# Vision – The Visual System

Guest lecturer: Melissa Faggella

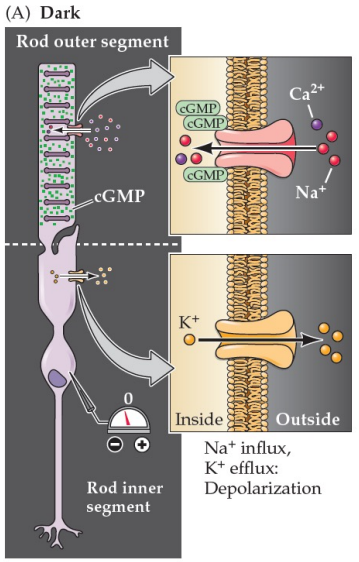
Reading: ***Purves*** **Chapter 12**

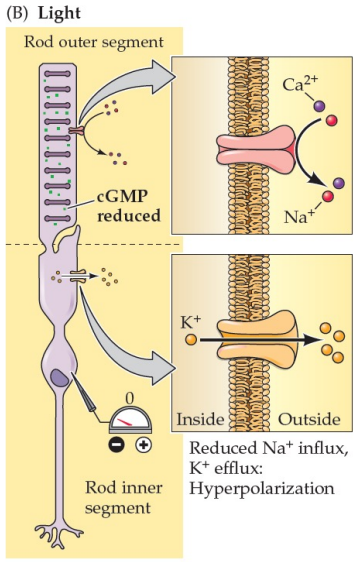
BIO-311

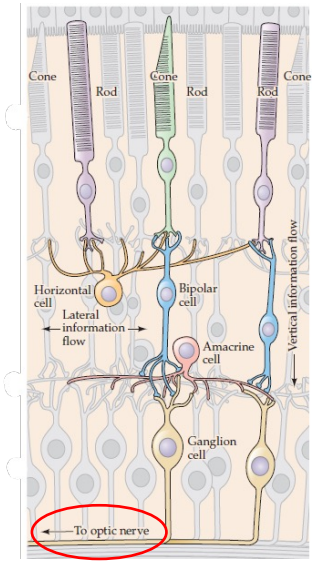
# Important concepts from last week

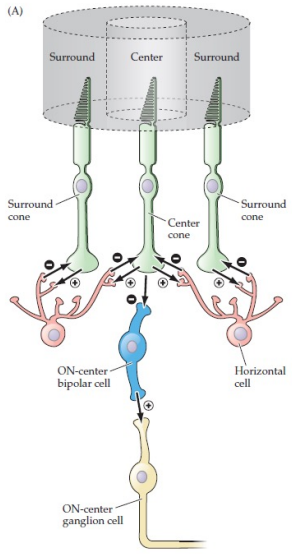
**The retina transduces and pre-process light signals**:

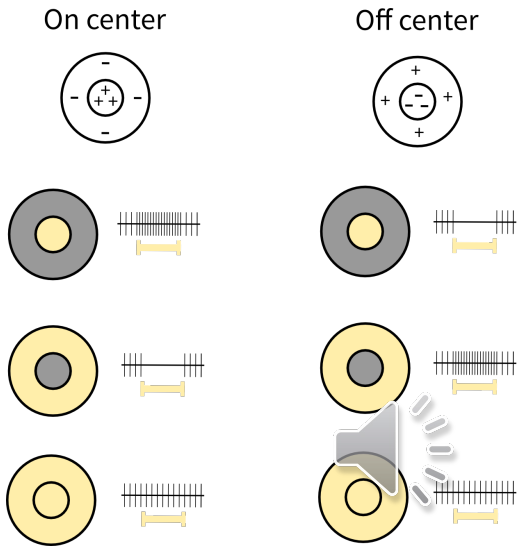
- The photoreceptors (cones & rods) transduce light into electrical signals
- Several other neuron types (bipolar, amacrine, horizontal cells) pre-process this signal across the different retina layers
- Retinal ganglion are the output neurons of the retina and have center-surround receptive fields (ON- and OFF-center cells)



