

The logo of The University of Texas at Dallas, featuring a circular seal with the letters 'UTD' in the center, the text 'THE UNIVERSITY OF TEXAS AT DALLAS' around the top, and 'EST. 1969' at the bottom. Two stars are positioned on either side of the 'EST. 1969' text.

# Visual Perception: Human Visual System and Color Perception

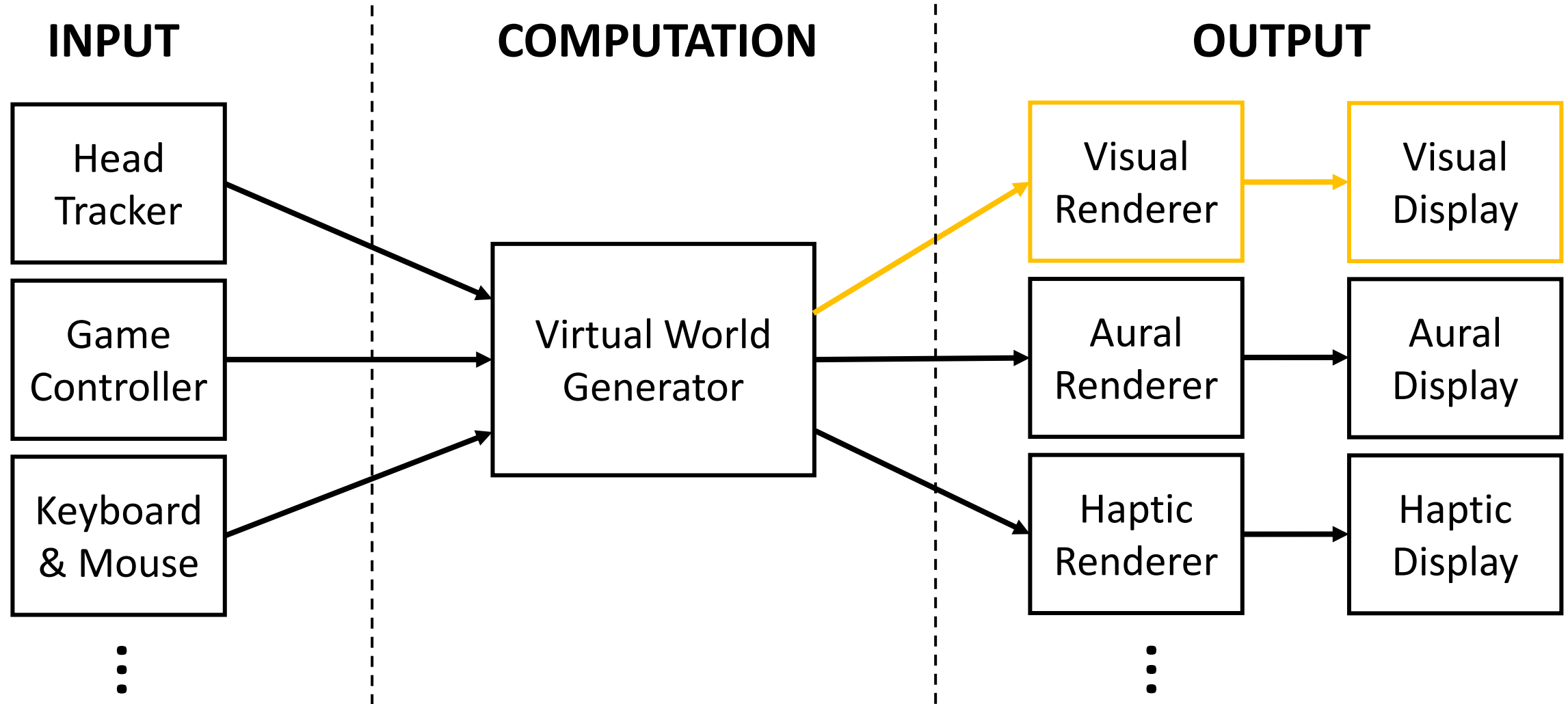
CS 6334 Virtual Reality

Professor Yu Xiang

The University of Texas at Dallas

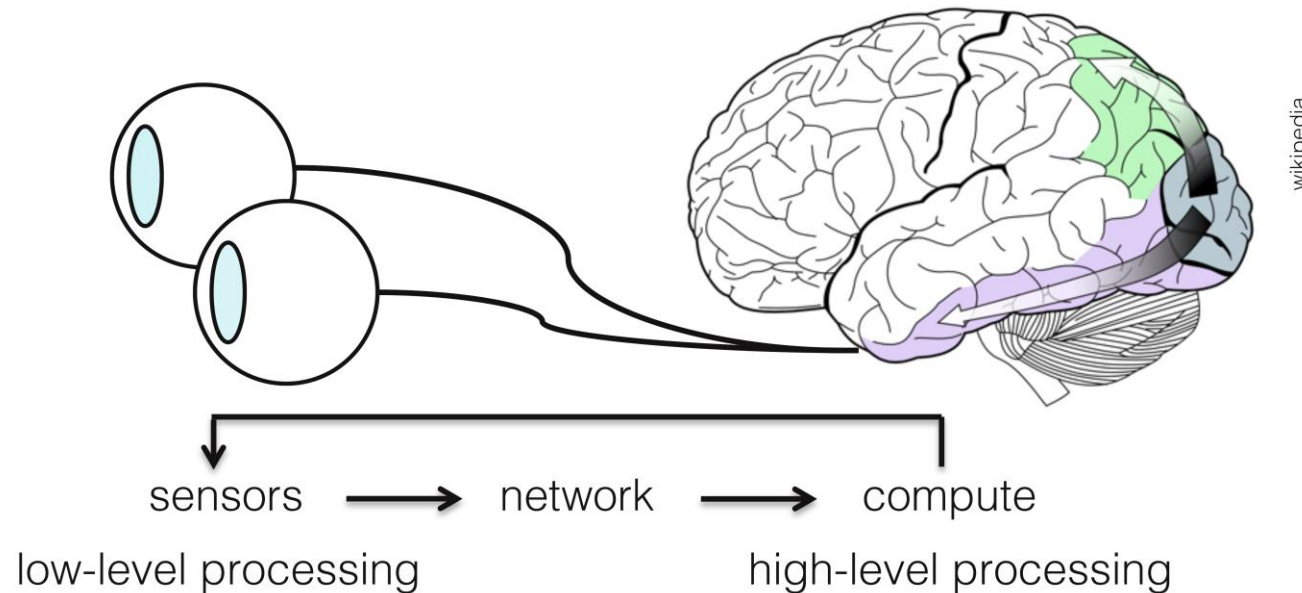
# Review of VR Systems

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



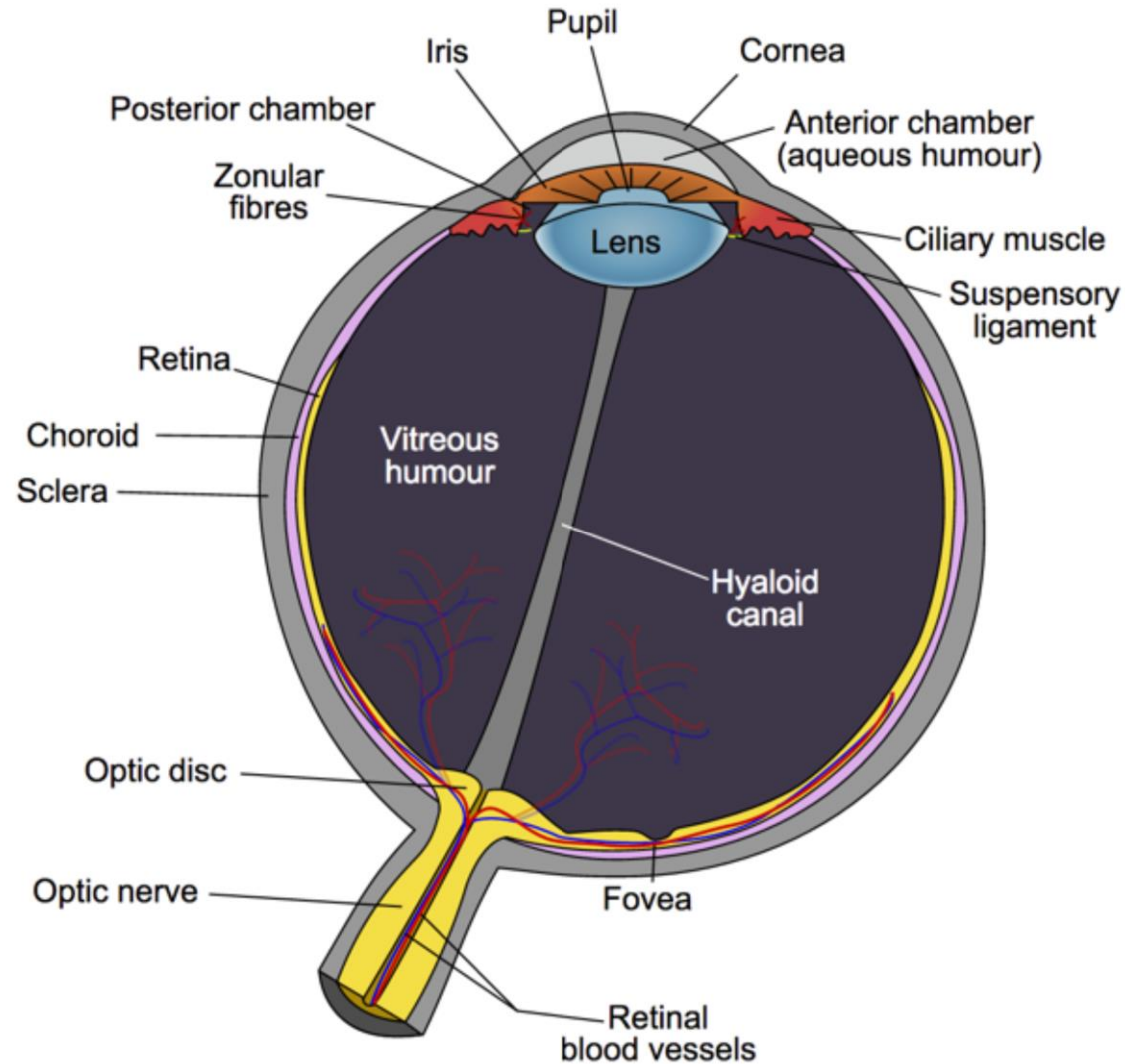
