Brain Vision System

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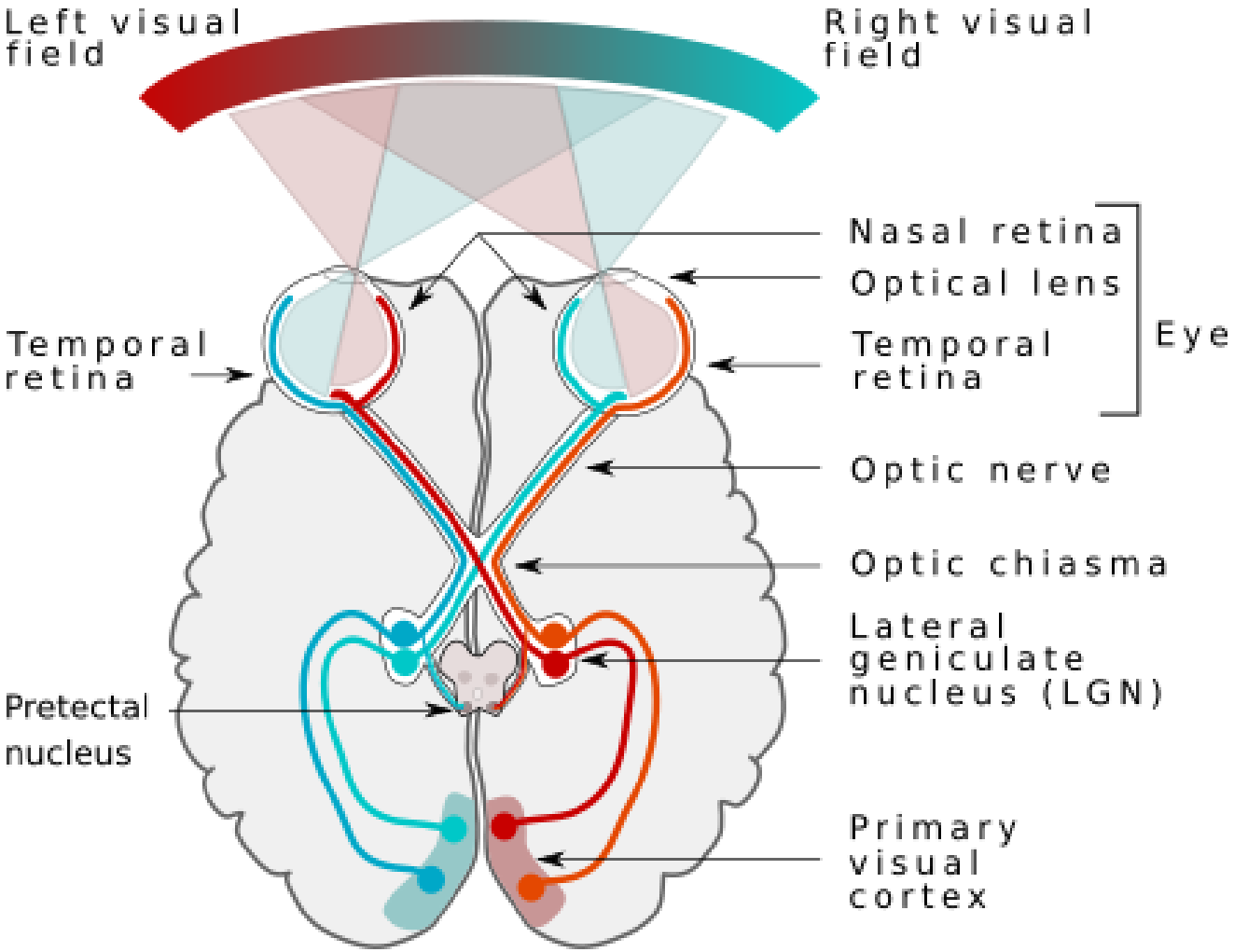


Figure: A Simplified Schema of The Human Visual Pathway

History

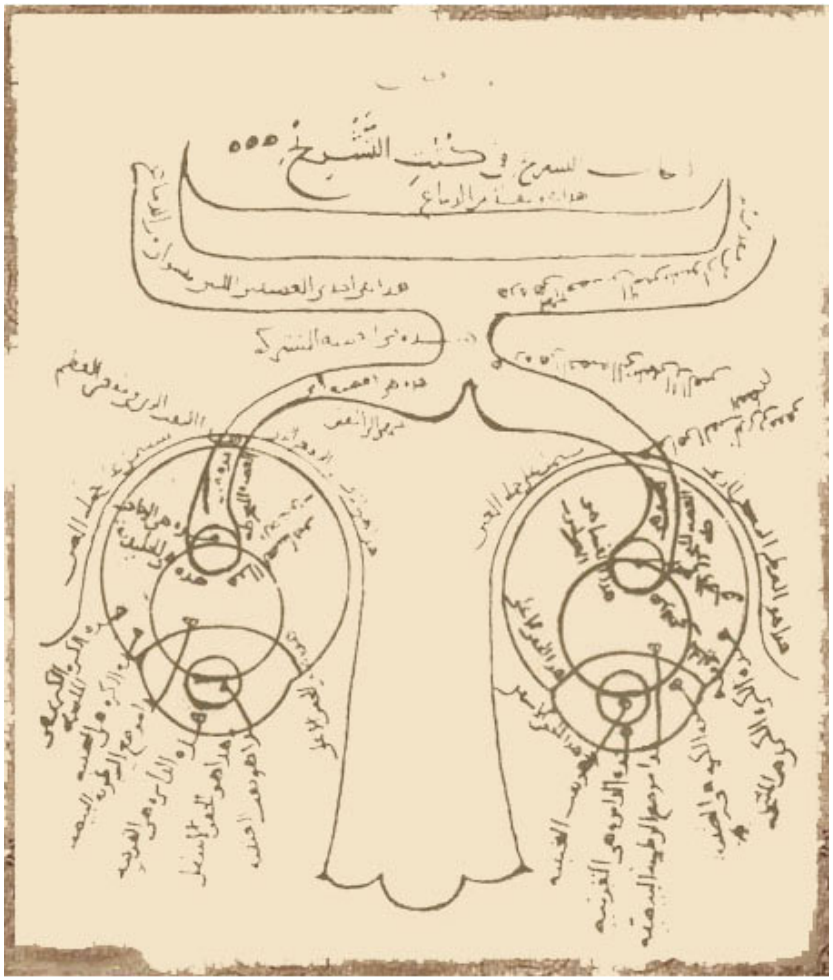


Figure 1. Diagrammatic representation of the visual system from the oldest existing copy of the Book of Optics by Ibn Al-Haitham, an arab physicist written in the 11 century AD. From Polyak (1957).

Ancient Understanding of Vision

- Early Greek philosophers like **Plato** and **Aristotle** debated vision's nature:
  - Plato proposed the "fire within the eyes" theory.
  - Aristotle argued for the role of external light interacting with the eye.

- The first anatomical studies of the eye and vision pathways were performed by **Galen** in ancient Rome.

- Early theories lacked knowledge of neural pathways but recognized the connection between the eye and the brain.

The Renaissance: Advancements in Eye Anatomy

Figure 2. Drawing by Leonardo DaVinci of the projection of the eyes to the ventricles of the brain. From Polyak (1957).