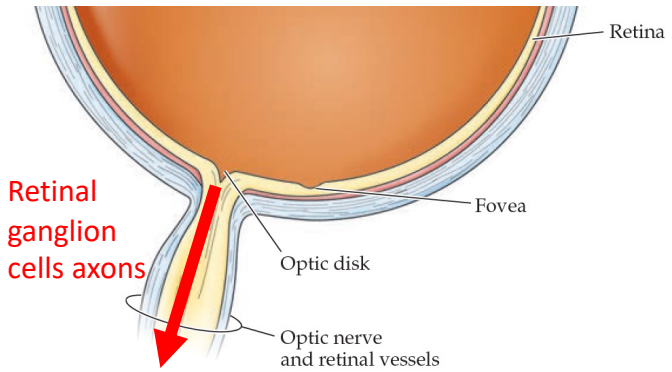



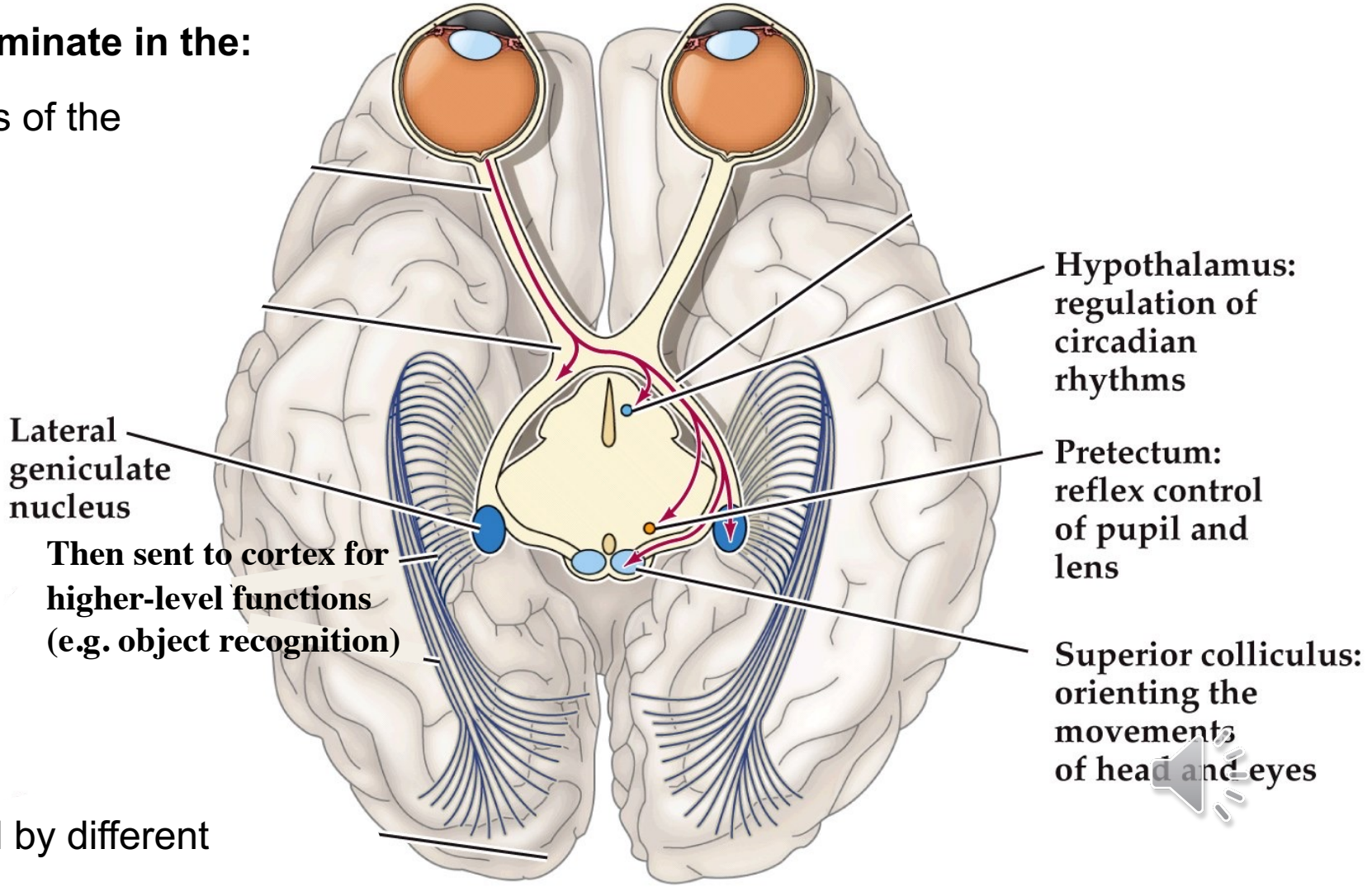

**Purves Fig. 11.8; 11.5; 11.21; 11.18**

# Targets of the Retinal Ganglion Cells

**Retinal ganglion cell axons terminate in the:**

- Lateral geniculate nucleus of the thalamus (LGN)
- Superior colliculus
- Pretectum
- Hypothalamus