# Visual Perception

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

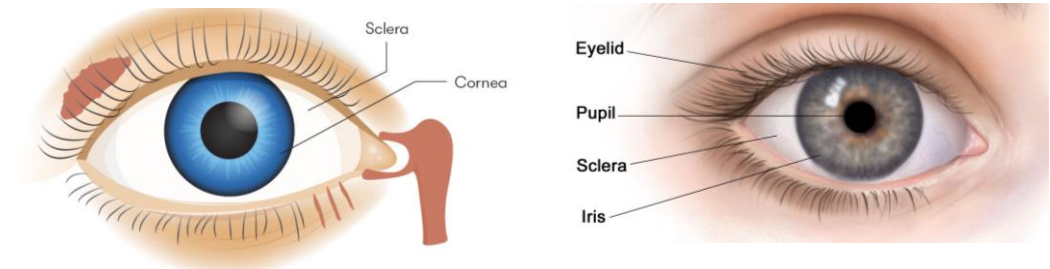


- We need to understand visual perception to achieve visual unawareness in VR systems

# Physiology of the Human Eye

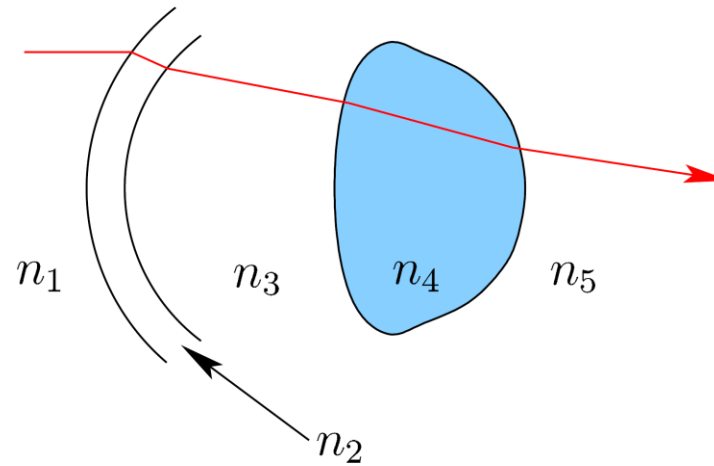
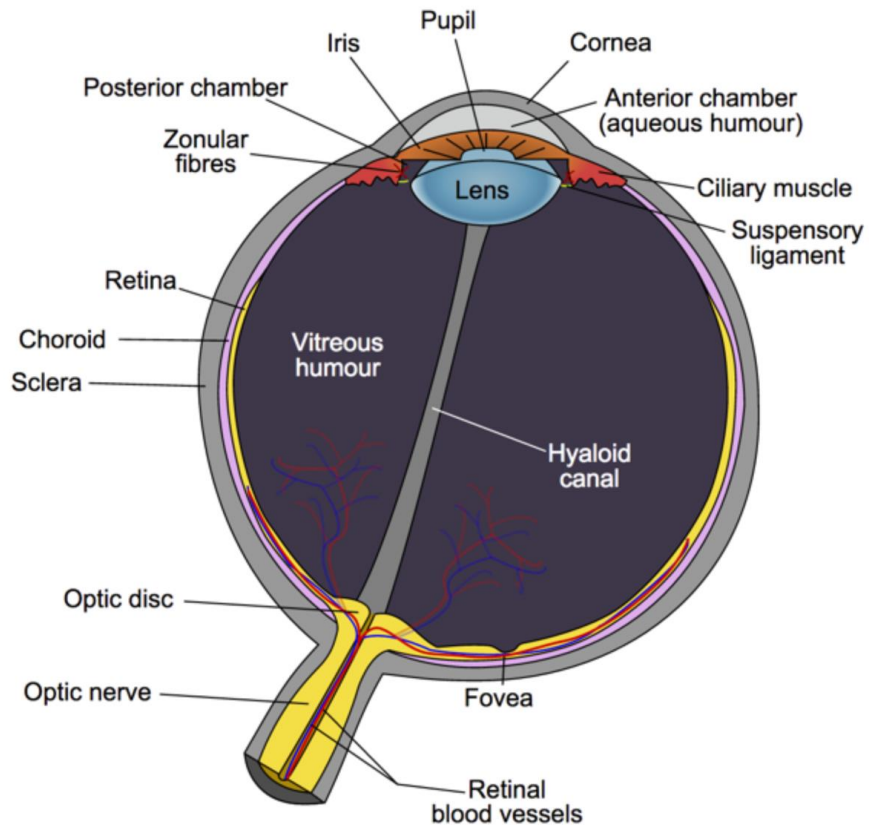


- Cornea: hard, transparent surface
- Sclera: hard, white layer



- 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

# Light through the Human Eye



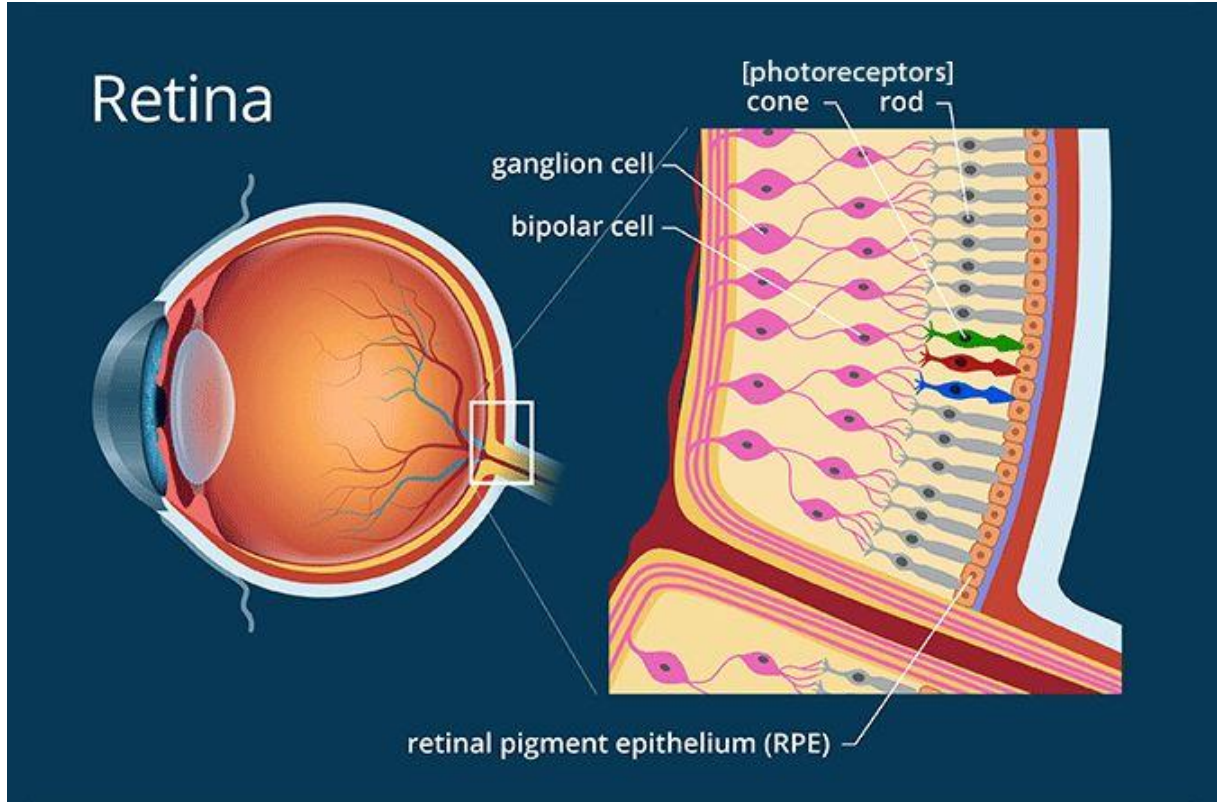
1.  $n_1 = 1.009$  (air)
2.  $n_2 = 1.376$  (cornea)
3.  $n_3 = 1.336$  (aqueous fluid)
4.  $n_4 = 1.413$  (lens)
5.  $n_5 = 1.337$  (vitreous fluid)

