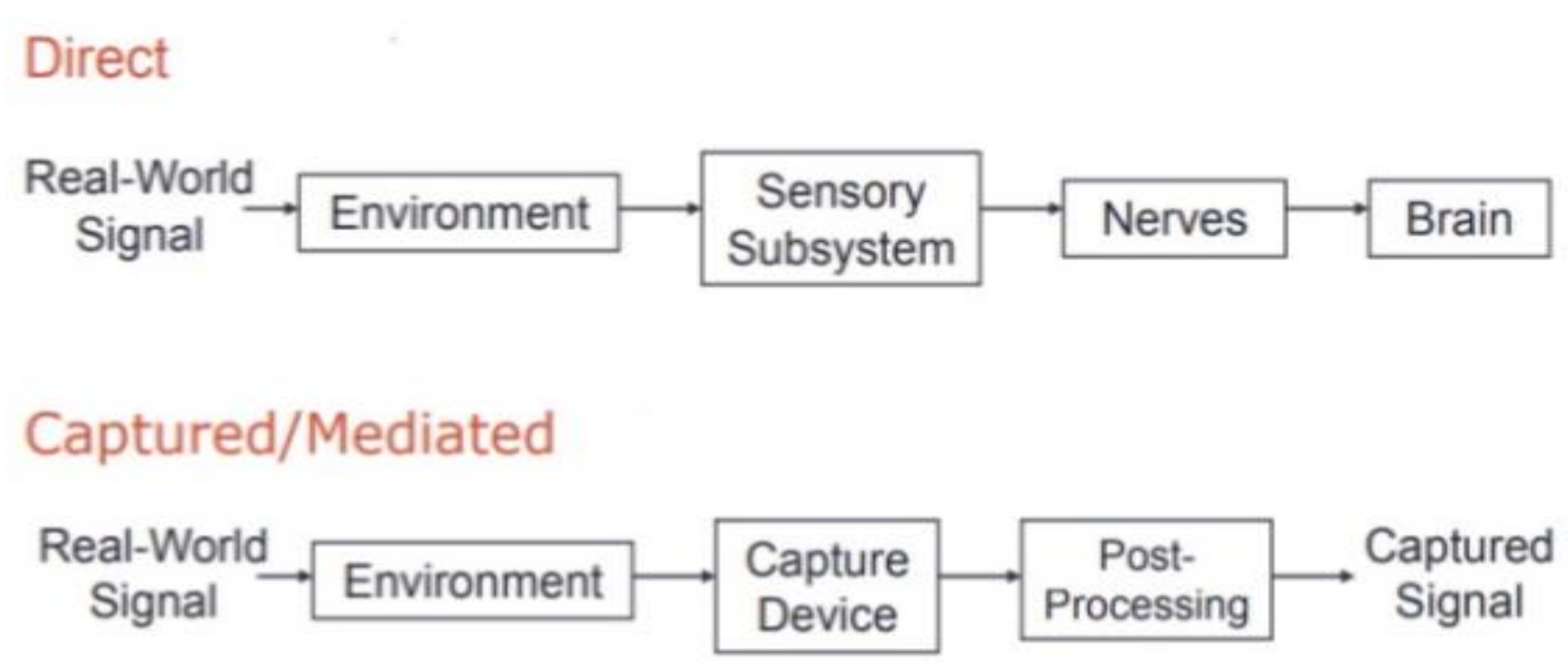
Digital Image Fundamentals:

