Human vision based on information theory

Neuroscience

Fall 403

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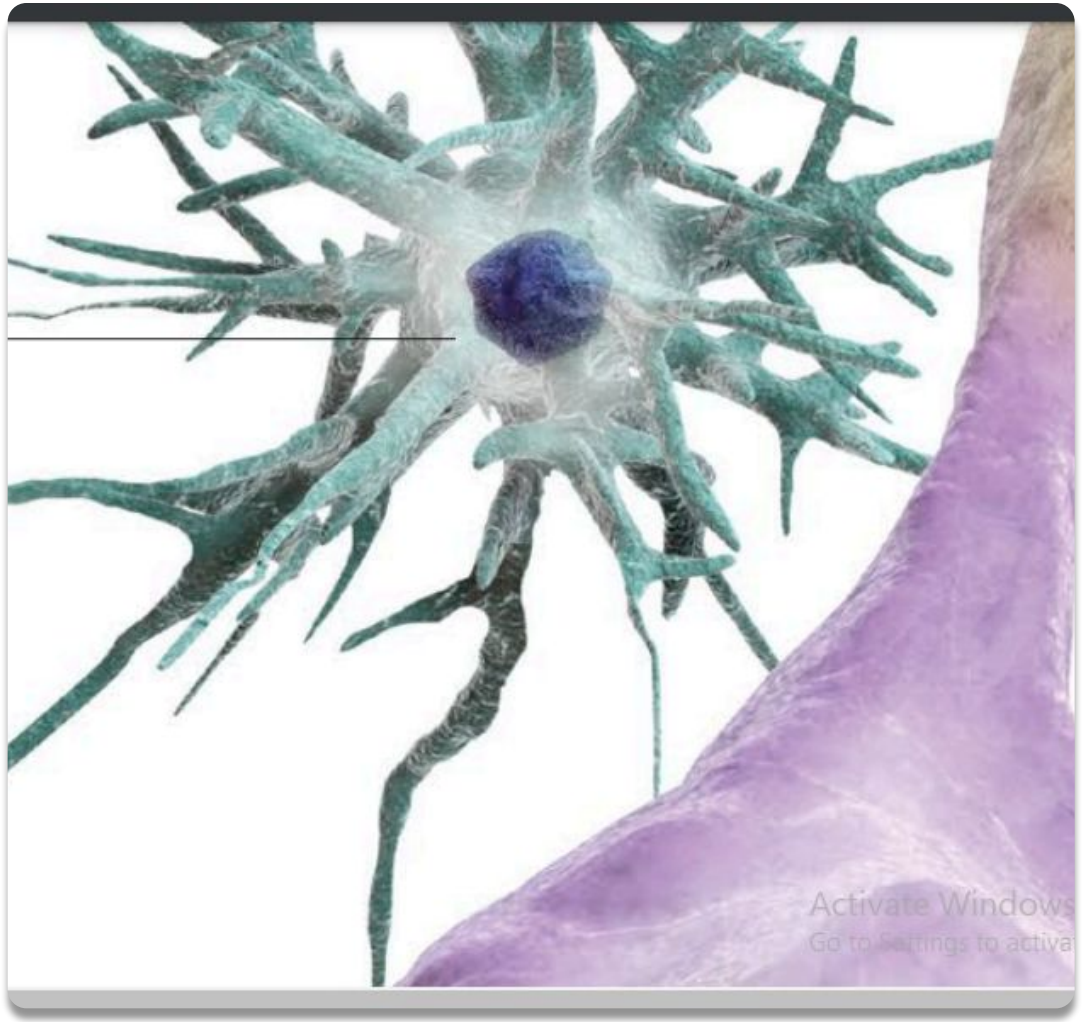

The eyes relentlessly scan the surroundings to collect light rays reflected or generated by objects in view.
When light hits the retina's photoreceptors, they generate billions of nerve impulses that stream along the optic nerve to the visual areas at the back of the brain.

