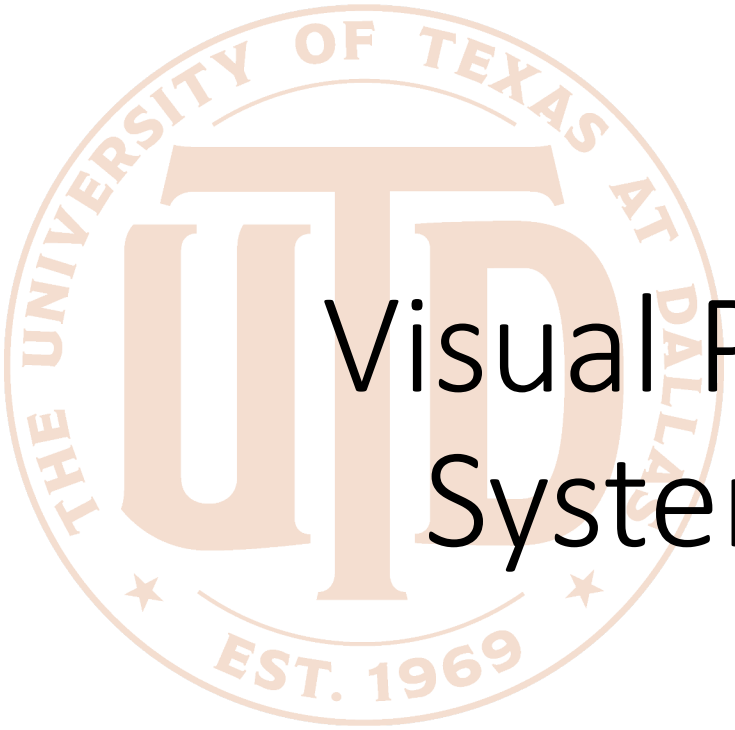


Visual Perception: Human Visual System and Color Perception

CS 6334 Virtual Reality

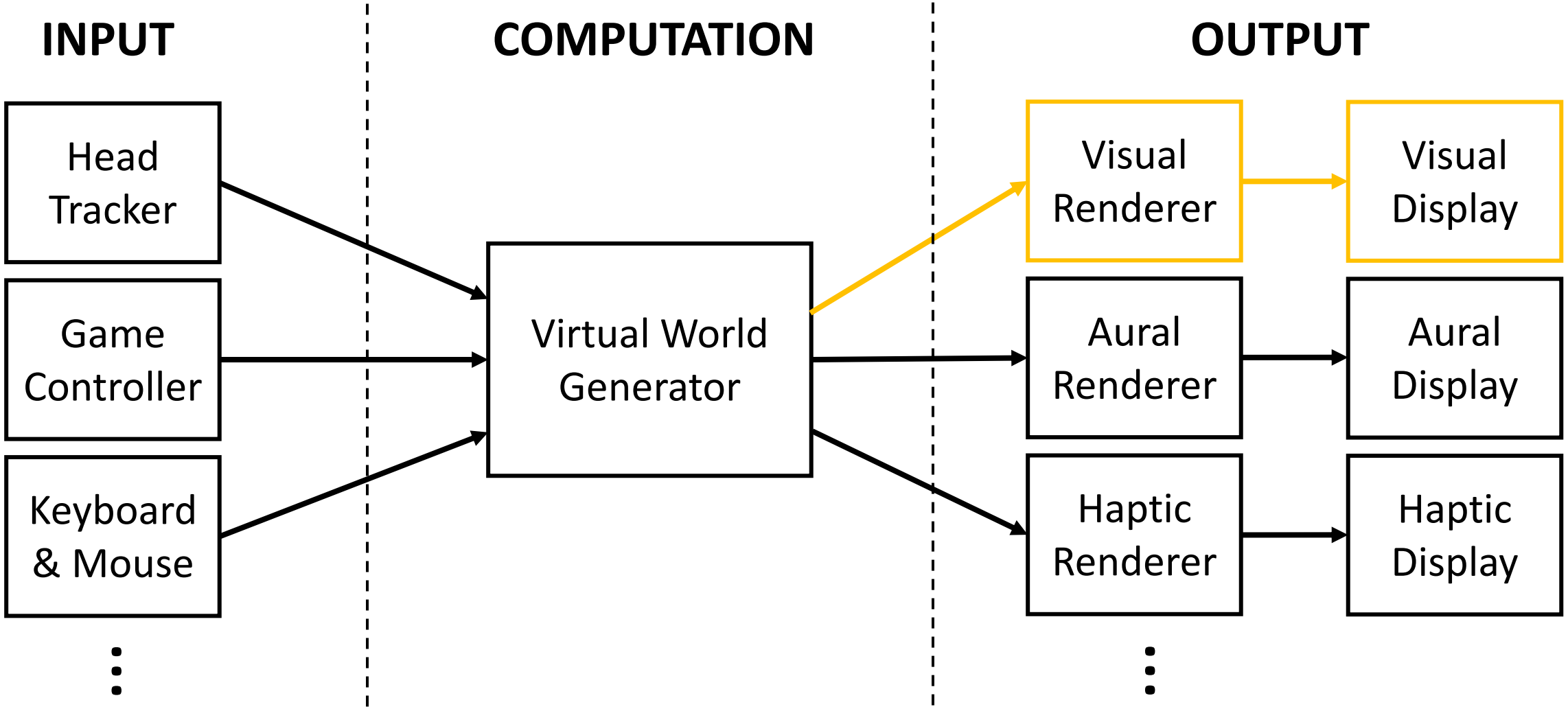
Professor Yapeng Tian

The University of Texas at Dallas

A lot of slides of course lectures borrowed from Professor Yu Xiang's VR class

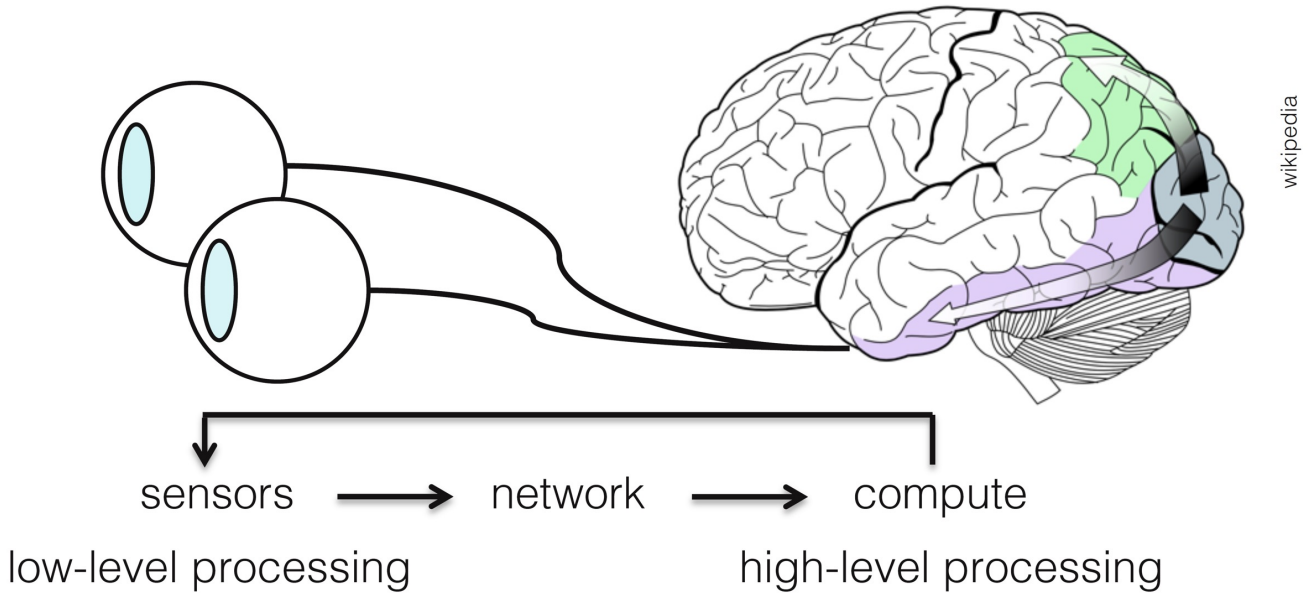
Review of VR Systems

Unawareness: unawareness of the interface, being “fooled” in a virtual world



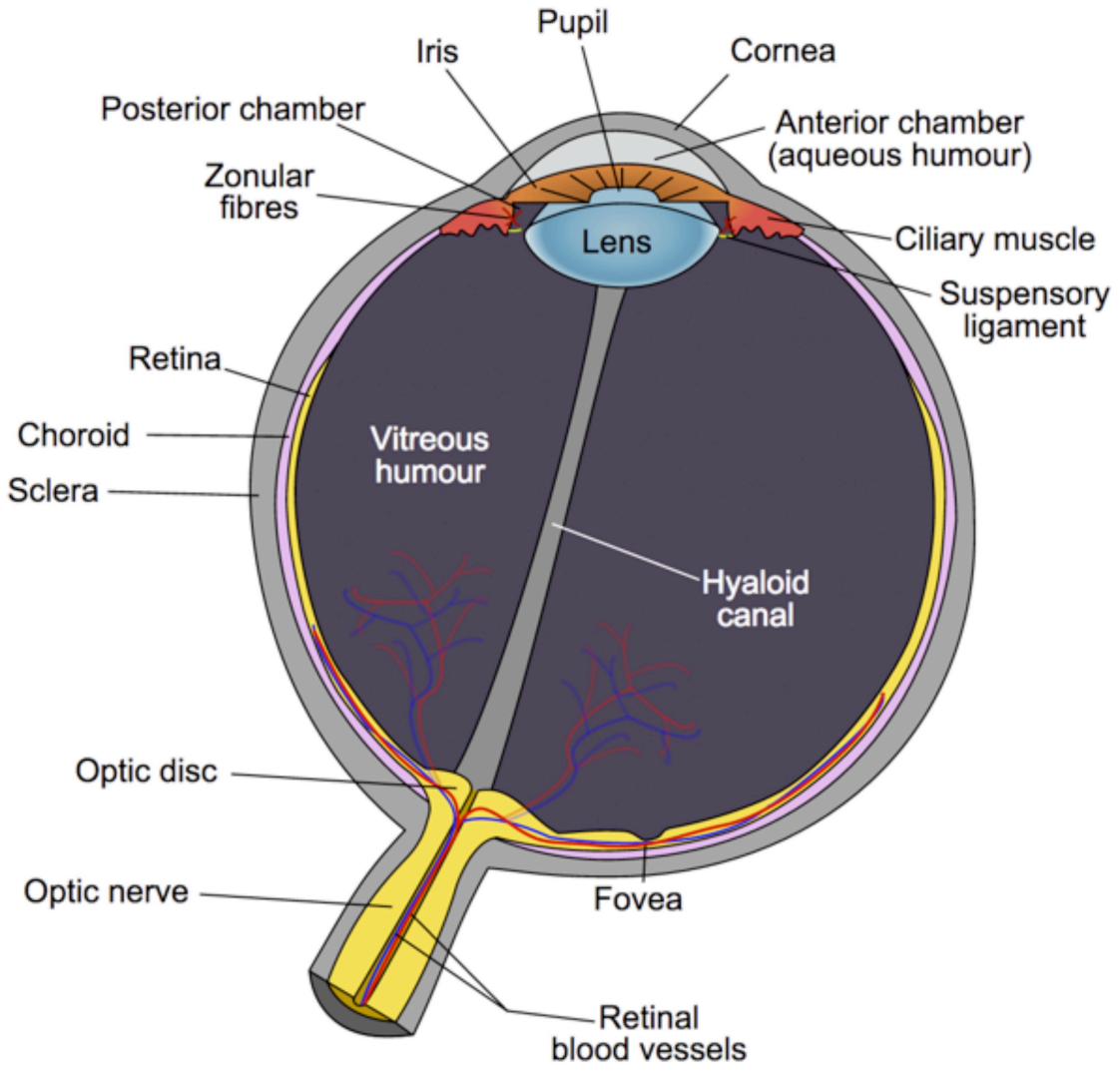
Visual Perception

- How humans perceive or interpret the real world using vision?

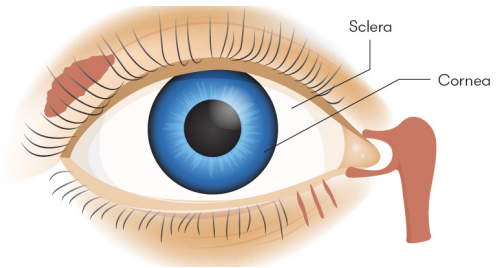


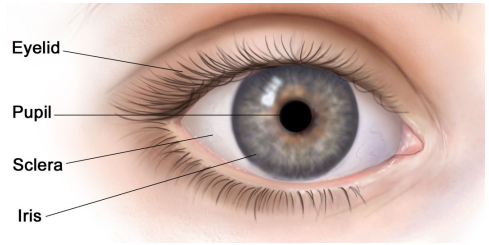