Elements of Visual Perception

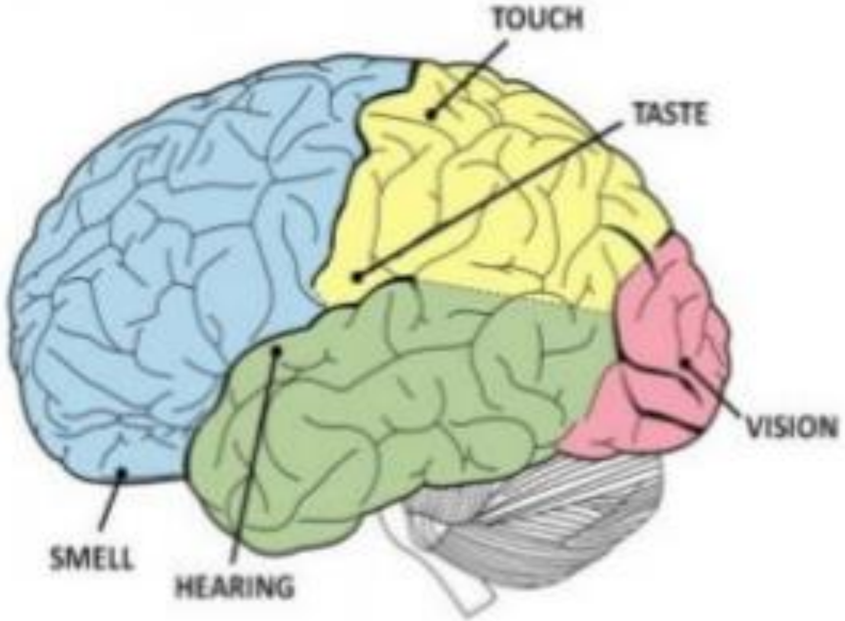
Visual Perception



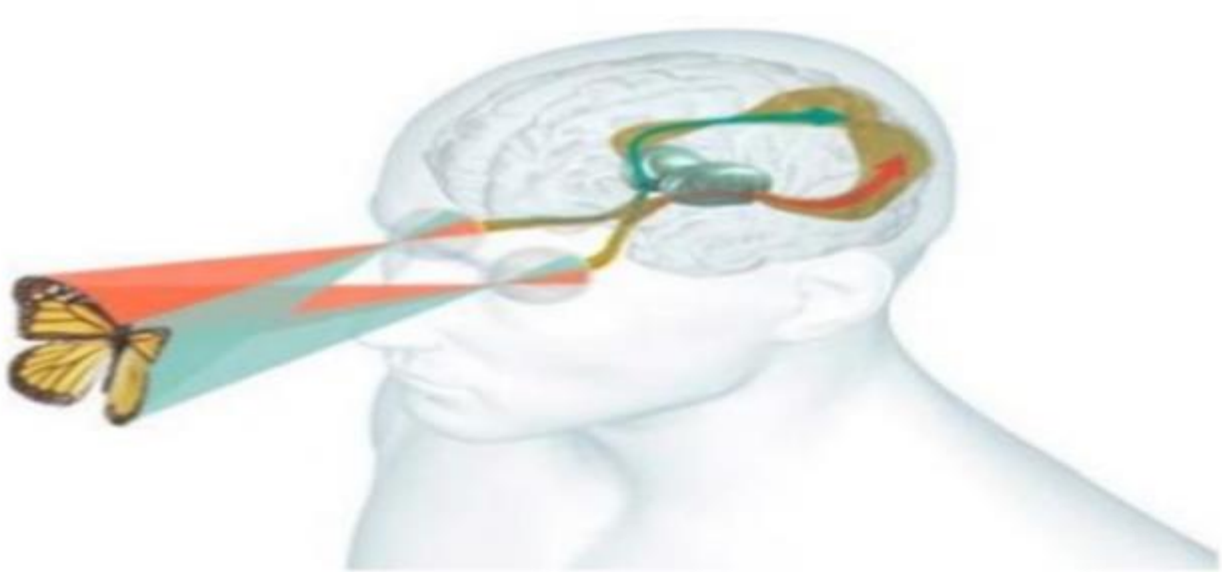
Relative Importance of Each Sense

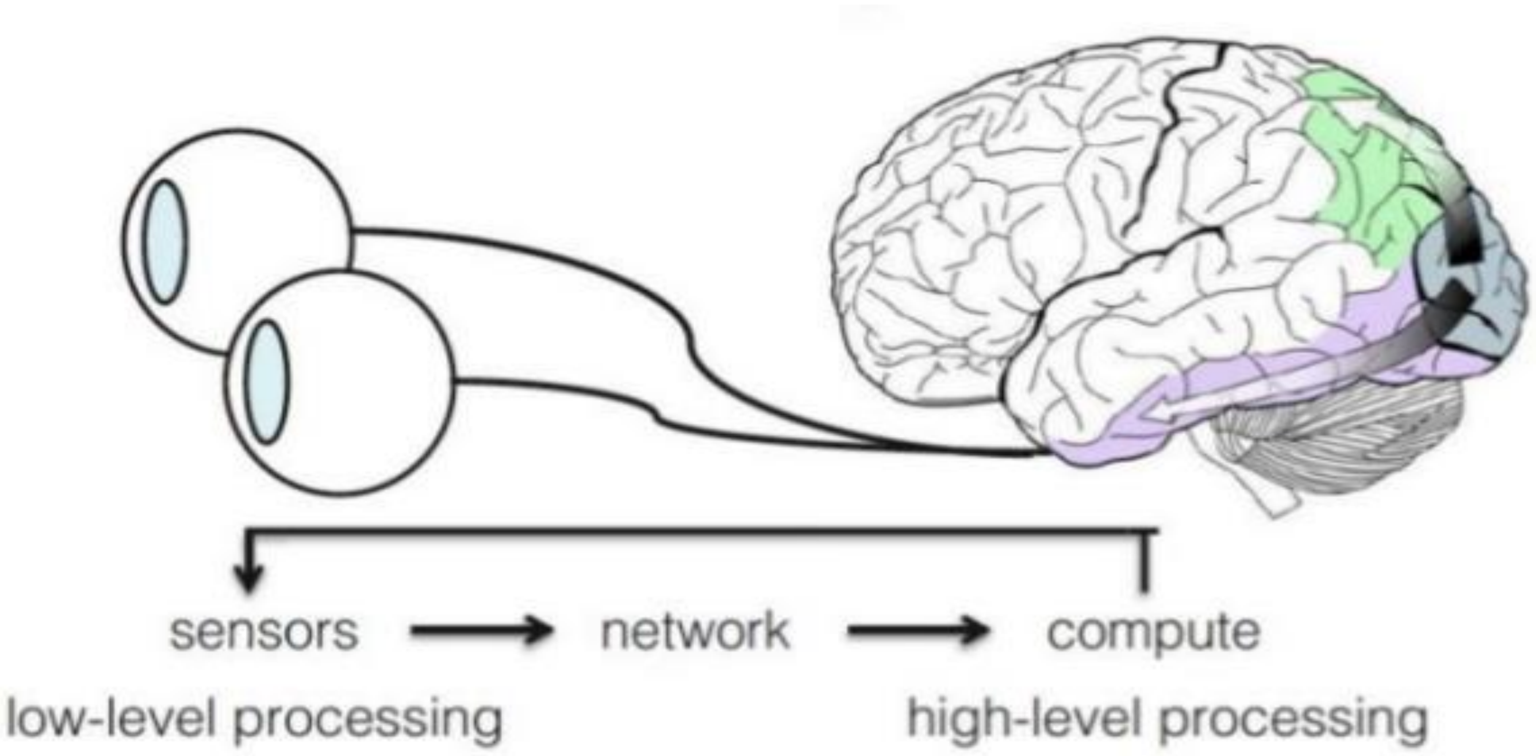
- Percentage of neurons in brain devoted to each sense
  - Sight – 30%
  - Touch – 8%
  - Hearing – 2%
  - Smell - < 1%