WE SHOW THAT THE PHOTOPIC AND SCOTOPIC VISION ABSORPTION PEAKS IN HUMANS ARE DETERMINED NOT ONLY BY THE INTENSITY BUT ALSO BY THE ENTROPY OF RADIATION. THE HUMAN EYE HAS NOT ADAPTED ONLY TO THE MAXIMUM INTENSITY OR TO THE MAXIMUM INFORMATION BUT TO THE OPTIMAL WAVELENGTH FOR OBTAINING INFORMATION.

Vision process

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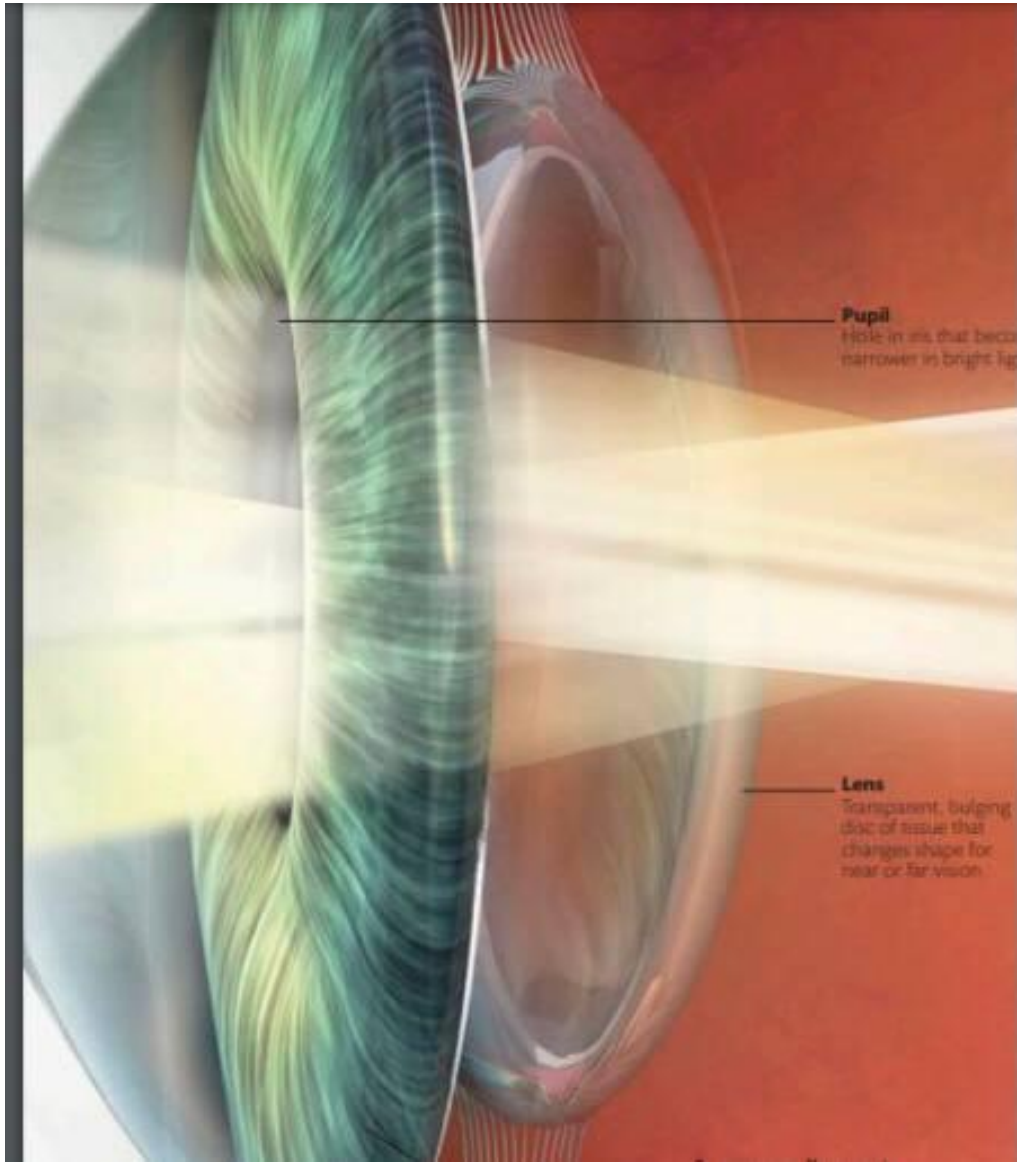
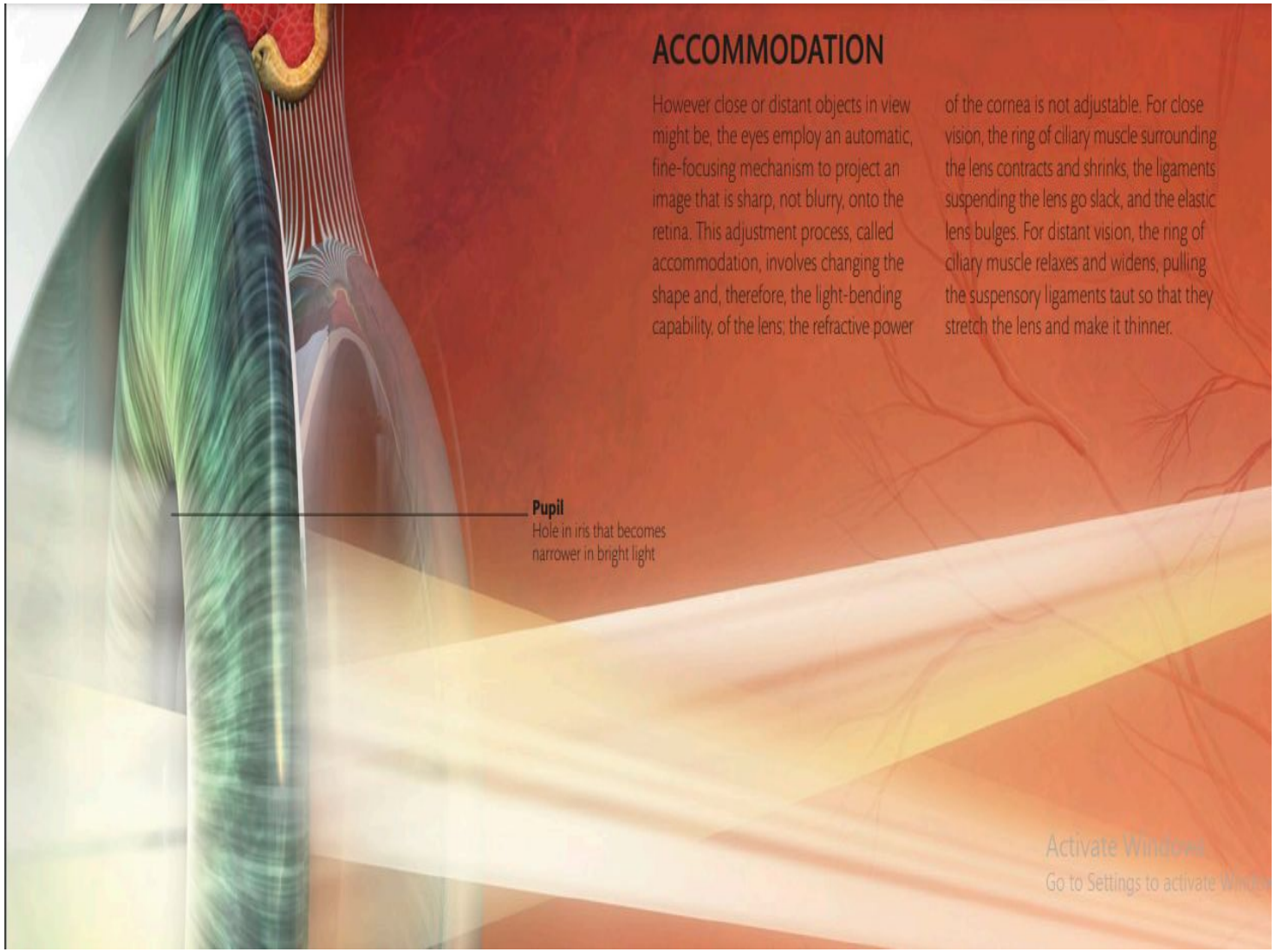