- We need to understand visual perception to achieve visual unawareness in VR systems

Physiology of the Human Eye



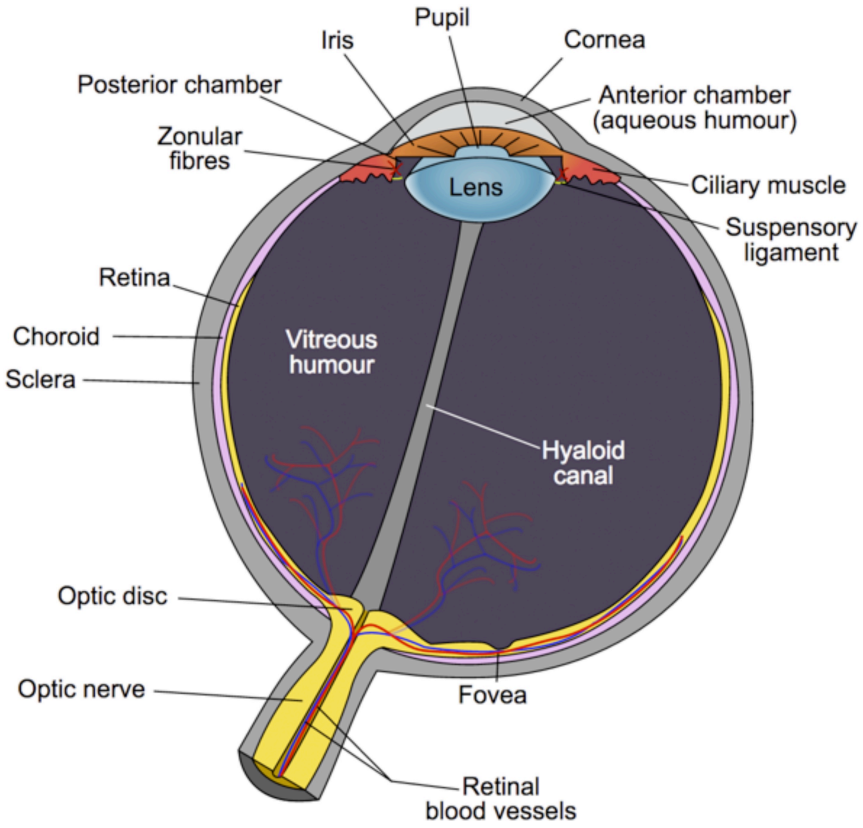
- Cornea: hard, transparent surface
- Sclera: hard, white layer

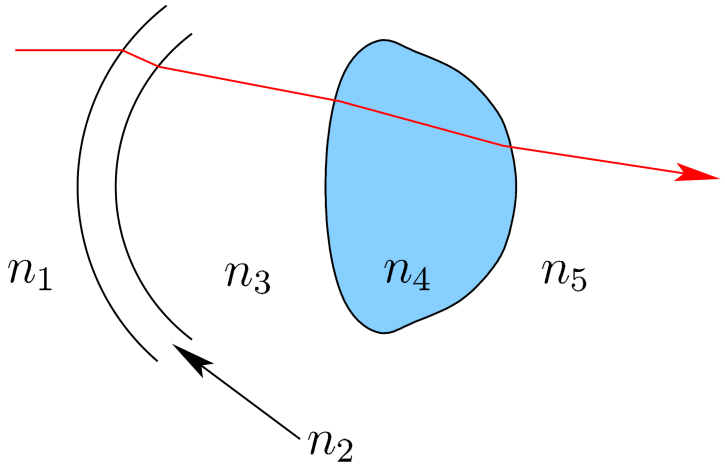




- Iris: control the size of the pupil (aperture)
- Ciliary muscle: alter the optical power of the lens
- Retina: more than 180 degree (image)
- Fovea: the highest visual acuity
- Optic nerve: transmits electrical impulses from your eyes to your brain

Light through the Human Eye





1. $n_1 = 1.009$ (air)
2. $n_2 = 1.376$ (cornea)
3. $n_3 = 1.336$ (aqueous fluid)
4. $n_4 = 1.413$ (lens)
5. $n_5 = 1.337$ (vitreous fluid)

