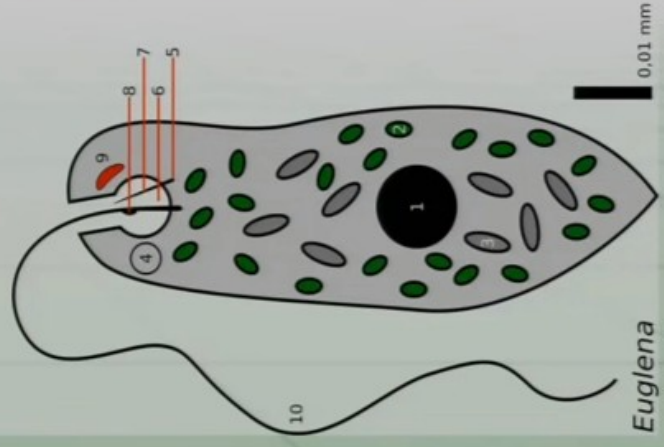
Why do things have eyes?

- To see other things!
- Visual stimulus is an important signal
- Started as photoreceptive protein (eyespots)

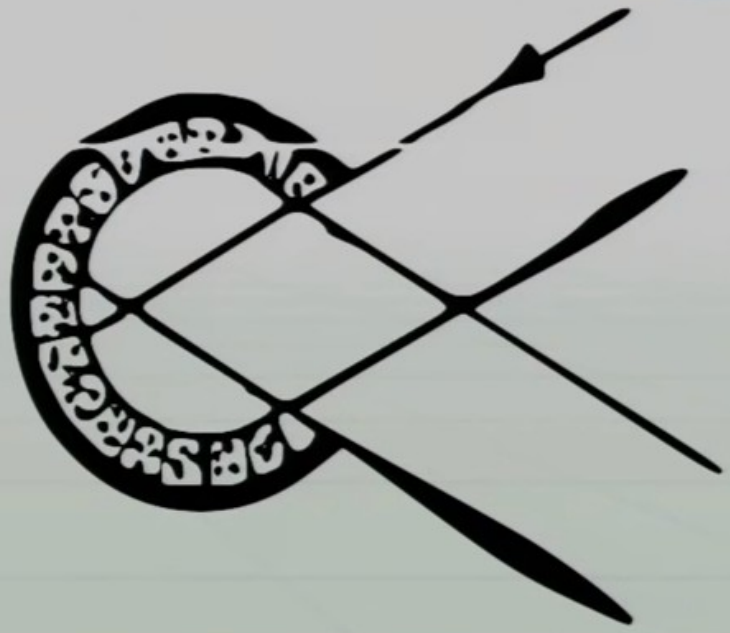
Eyespots - the beginning of vision

- Eyespots are sensitive to ambient light
- Just rough direction:
  - Euglena swim towards light for better photosynthesis
  - Snails move away from light
- No nerves, brain, or processing
- Very low acuity (light from many directions all hits same sensitive area)
- Started EVOLVING...



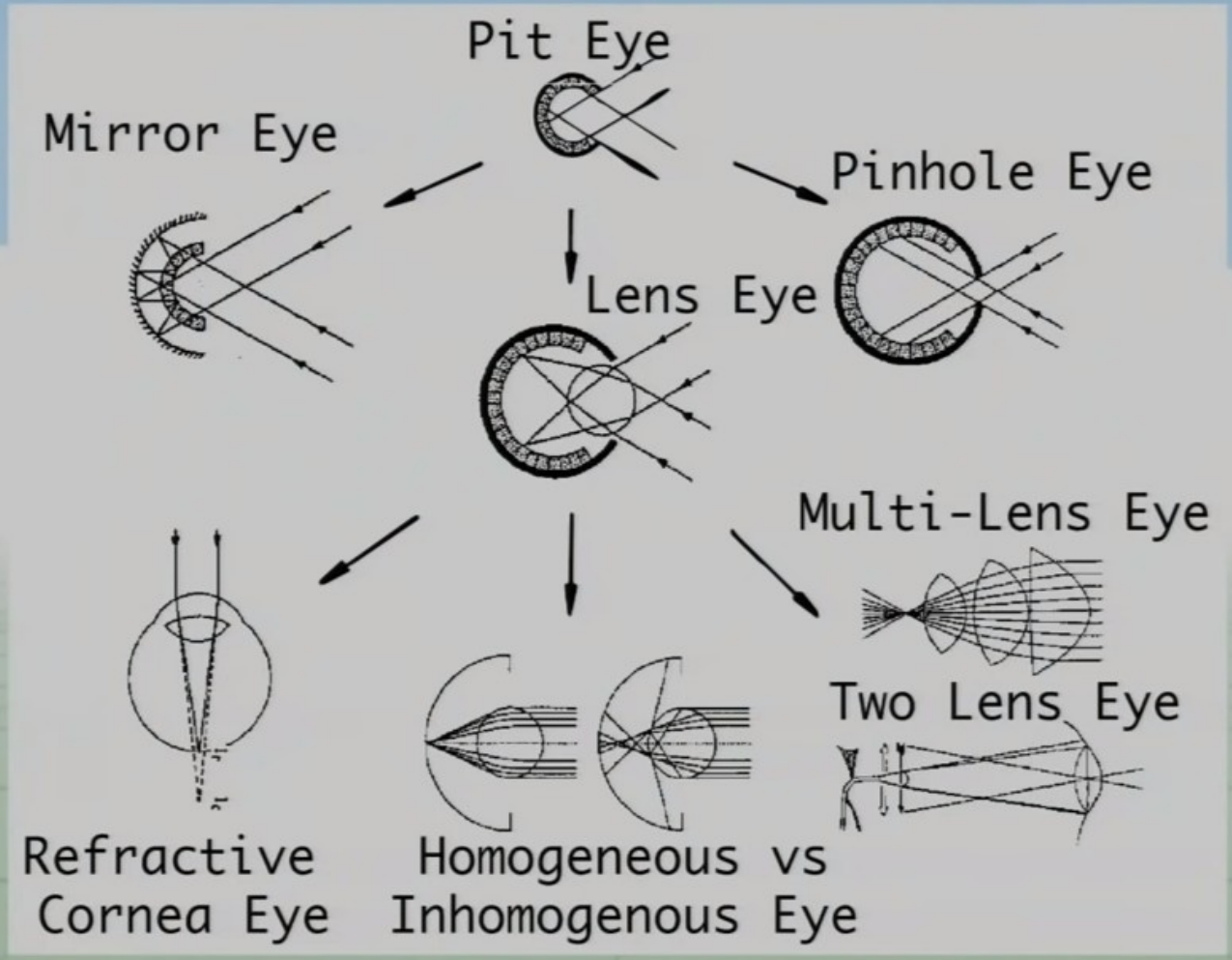
Pit eyes - the first eyes?