- Over 60% of brain involved with vision in some way

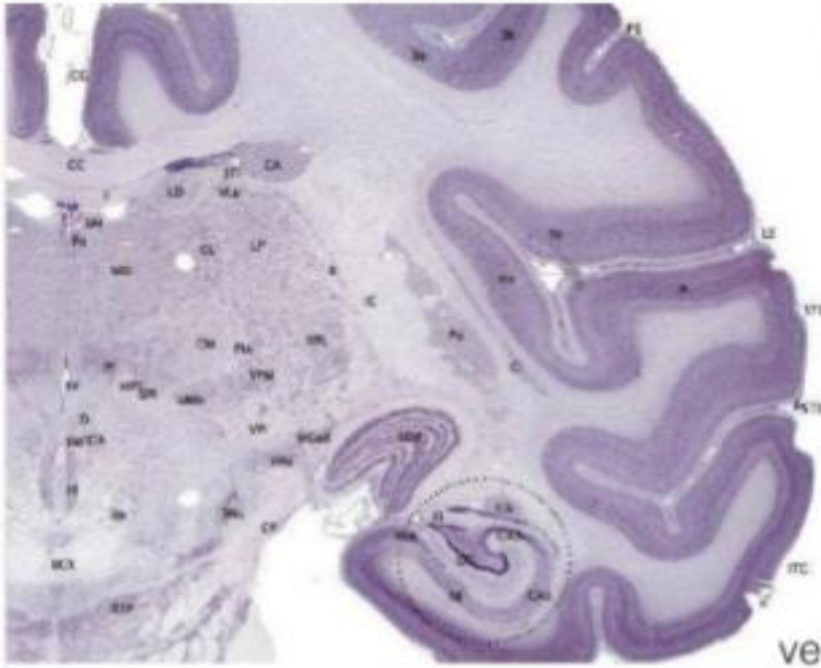


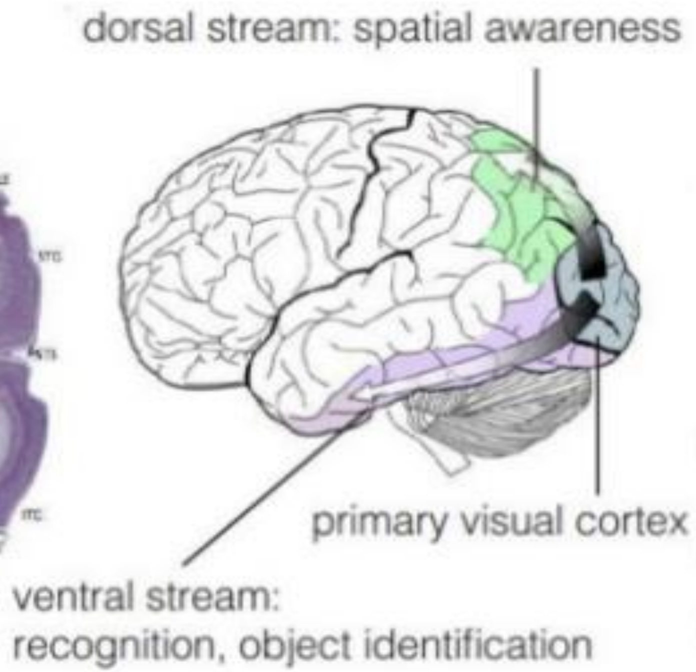
Human visual system



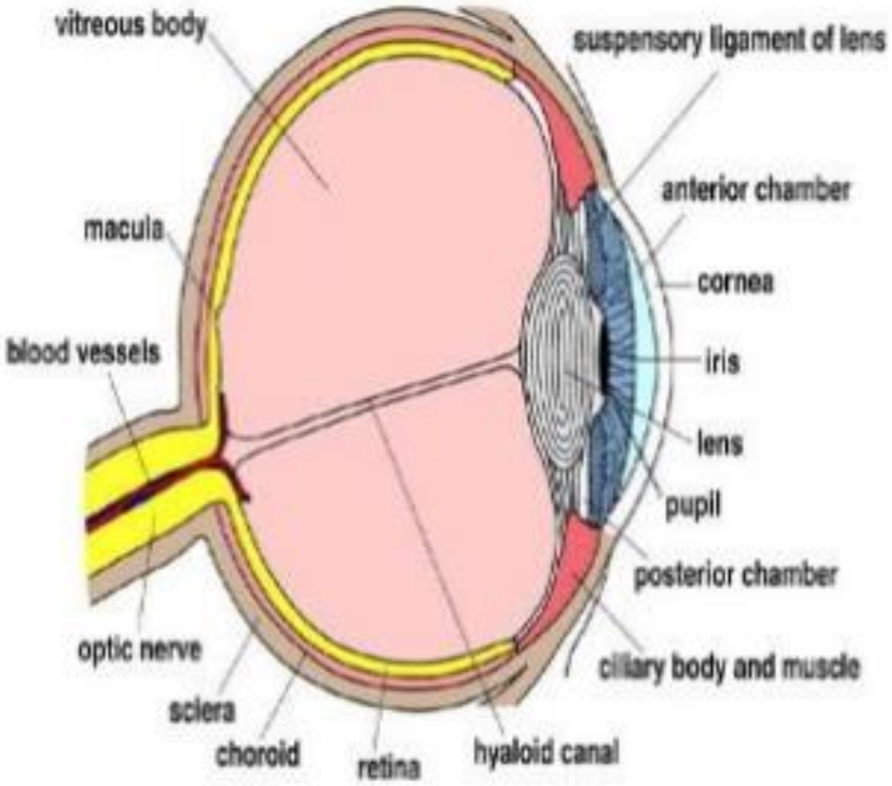

sensors
network
compute
low-level processing
high-level processing

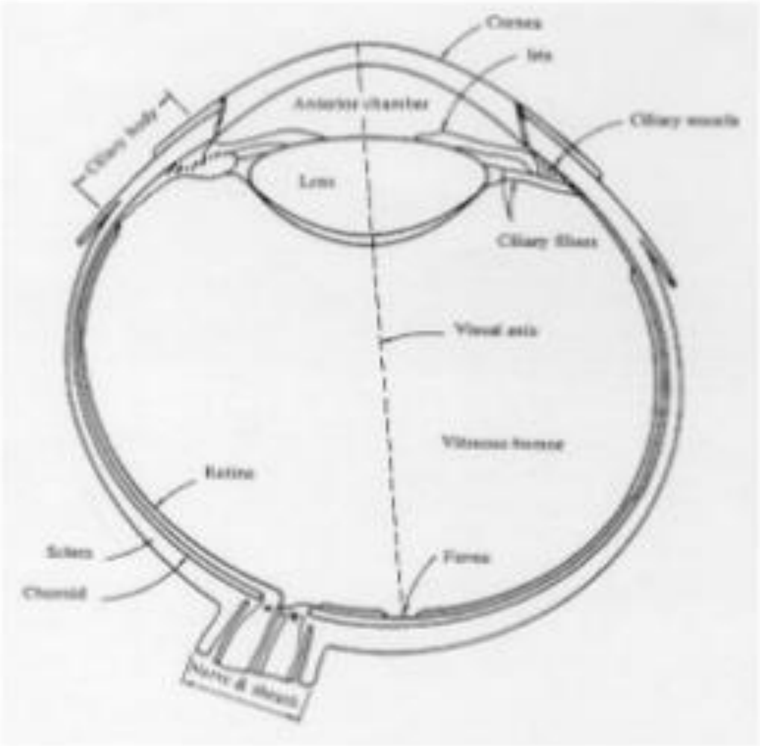
Parts of Brain Associated with Vision





Structure of the Human Eye





Structure of the Human Eye

- The eye is nearly spherical in form with an average diameter of approximately 20 mm.

• It is enclosed by three membranes; the **cornea and sclera** outer cover, the **choroid**, and the retina.

• The cornea is a tough, transparent tissue that covers the anterior or front surface of the eye. The sclera is continuous with the cornea.

• It is the opaque membrane that encloses the remainder of the eye.

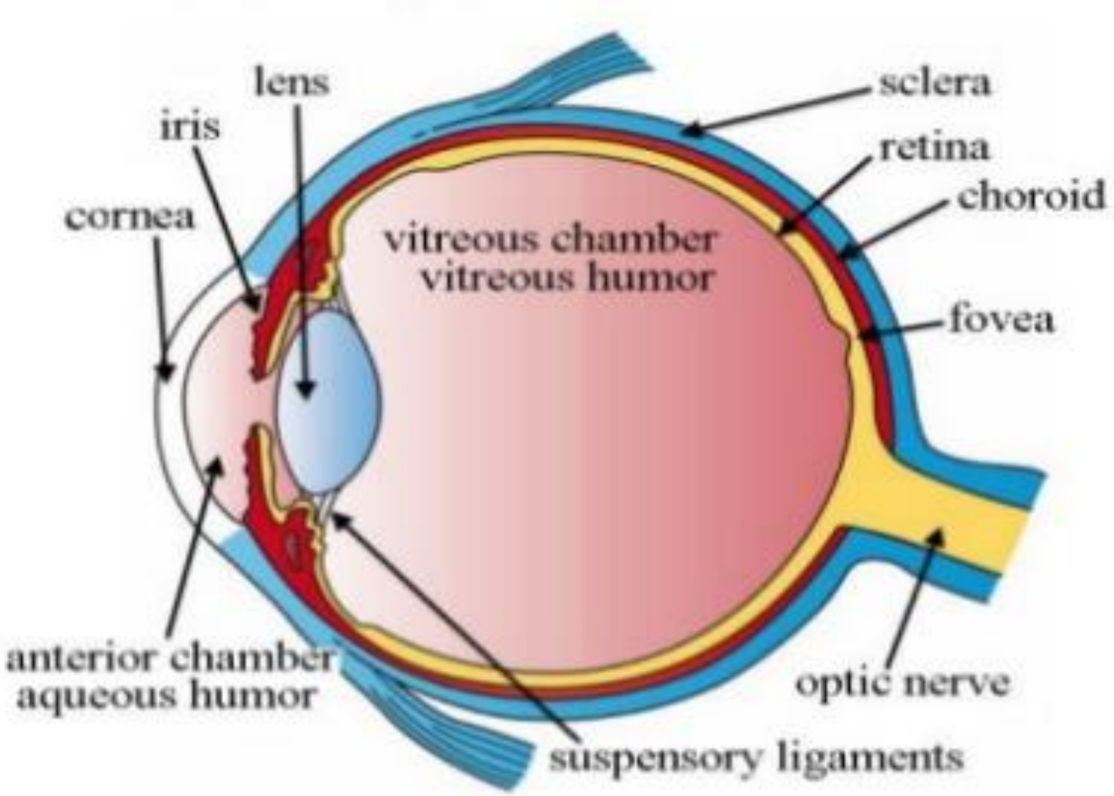
Elements of visual perception

- The complex physical process of visualizing something involves the nearly simultaneous interaction of the eyes and the brain through a network of neurons, receptors, and other specialized cells.

• The human eye is equipped with a variety of optical elements including the cornea, iris, pupil, a variable-focus lens, and the retina.

• Together, these elements work to form images of the objects in a person's field of view.

Human eye



- Light passes through cornea and lens onto retina
- Photoreceptors in retina convert light into electrochemical signals

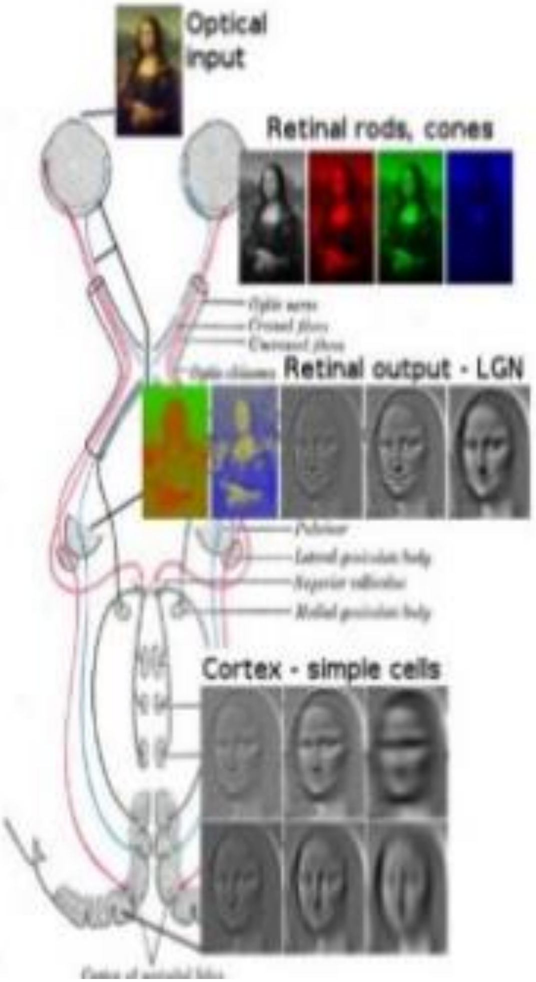
Human vision

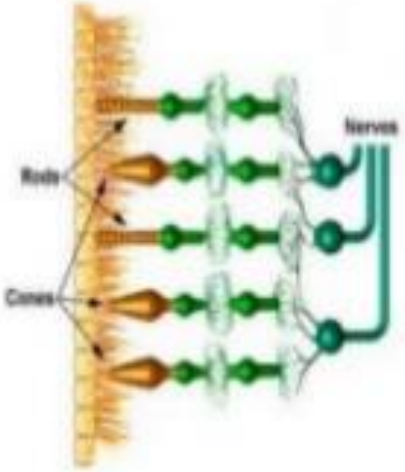
- When an object is observed, it is first focused through the cornea and lens onto the retina.
- Retina is a multilayered membrane that contains millions of light- sensitive cells that detect the image and translate it into a series of electrical signals.
- These image capturing receptors of the retina are termed rods and cones
- **Cones and Rods** are connected with the fibers of the optic nerve bundle through a series of specialized cells that coordinate the transmission of the electrical signals to the brain.
- In the brain, the optic nerves from both eyes join at the optic chiasma where information from their retinas is correlated.
- The visual information is then processed through several steps, eventually arriving at the visual cortex, which is located on the lower rear section of each half of the cerebrum.