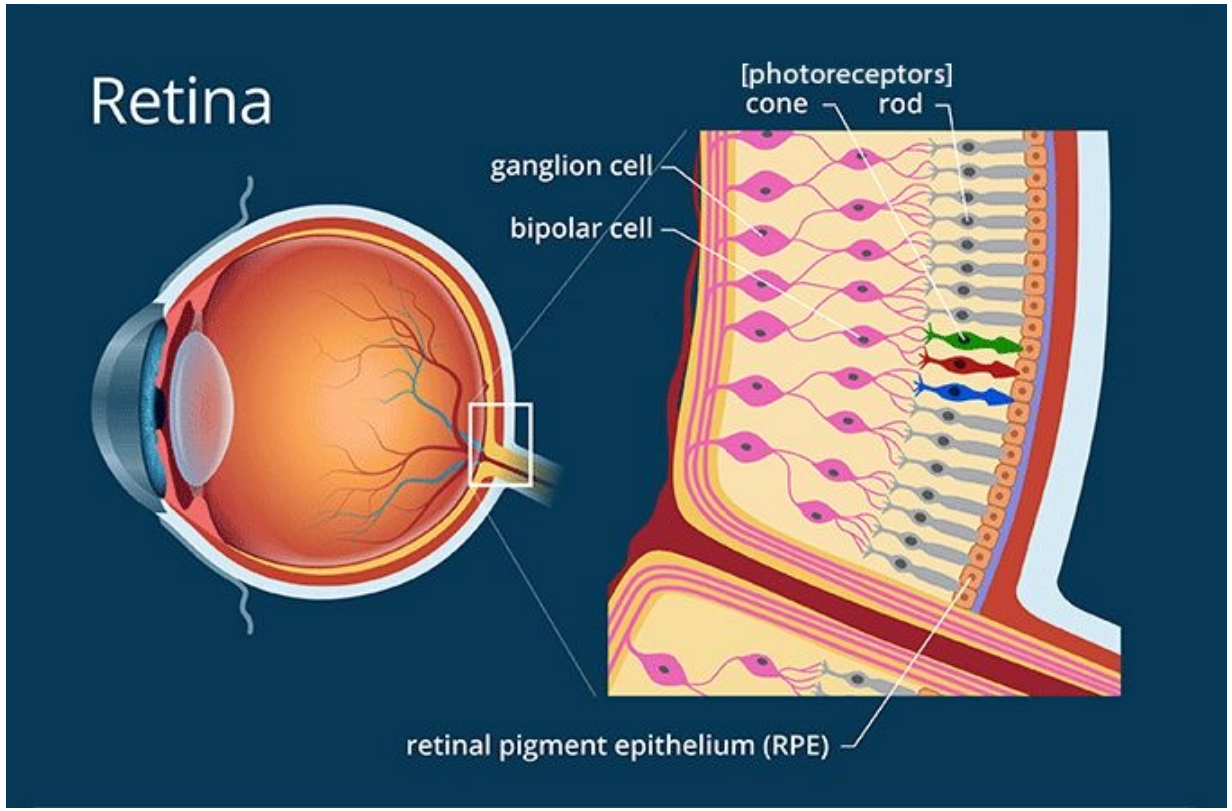
Reflective index

$$n = \frac{c}{s}$$

c ← Speed of light in a vacuum

s ← Speed of light in the medium

Photoreceptors

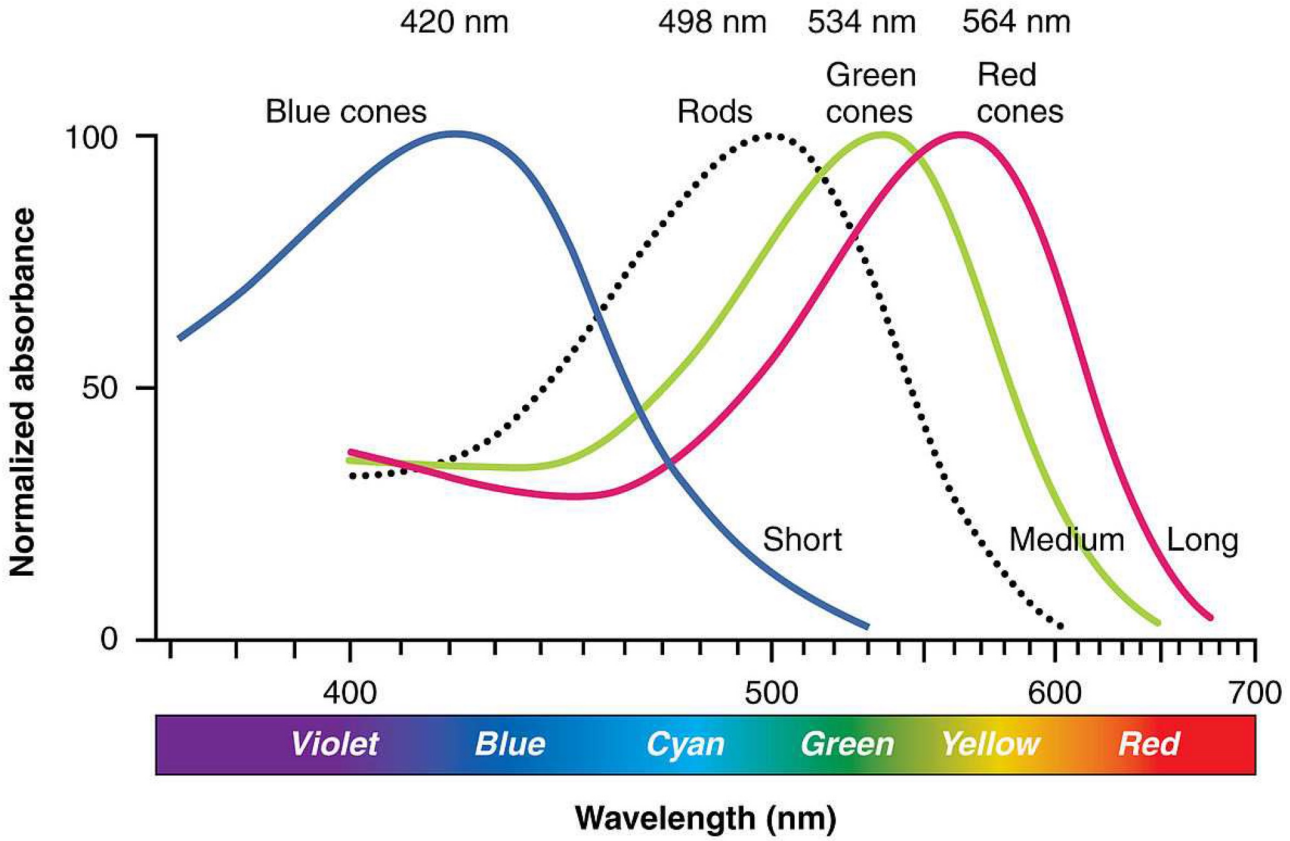


- Two types of photoreceptors in Retina
  - **Rod**: triggered by very low levels of lights, night vision, seeing black and white
  - **Cone**: activated by bright light and see colors
- 120 million rods and 6 million cones in human retina

https://www.allaboutvision.com/eye-care/eye-anatomy/photoreceptors/

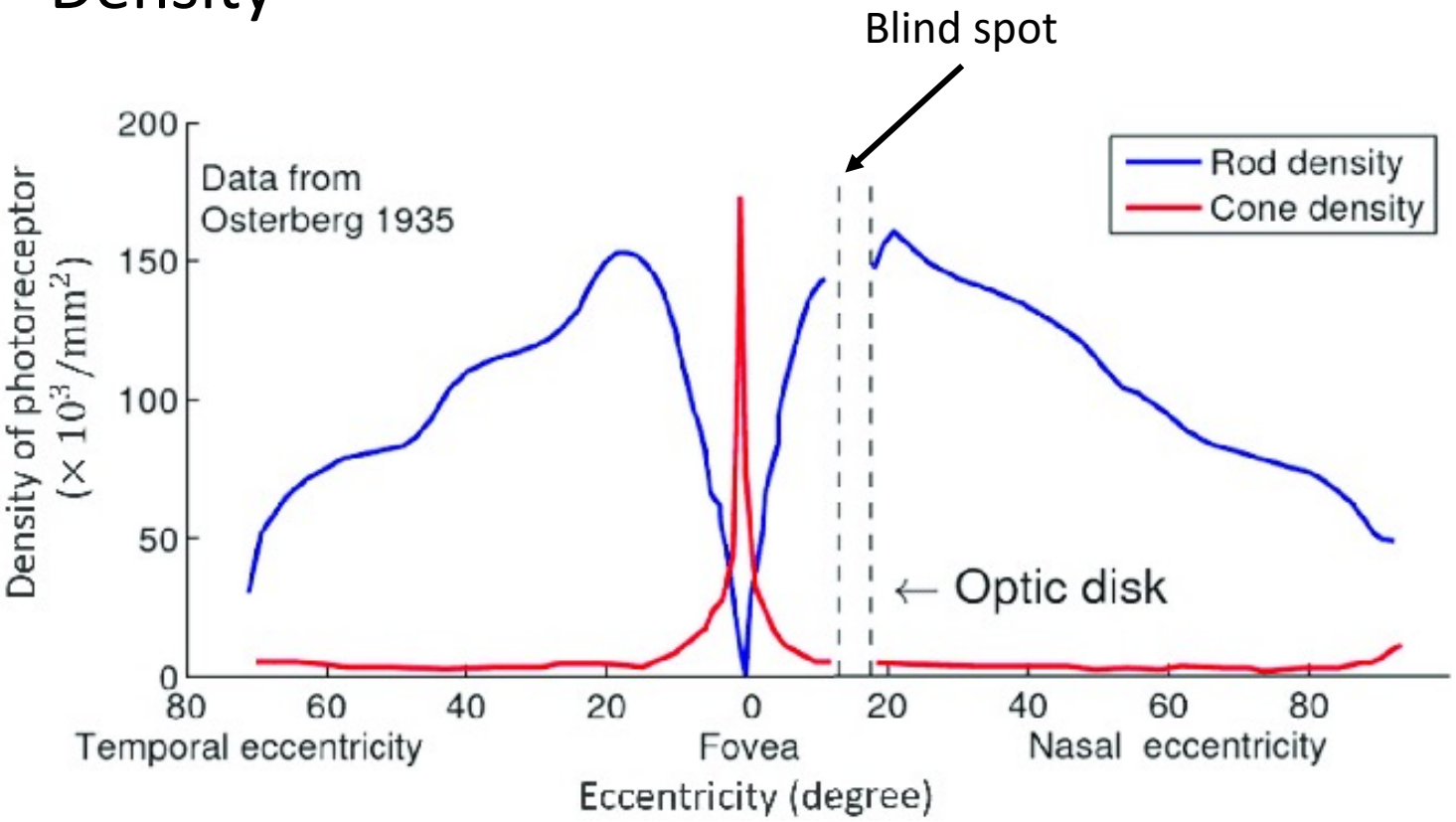
Photoreceptors

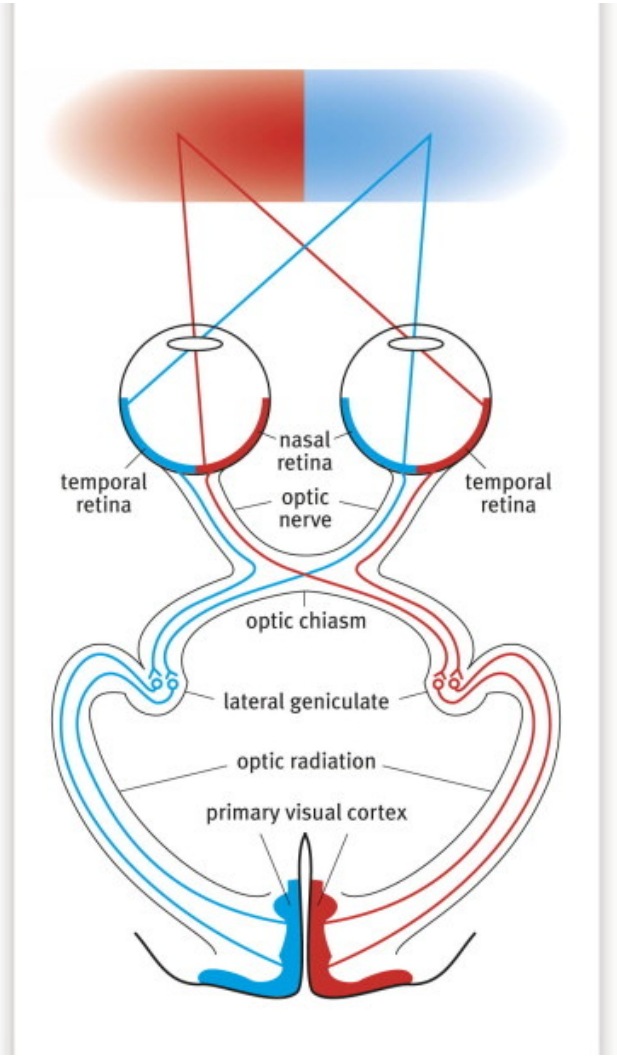
- The sensitivity of rods and cones as a function of wavelength