- Photosensitive cells in pits
- Block some light
- More information about where light direction
- Very common
  - Evolved 40-65 times
  - 28 of 33 animal phyla have them
- Very simple, low acuity



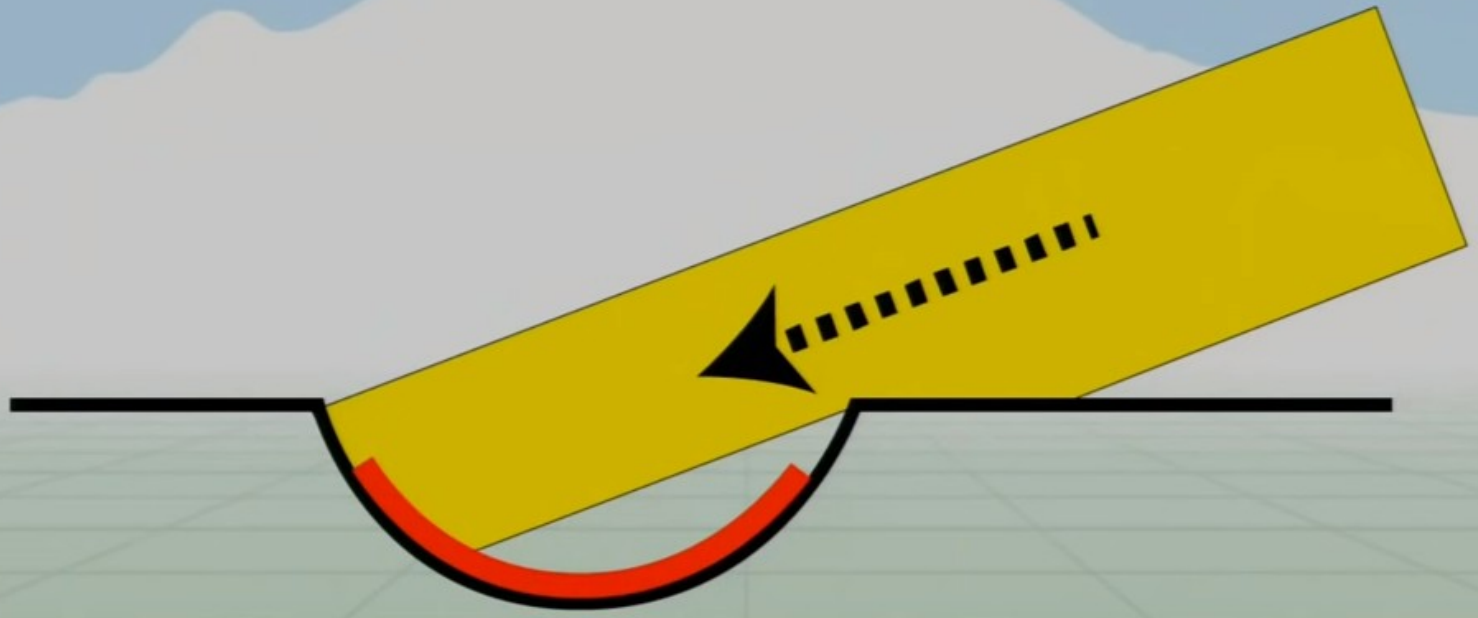
http://www.rctn.org/vs265/landfernald92.pdf