Vision process

The retina's outermost layer contains photoreceptive cells called rods and cones, Photoreceptor Count: With ~120 million rods and ~6 million cones, the retina has a vast number of photoreceptors.



Photoreceptor count

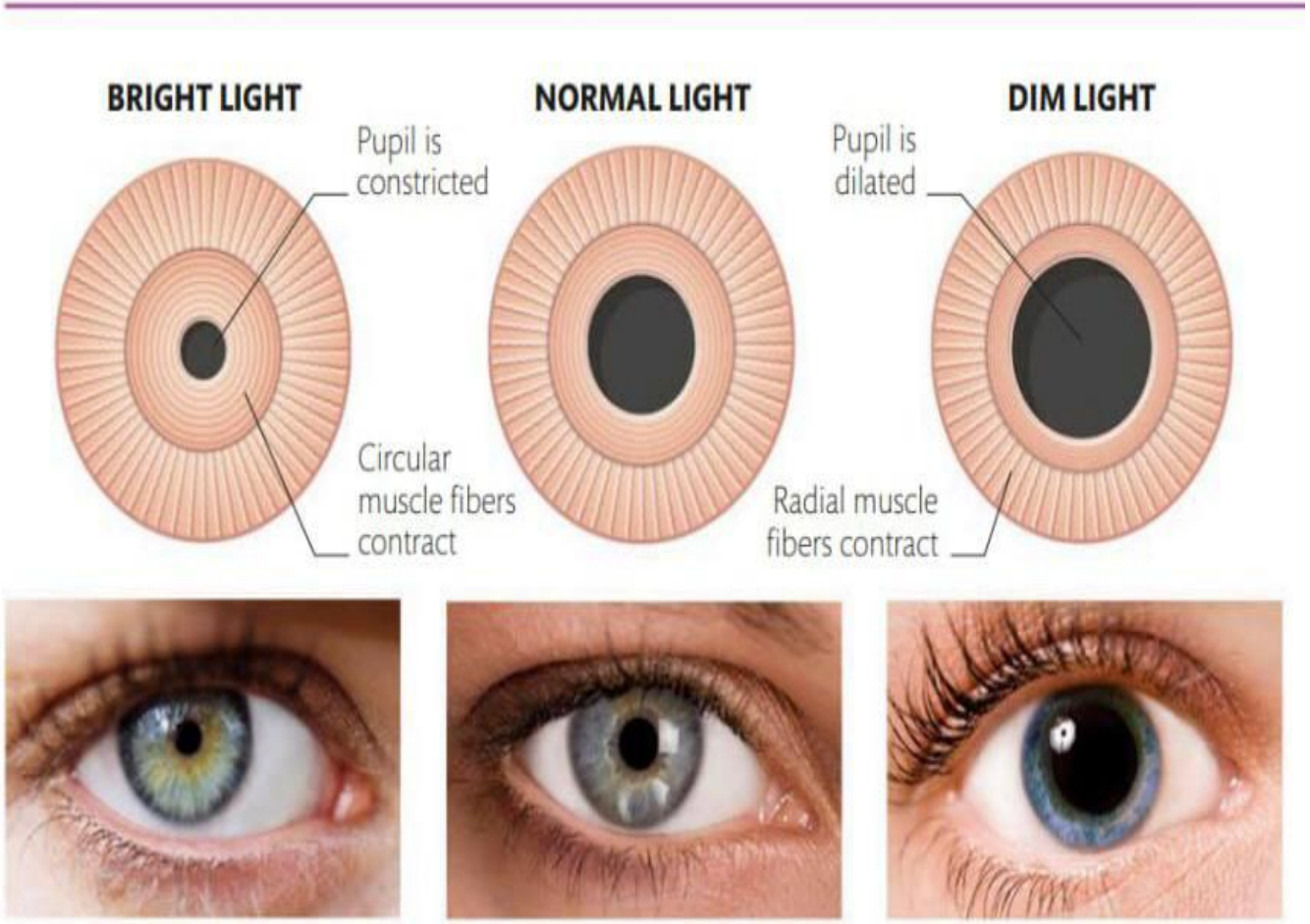
Photopigments: Each photoreceptor contains photopigments (rhodopsin in rods and photopsins in cones).