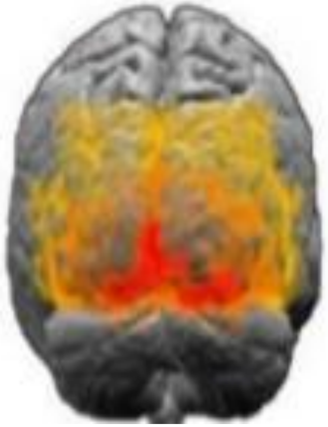
- Our eyes take in light waves for our visual cortex to process into a perception.
- The light passes through the cornea and is focused onto the retina with the lens.
- The retina then controls the amount of light that enters the eye.
- Rods and cones are used to process color in the light and dark.
- Rods are responsible for processing images in a dark atmosphere.
- They are more sensitive and account for peripheral vision.
- The cones are prominent in daylight.
- The optic nerve primarily routes information to the cerebral cortex, where visual perception occurs.

- A particularly specialized component of the eye is the **fovea centralis**, which is located on the optical axis of the eye in an area near the center of the retina.
- This area exclusively contains high-density tightly packed cone cells and is the area of sharpest vision.
- The density level of cone cells decreases outside of the fovea centralis and the ratio of rod cells to cone cells gradually increases.
- At the periphery of the retina, the total number of both types of light receptors decreases substantially, causing a dramatic loss of visual sensitivity at the retinal borders.
- This is offset, however, by the fact that humans constantly scan objects in their field of view, usually resulting in a perceived image that is uniformly sharp