Reflective index

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

$c$  ← Speed of light in a vacuum  
 $s$  ← Speed of light in the medium

# Photoreceptors

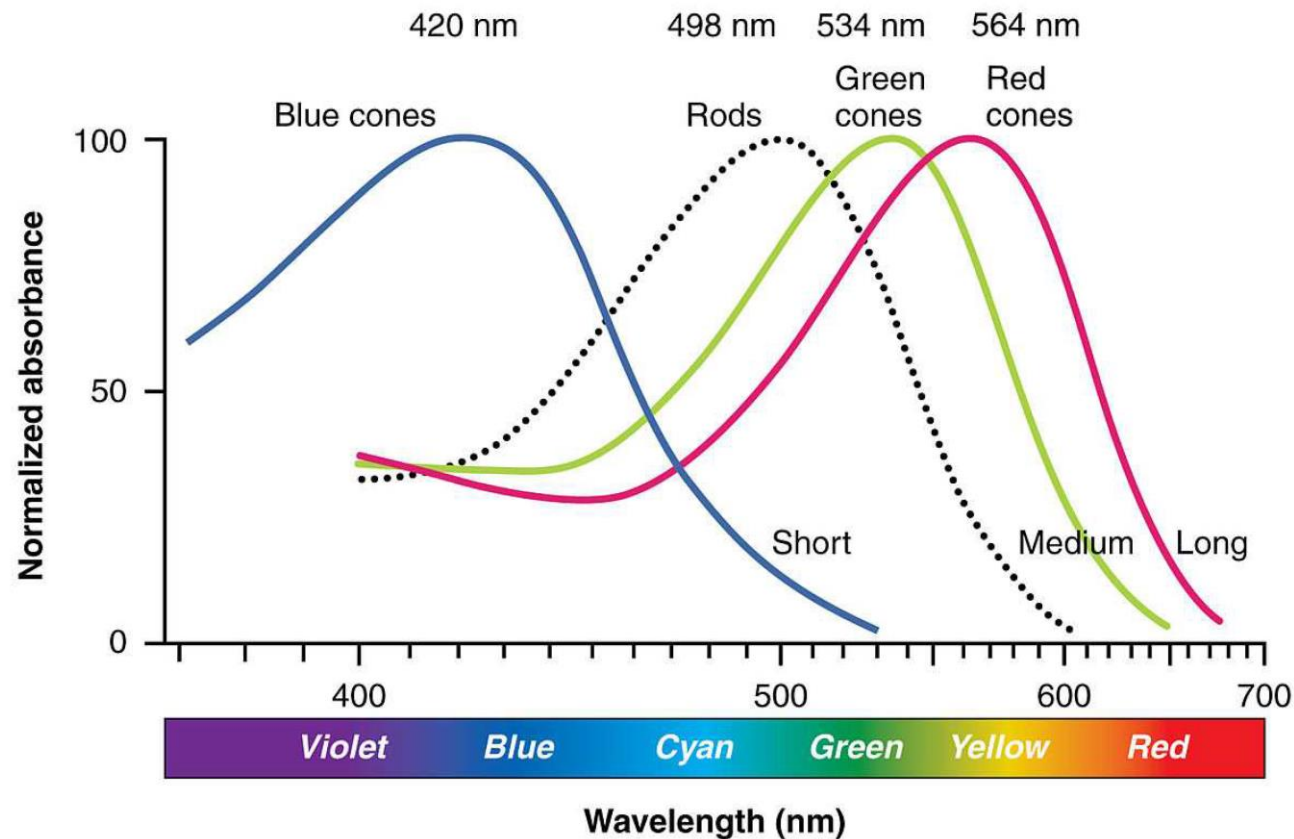


- Two types of photoreceptors in Retina
  - **Rod**: triggered by very low levels of lights, night vision, seeing black and white
  - **Cone**: activated by bright light and see colors
- 120 million rods and 6 million cones in human retina

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

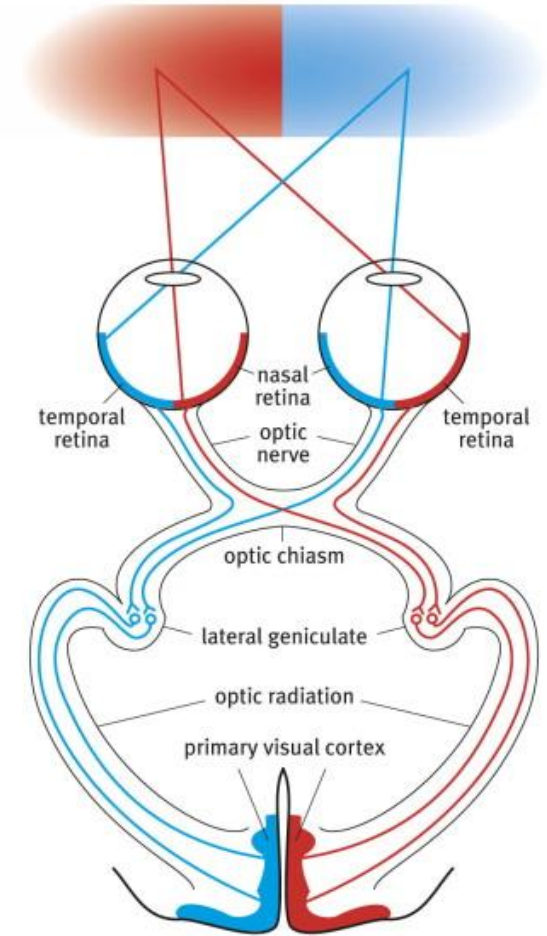
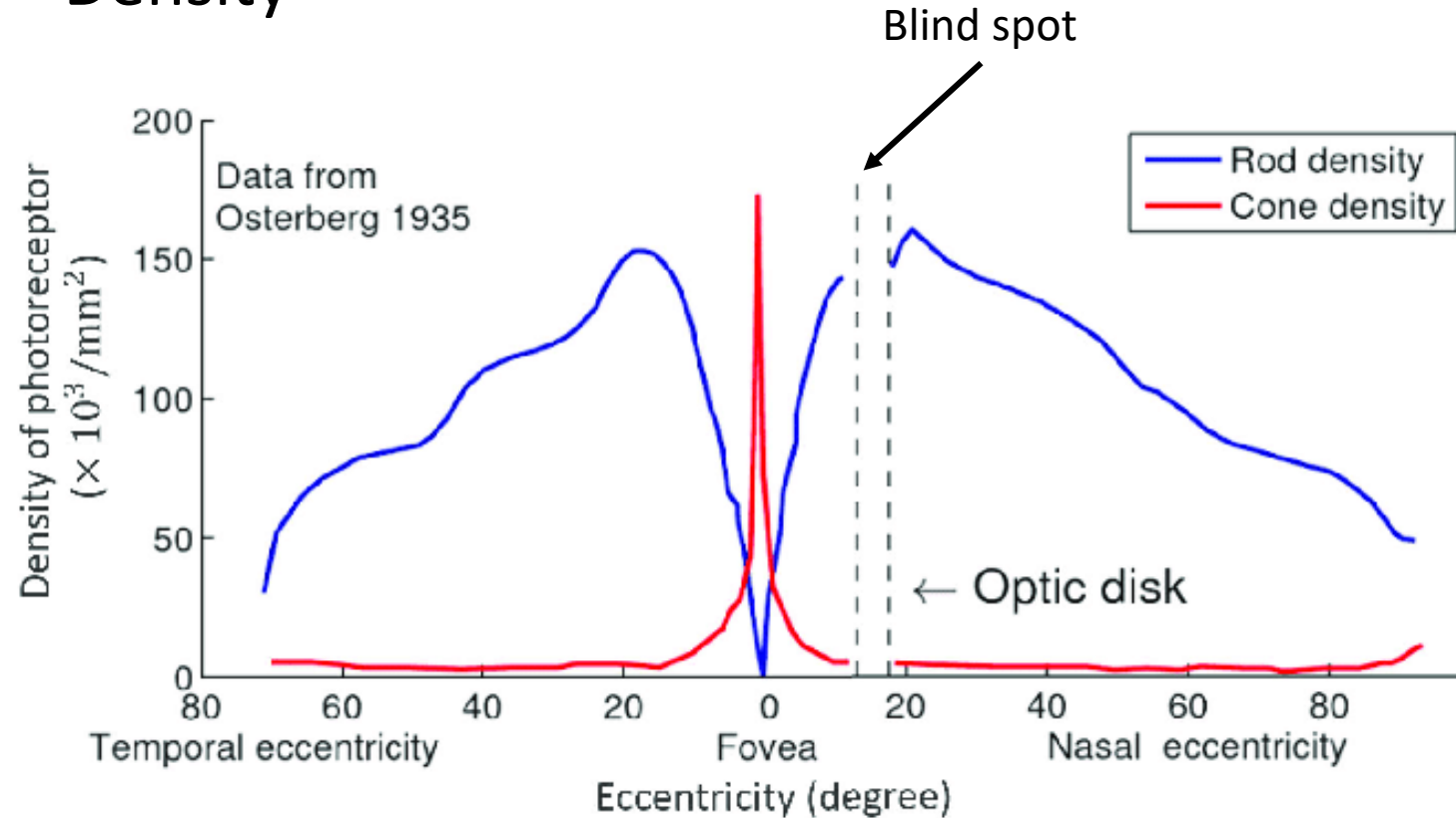
# Photoreceptors