Quantum Efficiency: The probability that a photon will be absorbed by a photopigment. While quantum efficiency is low (typically ~1-3%), the vast number of photoreceptors compensates for this.

c. Absorption Process

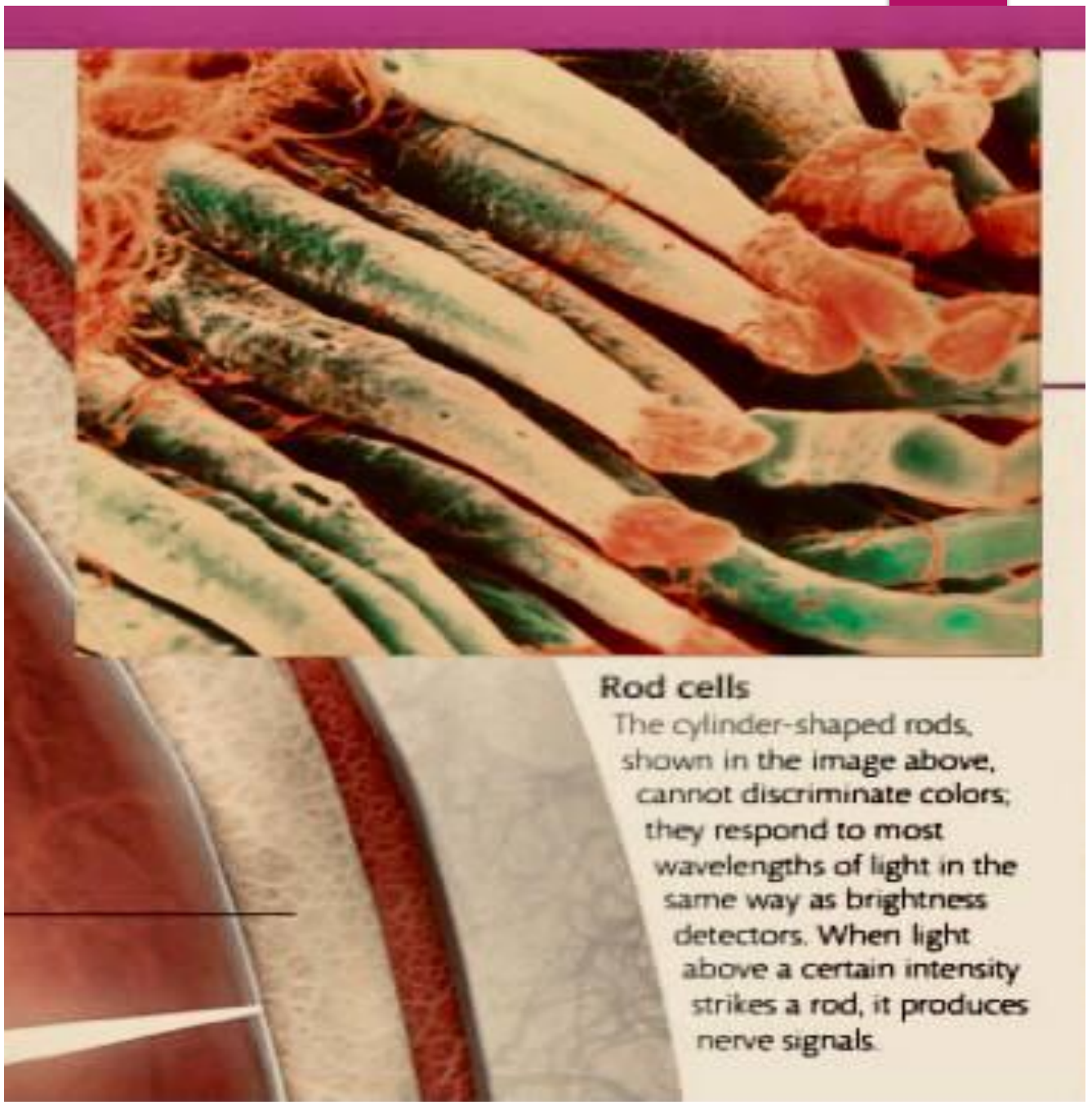
Photon Hits Photopigment: A photon strikes a photopigment molecule, causing a conformational change (e.g., 11-cis-retinal to all-trans-retinal in rhodopsin).