The Renaissance: Advancements in Eye Anatomy

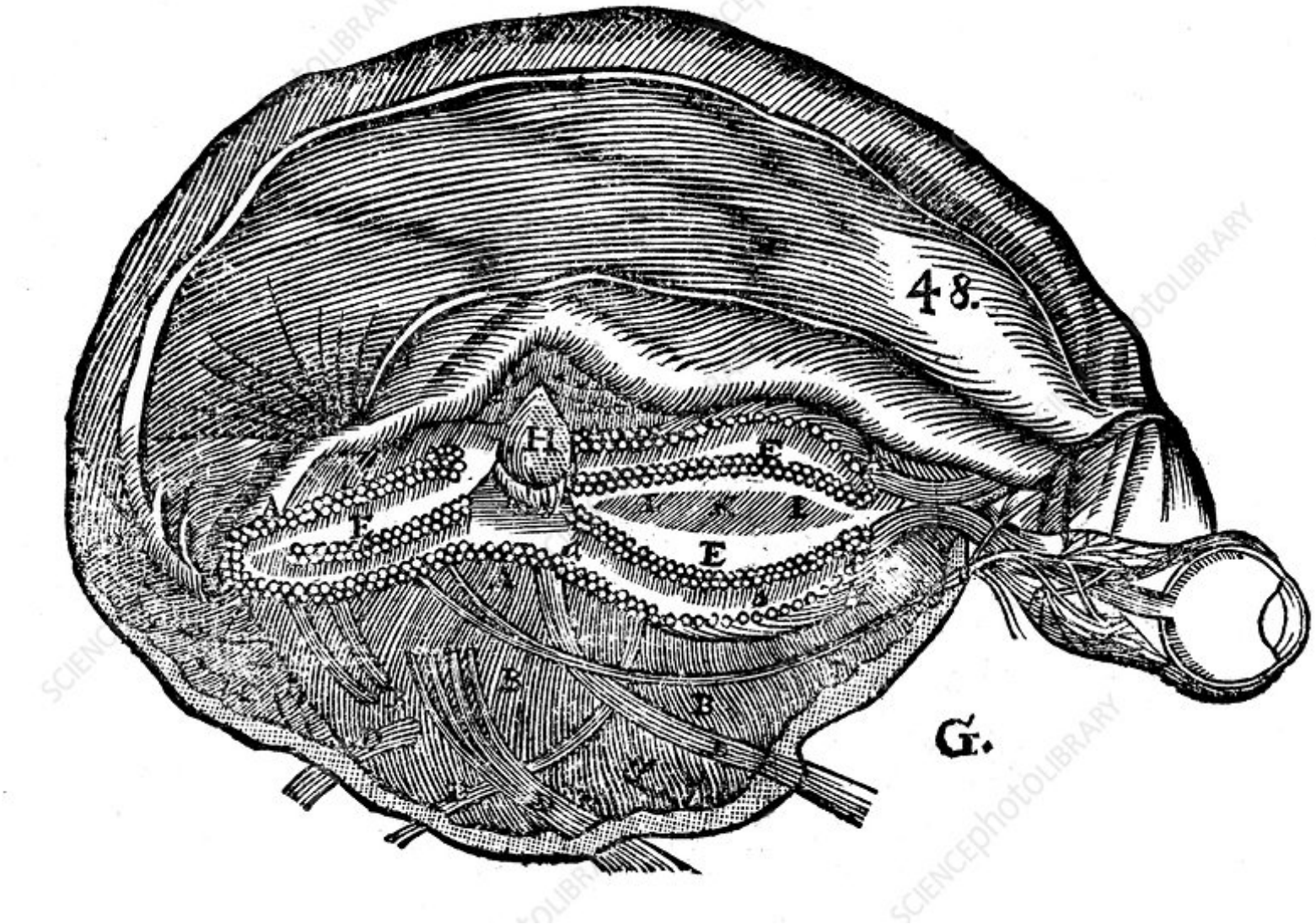


Figure: Rene Descartes' diagram of the human brain and eye

The Renaissance: Advancements in Eye Anatomy

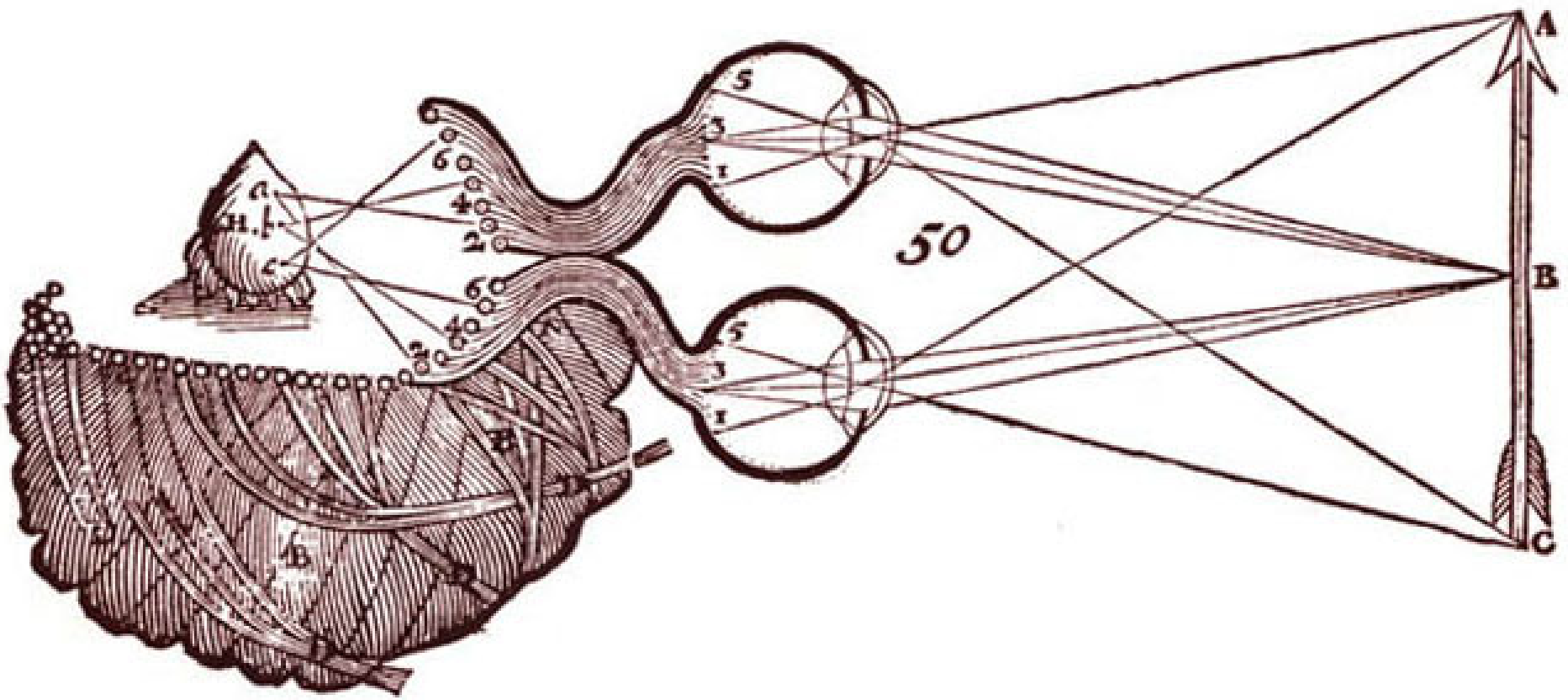


Figure 3. Binocular stereoscopic visual system as imagined by Des Cartes. The two retinal images of the arrow are accurately, point for point, projected upon the surface of the cerebral ventricles and thence to the centrally located pineal gland, H, the supposed "seat of imagination and common sense". From Polyak (1957).

The Renaissance: Advancements in Eye Anatomy

- **Leonardo da Vinci** and **Andreas Vesalius** conducted detailed dissections of the eye.
- **Kepler** (1604): Described the function of the lens in focusing light.
- **Descartes** (17th century): Hypothesized a neural relay between the eye and the brain.

19th Century: Discovery of Visual Pathways

- **Johannes Müller** introduced the "specific nerve energy" concept, suggesting specialized pathways for vision.
- **Hermann von Helmholtz**: Studied optics and neural conduction speed.
- **Golgi and Cajal** (late 1800s): Used staining techniques to map retinal and cortical circuits.

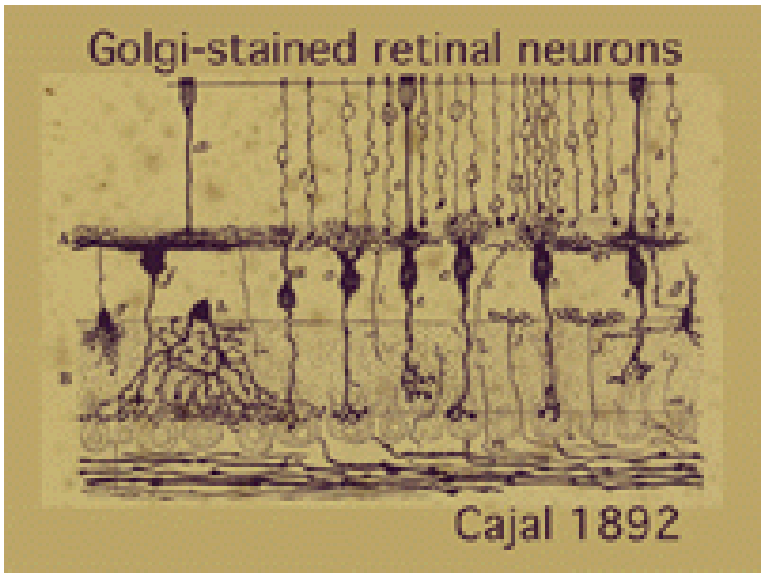


Figure: Retinal circuitry as visualized by Cajal

20th Century: Understanding Visual Circuits

Figure: Tatsuji Inouye: the mind's eye

Retina: The Gateway to Vision

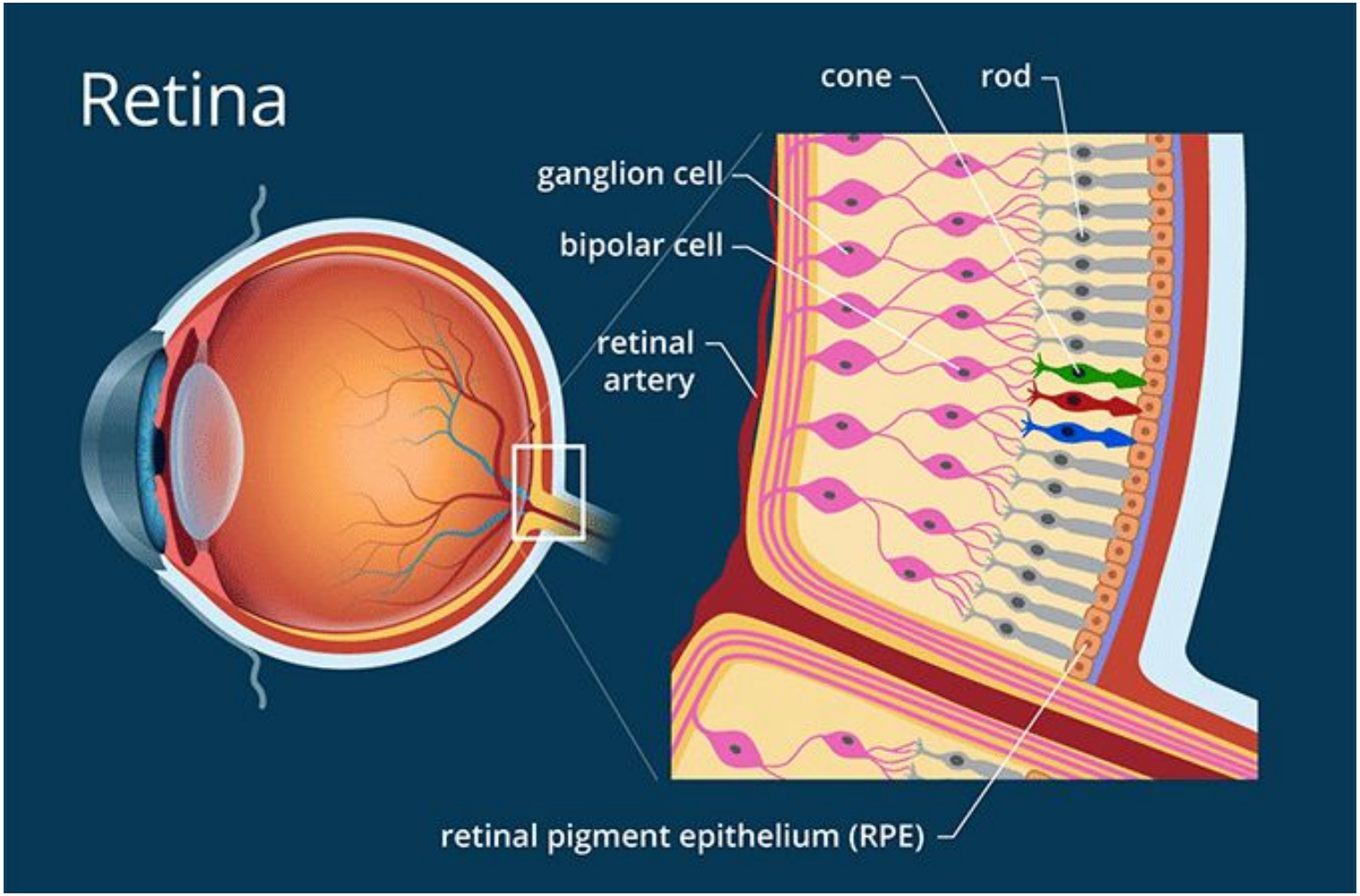


Figure: Structure of the Retina

Retina: The Gateway to Vision

- The retina, part of the central nervous system, converts light into neural signals through photoreceptors (rods and cones).
- This initial stage includes computations integrating spatial, temporal, and chromatic information.
- Ganglion cells, whose axons form the optic nerve, carry processed signals to the brain.