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



# Photoreceptors

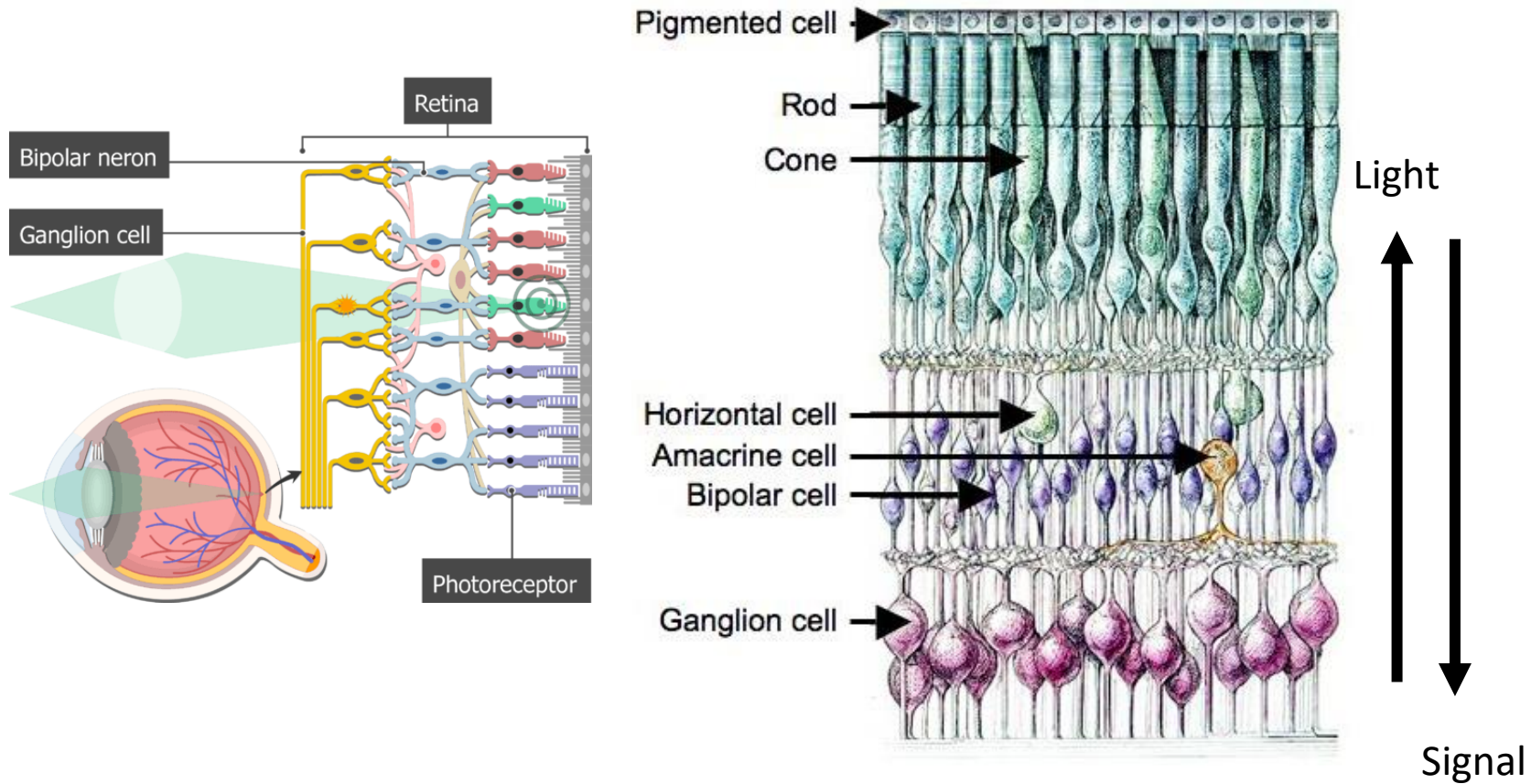
- Density



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

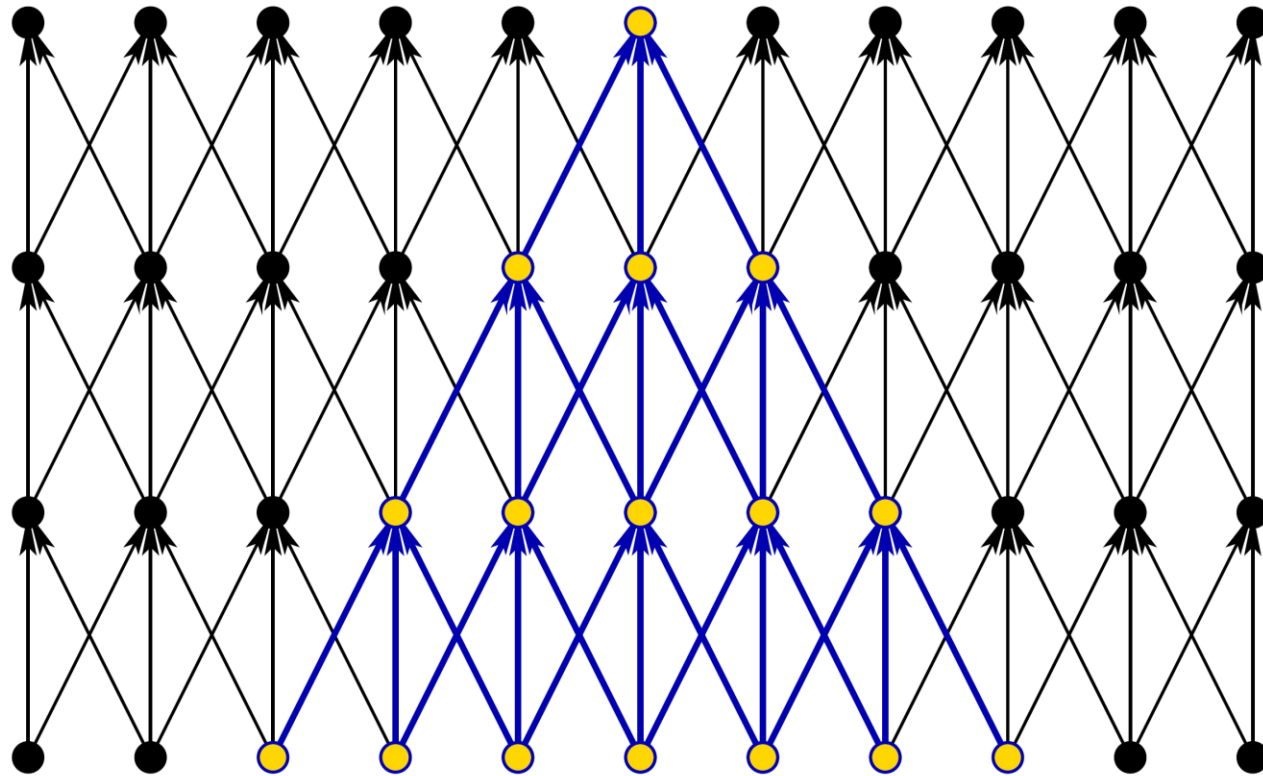


# Retinal Circuitry



- **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



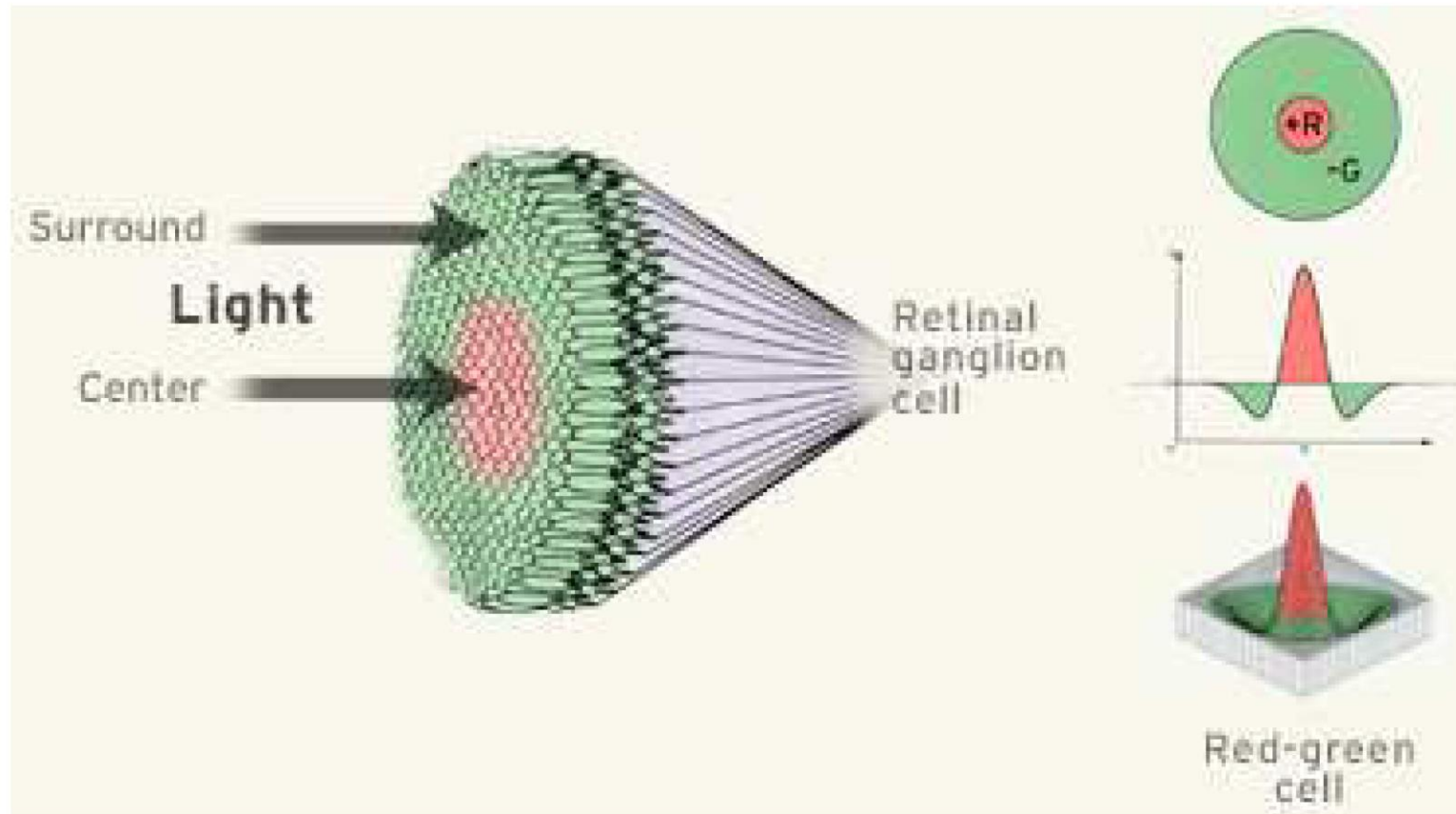
Level 3: Neural Cells

Level 2: Neural Cells