Activation of Transducin: This change activates a G-protein called transducin.



Signal processing

Phototransduction: When light photons strike the photoreceptors, a chemical change occurs in the visual pigments (rhodopsin in rods and photopsins in cones). This process is called phototransduction and converts the light signal into an electrical signal.



Signal processing:

Bipolar Cells and Ganglion Cells: The electrical signals from photoreceptors are transmitted to bipolar cells and then to ganglion cells within the retina.

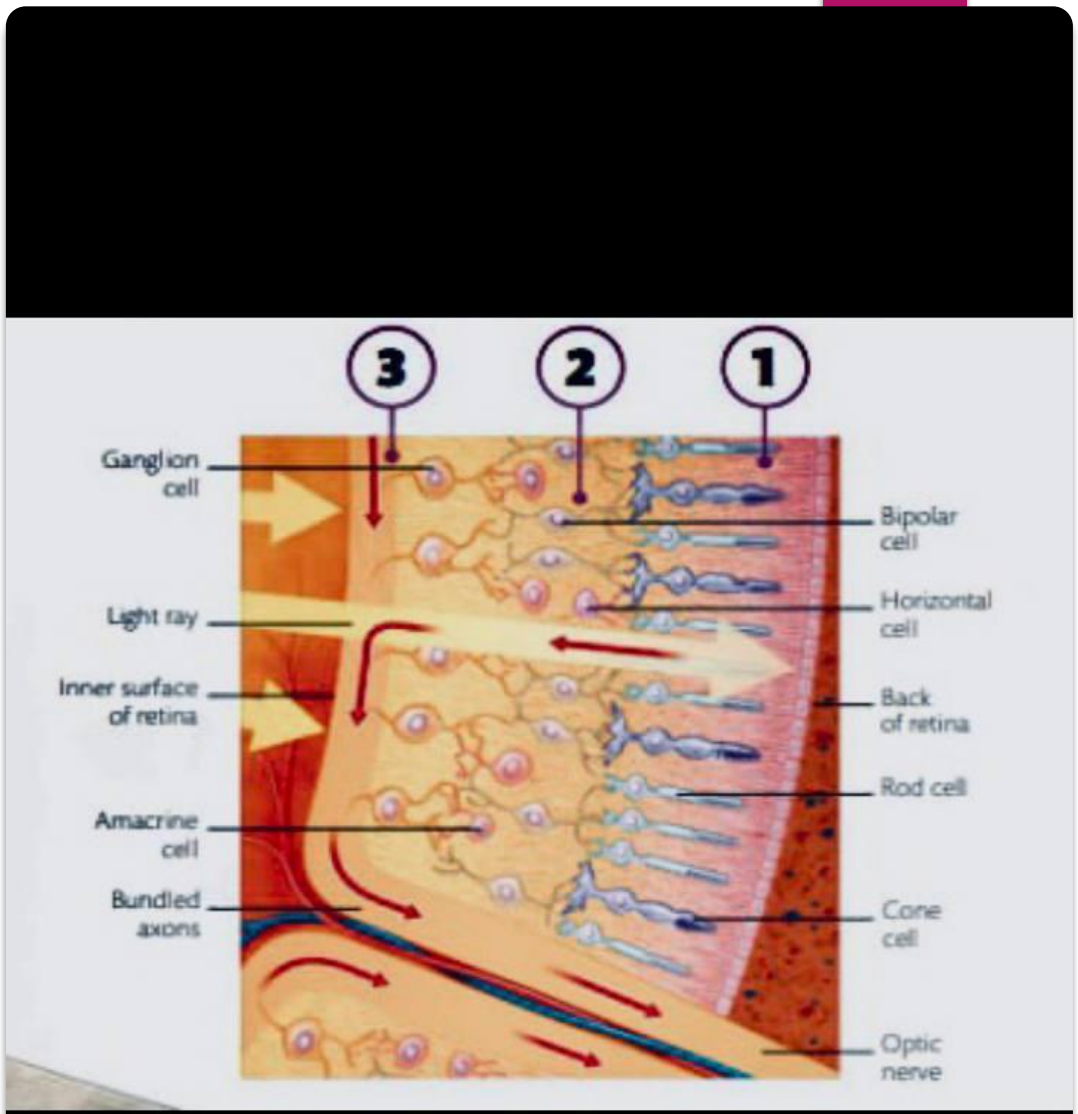
Horizontal and Amacrine Cells: These cells help integrate and regulate the signals, enhancing contrast and processing visual information before it leaves the eye.