Major Visual Pathways

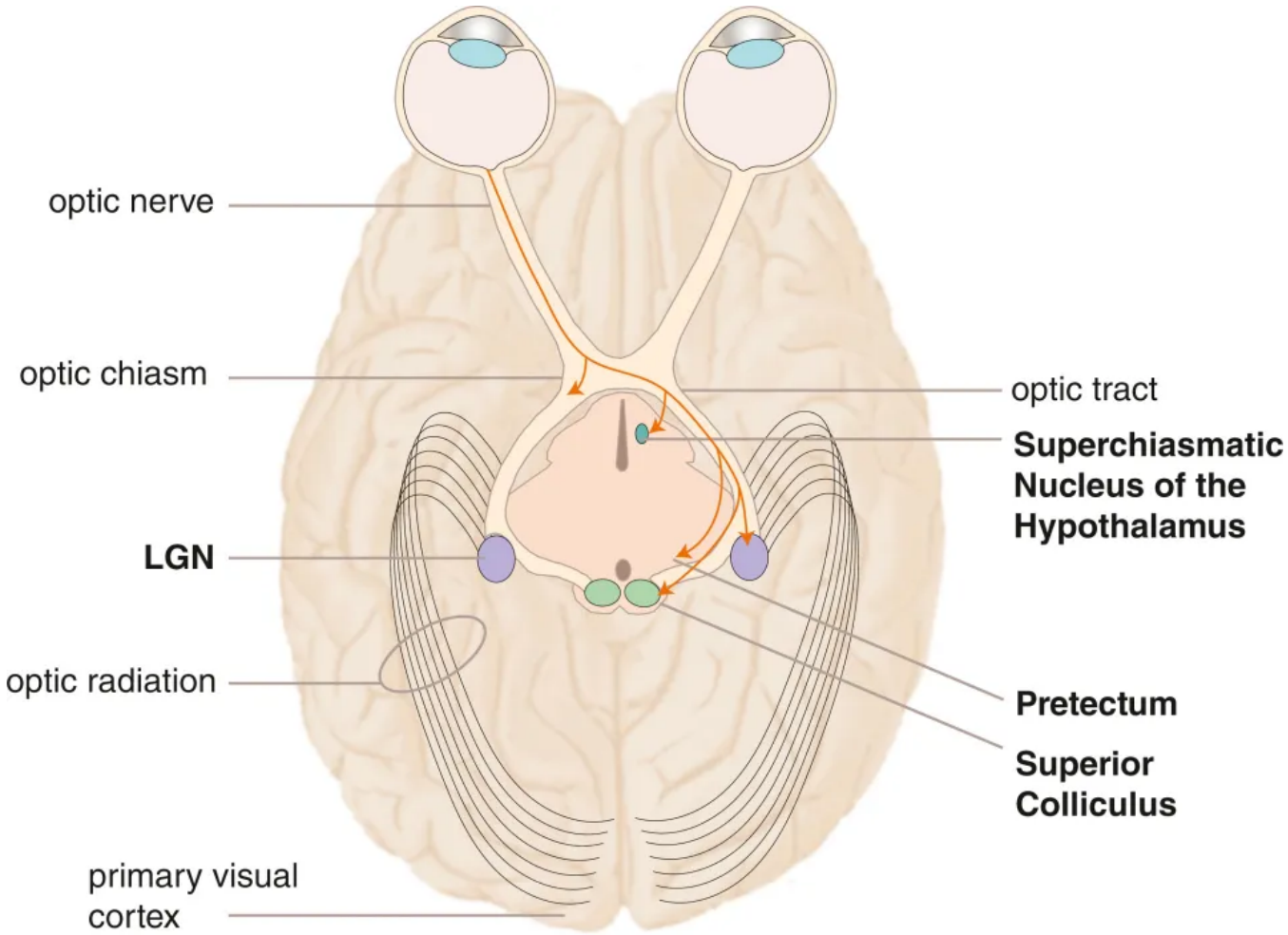


Figure: Major Visual Pathways:Retinotectal Pathway and Retinogeniculate Pathway

Major Visual Pathways

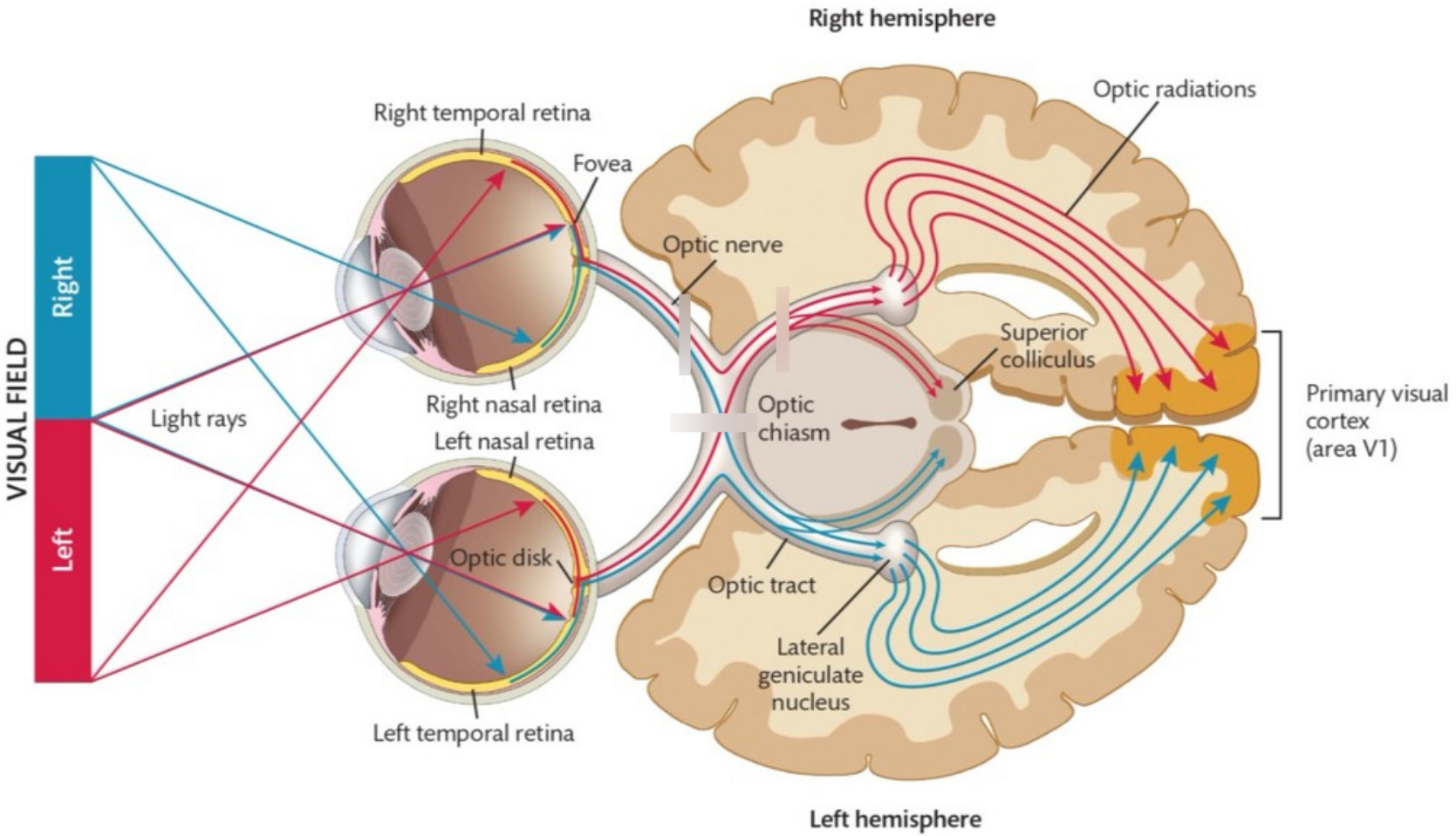


Figure: Major Visual Pathways:Retinotectal Pathway and Retinogeniculate Pathway

Major Visual Pathways

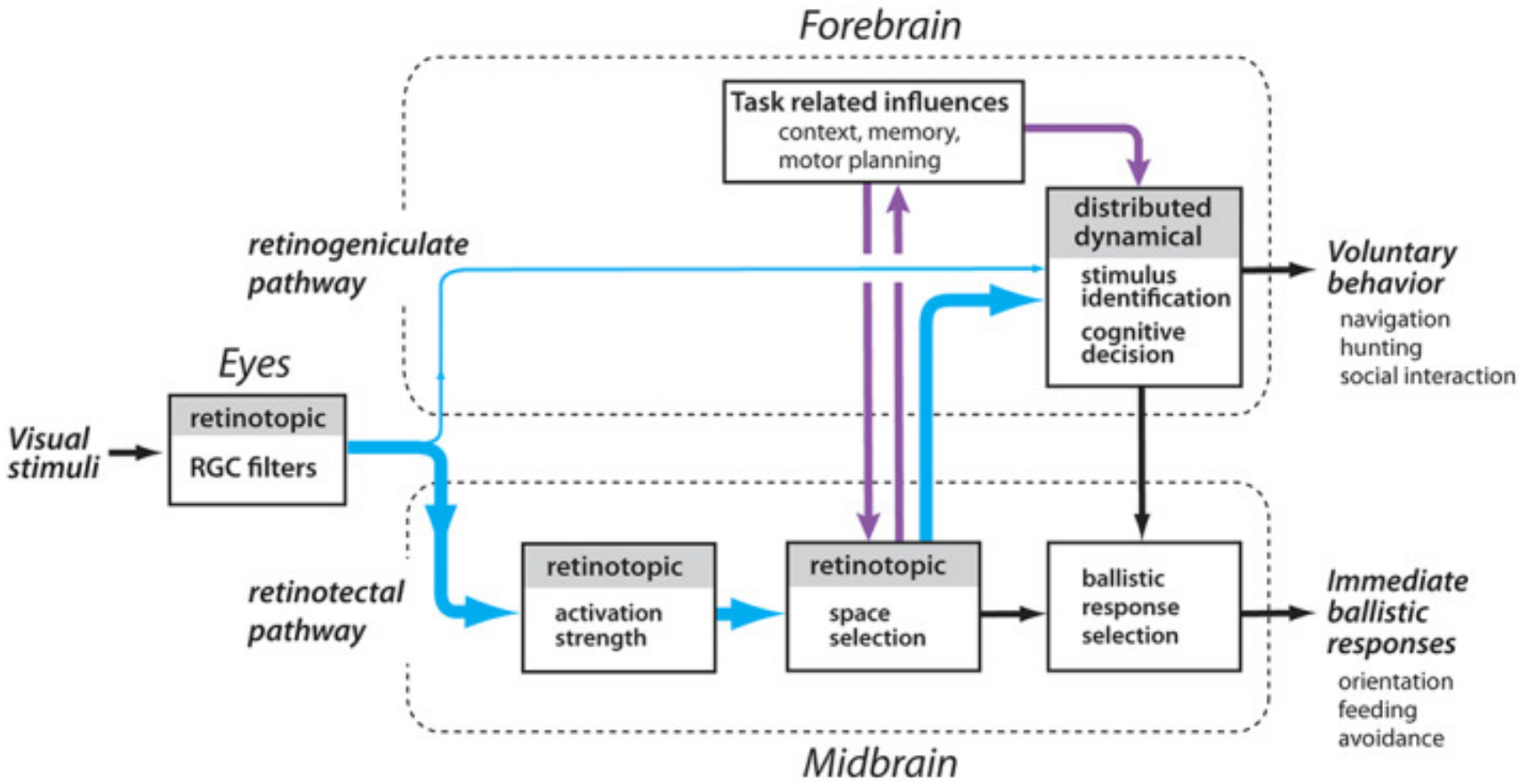


Figure: Schema for visual perception in reptiles

Major Visual Pathways

- **Retinotectal Pathway:**
  - Projects to the superior colliculus.
  - Controls saccadic eye movements and visual-motor coordination.

- **Retinogeniculate Pathway:**
  - Projects to the lateral geniculate nucleus (LGN) of the thalamus.
  - Signals proceed to the primary visual cortex (*Area V1*), essential for conscious vision.

The Retinogeniculate Pathway

- The lateral geniculate nucleus (LGN) receives input from retinal ganglion cells.
- LGN neurons send projections to the striate cortex (*Area V1*) in the occipital lobe.
- This pathway supports detailed visual analysis, such as object recognition and spatial perception.

The Retinotectal Pathway

- Connects retinal ganglion cells to the superior colliculus.
- The superior colliculus integrates sensory inputs and coordinates eye and head movements.
- Important for reflexive visual behaviors and spatial awareness.

Overview of Visual Pathways

- The visual system relies on two major pathways for processing information from the retina:
  - **Retinotectal Pathway**: Responsible for reflexive visual responses and orientation.
  - **Retinogeniculate Pathway**: Responsible for conscious vision and high-resolution processing.
- Both pathways have distinct structures, functions, and evolutionary significance.

Retinotectal Pathway

- **Overview:**
  - Evolutionarily older pathway, prominent in non-mammalian species.
  - Primary target: **Superior colliculus** (optic tectum in non-mammals).