Level 1: Neural Cells

Level 0: Photoreceptors

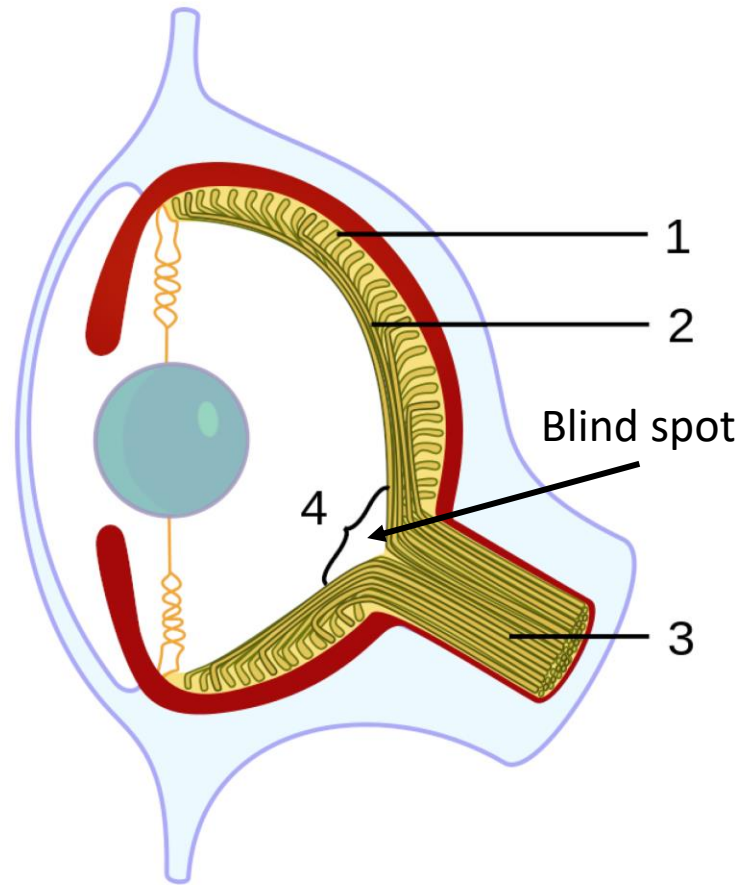
# An Example of Ganglion Cell



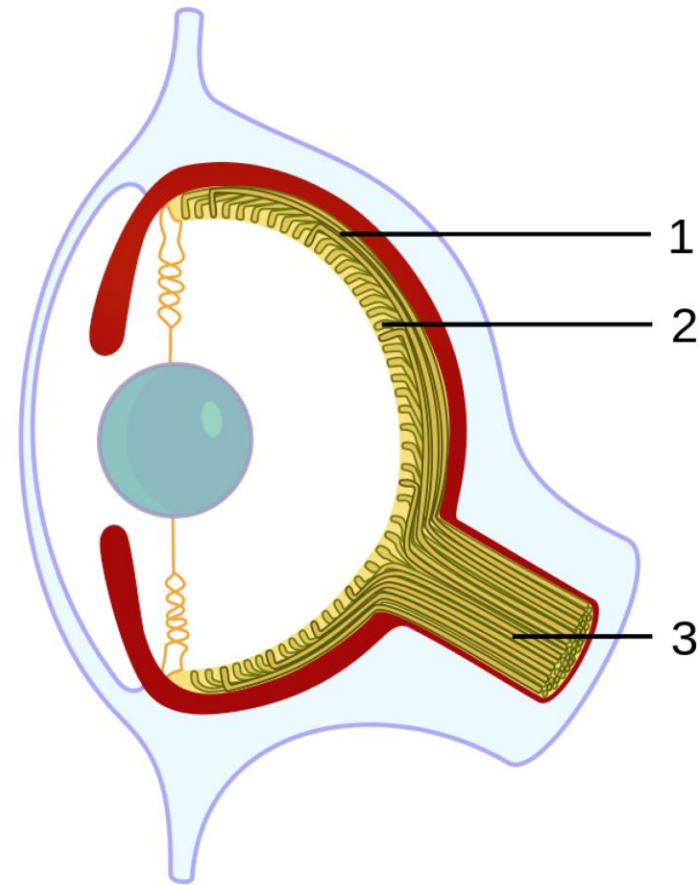
A ganglion cell is triggered when red is detected in the center but not green in the surrounding area.

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

# Inside-out Retina

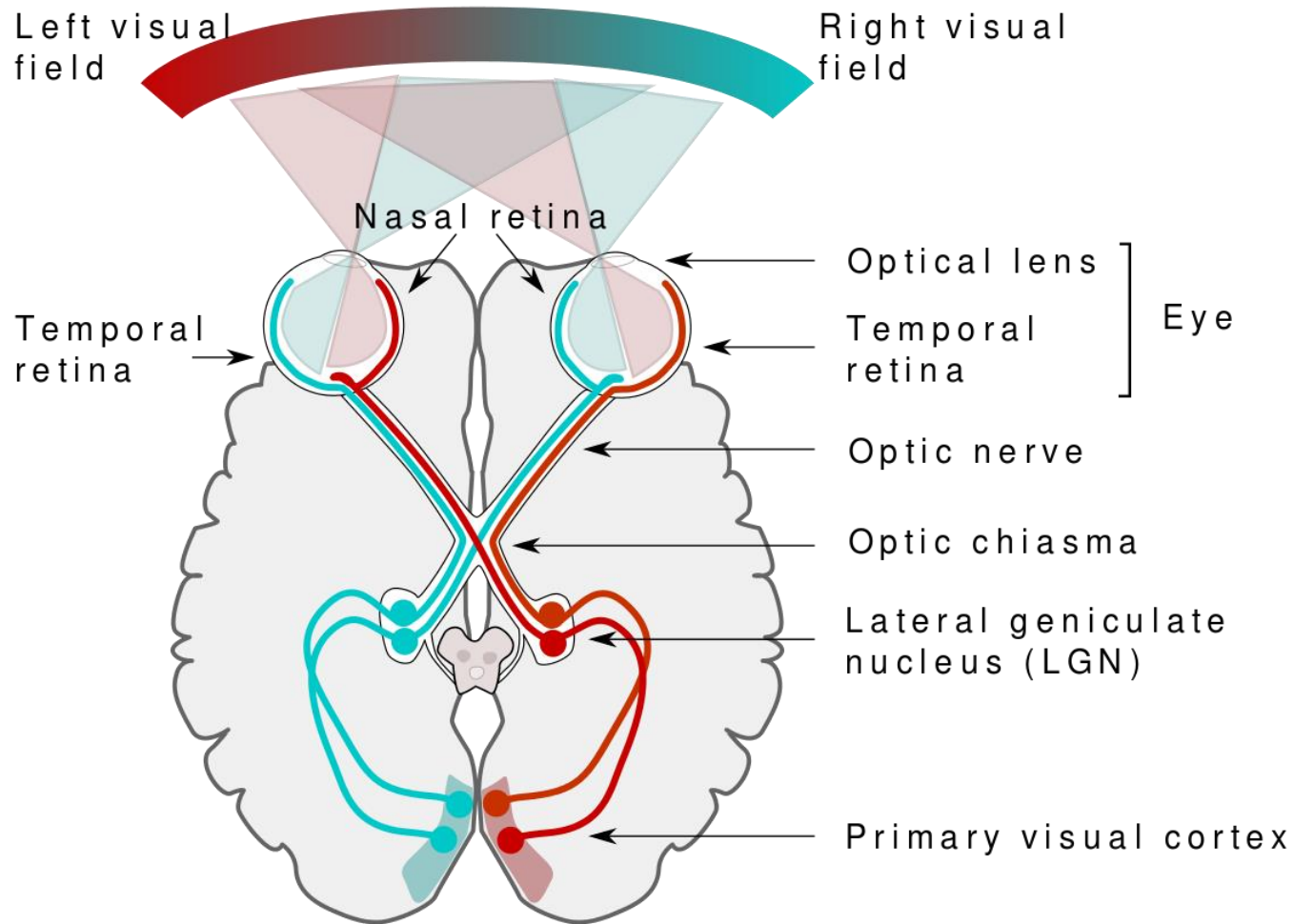


Vertebrates (including humans)