Simple -> complex eyes

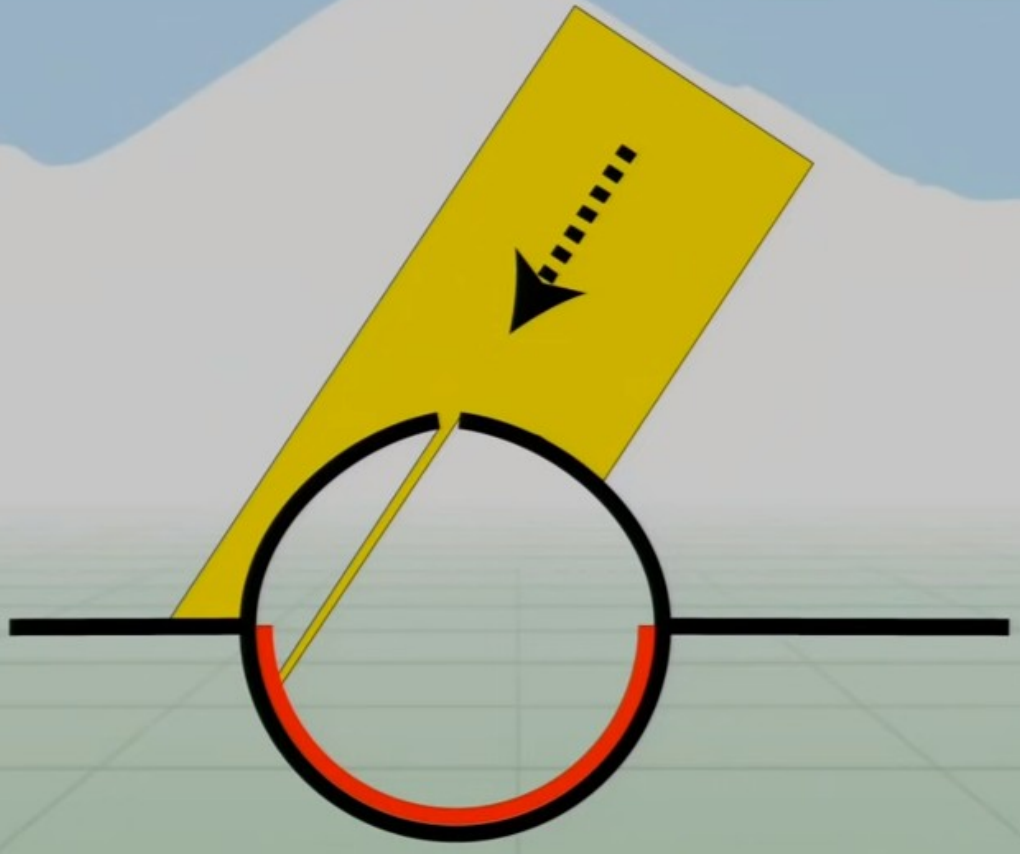


Eyespots - no acuity

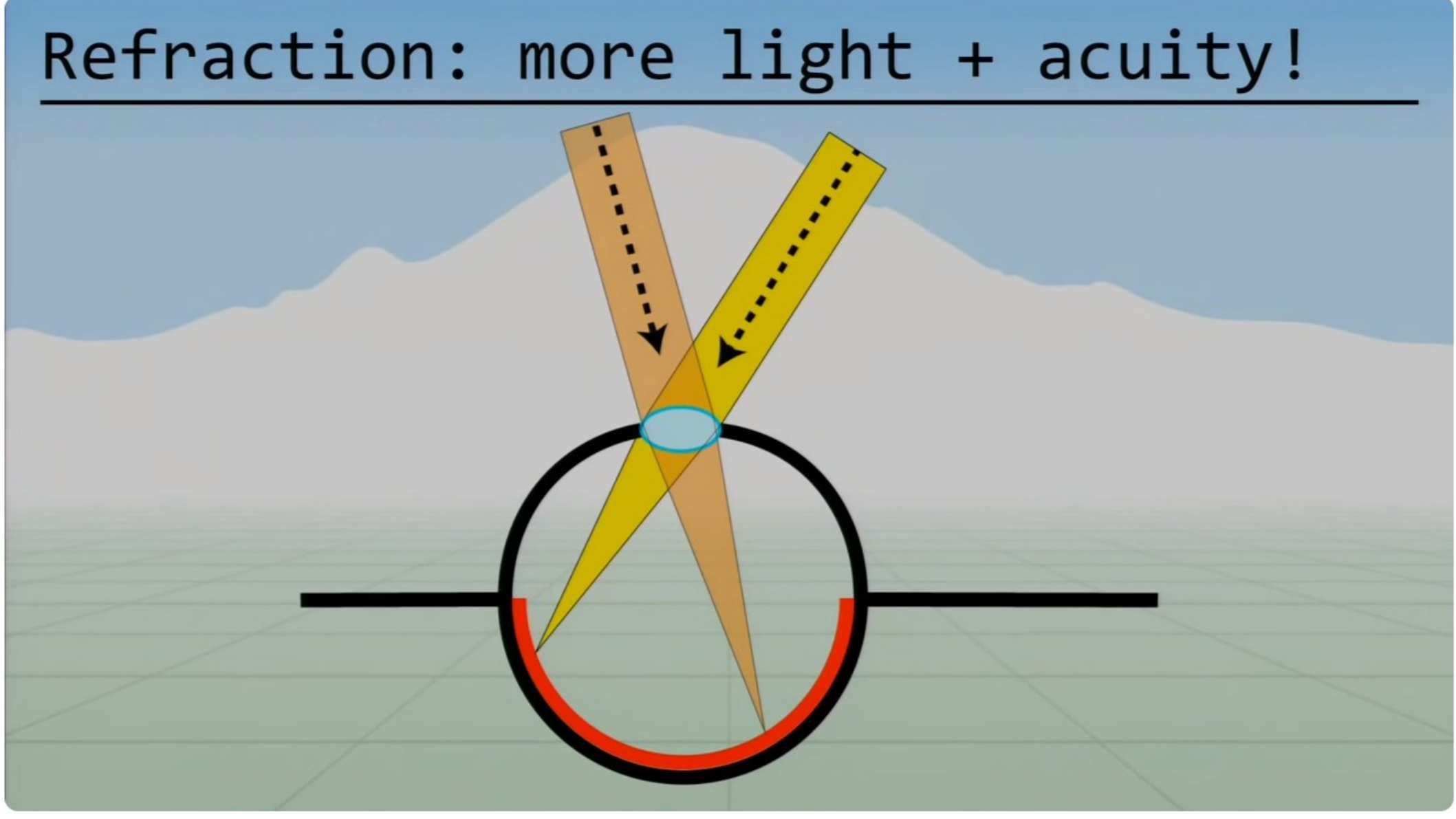