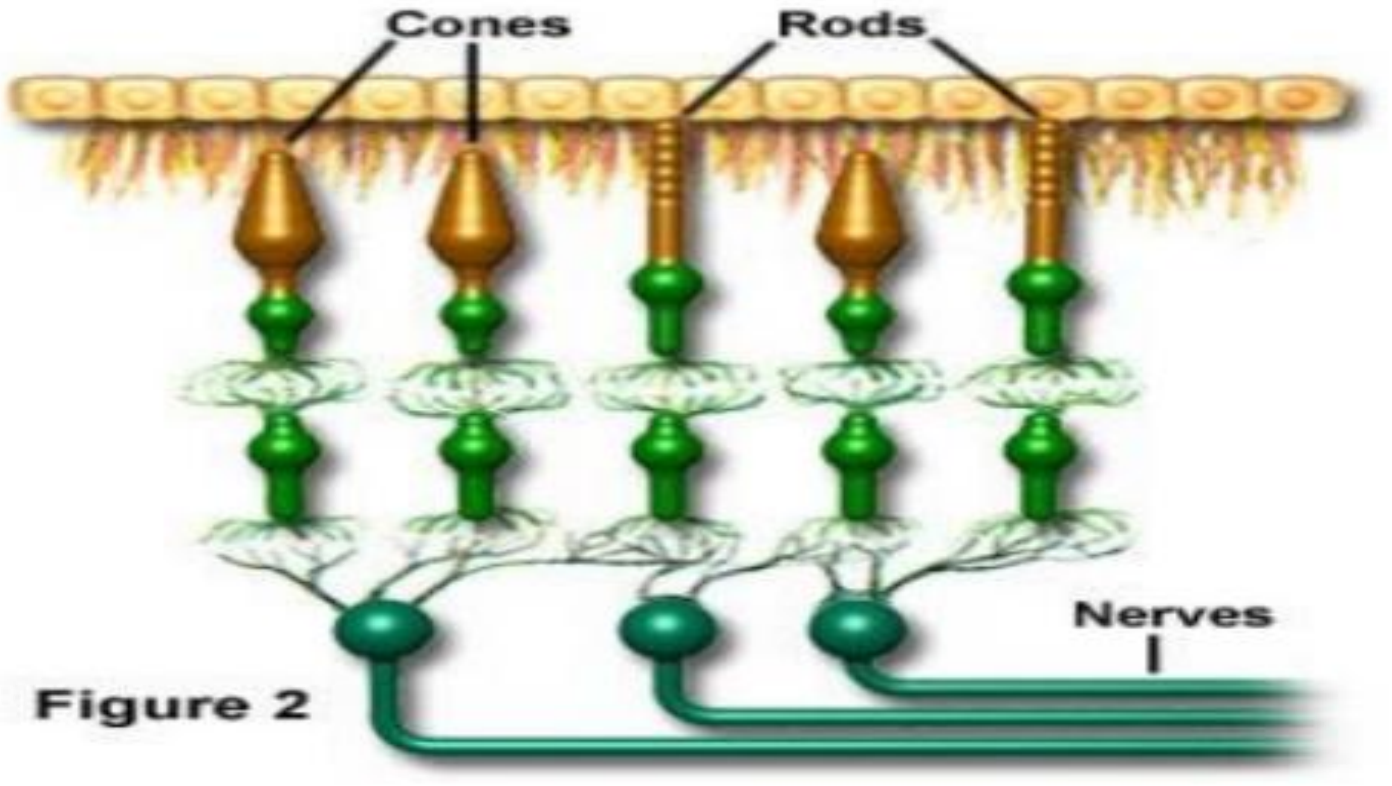
Eye/Brain combination: Visual cortex



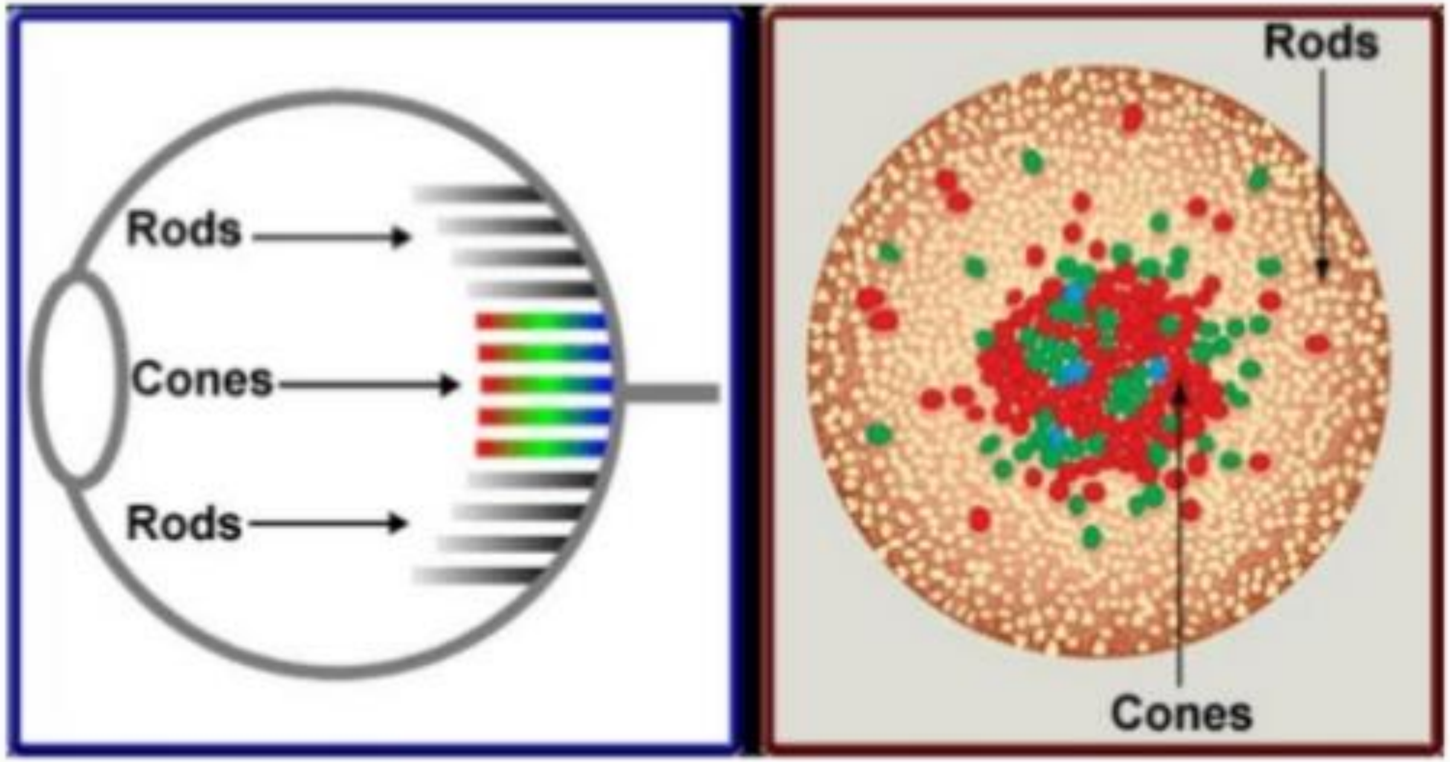




Cones and Rods



Distribution of rods and cones

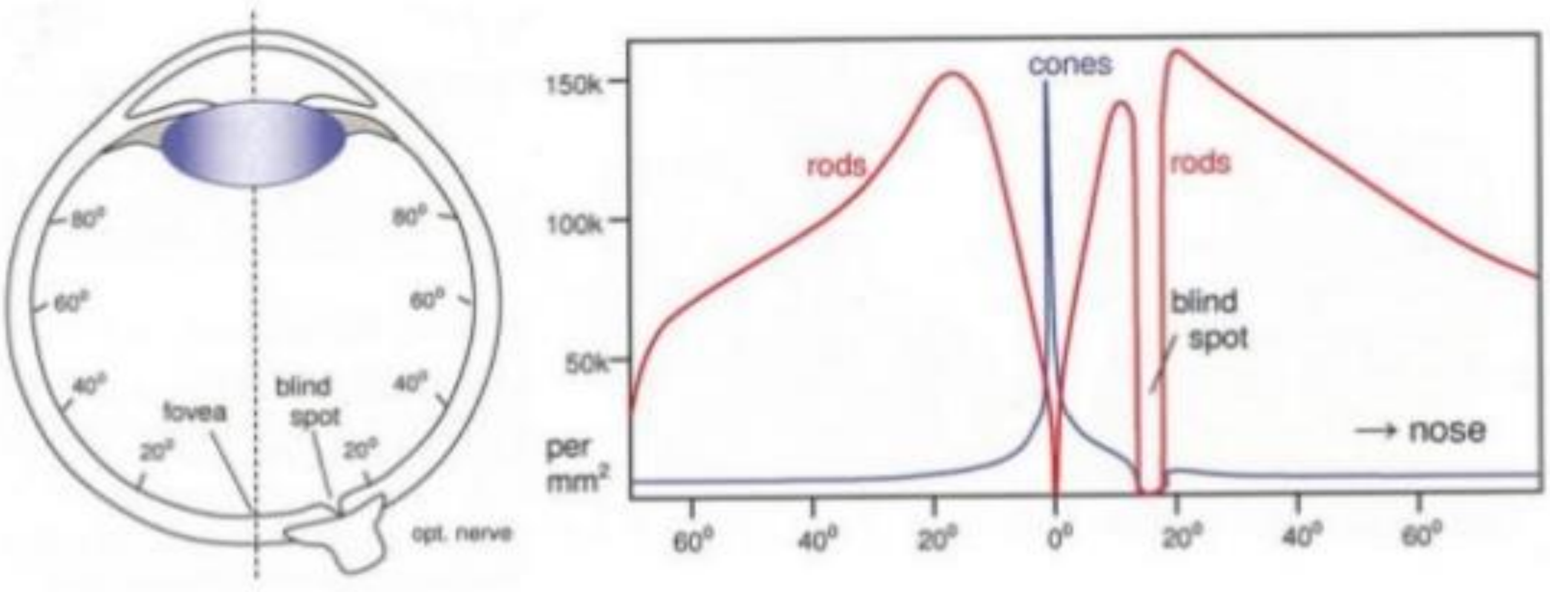


Rods vs. Cones

- **RODS**
  - 125 million cells in retina
  - Concentrated on periphery of retina
  - No color detection
  - Most sensitive to light
  - Scotopic (night) vision
  - Provide peripheral vision, motion detection

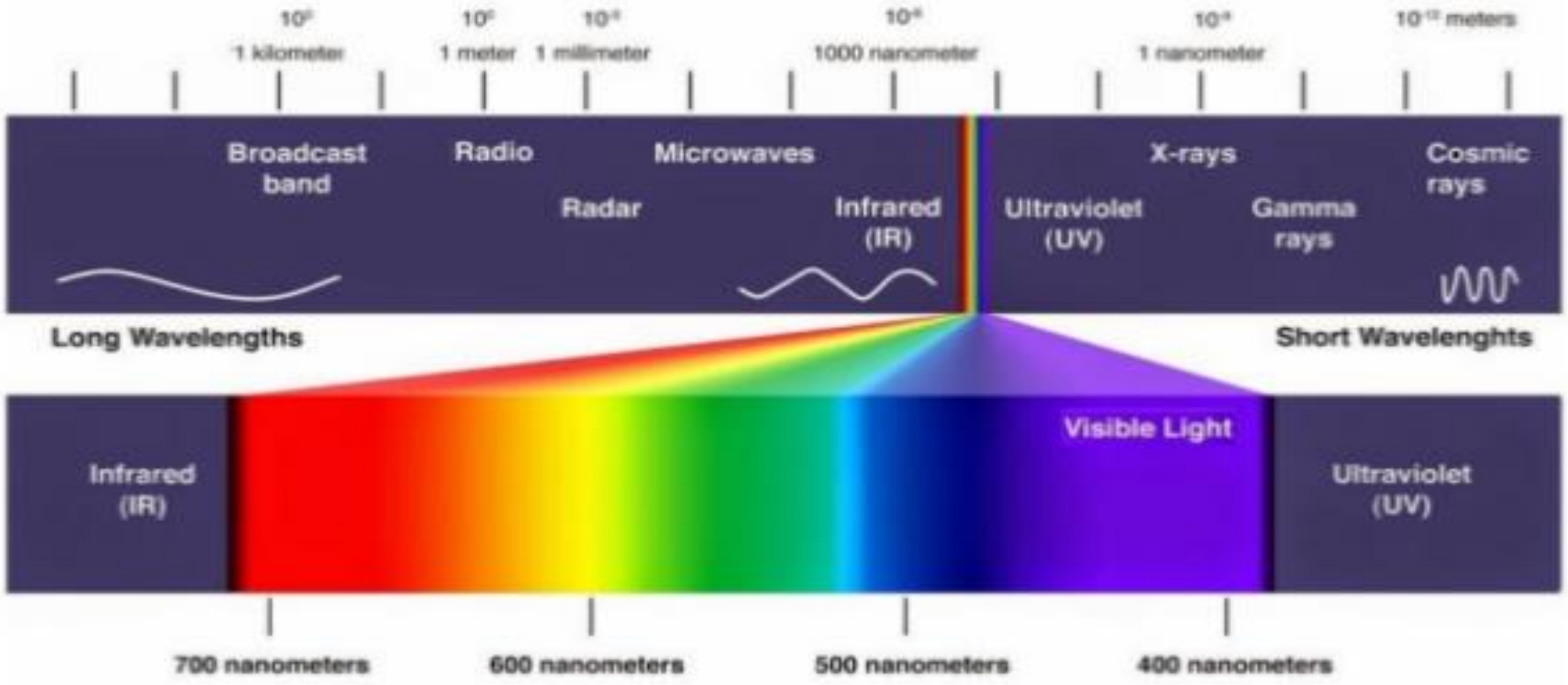
- **CONES**
  - 4.5-6 million in retina
  - Responsible for color vision
  - Sensitive to red, blue, green light
  - Work best in more intense light