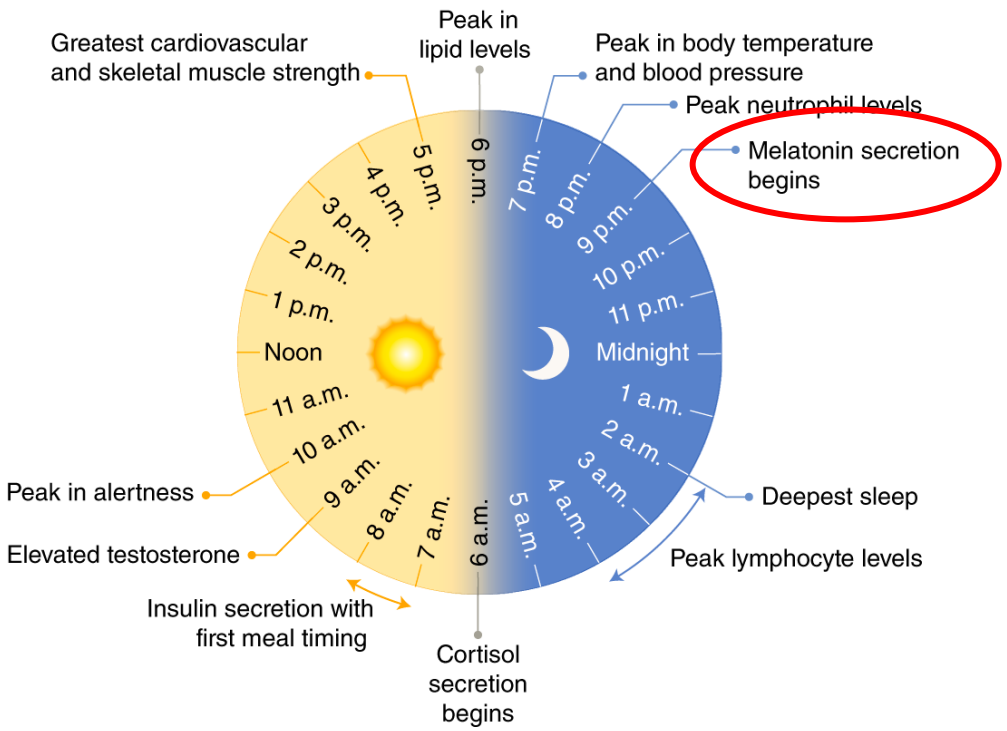



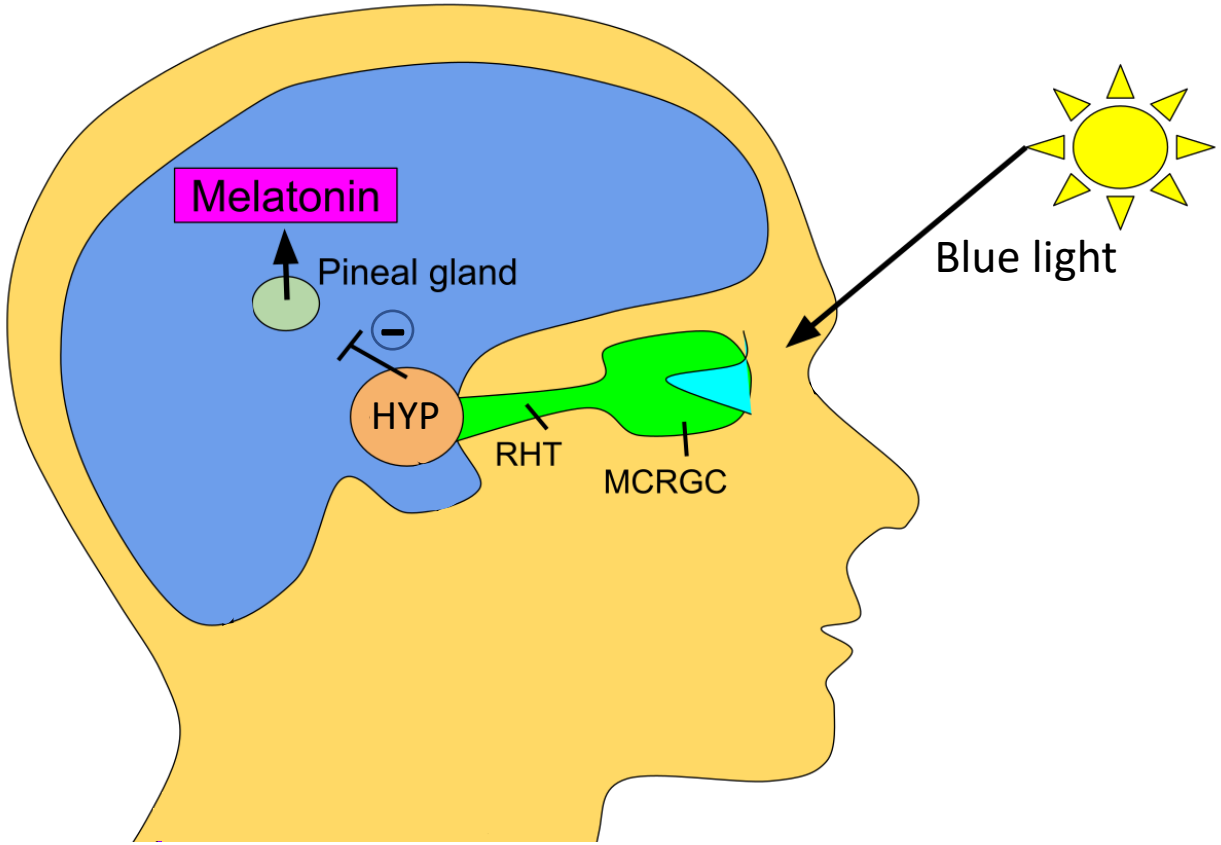

The different targets are innervated by different types of retinal ganglion cells