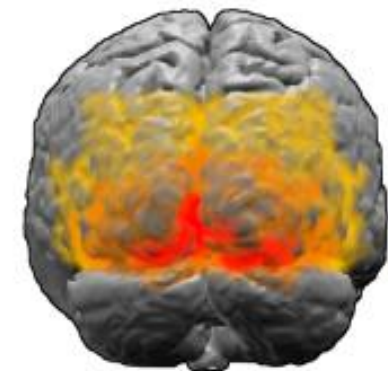


Cephalopods (e.g., octopuses)

# 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

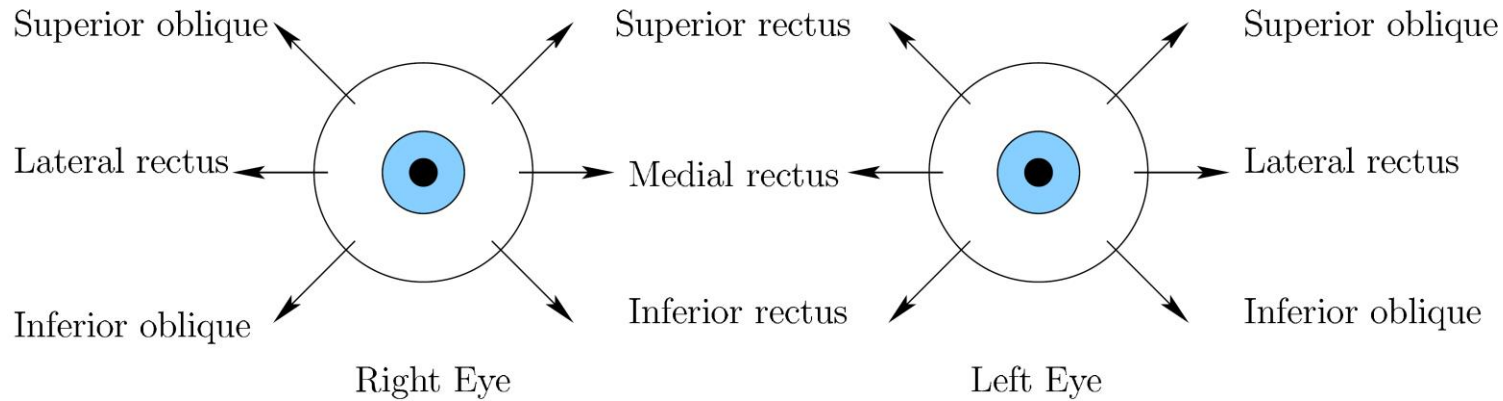
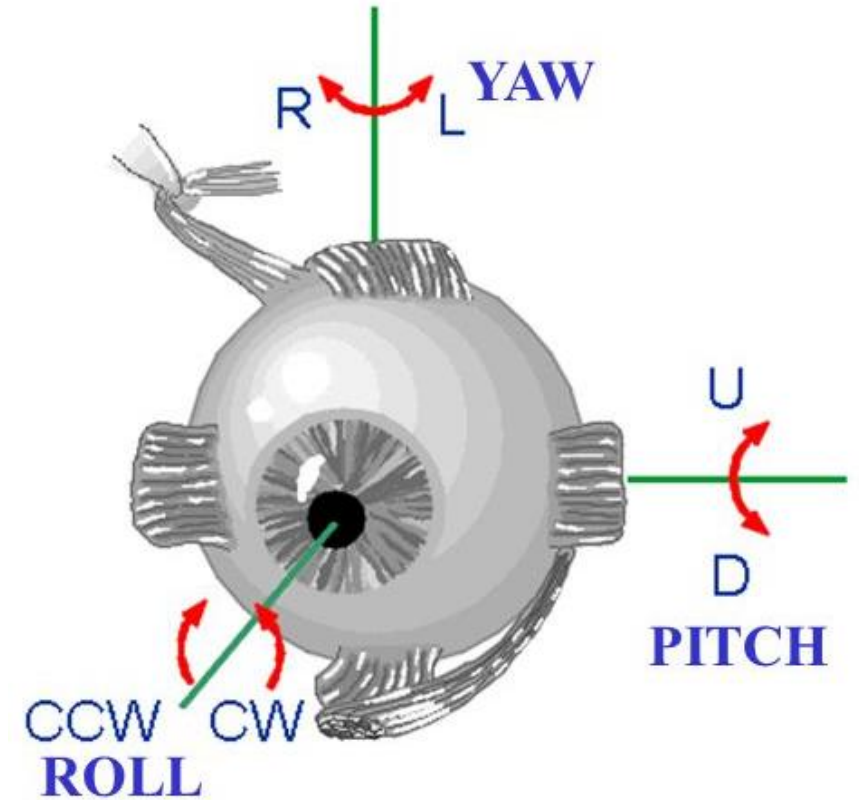
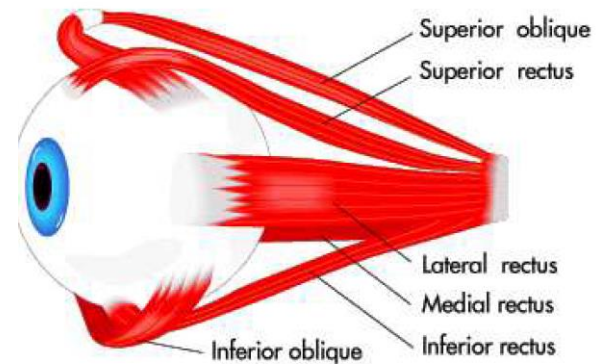


Figure 5.17: There are six muscles per eye, each of which is capable of pulling the pupil toward its location.



- 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  $900^\circ$  per second
- Quickly relocate fovea to sense important features in a scene
- Little of no awareness of saccades

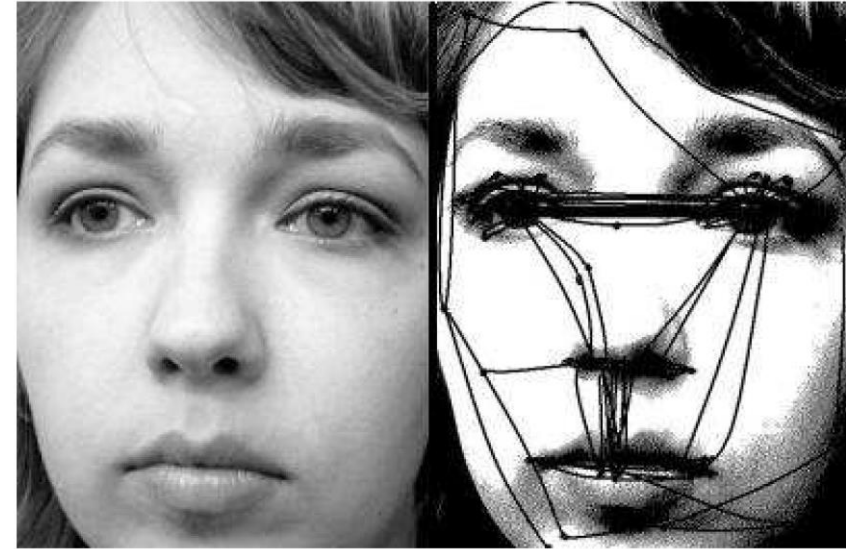
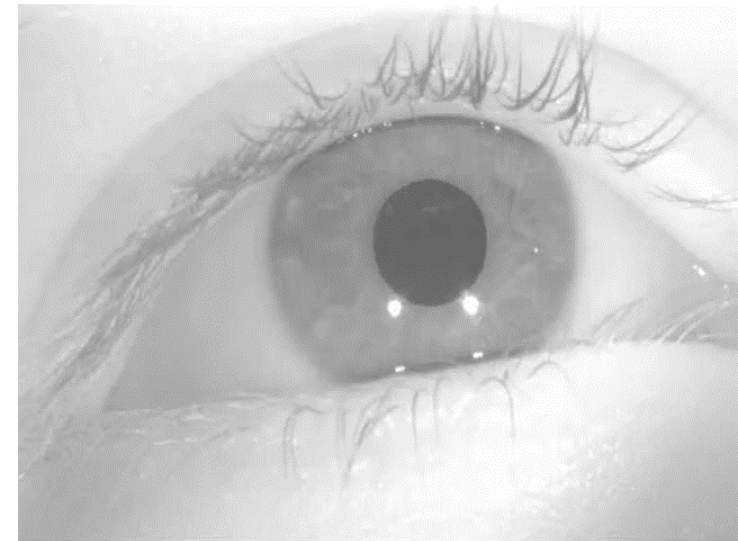


Figure 5.15: The trace of scanning a face using saccades.