Photoreceptors

- Density



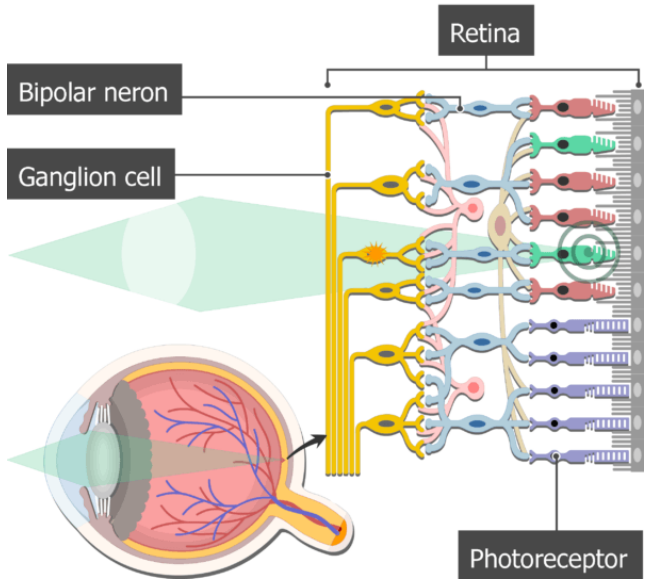


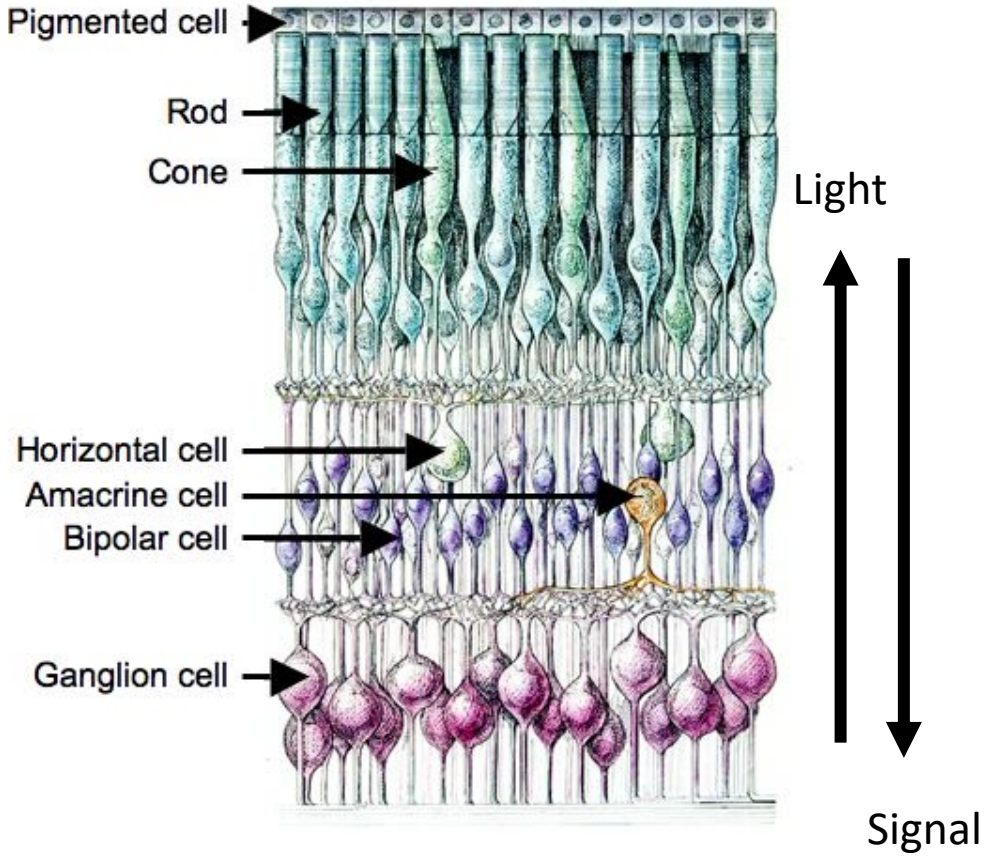
Fovea: the eye must be pointed straight at a target to perceive a shape, color image

Blind Spot

- Close your right eye and look directly at the “X”
- Vary the distance of the paper (or screen) from your eye
- Over some range, the dot should appear to vanish

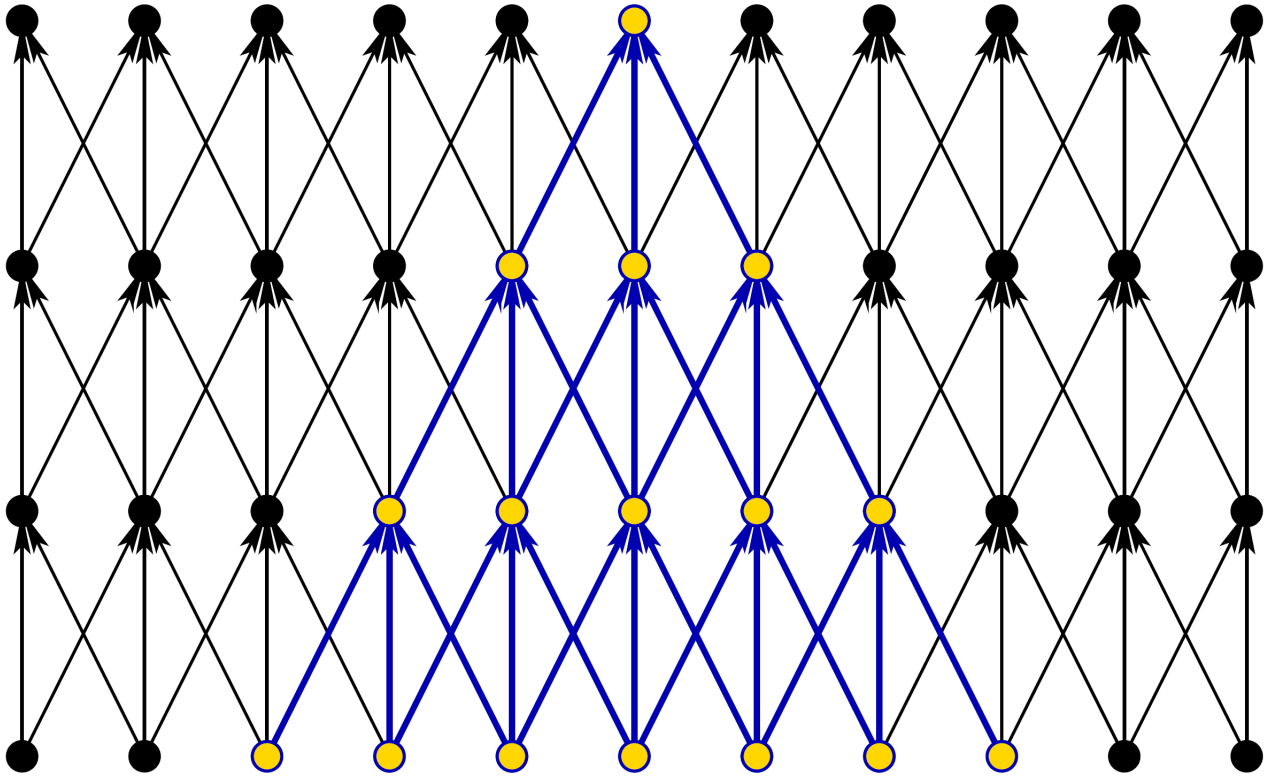
Retinal Circuitry





- **Bipolar cell**
  - ON bipolar: activates when photon absorption increases
  - OFF bipolar
- **Horizontal cell**: connect receptors to other receptors
- **Amacrine cell**: connect bipolar cells
- **Ganglion cell**: image processing unit to detect local change in time, space and color

