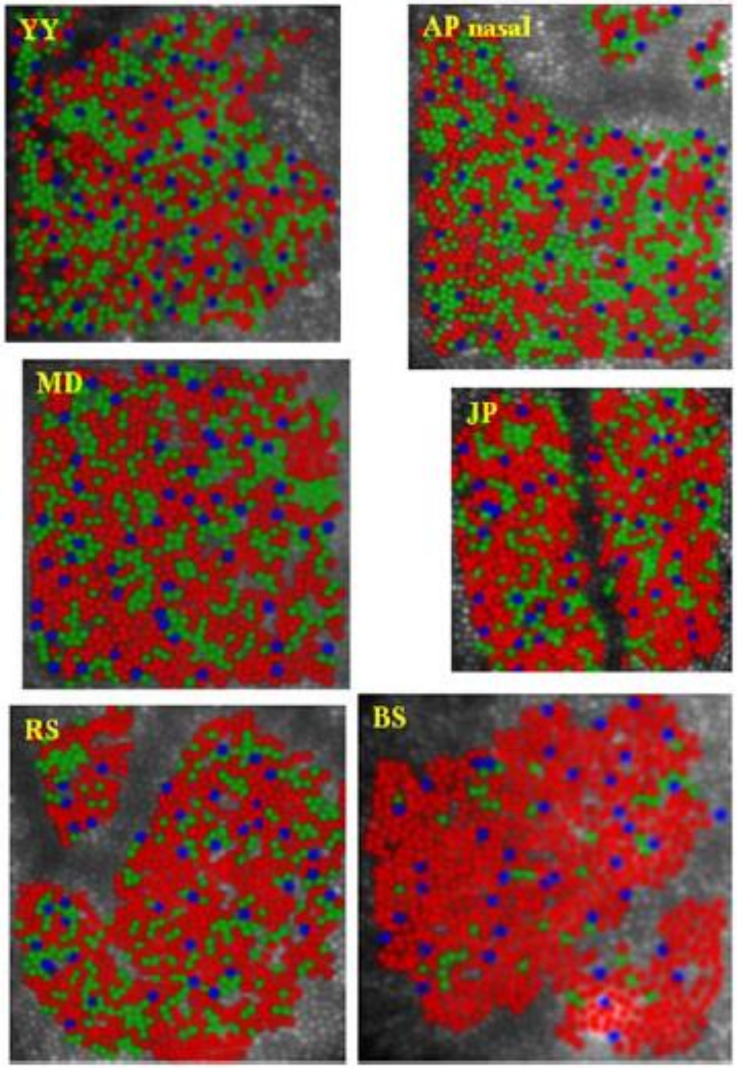
- Rod pigment (R) absorbs best at 500 nm.
- Cone pigments absorb best at 419nm (S), 532nm (M), and 558nm (L).
- Absorption of all cones equals the peak of (approximately) 560nm in the spectral sensitivity curve



Functional eye anatomy: rods & cones

The number and placement of cones subtypes can vary greatly

- L-cones are most numerous.
- Typically S-cones are the fewest in number (and least responsive).
- Distribution and number varies between people.
- Even in the same person, the cone types may vary across the retina.
- All subjects (in figure) have normal color vision.



Hofer et al. (2005)

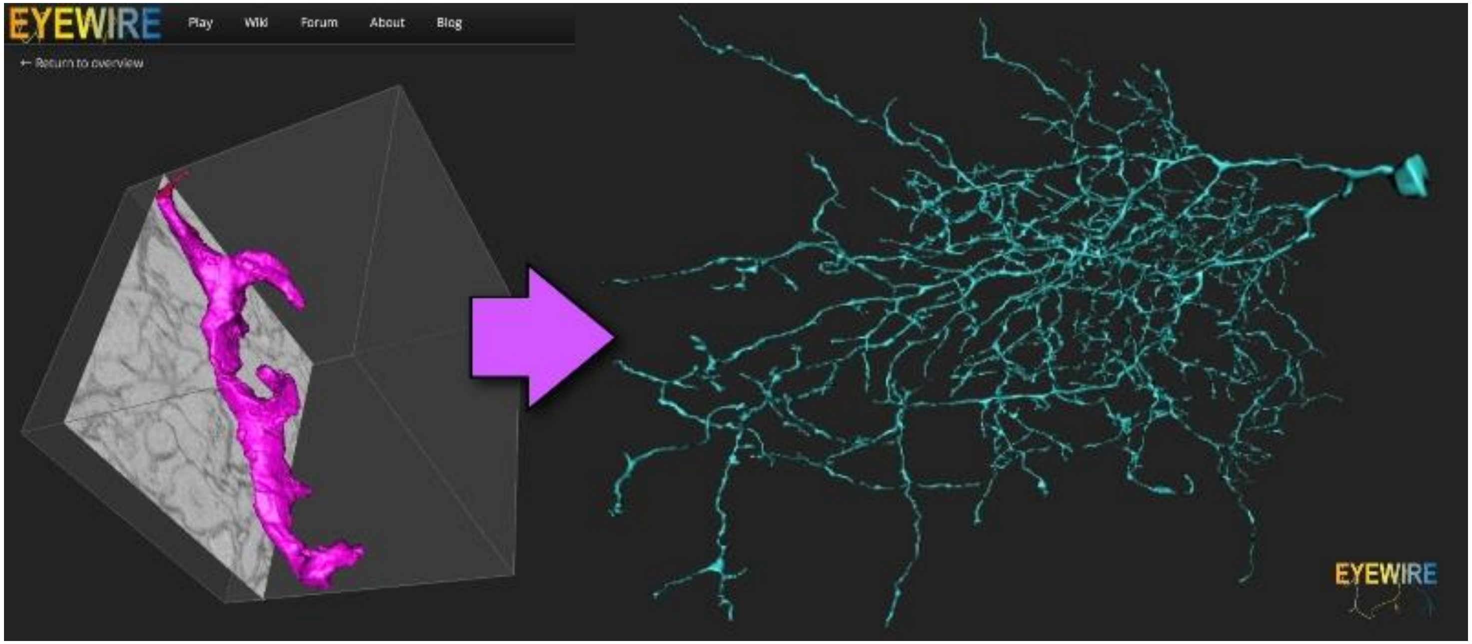
Extra credit opportunity

eyewire.org

Online game to create a 3D map of the retina (and beyond).

For 2% extra credit [max]: create ID, read instructions, and play for approx. 1.5 hours (completing at least 9 cubes). Send me an email with your ID, subject line "eyewire credit" and tell me what you think.

Note: This replaces SONA credit.



Next time

- Lab 1 will be done in section this week.
- Review chapter 3