Pit eyes - some acuity



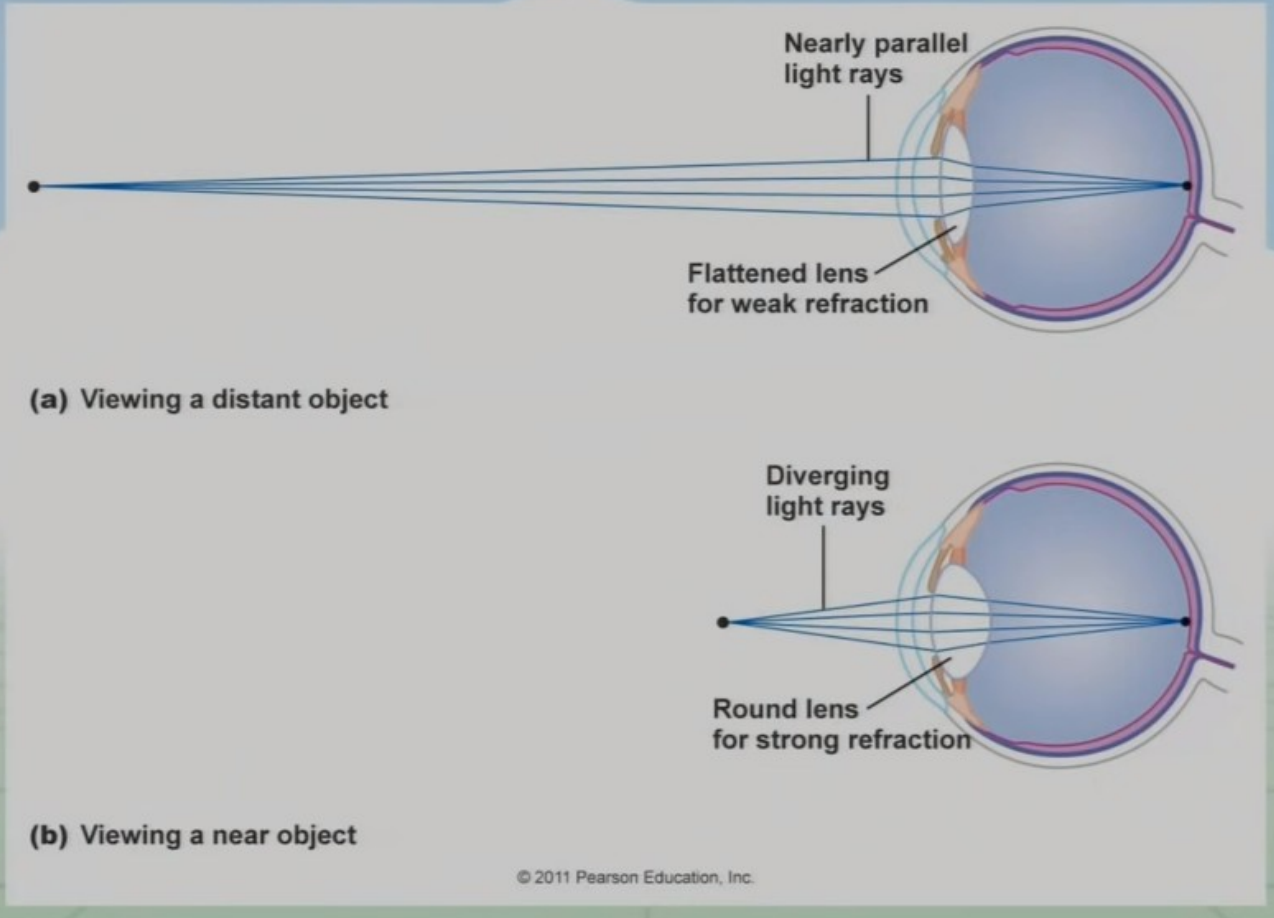
Complex eyes - high acuity



Refraction: more light + acuity!