- **Pathway:**
  - Retinal ganglion cells $\rightarrow$ Superior colliculus.
  - Superior colliculus $\rightarrow$ Motor nuclei (brainstem and spinal cord) and cerebral cortex (via pulvinar nucleus).
- **Functions:**
  - Reflexive responses to visual stimuli (e.g., turning toward a sudden light).
  - Coordination of rapid eye movements (**saccades**).
  - Integration of visual input for spatial orientation and motion detection.

Retinogeniculate Pathway

- **Overview:**
  - Dominant pathway in mammals, especially primates.
  - Crucial for **conscious vision** and high-resolution processing.
- **Pathway:**
  - Retinal ganglion cells $\rightarrow$ Lateral Geniculate Nucleus (LGN).
  - LGN $\rightarrow$ Primary Visual Cortex (V1) via optic radiations.
- **Functions:**
  - Conscious visual perception, object recognition.
  - Processing of fine details, color, and motion.
  - Relay to higher-order visual areas for advanced processing.

Comparison: Retinotectal vs. Retinogeniculate Pathways

Table: Comparison of the Retinotectal and Retinogeniculate Pathways

Feature	Retinotectal Pathway	Retinogeniculate Pathway
Evolutionary Age	Older, dominant in non-mammals	Newer, dominant in mammals
Primary Target	Superior colliculus (midbrain)	Lateral geniculate nucleus (thalamus)
Main Function	Reflexive visual responses, eye movements	Conscious vision, detailed processing
Role in Vision	Orientation and attention	Object recognition, fine detail
Importance in Mammals	Secondary pathway	Primary pathway for vision

Minor Visual Pathways

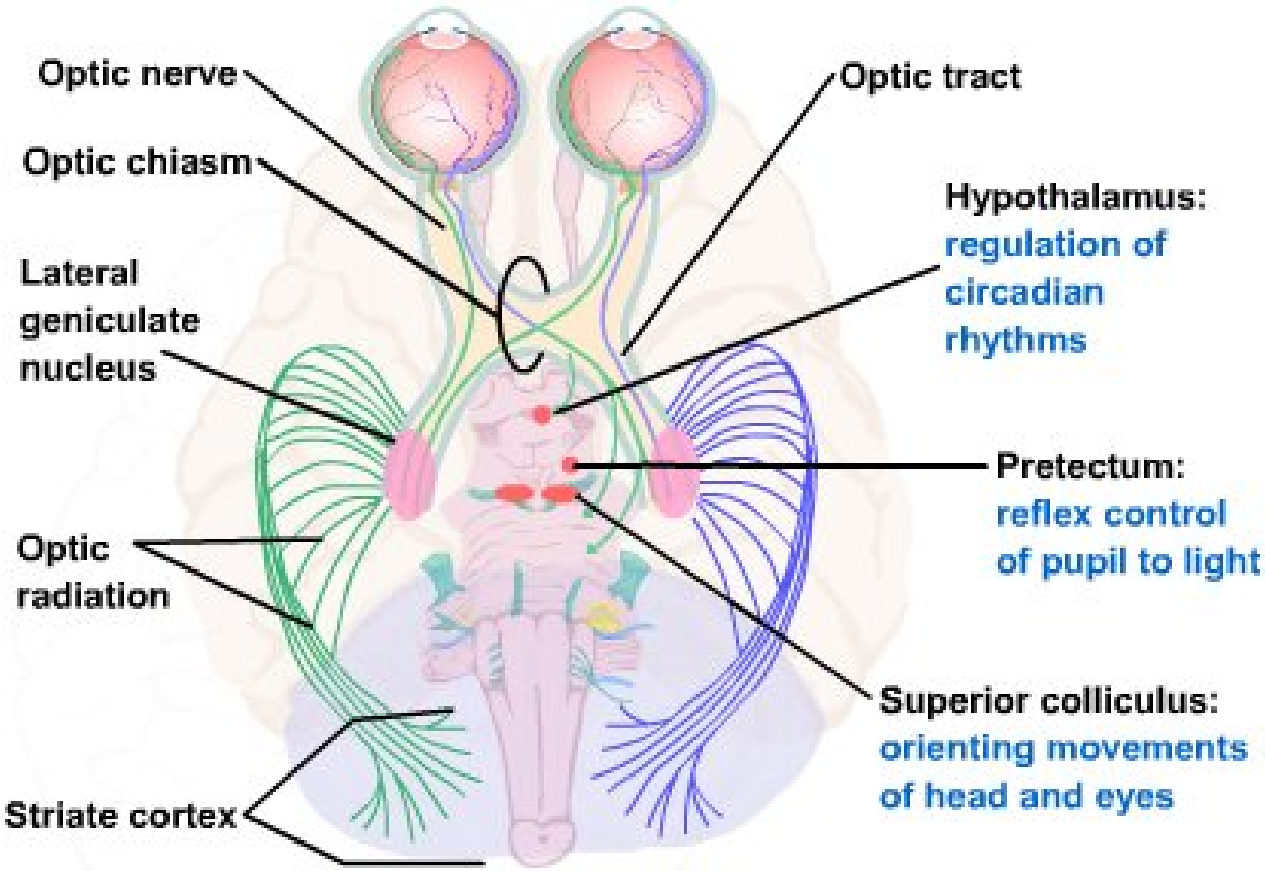


Figure: Minor Visual Pathways

Minor Visual Pathways

- **Suprachiasmatic Nucleus:** Regulates circadian rhythms.
- **Accessory Optic System:** Controls eye movements and posture through optic flow processing.
- **Pretectal Nuclei:** Involved in pupillary light reflexes.