**Purves Fig. 11.1; 12.1**

# Regulation of the circadian rhythm by the hypothalamus

Melatonin is a hormone produced at night that regulates sleep/wake cycle



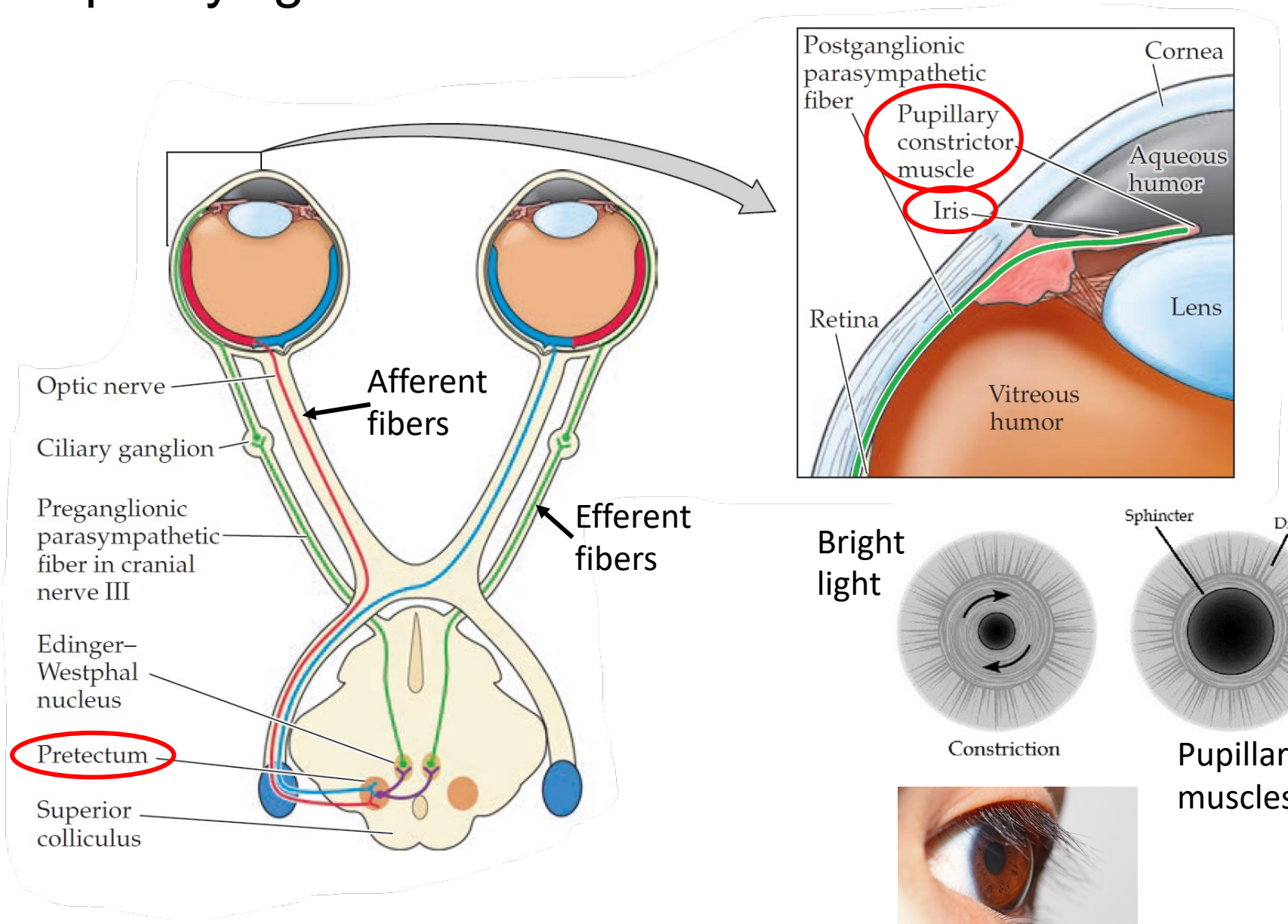

The hypothalamus is innervated by special retinal ganglion cells that produce their own photoreceptor: melanopsin

MCRGC: Melanopsin-containing retinal ganglion cells
RHT: Retinohypothalamic tract
HYP: Hypothalamus