Focussing: changing refraction

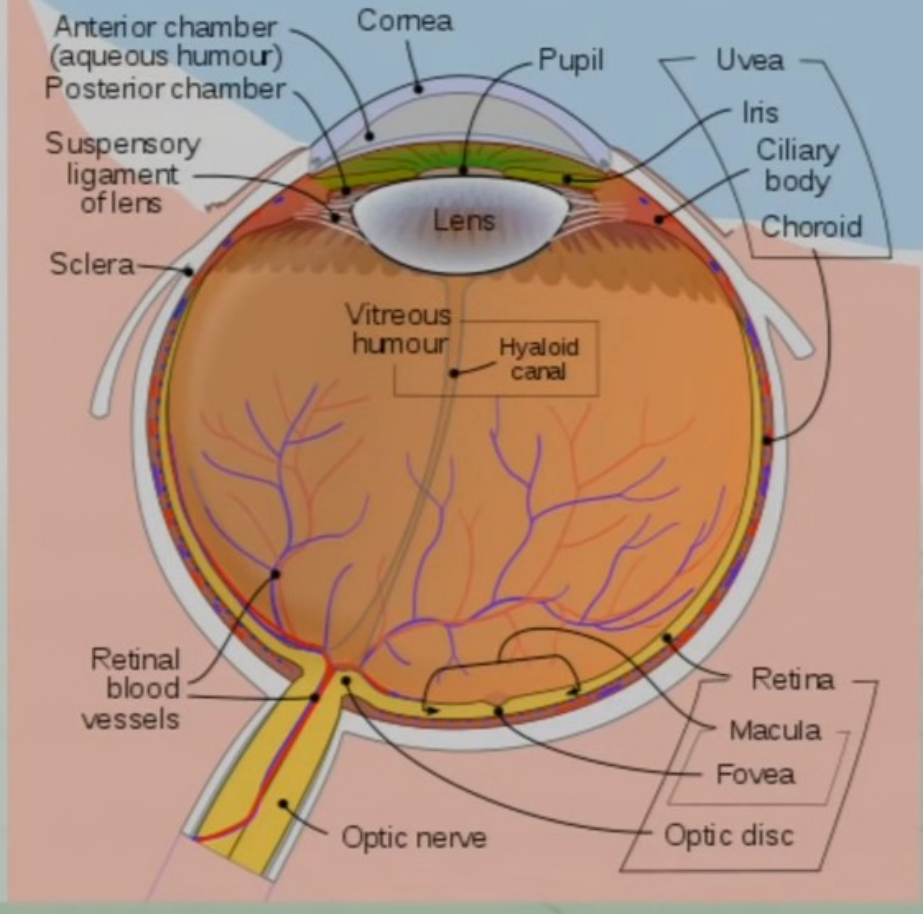


Complex eyes - a huge advantage

- Many different styles, mechanisms
  - >= 10, accounting for many of the ways our cameras work now
- Same goal: better visual acuity (resolution)
- Rare: 6 of 33 animal phyla
- Beneficial: 96% of known species
  - Is it all because of the eyes??
- Image forming - high enough acuity to perceive shapes, objects, etc.

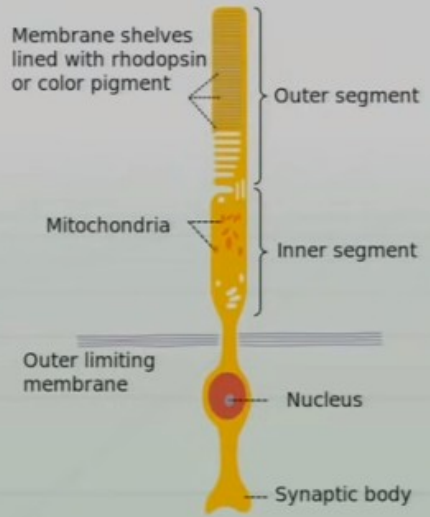
So how do human eyes work?