Lateral Geniculate Nucleus (LGN)

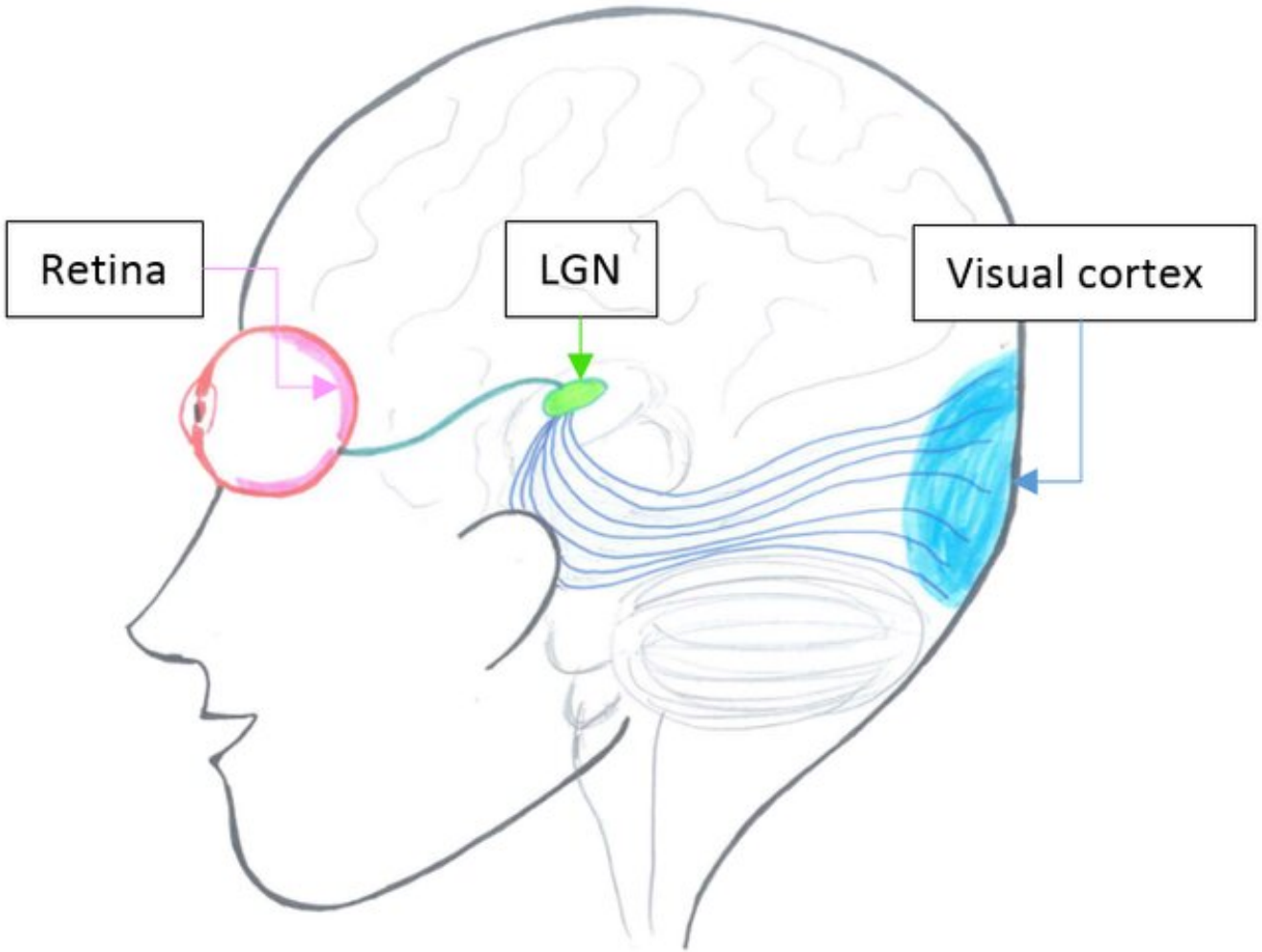


Figure: The retina, the LGN and the visual cortex

Lateral Geniculate Nucleus (LGN)

- **Location:** The LGN is located in the thalamus and serves as a relay station for visual information from the retina to the primary visual cortex.
- **Main Function:** It filters and processes visual signals from the retina before transmitting them to the visual cortex.
- **Importance:** The LGN plays a key role in visual perception by organizing and prioritizing visual stimuli.

LGN Layers

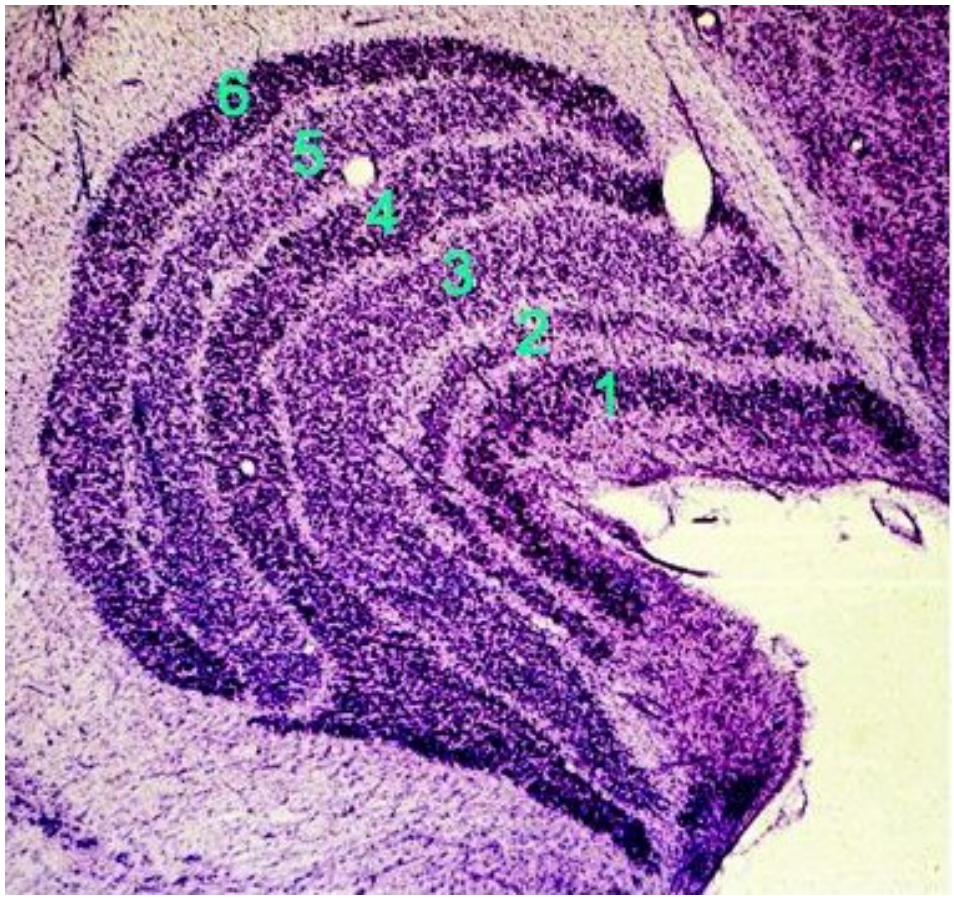


Figure: LGN Layers

Structure of the LGN

- The LGN consists of six layers:
  - **Magnocellular Layers (1 and 2):** Responsible for processing motion and low spatial frequency.
  - **Parvocellular Layers (3 to 6):** Process color vision and fine spatial detail.
  - **Koniocellular Layers:** Less understood but believed to be involved in color and visual attention.

- The LGN receives input from retinal ganglion cells and transmits this information to the visual cortex.

Connections with the Retina

- The retina sends visual information to the LGN via the retinogeniculate pathway.

- **Magnocellular Layers:** Receive input from parasol ganglion cells that detect motion and coarse visual features.

- **Parvocellular Layers:** Receive input from midget ganglion cells that provide high-resolution detail and color information.

Function of the LGN

- The LGN serves as a gateway for visual information and performs several key tasks before the information reaches the cortex:
  - Filtering: Enhances important visual features such as motion, contrast, and color.
  - Spatial Organization: Maintains a retinotopic map, preserving the layout of the image from the retina.
  - Top-Down Modulation: Receives feedback from the visual cortex to prioritize and modulate visual input.

- The LGN is influenced not only by retinal input but also by signals from the **visual cortex**.

The dLGN: Dorsal Lateral Geniculate Nucleus

- The term **dLGN** is sometimes used to emphasize the LGN's role in visual processing as a relay station.
- The "d" in dLGN stands for **dorsal**, indicating its anatomical location.
- The dLGN is essential for conscious visual perception, connecting the retina to the primary visual cortex (V1).

Visual Pathway from Retina to the LGN

- The visual pathway follows this route:
  - Retina $\rightarrow$ Optic Nerve $\rightarrow$ Optic Chiasm $\rightarrow$ Optic Tract $\rightarrow$ dLGN $\rightarrow$ Primary Visual Cortex (V1).

- The LGN receives processed visual signals from the retina and relays them to the primary visual cortex for higher-level processing.

Summary of the LGN's Role in Vision

- The LGN acts as a relay station between the retina and the primary visual cortex, crucial for visual processing.
- The six-layer structure of the LGN allows for the parallel processing of different types of visual information, such as motion, color, and detail.
- Feedback from the visual cortex helps modulate and prioritize visual signals, ensuring efficient processing of important visual features.

Visual Cortex

Figure: Visual Cortex

Overview of Visual Cortex

- The visual cortex is located in the occipital lobe and plays a critical role in processing visual information.
- It consists of five primary areas: V1 (primary visual cortex), V2, V3, V4, and V5 (also known as MT).
- Pathways: The visual cortex integrates input from the lateral geniculate nucleus (LGN) and distributes output to dorsal and ventral streams.