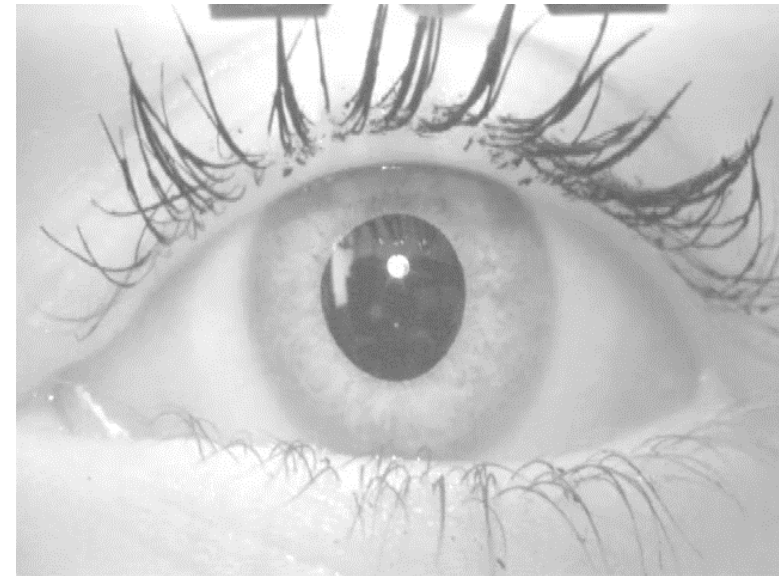
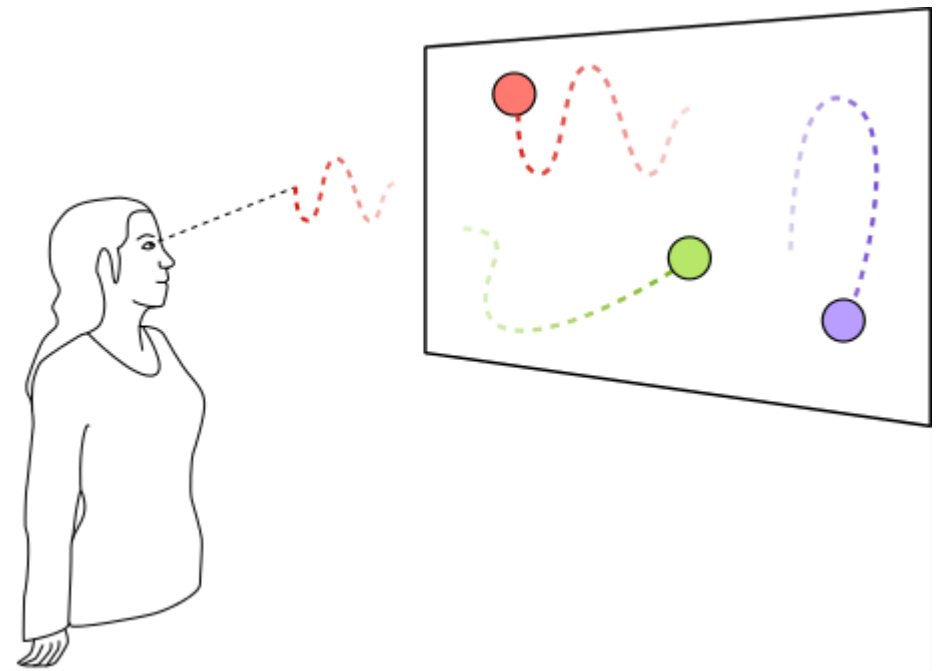
Wikipedia



# 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  $30^\circ$  per second
- Reduce motion blur on retina



Wikipedia

# Eye Movement Types

- **Vestibulo-ocular reflex (VOR)**

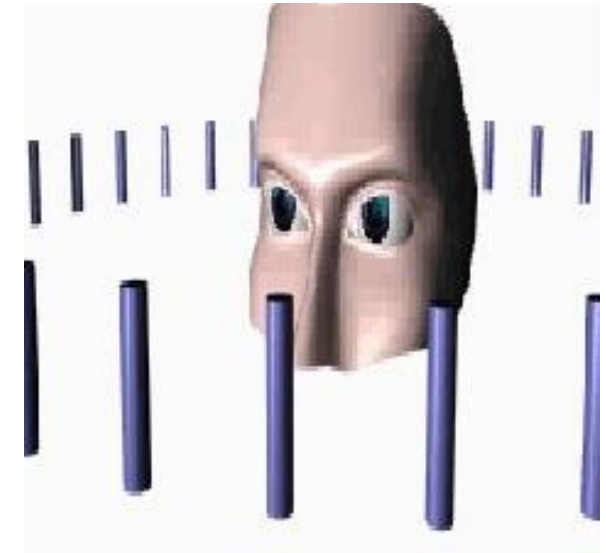
- Eyes effortlessly rotate to counteract head rotation
- Based on the angular accelerations sensed by vestibular organs, signals are sent to eye muscles
- Provide image stabilization



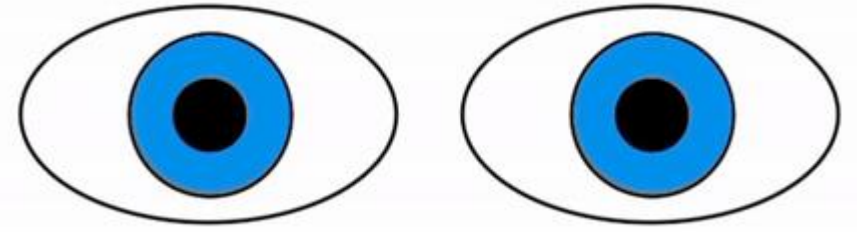
# Eye Movement Types

- **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

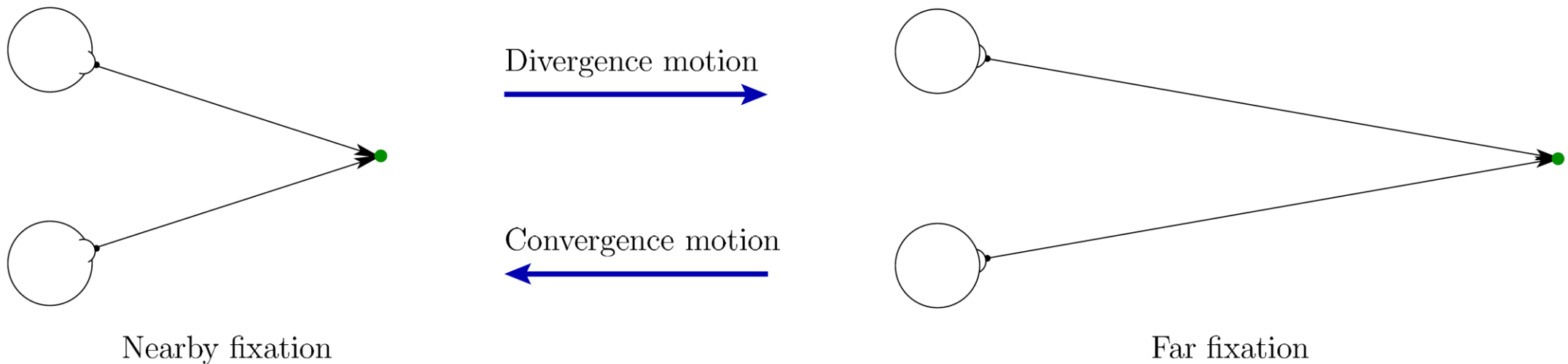


# Eye Movement Types



- **Vergence**

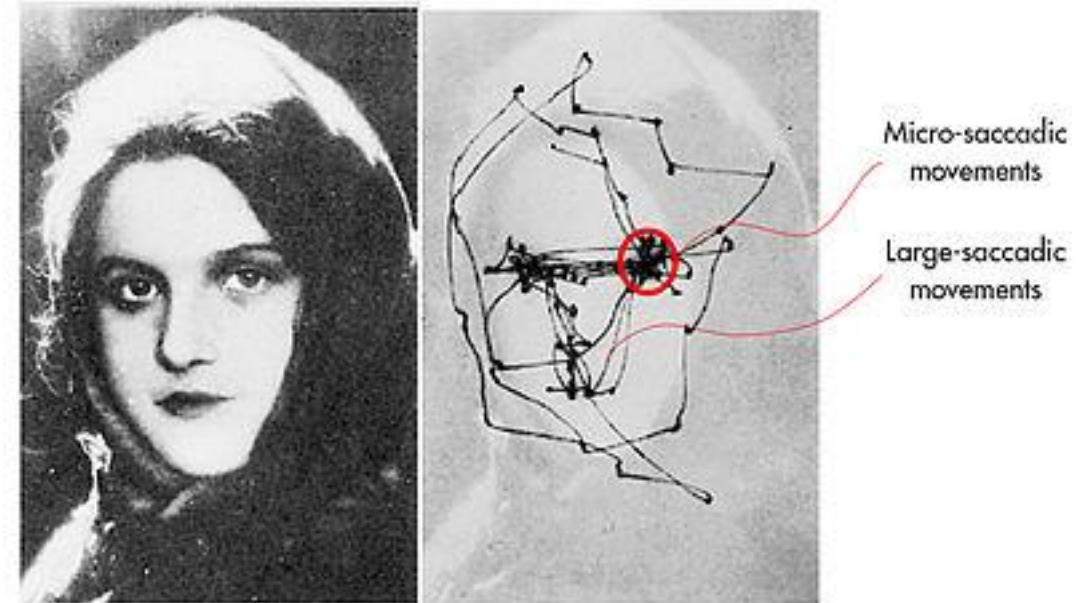
- Convergence motion: object is closer than a previous fixation
- Divergence motion: object is further than a previous fixation