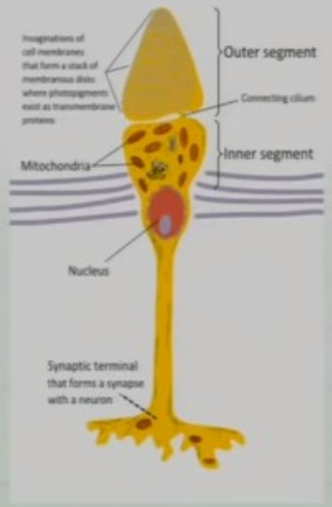
- Complex!
- Light passes through
  - Cornea, humours, lens refract light to focus
- Hit the retina
- Absorbed by photosensitive cells
- Info transmitted through optic nerve, processed by visual cortex

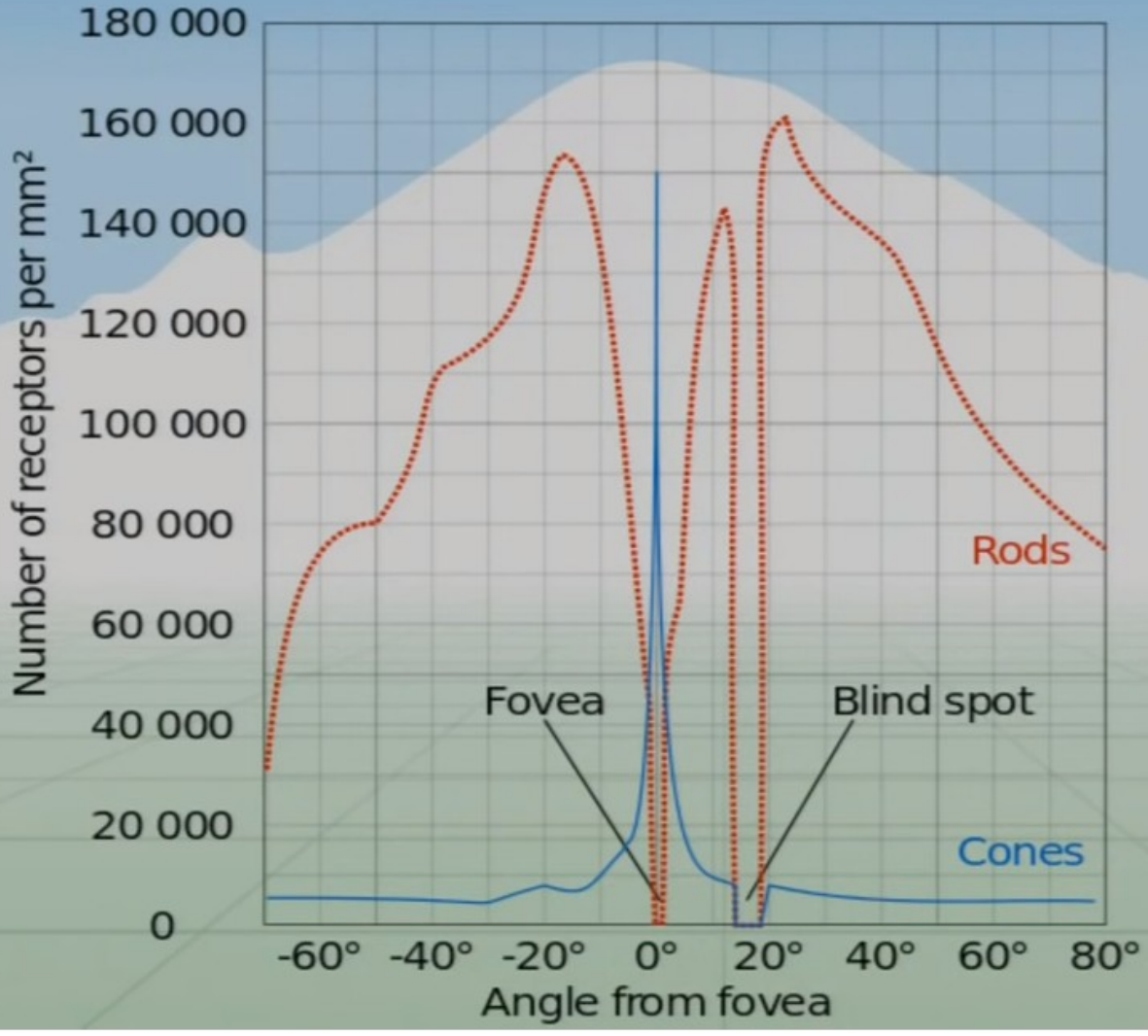


How do we process this light?

- Hit photoreceptive cells (rods and cones)
- ~120 million of them in retina
- Not all the same, not evenly distributed






180 000
160 000
140 000
120 000
100 000
80 000
60 000
40 000
20 000
0
Number of receptors per mm²
Rods
Cones
Fovea
Blind spot
-60° -40° -20° 0° 20° 40° 60° 80°
Angle from fovea

Rods - low light, monochrome vision

- ~120 million
- Sensitive to 1 photon
- Can pool responses
- Slow response time
- Only operate in low-light conditions
- Saturate quickly in lots of light
- Take ~7 minutes to adjust (night vision)