Visual Cortex Layers

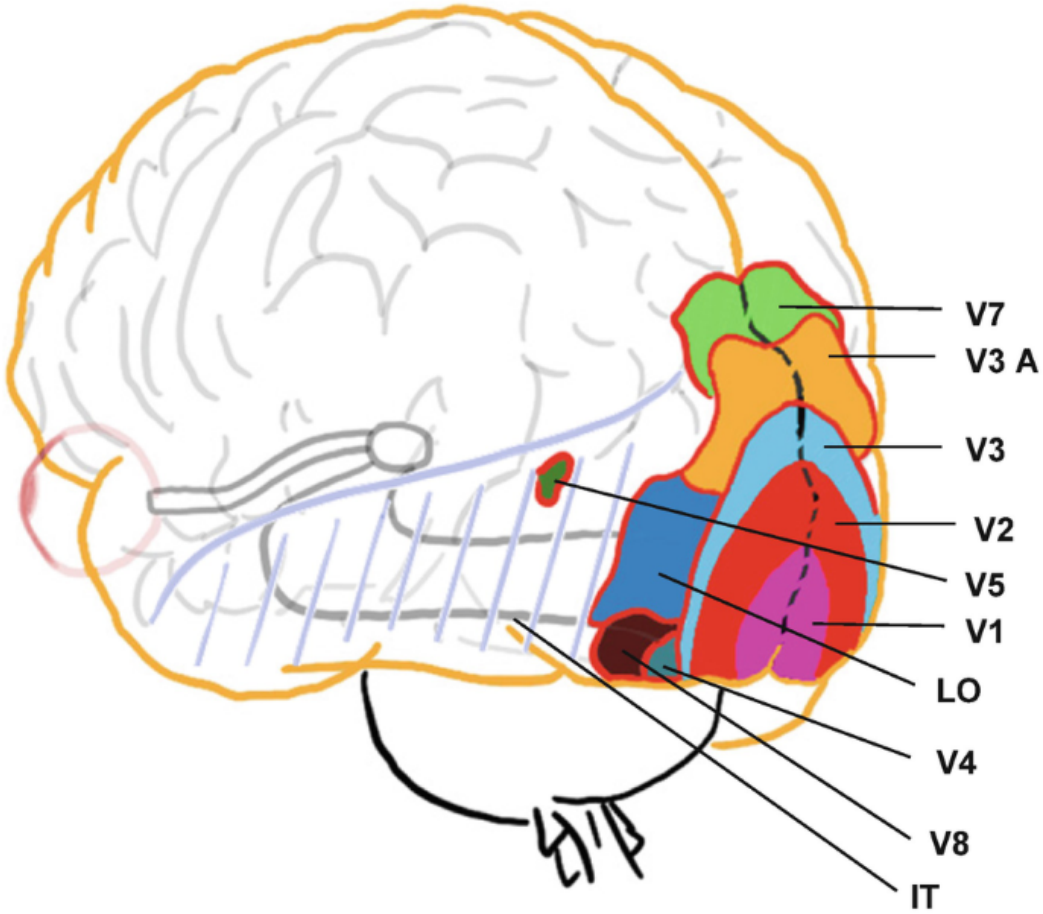


Figure: Visual Cortex Layers

Visual Cortex Layers

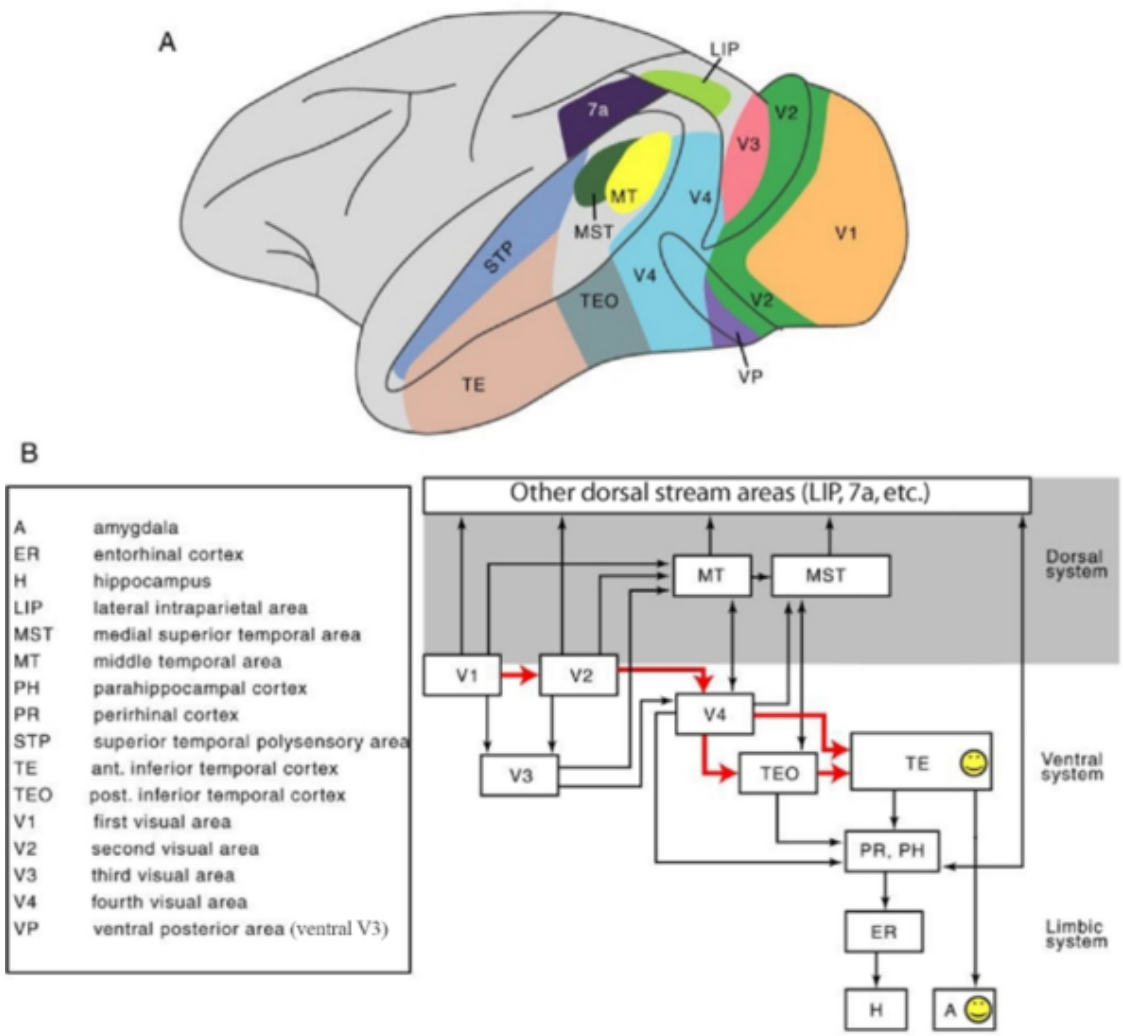


Figure: Visual Cortex Layers in Monkey

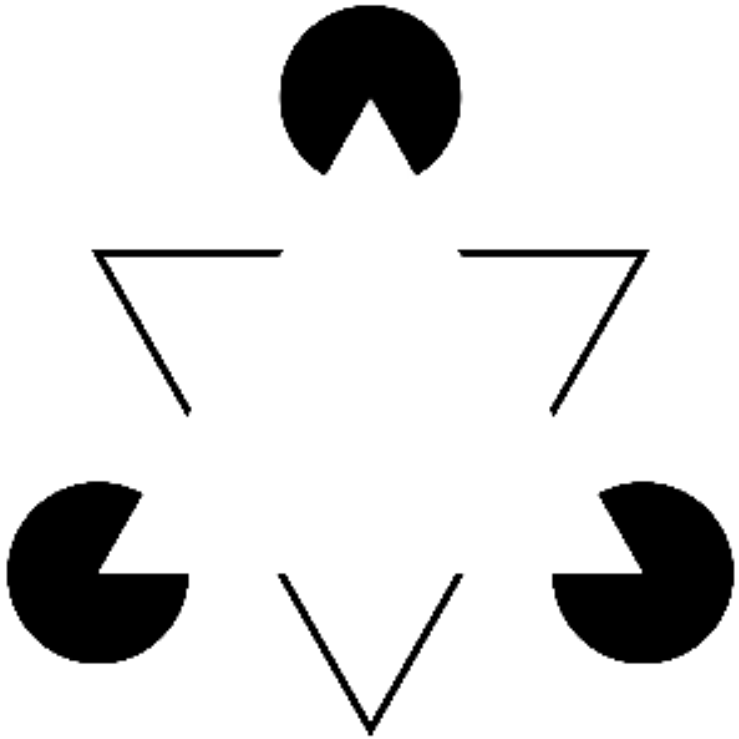
Primary Visual Cortex (V1)

- Input: Receives input from the LGN of the thalamus.
- Function: Responsible for detecting basic features like edges, orientation, and motion.
- Output: Sends processed information to higher visual areas (e.g., V2, V3).

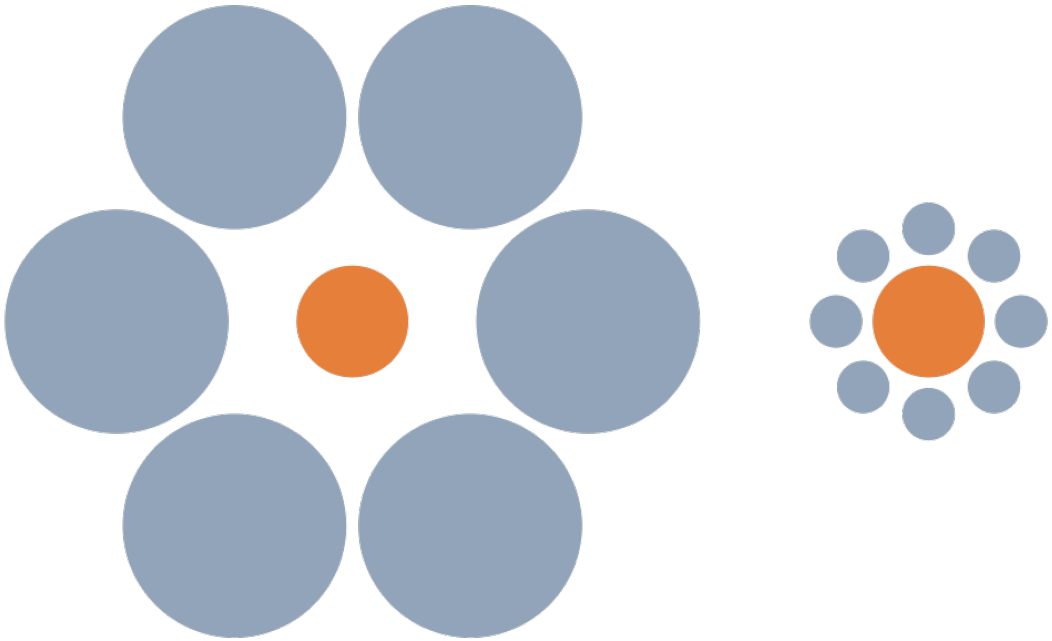
Secondary Visual Cortex (V2)

- Input: Receives input from V1.
- Function: Processes complex features, such as texture and depth.
- Output: Sends information to V3, V4, and V5 (MT).