Distribution of Cones and Rods



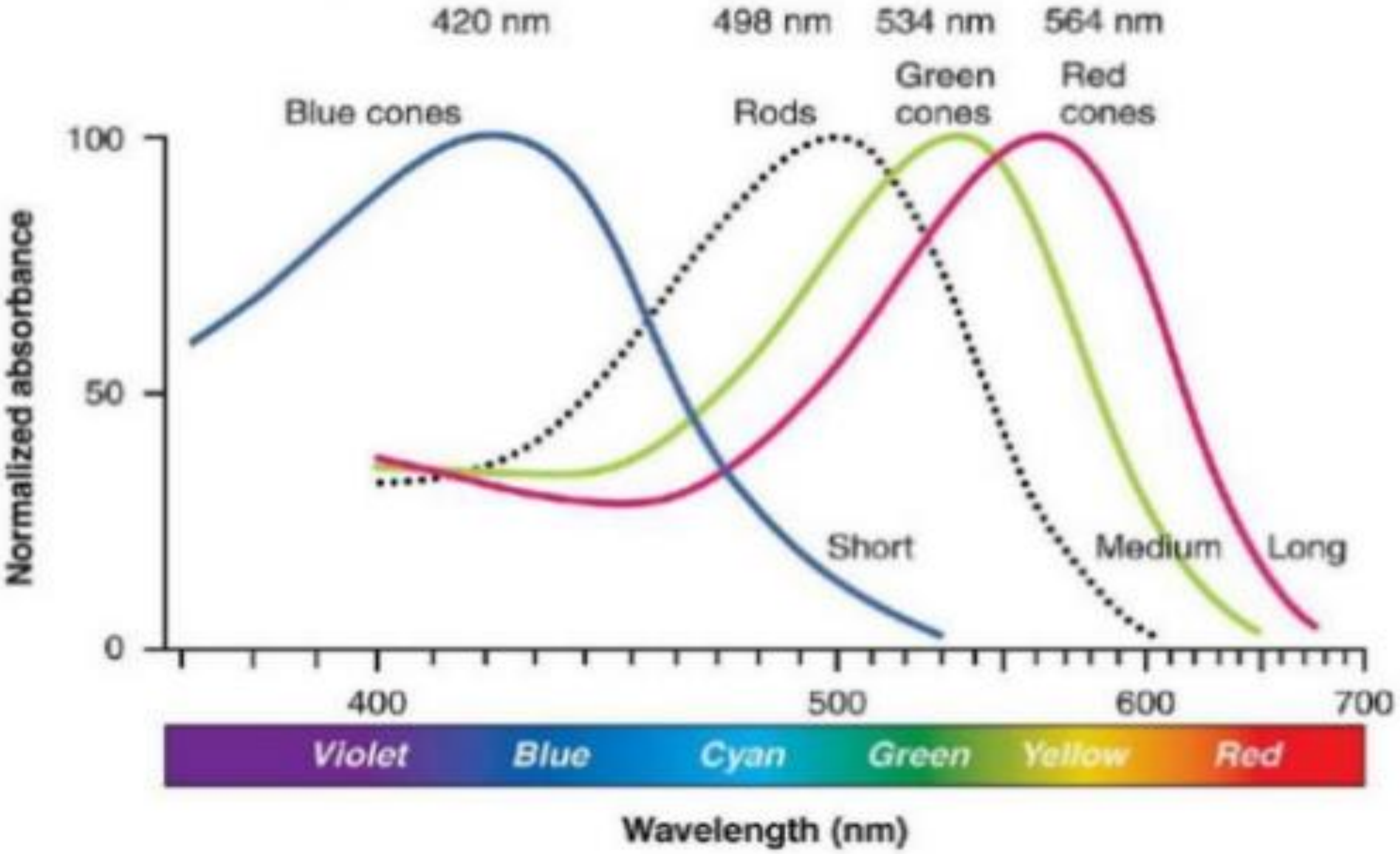
- Highest density of cones around fovea
- Blind spot at Optic Nerve exit point

Colour Perception



- Humans only perceive small part of electromagnetic spectrum

Sensitivity of Rods and Cones



Cones and Rods

- In the human eye, there are two distinct visual systems (based on two types of retinal cells)

• Scotopic vision: not color sensitive, more sensitive to light and mainly peripheral (rods)

• Photopic vision : color sensitive, less sensitive to light and mainly central (cones)

Image formation in the Eye

1. Representation of an object

2. Light leaves the object - propagating in all directions

3. Some of the light leaving the object reaches the eye

4. Light changes direction when it passes from the air into the eye

5. Location of Focused Image

Image formation in the Eye

An interactive guide to the human eye and how it works.

From the moment light enters the eye to the interpretation of an image in the brain.

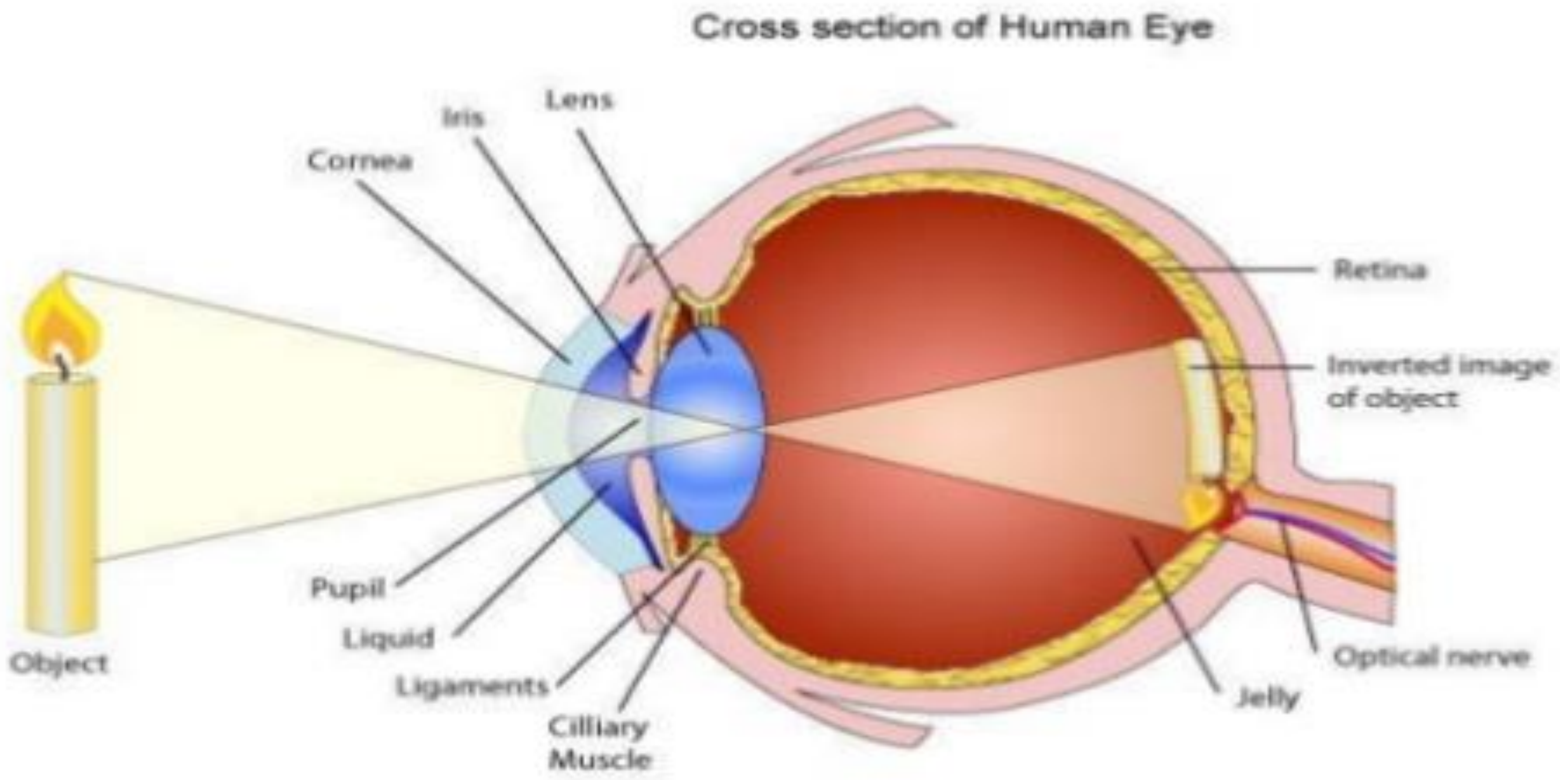
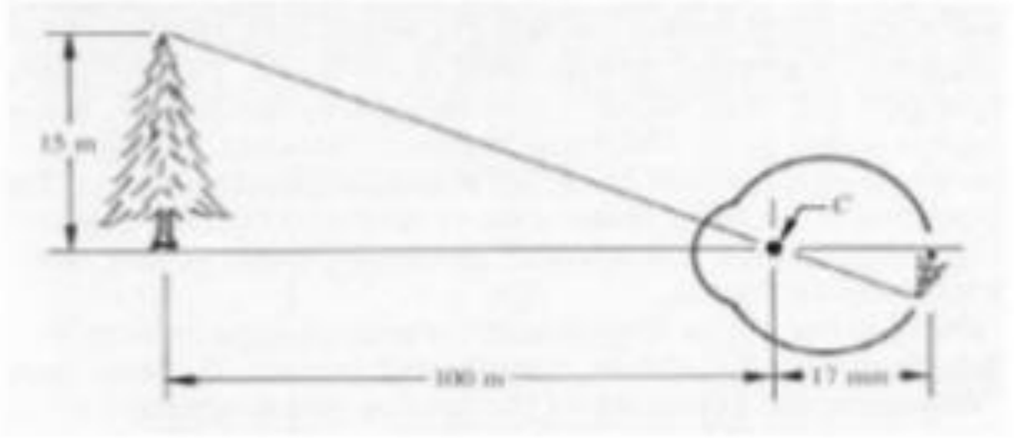

Cross section of Human Eye
Iris
Lens
Cornea
Retina
Inverted image
of object
Pupil
Liquid
Object
Ligaments
Cilliary
Muscle
Jelly
Optical nerve