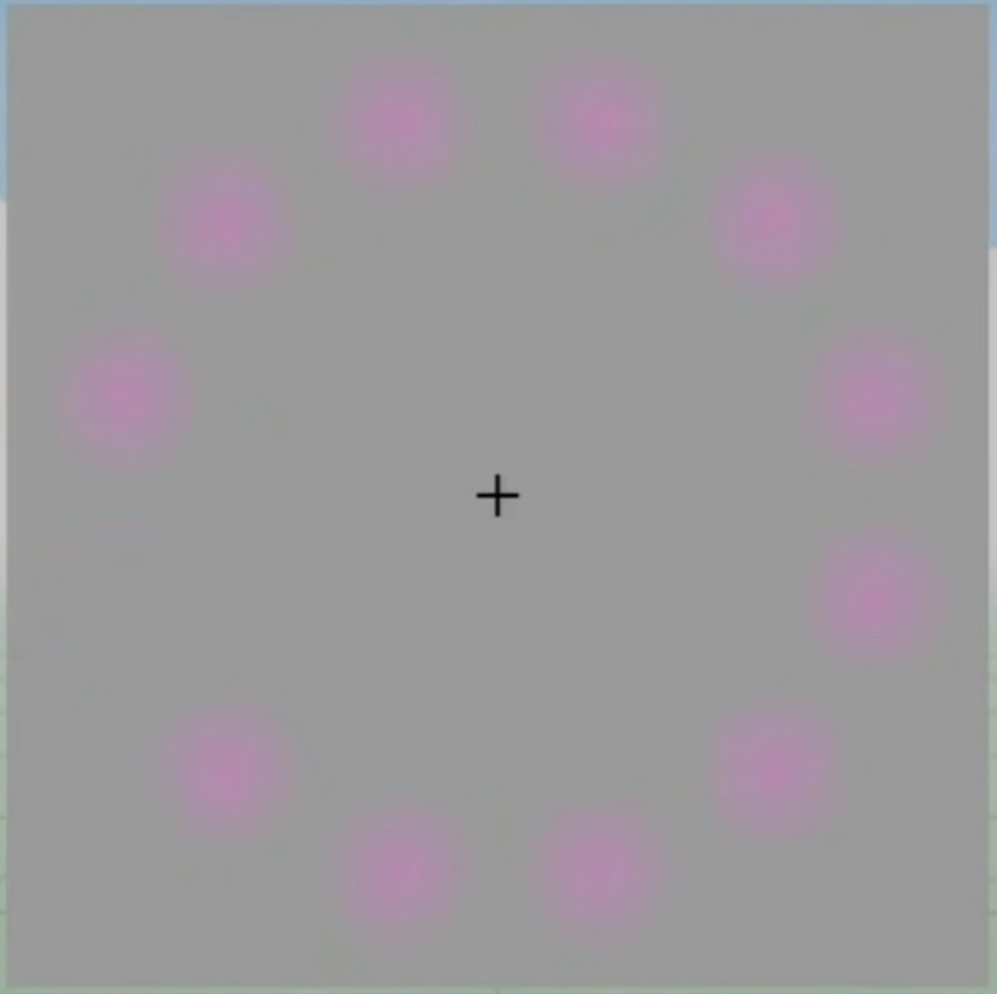
Cones - detailed, color vision

- ~6 million
- Need many photons to activate, bright light
- Fast response time
- Fine details
- Fast changes over time
- Responsible for most daytime vision
- Mostly packed into one region: Fovea

Peripheral vision: don’t get eaten

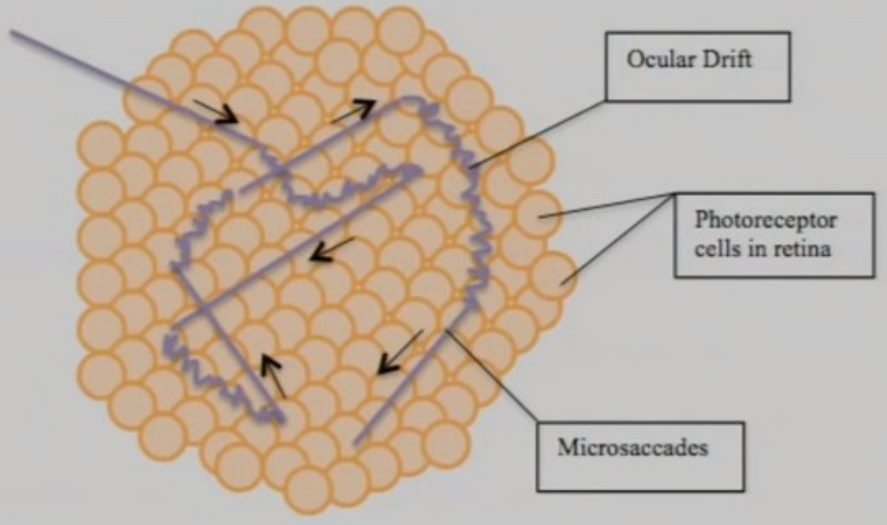
- Few cones
  - Low acuity
  - Low perception of color
- Lots of rods, good at night
- At night: look at stars straight on vs slightly next to them. Brighter when you don’t look right at them!

Photoreceptors need change!