Receptive Field



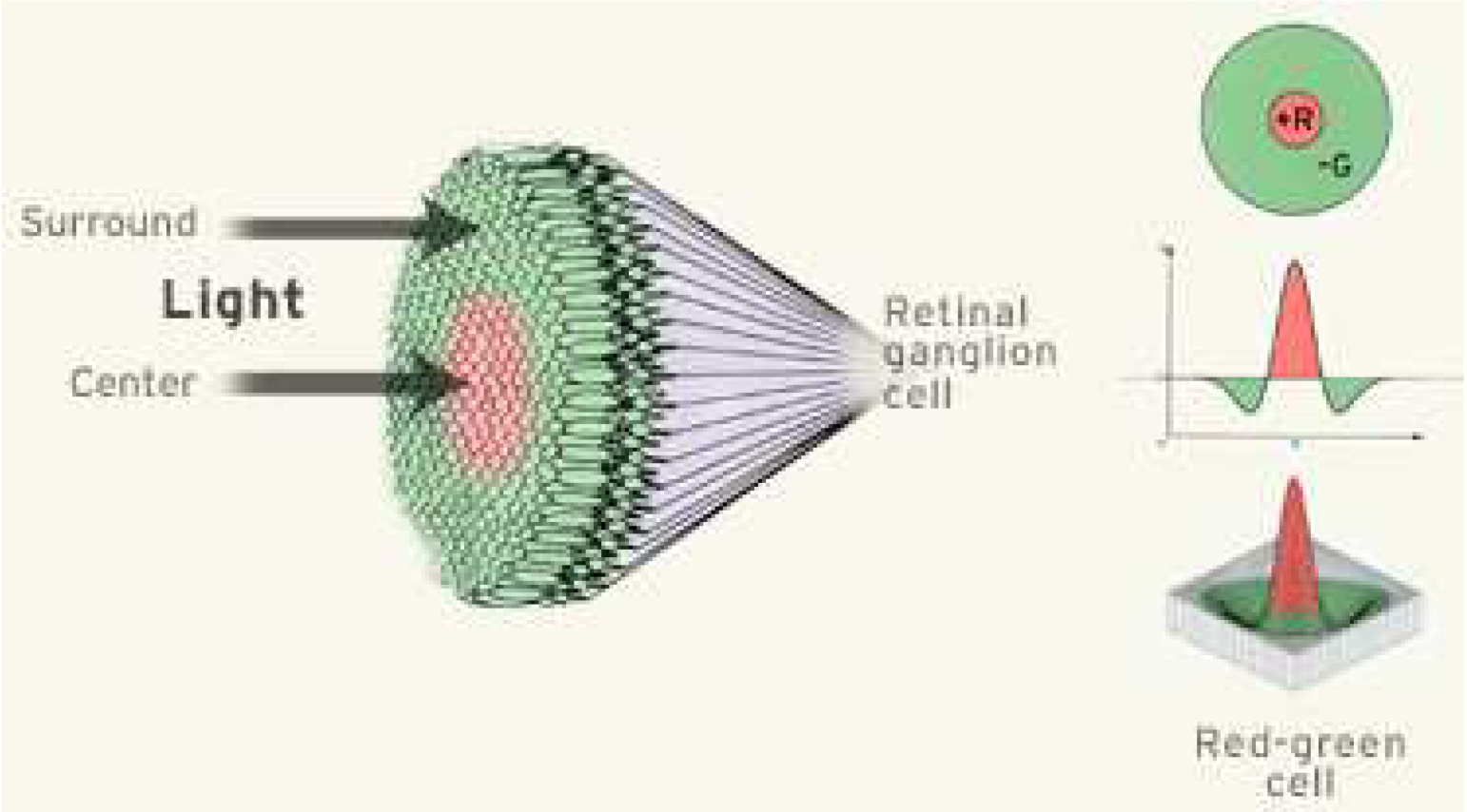
Level 3: Neural Cells

Level 2: Neural Cells

Level 1: Neural Cells

Level 0: Photoreceptors

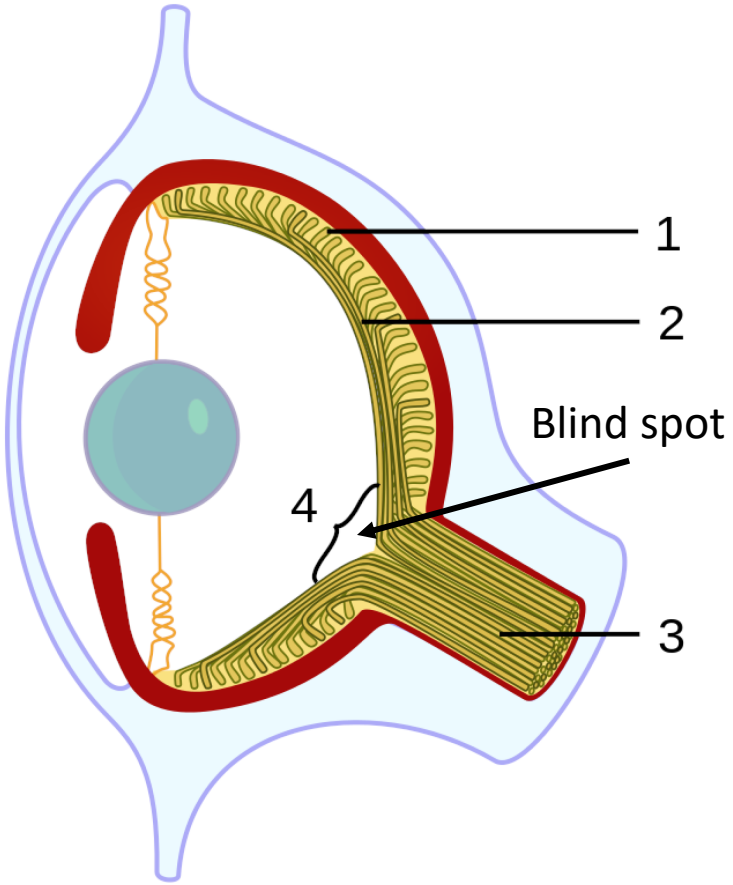
An Example of Ganglion Cell



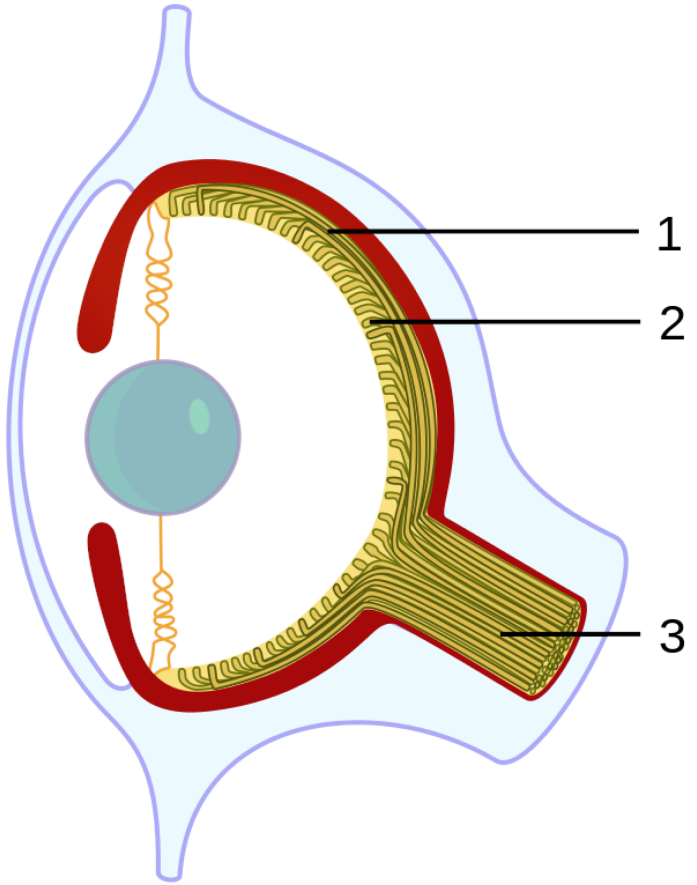
A ganglion cell is triggered when red is detected in the center but not green in the surrounding area.

Figure 5.11: The receptive field of an ON-center ganglion cell. (Figure by the Institute for Dynamic Educational Advancement.)

Inside-out Retina

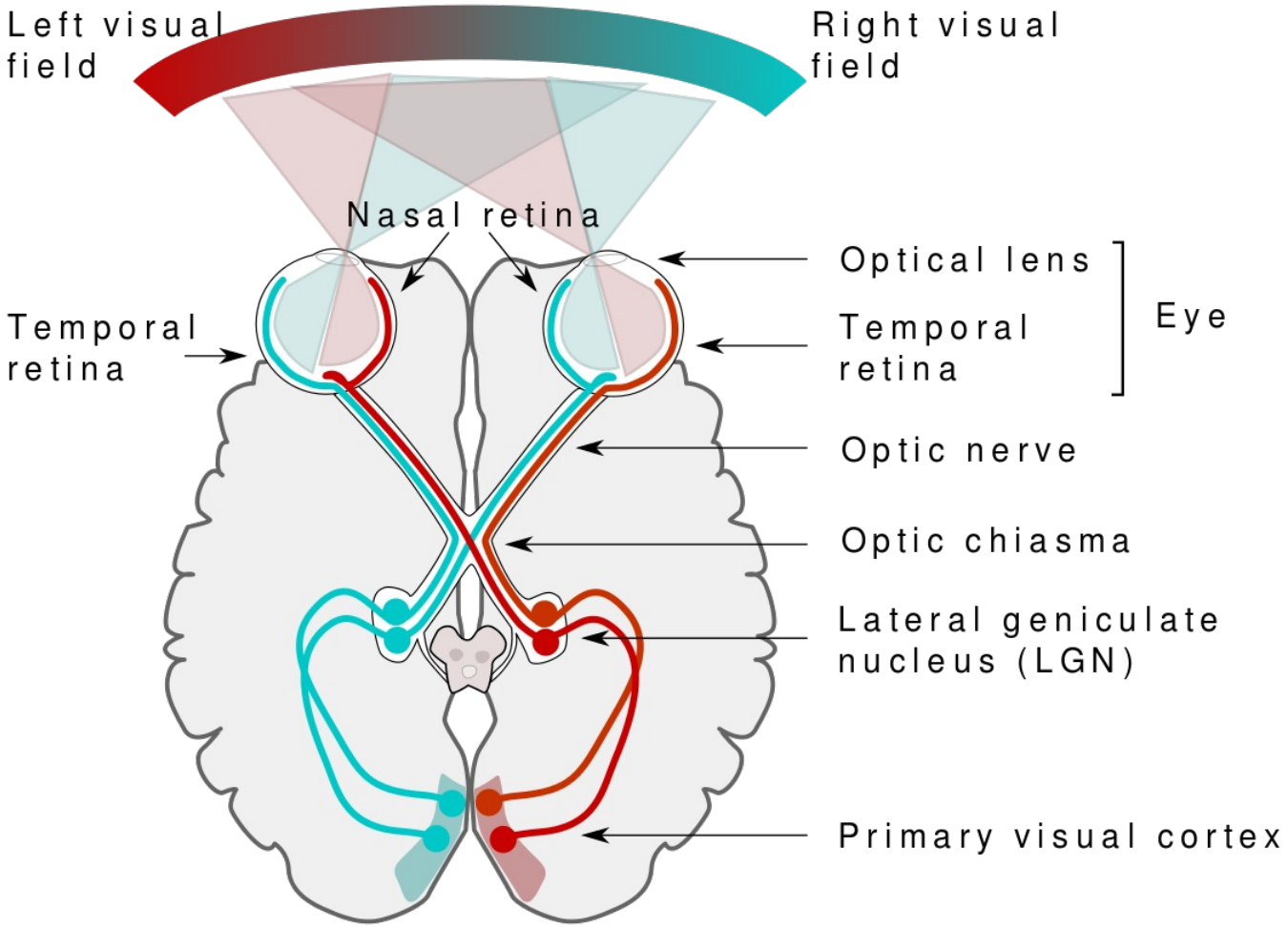


Vertebrates (including humans)