Image formation

- Example:
  - Calculation of retinal image of an object



$$\frac{15}{100} = \frac{x}{17}$$

$$x = 2.55mm$$

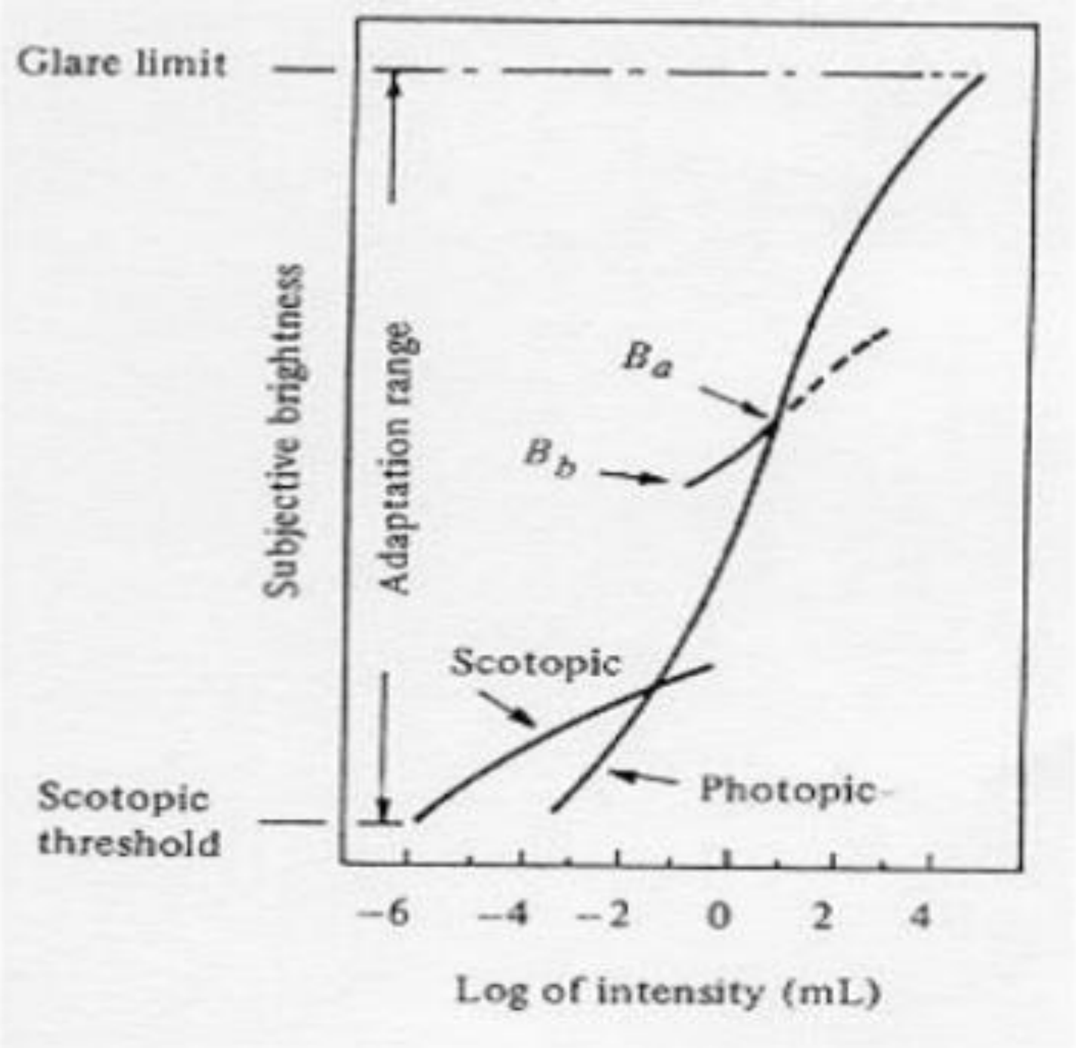
Brightness Adaptation and Discrimination

- The ability of the eye to discriminate between different brightness levels is an important consideration in creating and presenting images.

- The range of light intensity levels to which the human visual system can adapt is on the order of 1010 from the scotopic threshold (minimum low light condition) to the glare limit (maximum light level condition).

Subjective brightness

- Subjective brightness is brightness as perceived by the human visual system
- Subjective brightness is a logarithmic function of the light intensity incident on the eye.
- This characteristic is illustrated in the figure below, which is a plot of light intensity versus subjective brightness.


Glare limit
Subjective brightness
Adaptation range
B_a
B_b
Scotopic
Photopic
Scotopic threshold
−6
−4
−2
0
2
4
Log of intensity (mL)

Brightness adaptation

• The long solid curve represents the range of intensities to which the visual system can adapt.

• In photopic vision alone, the range is about 106.

• The transition from scotopic to photopic vision is gradual over the approximate range from 0.001 to 0.1 millilambert (-3 to -1 mL in the log scale), as illustrated by the double branches of the adaptation curve in this range.

Brightness adaptation

- For a given set of conditions, the current sensitivity level of the visual system is called the brightness-adaptation level which may correspond, for example, to brightness Ba in the figure.

- The short intersecting curve represents the range of subjective brightness that the eye can perceive when adapted to this level. This range is rather restricted, having a level Bb at and below which all stimuli are perceived as indistinguishable blacks.

- The upper (dashed) portion of the curve is not actually restricted but, if extended too far, loses its meaning because much higher intensities would simply raise the adaptation level to a higher value than B_a.

Brightness adaptation

- The visual system cannot operate over such a range simultaneously. It accomplishes this large variation by changes in its overall sensitivity. This phenomenon is known as brightness adaptation.

- The total range of intensity levels it can discriminate simultaneously is rather small compared with the total range.

- For any given set of conditions, the current sensitivity level of the visual system is called the brightness adaptation level.

Brightness adaptation

Two phenomena clearly demonstrate that perceived brightness is not a simple function of intensity:

- Mach Bands
- simultaneous contrast

Mach Bands

- The Mach bands effect is due to the spatial high-boost filtering performed by the human visual system on the luminance channel of the image captured by the retina.

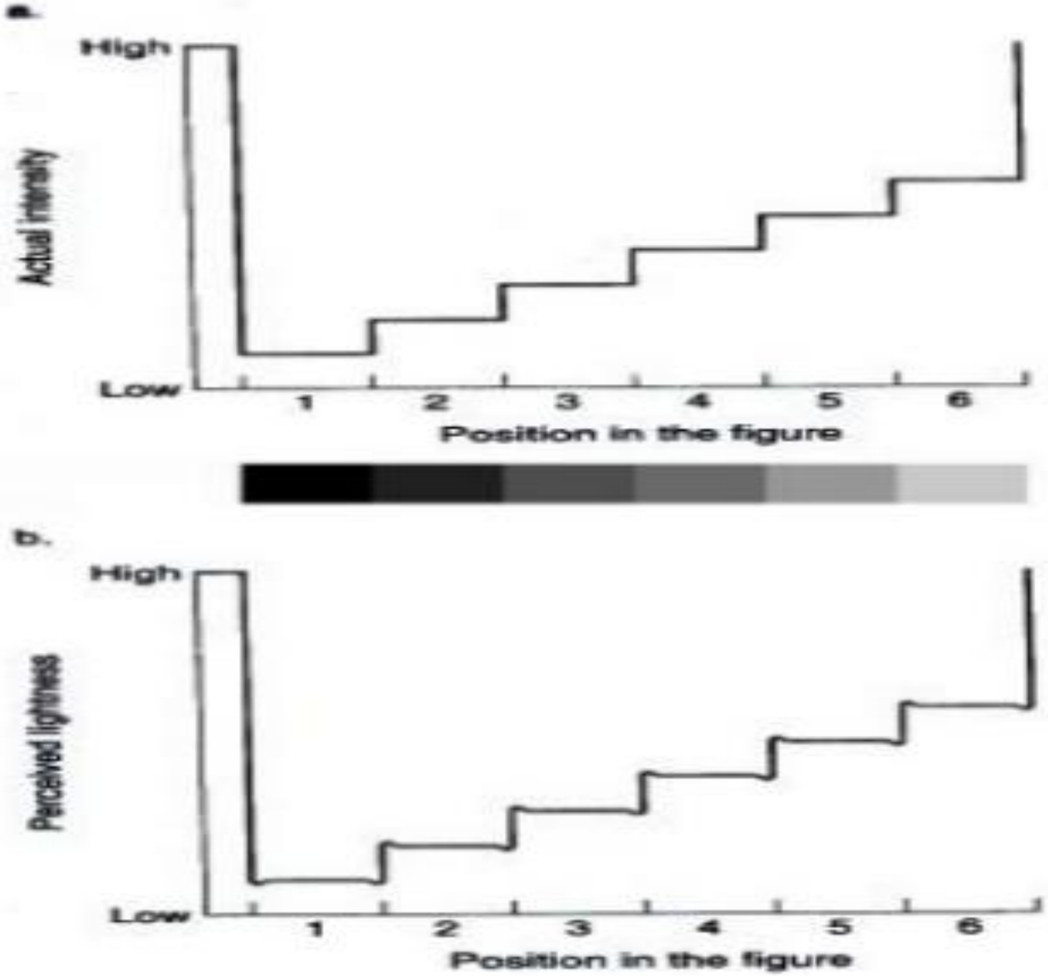
- Along the boundary between adjacent shades of grey in the Mach bands illusion, lateral inhibition makes the darker area falsely appear even darker and the lighter area falsely appear even lighter.