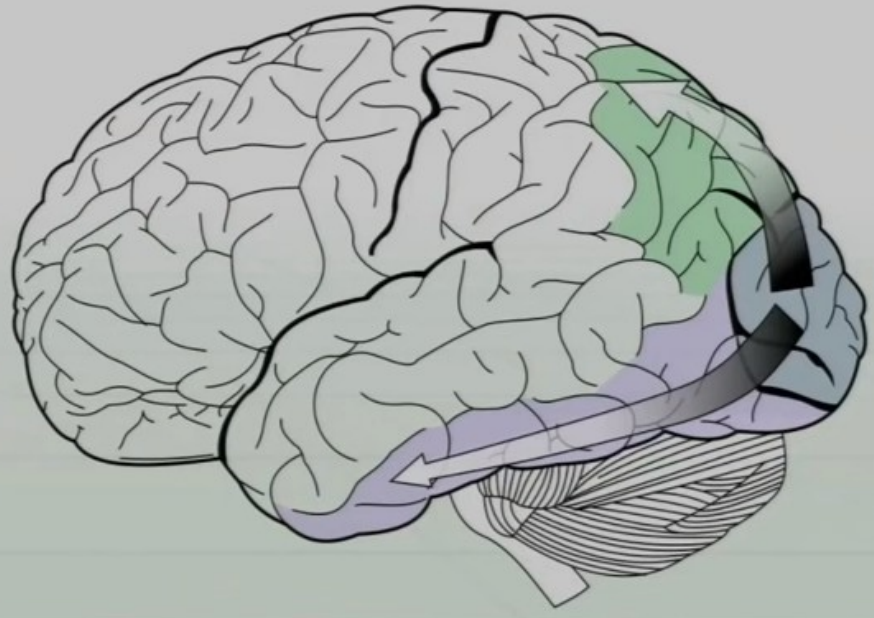
Fixational eye movement

- Receptors adjust, lose sensitivity over time
- Eye keeps moving to expose new parts to light
- Microsaccades
  - Short linear movement
  - Sporadic
- Ocular drift
  - Constant slow movement
- Microtremors
  - Tiny vibrations
  - Synchronized between eyes
  - For seeing fine details



Visual cortex is split (maybe)

- Ventral/dorsal hypothesis
- Information goes through V1 and V2
- Splits into streams for different purposes



Ventral vs dorsal stream

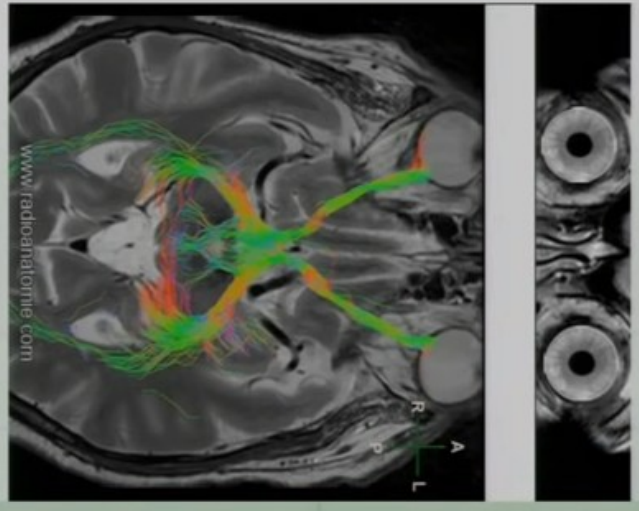
Factor	Ventral system	Dorsal system
Function	Recognition/identification	Visually guided behaviour
Sensitivity	High spatial frequencies - details	High temporal frequencies - motion
Memory	Long term stored representations	Only very short-term storage
Speed	Relatively slow	Relatively fast
Consciousness	Typically high	Typically low
Frame of reference	Allocentric or object-centered	Egocentric or viewer-centered
Visual input	Mainly foveal or parafoveal	Across retina
Monocular vision	Generally reasonably small effects	Often large effects e.g. motion parallax

What does this split mean?

- Recognition and action are split!
- Damage to dorsal system:
  - Can recognize objects
  - Poor visual control for tasks like grasping
- Damage to ventral system
  - Cannot recognize objects
  - Can still manipulate them, grasping, etc.
- Much of the information in the dorsal system is not consciously accessible

The brain and vision

- Enormous processing power devoted to vision
- Visual cortex is largest “system” in the brain
  - 30% of the cerebral cortex
  - ⅔ of the electrical activity
- Lots of processing happening “subconsciously”



Case study: How the brain sees 3d

- One eye
  - Focus - how much your lens must change to make object clear
  - Blur - objects that are blurry are at different depth
  - Parallax - observer or object moves, gets multiple views
- Two eyes
  - Stereopsis - images from eyes are different
  - Convergence - where your eyes are pointing
- Brain
  - Kinetic depth - infer 3d shape of moving objects
  - Occlusion - objects in front are closer
  - Familiar objects - you know how big a car is...
  - Shading - 3d shape from light/shadow cues

We don’t really understand vision

- Visual cortex - highly studied part of the brain
- Only rough idea of what different components do
- New discoveries in vision all the time
  - Eye uses blinking to reset its rotational orientation
  - Visual cortex can make some “high-level” decisions