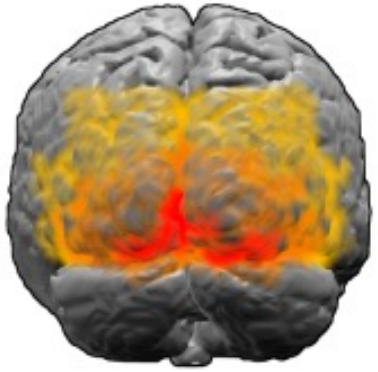


Cephalopods (e.g., octopuses)

Visual Pathway



- **Lateral geniculate nucleus (LGN)**: a router and performs some processing
- **Primary visual cortex (V1)**
- **Visual cortex**: largest system in brain for processing the visual image



V1, V2, V3, V4, V5

Eye Movements

- Position the feature of interest on the fovea
- Photoreceptors are slow to response to stimuli
  - 10ms to fully respond, product a response for up to 100ms
  - Keep the image fixed on the same set of photoreceptors
- Maintain a stereoscopic view and prevent adaptation to a constant stimulation

Eye Movements

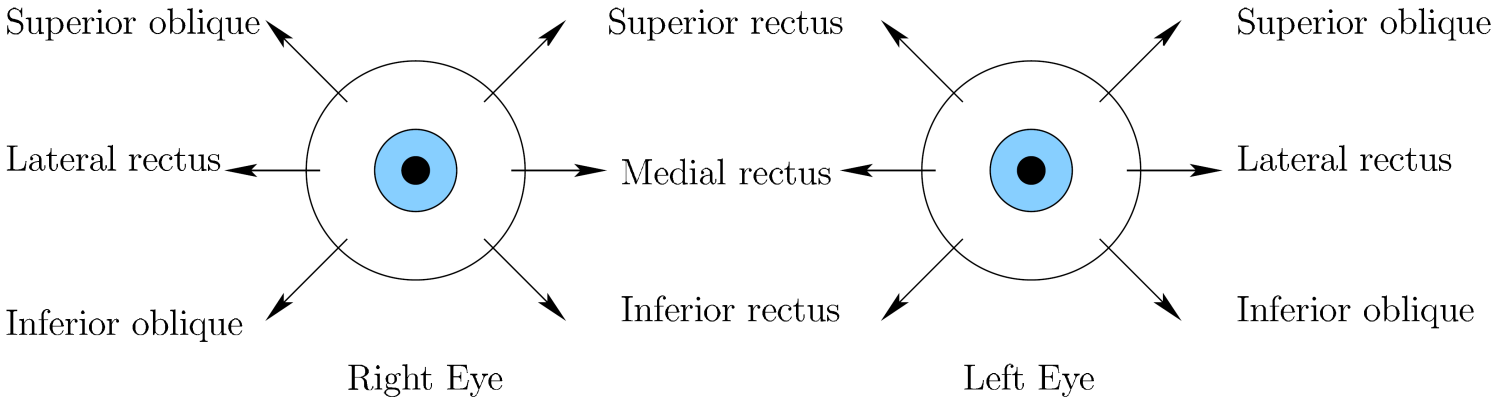
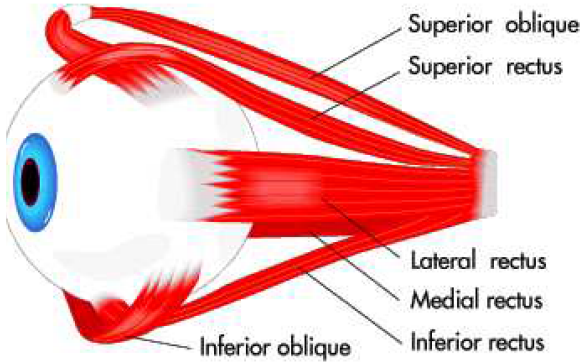
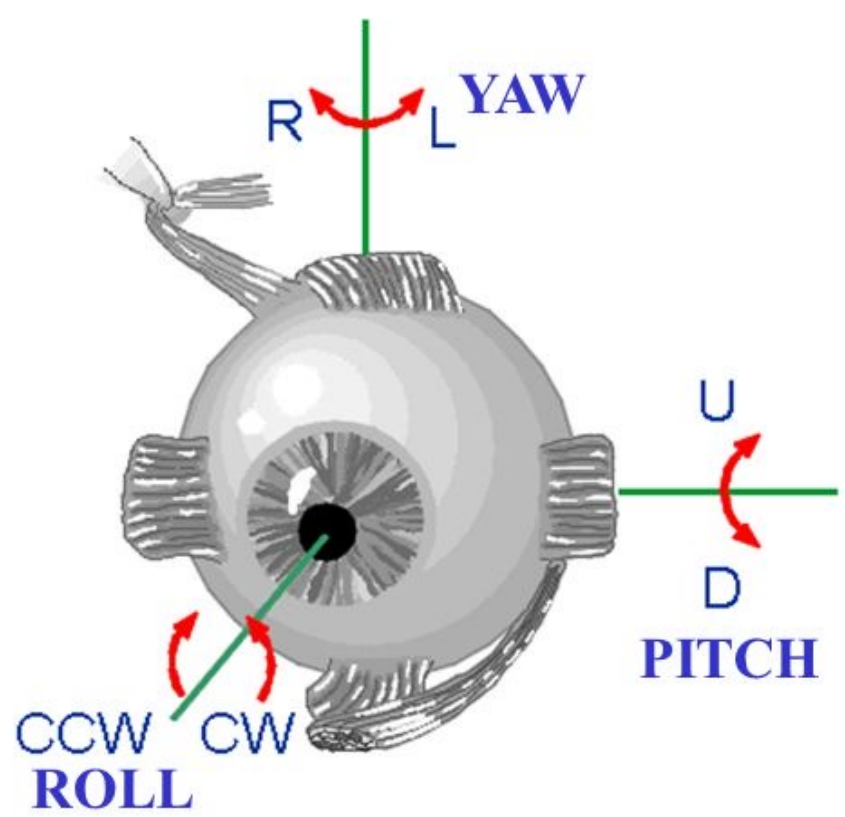


Figure 5.17: There are six muscles per eye, each of which is capable of pulling the pupil toward its location.





- Yaw: side-to-side rotation
- Pitch: up-down rotation
- Roll: rotate around line of gaze (small)

Eye Movement Types

- **Saccades**
  - Rapid motion, last less than 45ms with rotations of about 900° per second
  - Quickly relocate fovea to sense important features in a scene
  - Little of no awareness of saccades

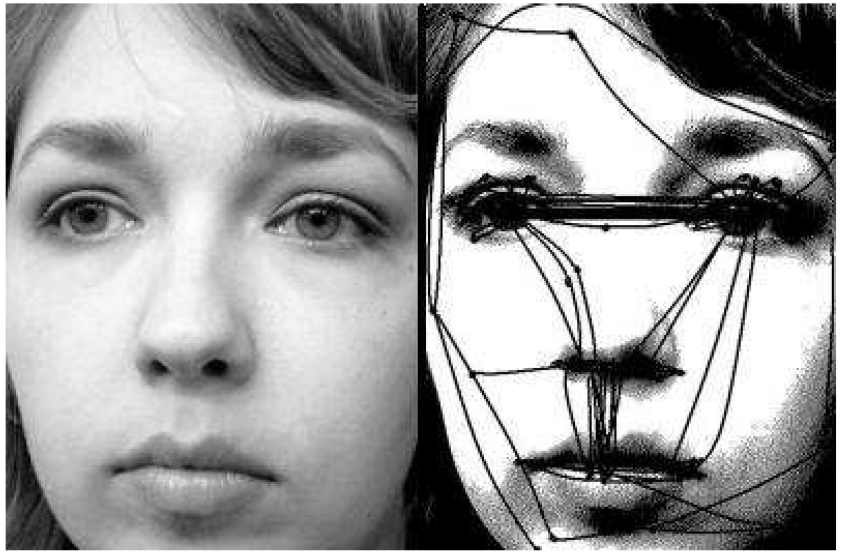
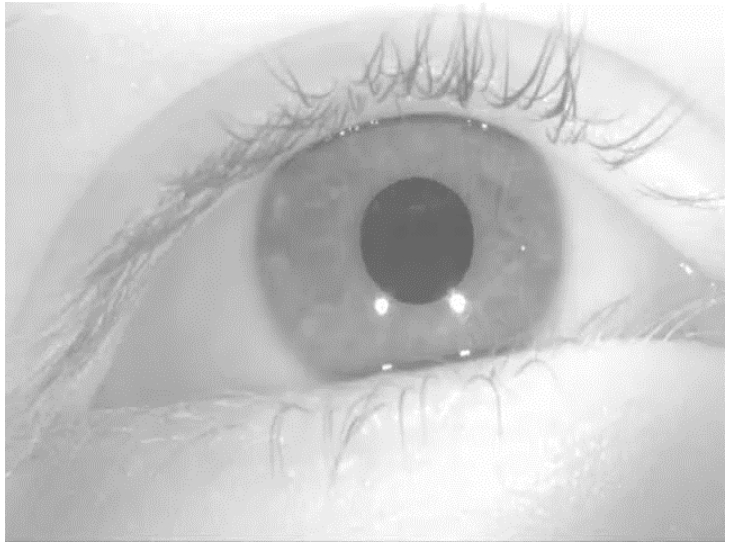