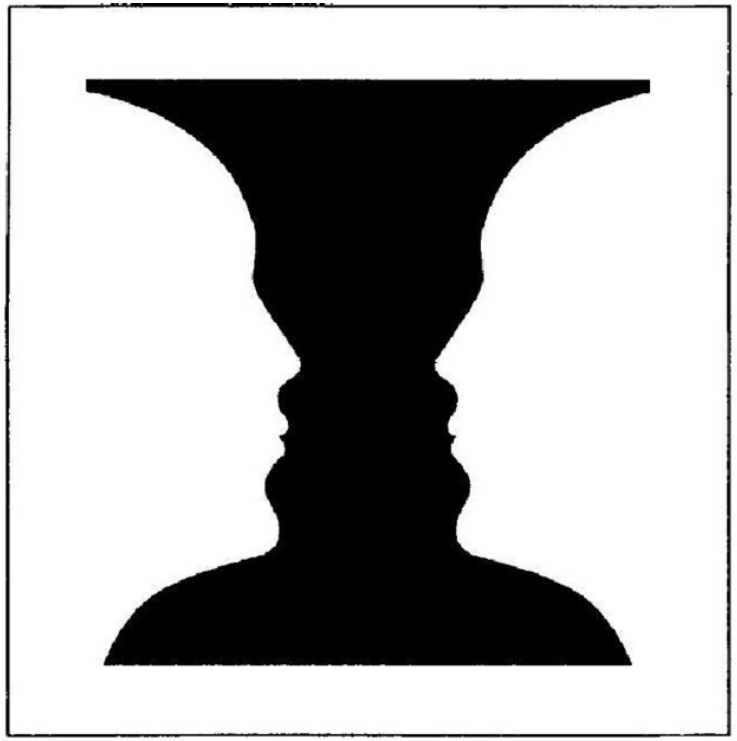
V2 Illusions



V2 Illusions



V2 Illusions



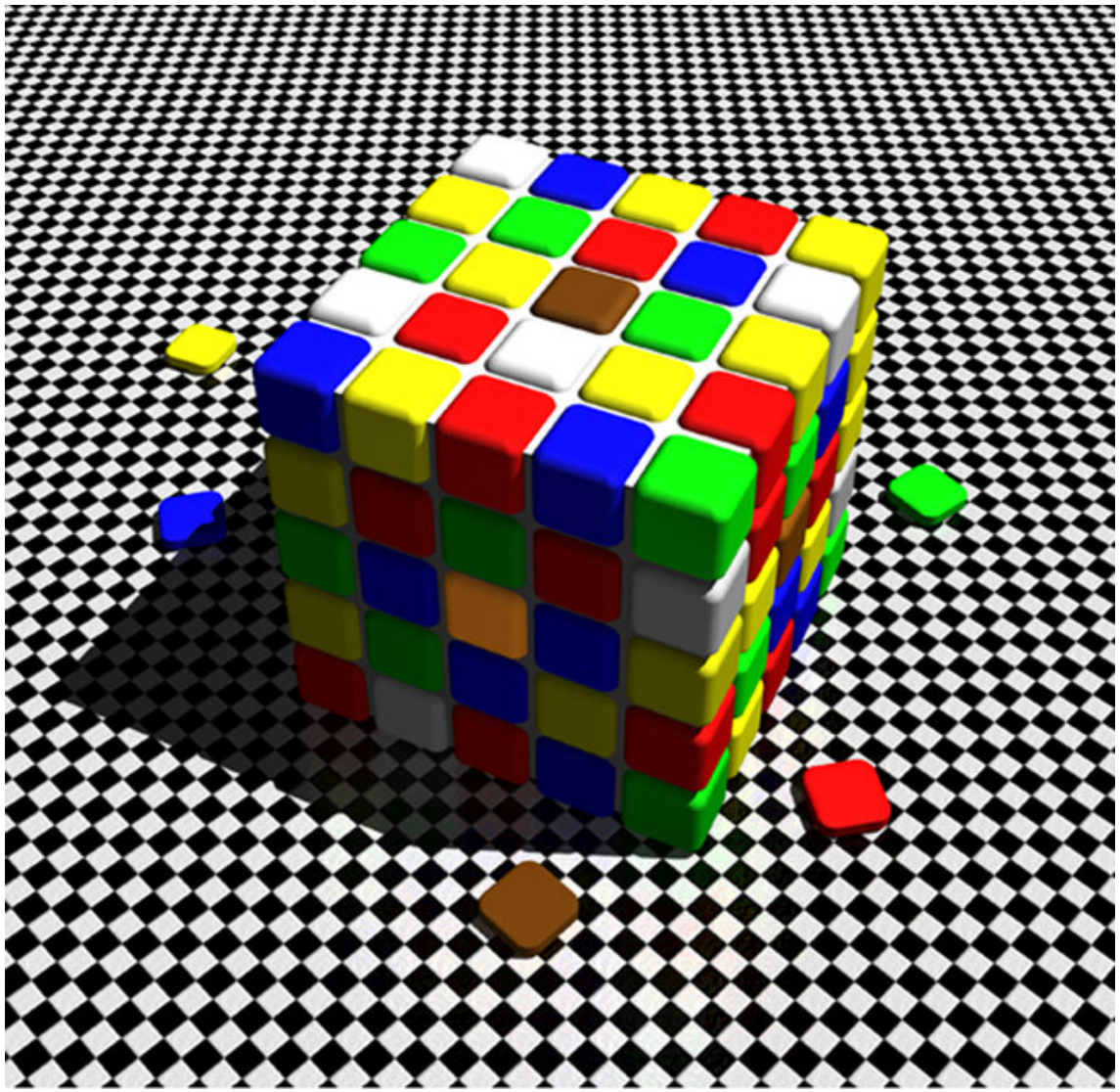
V3 - Dynamic Form

- Input: Receives input from V1 and V2.
- Function: Specialized in processing motion and dynamic forms.
- Output: Contributes to both dorsal and ventral streams.

V4 - Color Processing

- Input: Receives input primarily from V2.
- Function: Processes color, brightness, texture, and shape. Particularly, **Color Constancy**
- Output: Sends information to ventral stream areas for object recognition.

V4 Illusions



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V5 (MT) - Motion Detection

- Input: Receives input from V1, V2, and dorsal pathway.
- Function: Specialized in motion detection and spatial awareness.
- Output: Provides information to parietal regions for spatial navigation.

Visual Cortex Pathways

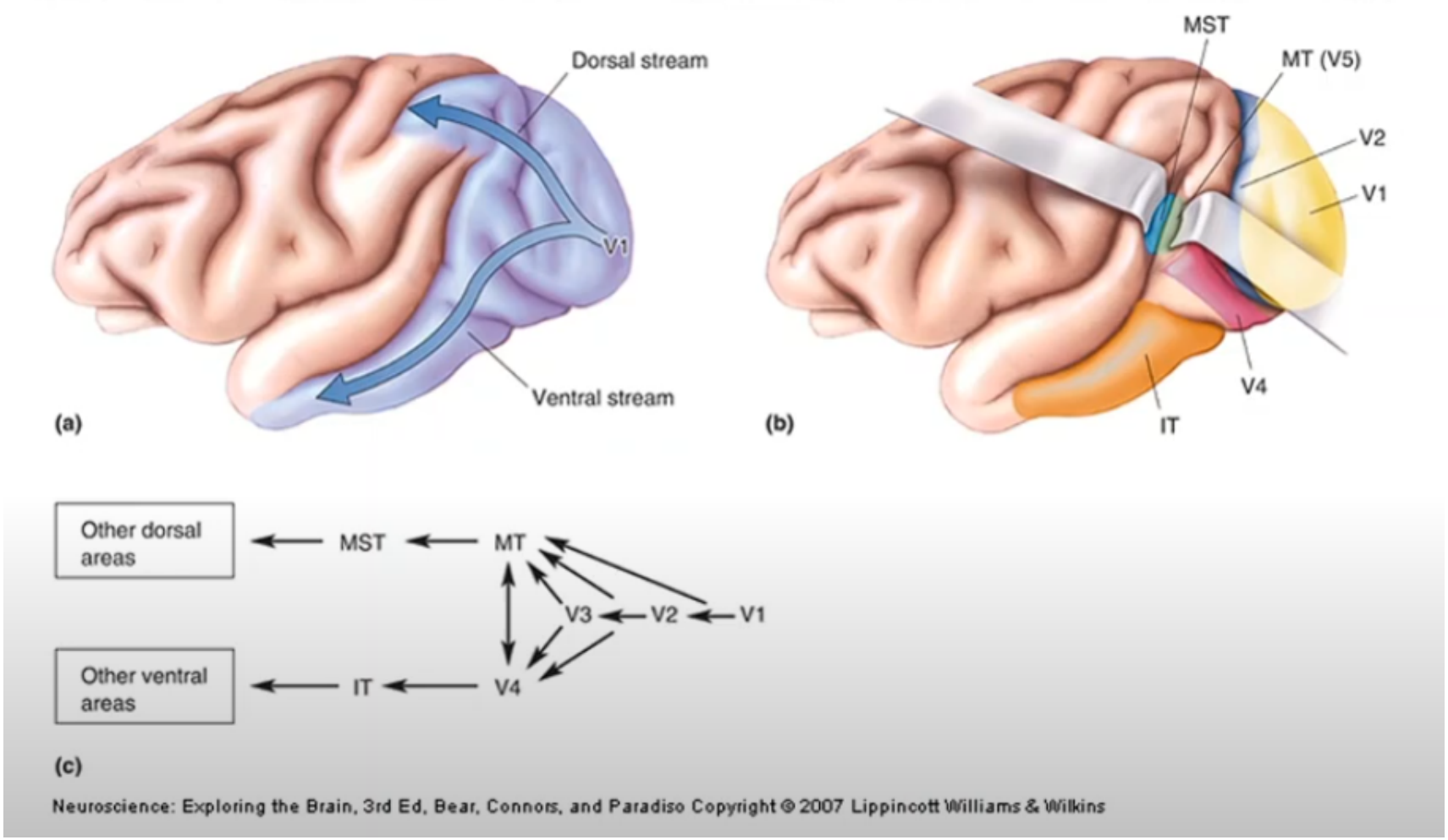

Figure: Visual Cortex Pathways

Dorsal and Ventral Pathways

- **Dorsal Pathway:**
  - Processes "where" information: spatial location, navigation, directing eye movement, motion of objects and response to it. It processes information to guide actions (**vision for action**)
  - Pathway: From V1 to parietal lobe via V5 (MT).