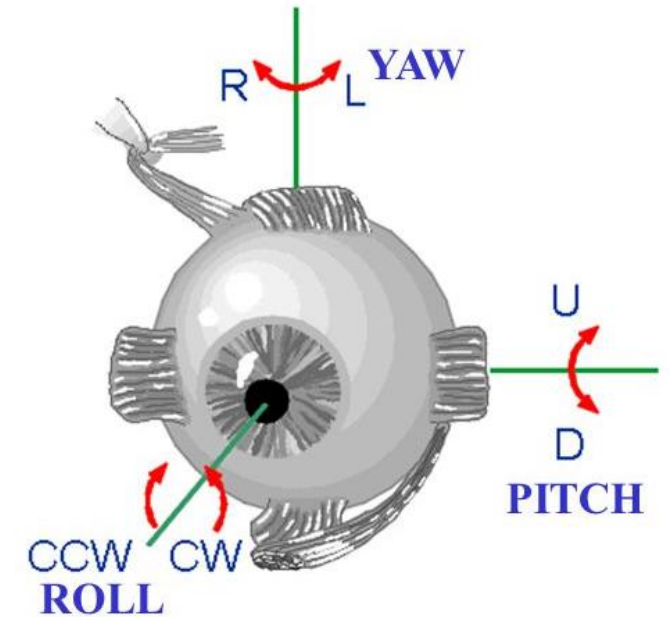
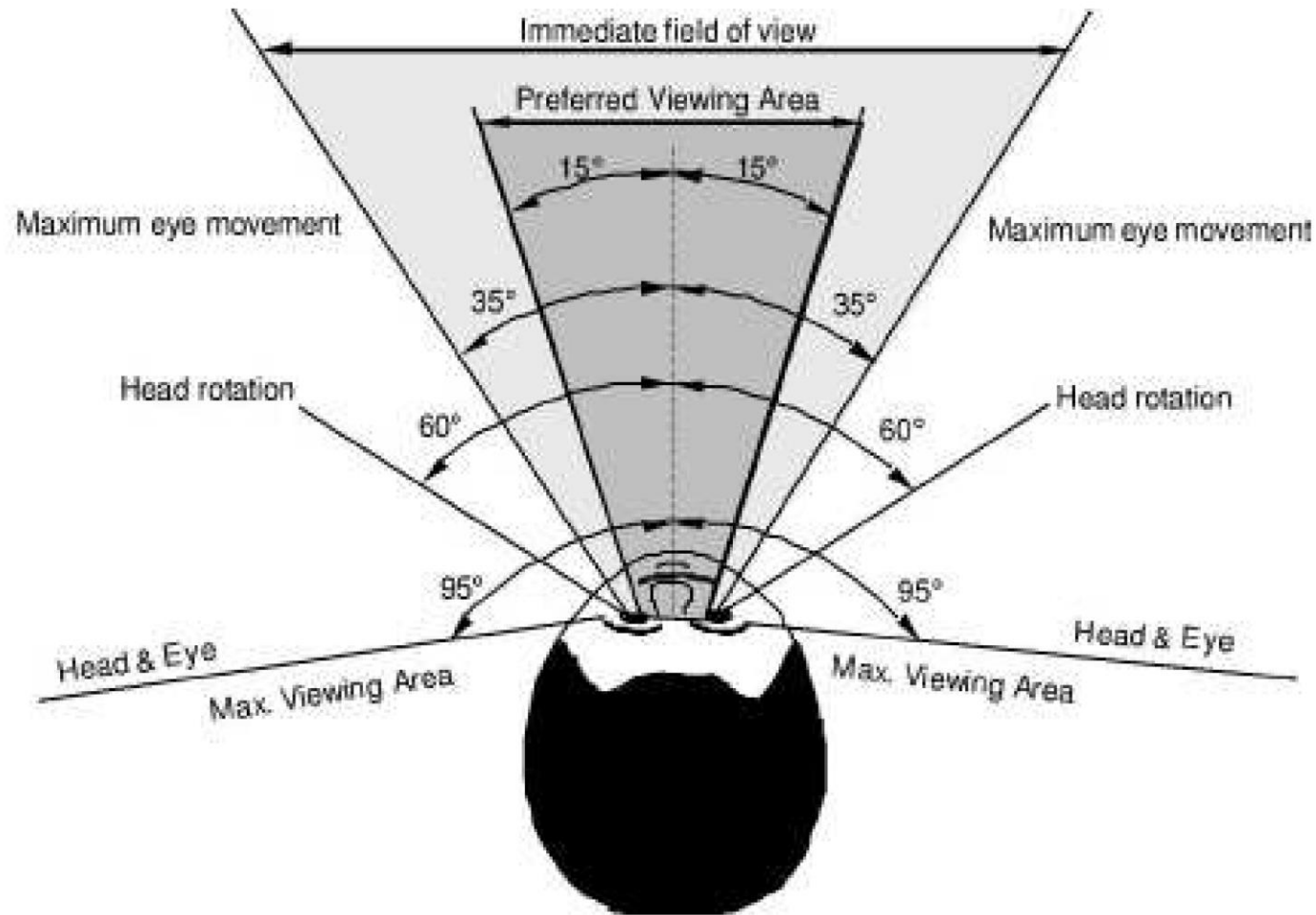
# Eye Movement Types

- **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



# Eye and Head Movements



- Eye yaw: 35° left and right
- Eye pitch: 20° up, 25° down

# Perception of Color

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

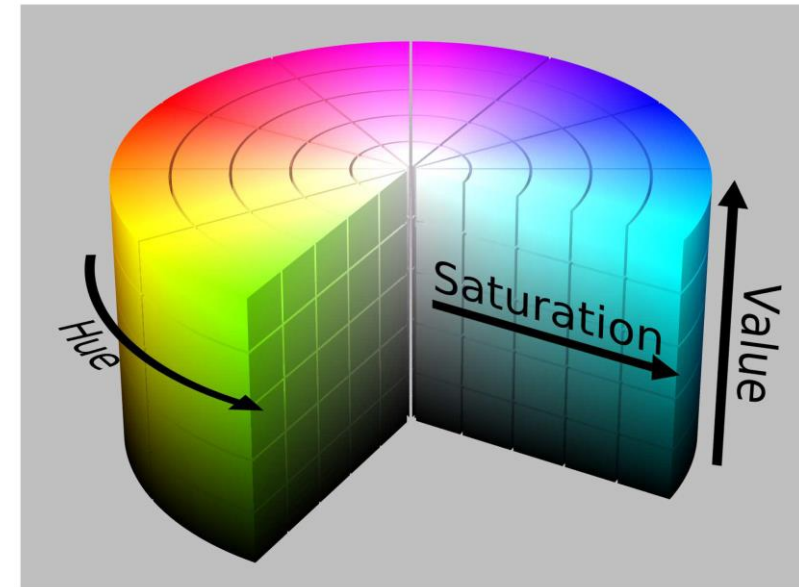
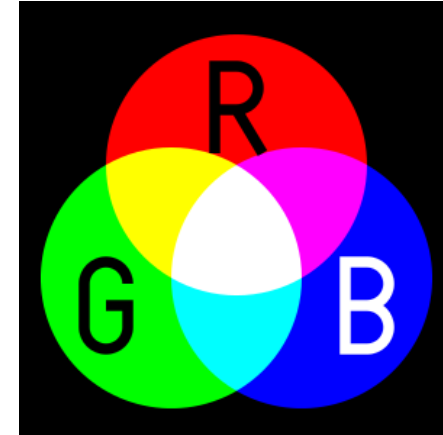


## Dress color illusion

- Blue and black? 57%
- White and gold? 30%
- 10% blue and brown
- 10% switch

# Color Spaces

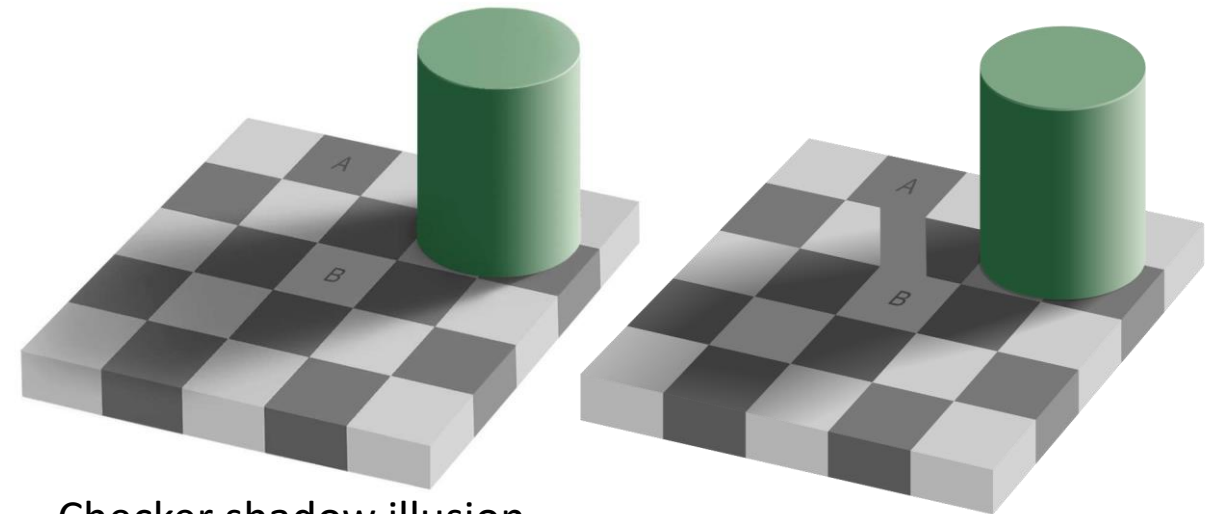
- RGB color space (yellow = green + red)
- HSV color space
  - Hue: the perceived color such as red or green
  - Saturation: purity of color
  - Value: brightness
  - Commonly used in graphics





# Constancy

- Color constancy
  - A red shirt appears to be red in different lighting conditions
- Lightness constancy
  - Overall brightness levels appear to be unchanged even after lighting conditions are dramatically changed



Checker shadow illusion

- The perception system accounts for the shadow

# Further Reading

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