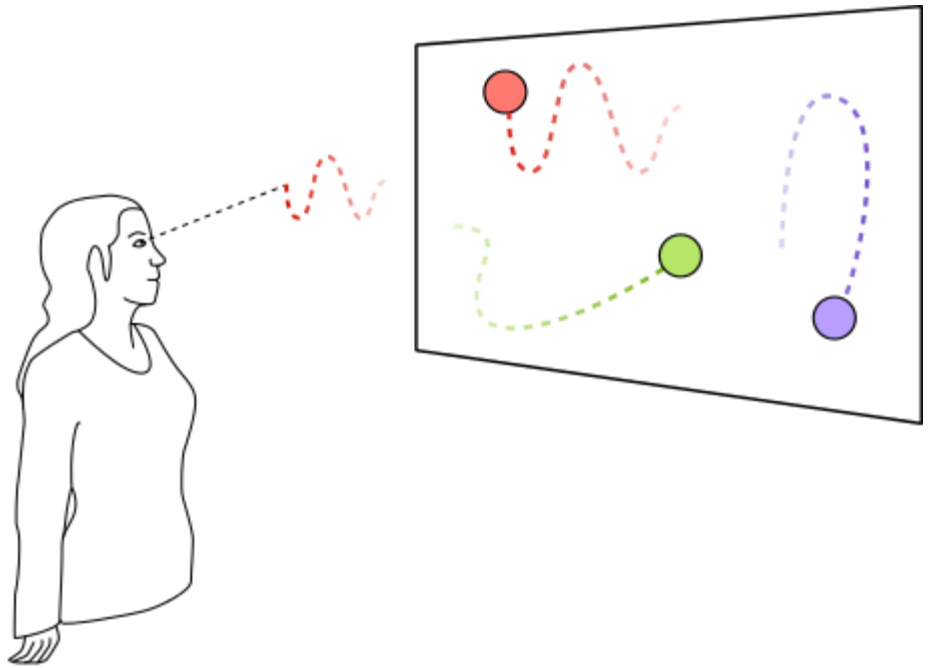
Figure 5.15: The trace of scanning a face using saccades.



Wikipedia

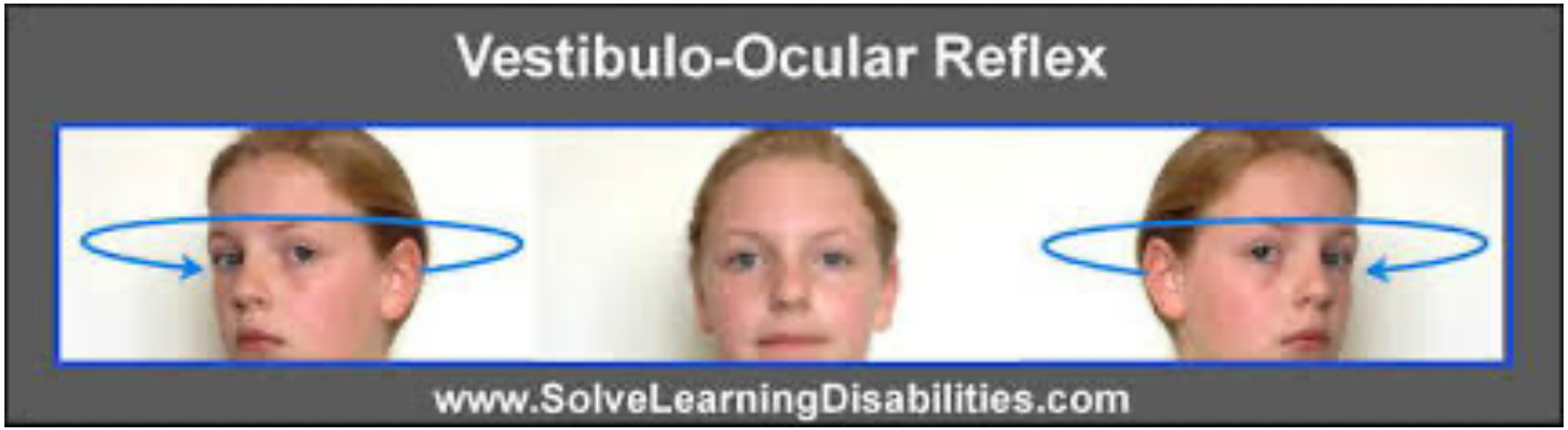
Eye Movement Types

- **Smooth pursuit**
  - The eye slowly rotates to track a moving target feature
  - A car, a tennis ball or a person walking by
  - Less than 30° per second
  - Reduce motion blur on retina



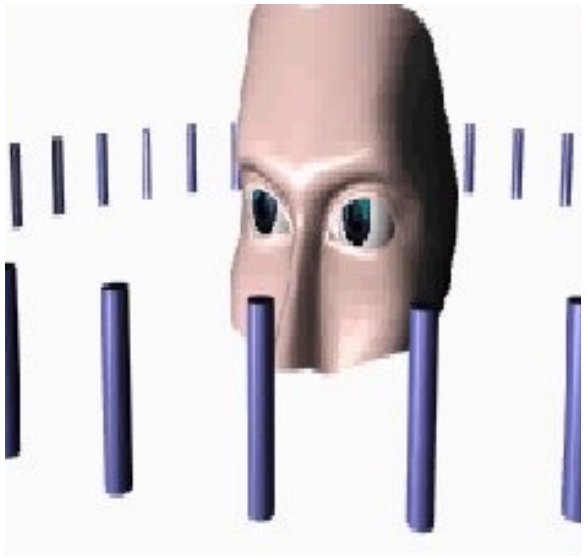
Eye Movement Types

- **Vestibulo-ocular reflex (VOR)**
  - Eyes effortlessly rotate to counteract head rotation
  - Based on the angular accelerations sensed by vestibular organs, signals are sent to eye muscles
  - Provide image stabilization

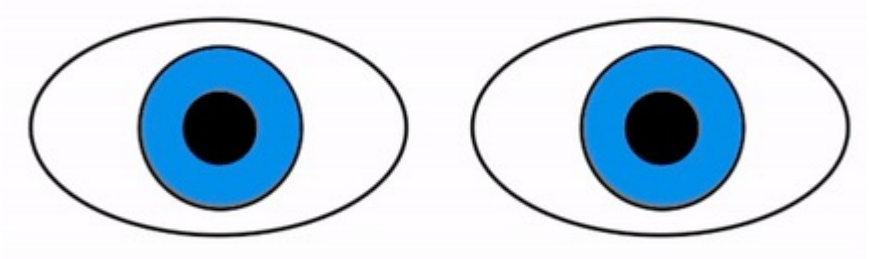


Eye Movement Types

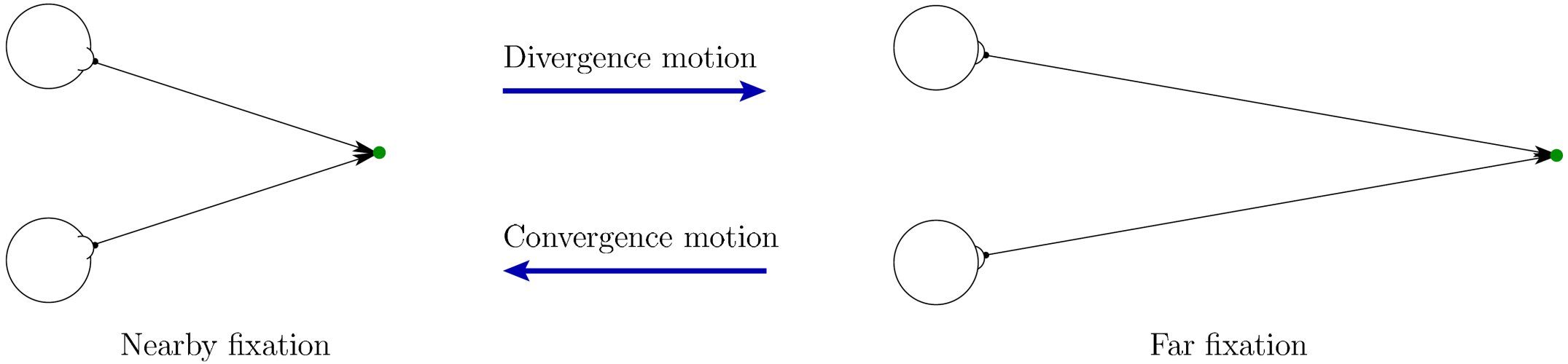
- **Optokinetic Reflex**
  - Combination of saccades and smooth pursuit that allow tracking of objects in turn (counting sheep as they jump over a fence)
  - Smoothly pursuit one target and then saccade in the opposite direction to pick up the next target