Mach Bands

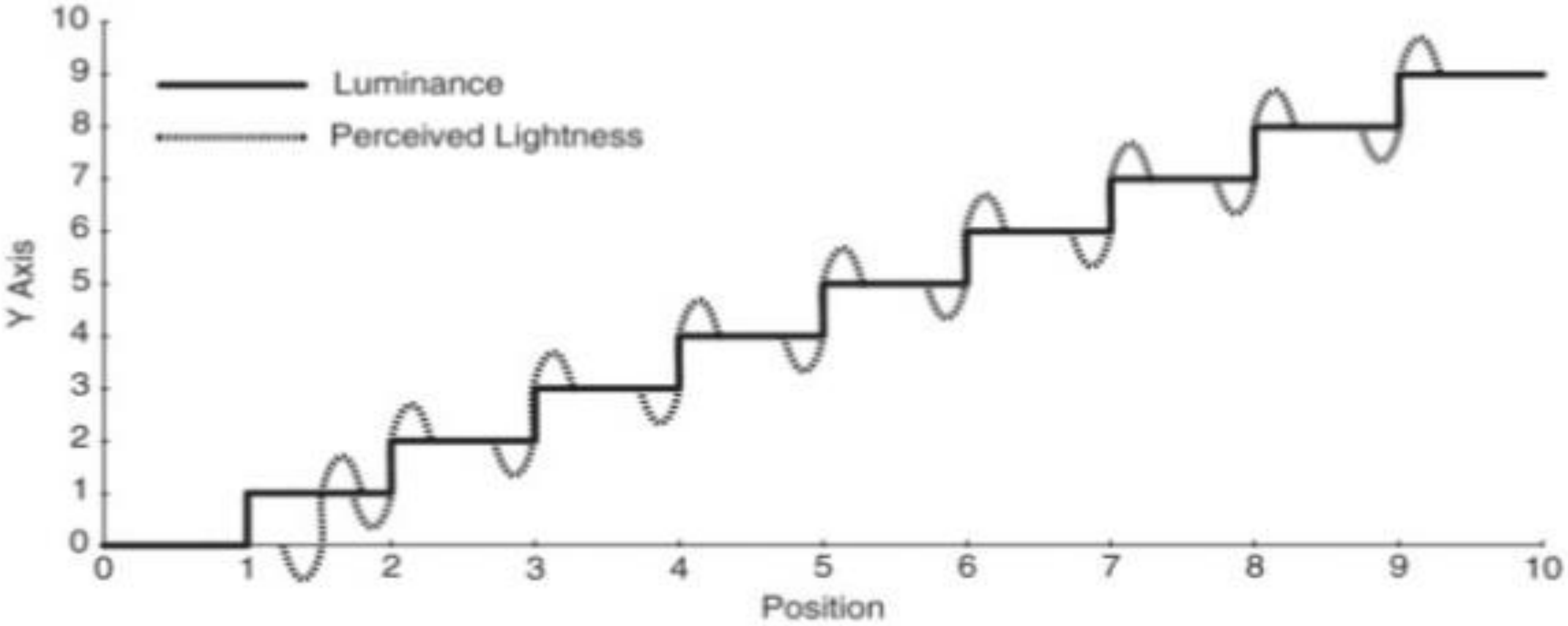
- In the case of visual information, such (spatial) differentiation causes gradual changes in the contrast between an object and its background to be enhanced, i.e., to become more visible.

- In human perception, this contrast enhancement produces what is known as Mach Bands: between two regions of different intensity a thin bright band appears at the lighter side and a thin dark band appears on the darker size.

- These bands are not physically present are "overshoot" and "undershoot" caused by our neural circuits in processing a step discontinuity in illumination.



The visual system tends to undershoot or overshoot around the boundary of regions of different intensities



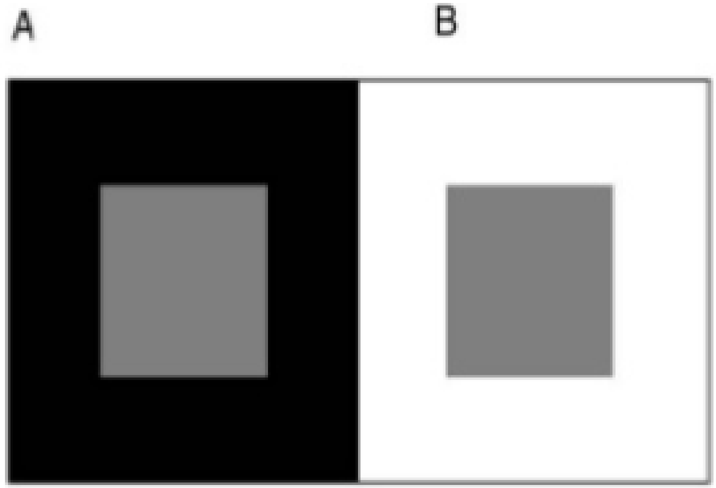
Luminance
Perceived Lightness
Y Axis
Position
0
1
2
3
4
5
6
7
8
9
10

Simultaneous Contrast

- The simultaneous contrast phenomenon: each small square is actually the same intensity but, because of the different intensities of the surrounds, the small squares do not appear equally bright.

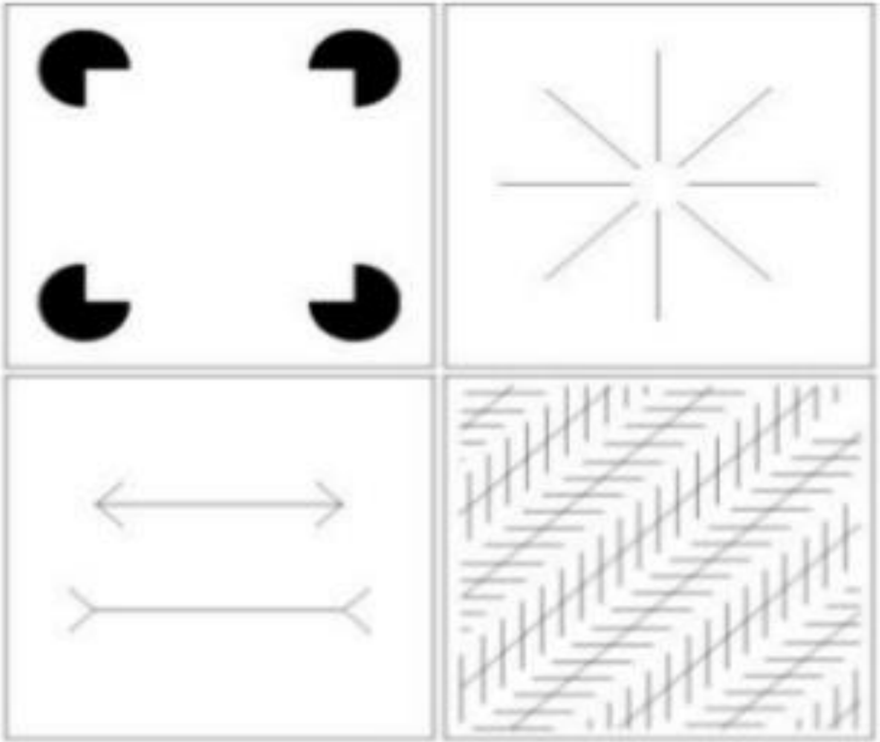
- The hue of a patch is also dependent on the wavelength composition of surrounding light.

- A white patch on a black background will appear to be yellowish if the surround is a blue light.


A
B

Optical illusion

- An optical illusion (also called a visual illusion is an illusion caused by the visual system and characterized by a visual percept that appears to differ from reality.
- The eye fills in non-existing information or wrongly perceives geometrical properties of objects



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.