- **Ventral Pathway:**
  - Processes "what" information: object recognition and color. It also contains "face cells". It is involved in the perception of information about objects (**vision for perception**)
  - Pathway: From V1 to temporal lobe via V4.

Ventral Pathway

Ventral Pathway

Visual Cortex Layers

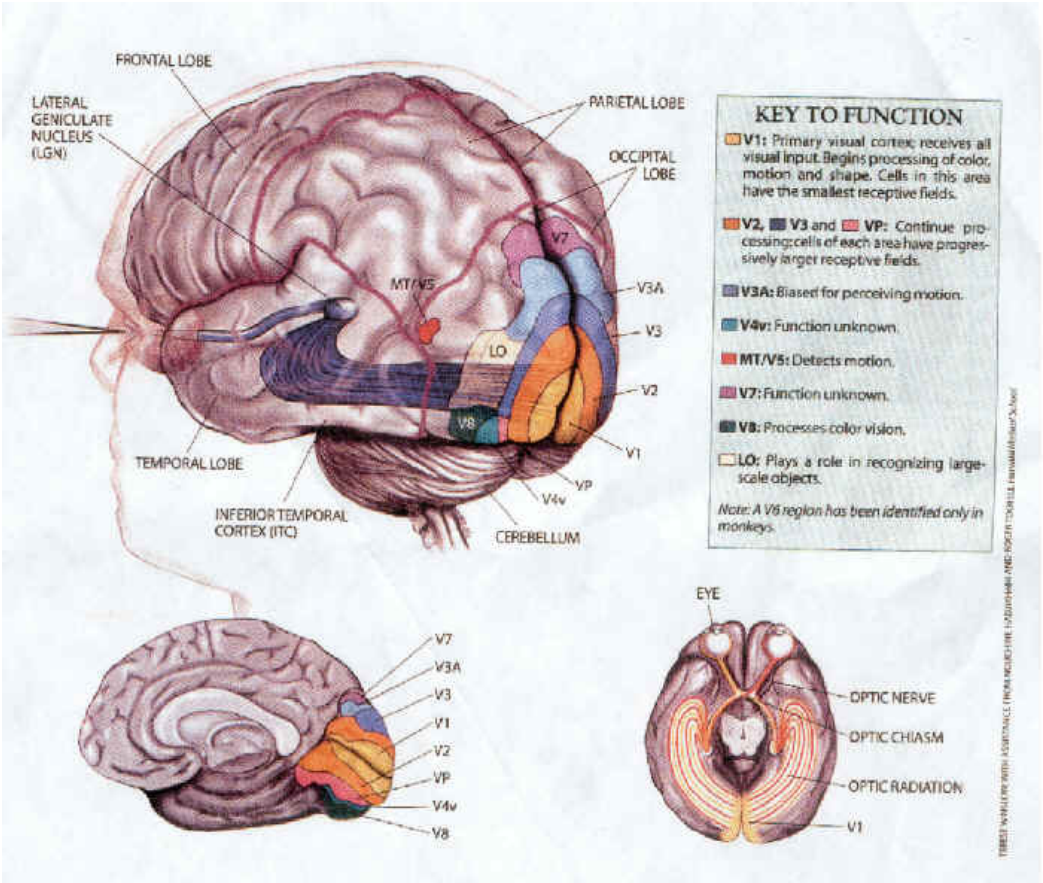

Figure: Visual Cortex Layers

Summary of Visual Areas

Area	**Input From**	**Function**
V1	LGN	Basic features (edges, orientation)
V2	V1	Complex features (depth, texture)
V3	V1, V2	Dynamic forms, motion
V4	V2	Color and object features
V5 (MT)	V1, V2	Motion detection

The Primary Visual Cortex Layers

The visual cortex is organized into six distinct layers (I-VI), and each layer has a specific role in processing visual information. These layers receive inputs from the Lateral Geniculate Nucleus (LGN) and other cortical areas and send outputs to various brain regions involved in visual processing.

Primary Visual Cortex Layers

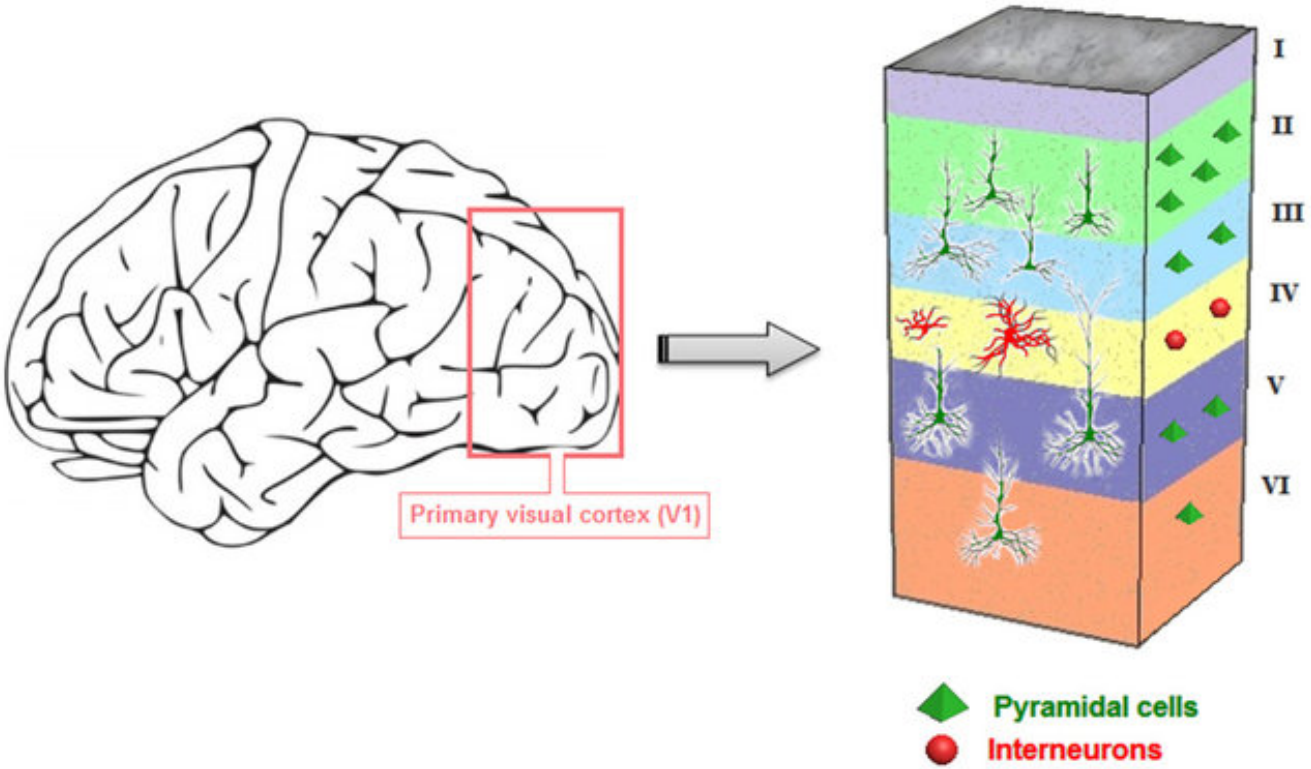

Figure: Visual Cortex Layers

Layer I - Molecular Layer

- **Input**:
  - Receives dendritic inputs from higher cortical areas, involved in feedback processing.

- **Output**:
  - Sends output to deeper cortical layers (Layer II, III, IV), modulating visual processing.

- **Function**:
  - Primarily involved in feedback processing and shaping visual perception based on context.

Layer II - External Granular Layer

- **Input**:
  - Receives corticocortical input from other areas of the cortex.

- **Output**:
  - Sends output to higher cortical areas for further interpretation of visual stimuli.

- **Function**:
  - Involved in integrating visual information with other sensory inputs, supporting higher-order processing.

Layer III - External Pyramidal Layer

- **Input**:
  - Receives input from Layer II and Layer IV (the sensory processing layer).

- **Output**:
  - Sends output to other cortical regions, contributing to the integration of visual and higher-order cognitive functions.

- **Function**:
  - Helps link visual information with functions like attention, spatial awareness, and recognition.

Layer IV - Internal Granular Layer

- **Input**:
  - Primary recipient of thalamocortical input from the LGN, receiving visual signals processed by the retina.

- **Output**:
  - Sends output to Layers III, V, and VI, which help integrate sensory information.

- **Function**:
  - Crucial for processing basic visual features like edges, motion, orientation, and contrast.

Layer V - Internal Pyramidal Layer

- **Input**:
  - Receives input from Layer IV (sensory input) and higher cortical areas.

- **Output**:
  - Sends output to subcortical regions, including the superior colliculus (SC), involved in visual reflexes.

- **Function**:
  - Plays a key role in visual motor control, guiding eye movements such as saccades and pursuit.

Layer VI - Multiform Layer

- **Input**:
  - Receives input from Layers V and other cortical regions.

- **Output**:
  - Sends feedback to the LGN and other areas of the brain, modulating sensory input to the cortex.

- **Function**:
  - Regulates visual processing and cognitive control by providing feedback to the LGN.

Thank you!