Action Potentials: Ganglion cells generate action potentials (nerve impulses) based on the processed information from the photoreceptors.

4. Transmission via the Optic Nerve

Optic Nerve Formation: The axons of ganglion cells bundle together to form the optic nerve, which carries the visual information from each eye toward the brain.

Optic Chiasm: At the optic chiasm, some nerve fibers cross to the opposite side, ensuring that visual information from both eyes is processed together, allowing for depth perception and a cohesive visual field.



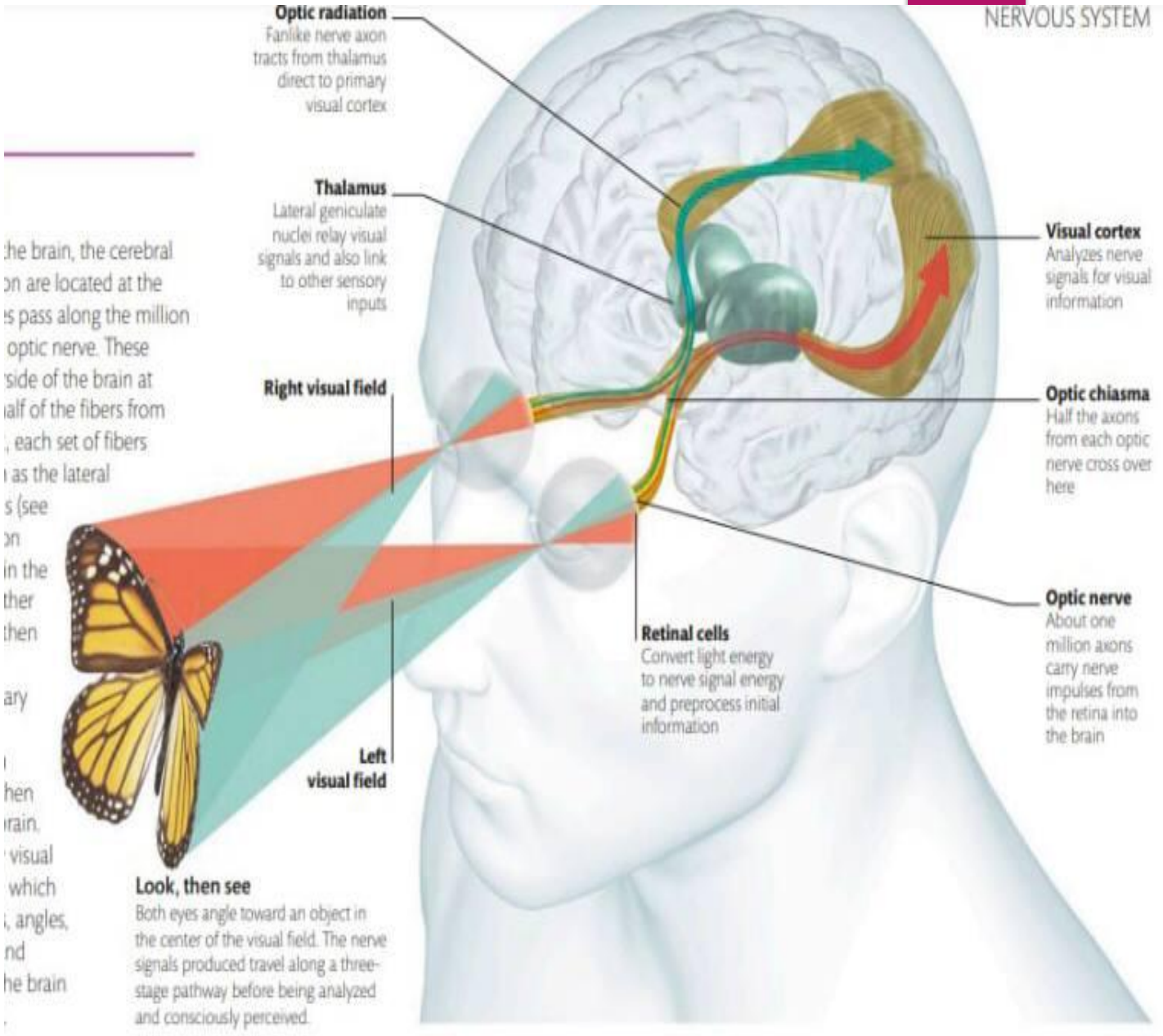
Processing in the Brain

Processing in the Brain

Lateral Geniculate Nucleus (LGN): The optic nerves project to the LGN in the thalamus, which acts as a relay and processing center for visual information.

Optic Radiations: From the LGN, signals travel along the optic radiations to the primary visual cortex (V1) located in the occipital lobe at the back of the brain.

Visual Cortex Processing: In the visual cortex, the brain interprets the signals to form images. This involves various areas specialized for different aspects of vision, such as color, motion, and shape recognition.