Eye Movement Types

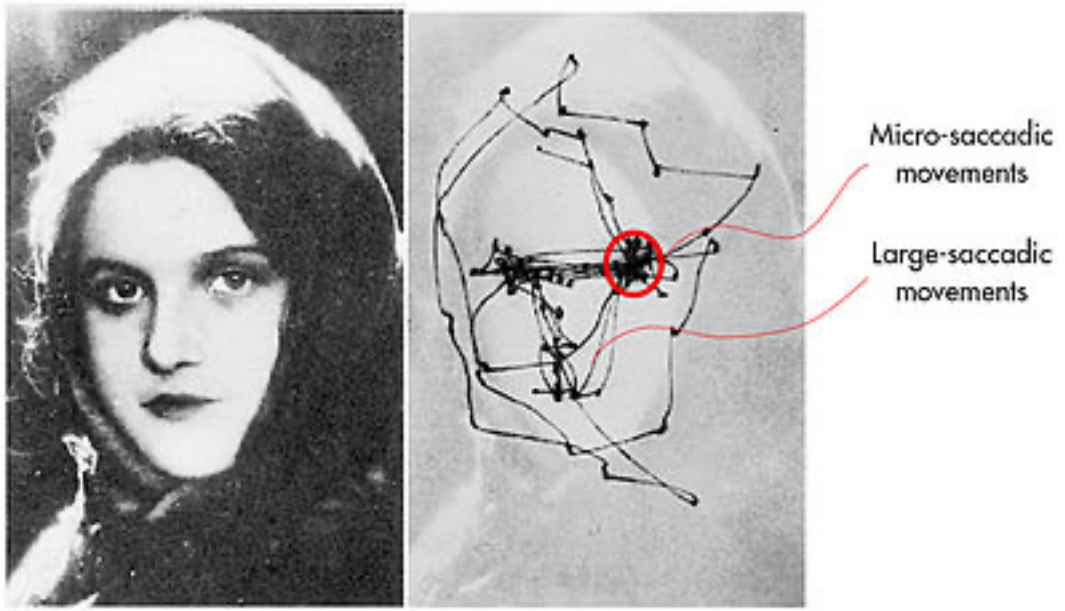


- **Vergence**
  - Convergence motion: object is closer than a previous fixation
  - Divergence motion: object is further than a previous fixation



Eye Movement Types

- **Microsaccades**
  - Small, involuntary jerks of less than one degree that trace out an erratic path
  - Believed to augment other processes (control of fixations, reduction of perceptual fading due to adaptation, improvement of visual acuity, resolving perceptual ambiguities)
  - Not fully understood



Perception of Color

- Color perception is “all in your head”
  - Results of our visual physiology and neural structures

Dress color illusion

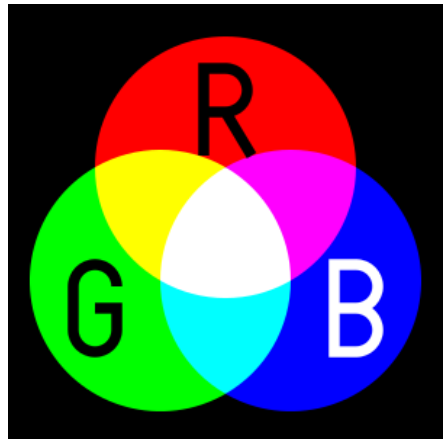
- Blue and black? 57%
- White and gold? 30%

10% blue and brown

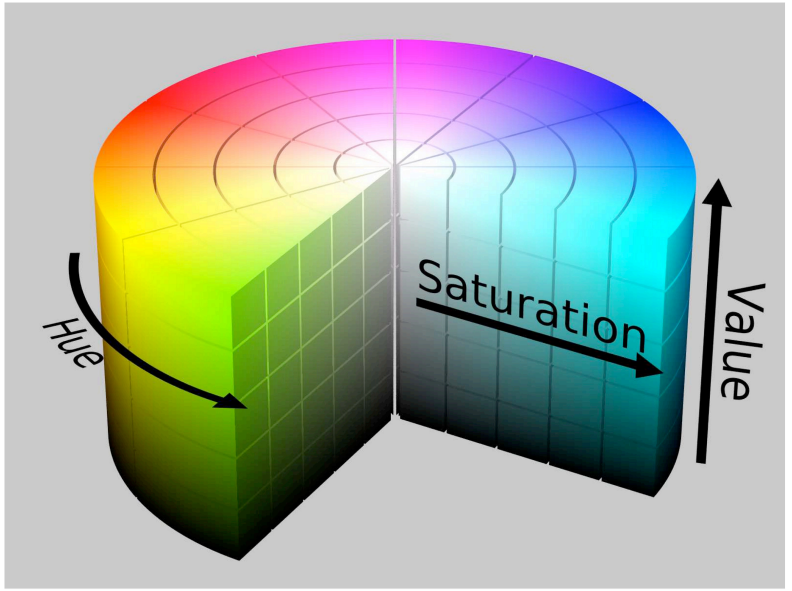
10% switch

Color Spaces

- RGB color space (yellow = green + red)



- HSV color space
  - Hue: the perceived color such as red or green
  - Saturation: purity of color
  - Value: brightness
  - Commonly used in graphics



Constancy

- Color constancy
  - A red shirt appears to be red in different lighting conditions

- Lightness constancy
  - The tendency to perceive an object as maintaining its level of brightness in relation to its surrounding despite changes in the amount of light being reflected from object to the retina

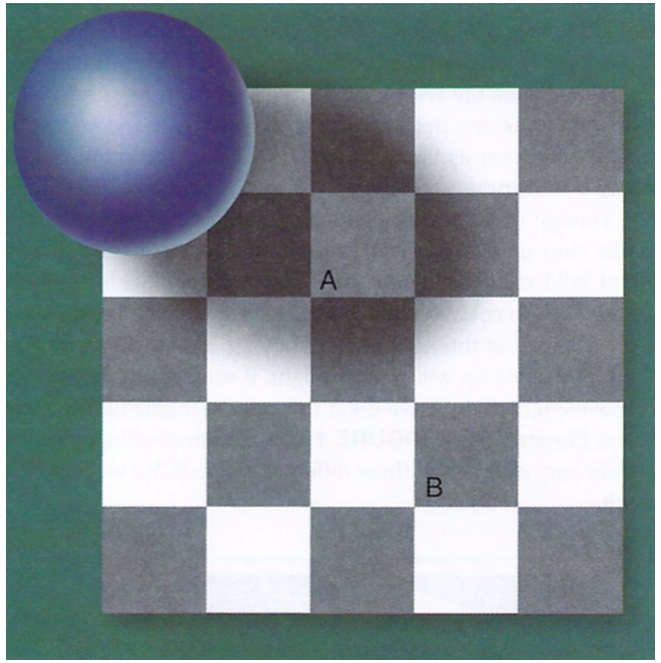
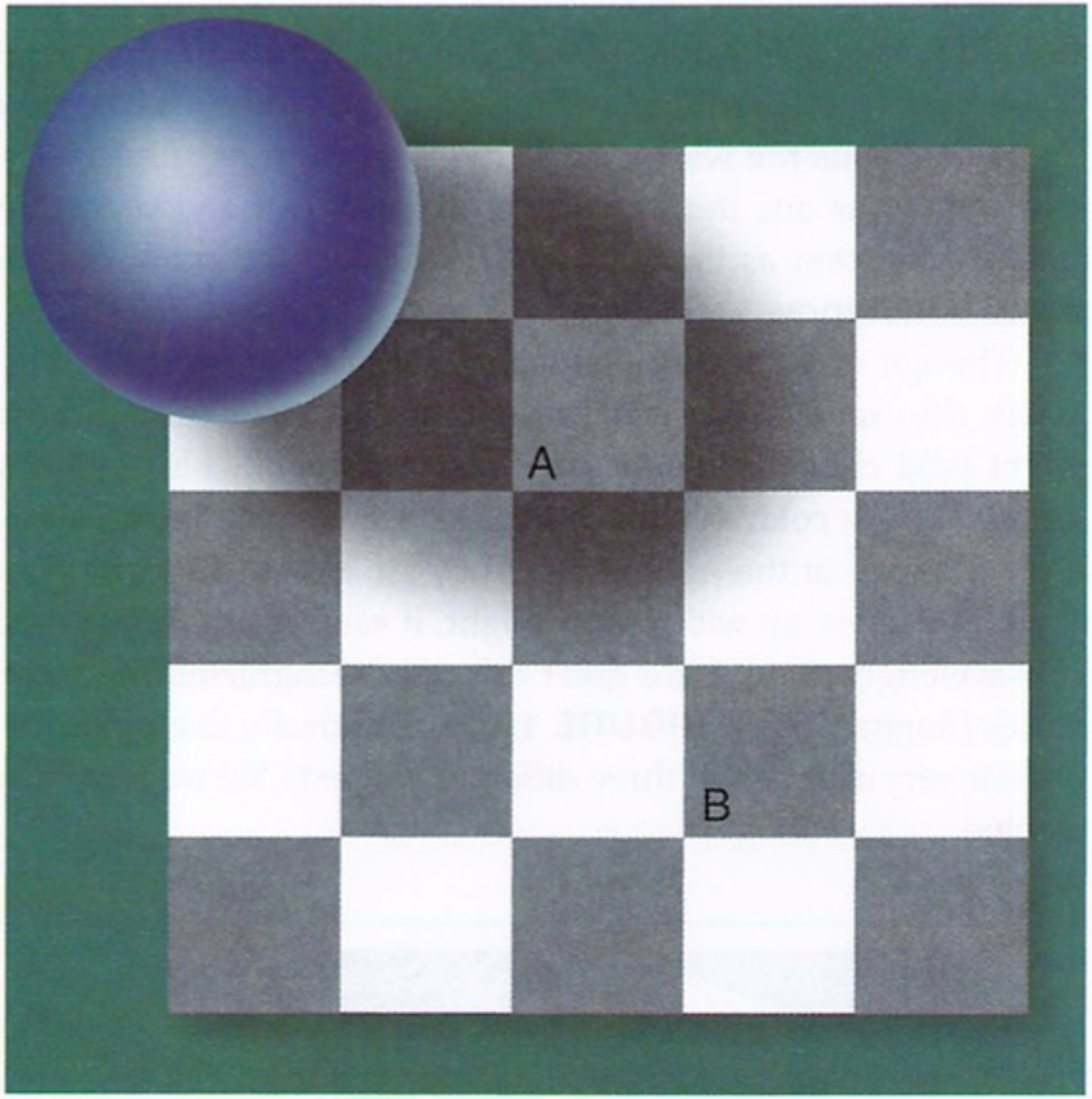


Figure 19.7

Relative luminance Squares A and B are identical in color, believe it or not. (If you don't believe me, photocopy the illustration, cut out the squares, and compare.) But we perceive A as lighter, thanks to its surrounding context.



http://fiatlux-day.org/psych/semester_1/unit_4/module_19.html

Further Reading

- Chapter 5, Section 6.3, Virtual Reality, Steven LaValle