Information theory

MUTUAL INFORMATION IS A FUNDAMENTAL CONCEPT IN INFORMATION THEORY THAT QUANTIFIES THE AMOUNT OF INFORMATION ONE RANDOM VARIABLE CONTAINS ABOUT ANOTHER. IN THE CONTEXT OF THE VISUAL SYSTEM, MUTUAL INFORMATION HELPS US UNDERSTAND HOW EFFECTIVELY VISUAL STIMULI (INPUT) ARE TRANSMITTED AND REPRESENTED BY NEURAL SIGNALS (OUTPUT) THROUGH VARIOUS STAGES OF THE VISUAL PATHWAY, PARTICULARLY THE OPTIC NERVE.

MUTUAL INFORMATION IN THE VISUAL SYSTEM

IN THE VISUAL PATHWAY, WE CAN CONSIDER:

X: THE VISUAL STIMULUS (E.G., LIGHT PATTERNS, IMAGES) ENTERING THE EYE.

Y: THE NEURAL RESPONSES (E.G., NERVE IMPULSES IN THE OPTIC NERVE) GENERATED BY THE RETINA.

ADAPTIVE CODING STRATEGIES

Dynamic Adaptation: The visual system adapts its encoding strategies based on the statistical properties of the visual environment (light levels, contrast).
Maximizing Mutual Information: By adapting to maximize mutual information under varying conditions, the visual system ensures efficient information transmission tailored to current visual demands.