**Masri & Sassone-Corsi 2018 Nature Medicine**

**Wikipedia: Circadian rhythm**

# Pupillary light reflex







The pretectum also recieves input from melanopsin-containing retinal ganglion cells

Bright light

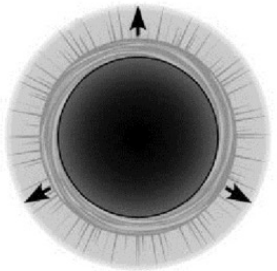


Constriction






Pupillary muscles



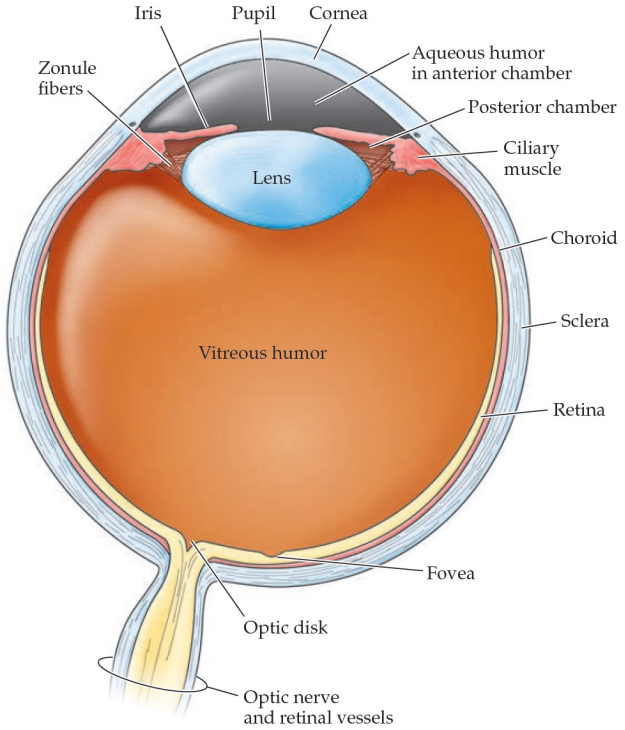
Dilation

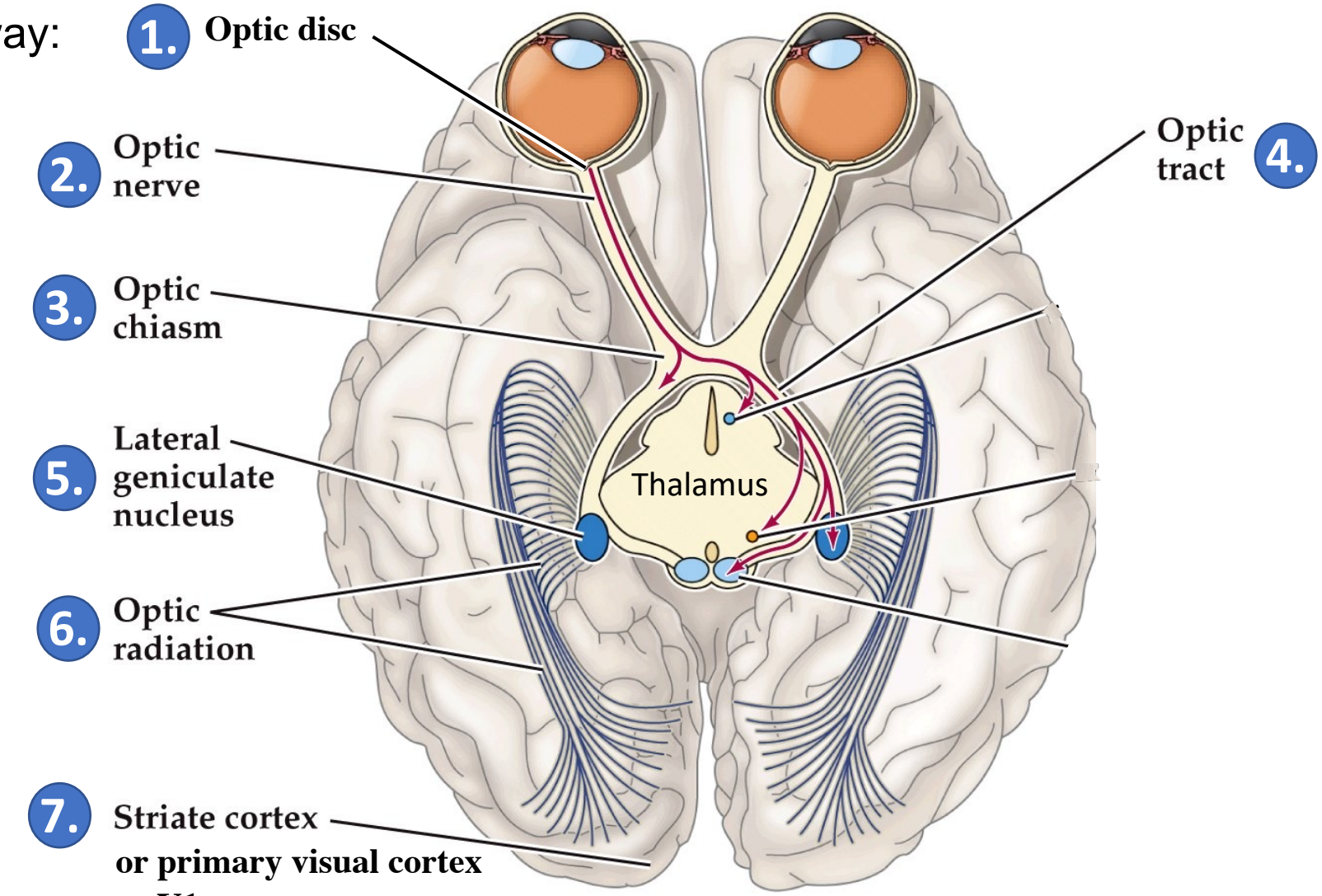
Dim light

**Purves Fig. 12.2**

# From the retina to the primary visual cortex

Retinogeniculostriate pathway:

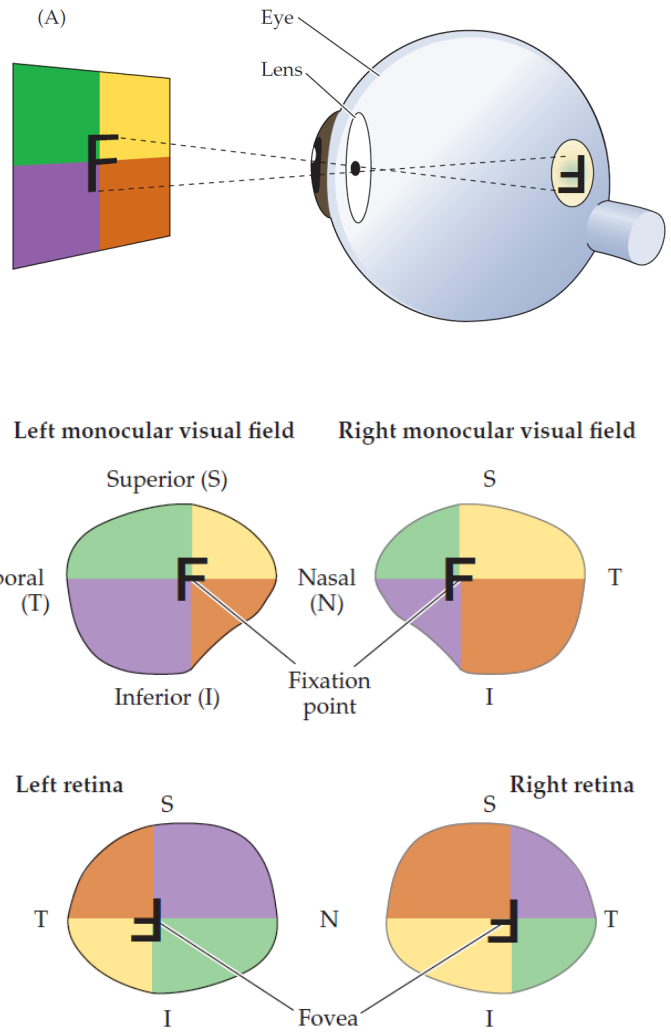


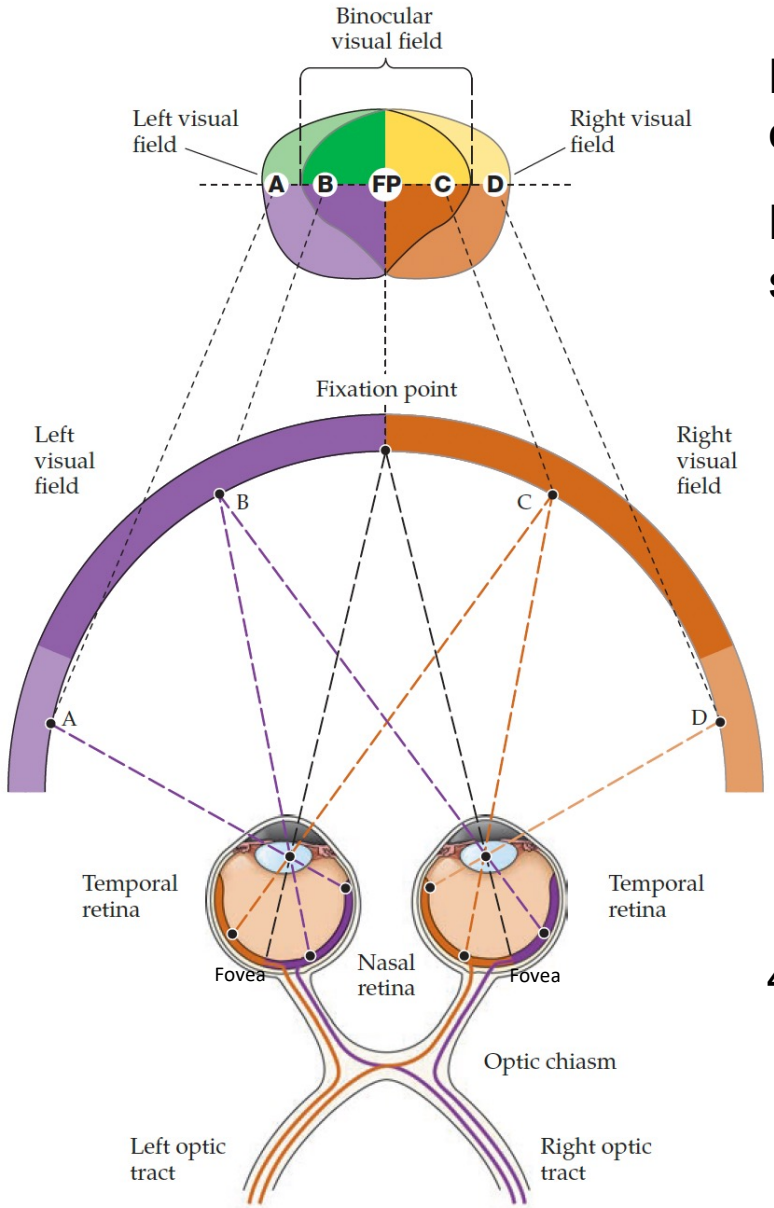




Consciousness is thought to arise between the thalamus and the cortex

Purves Fig. 11.1 & 12.1

# Binocular vision and the Optic Chiasm



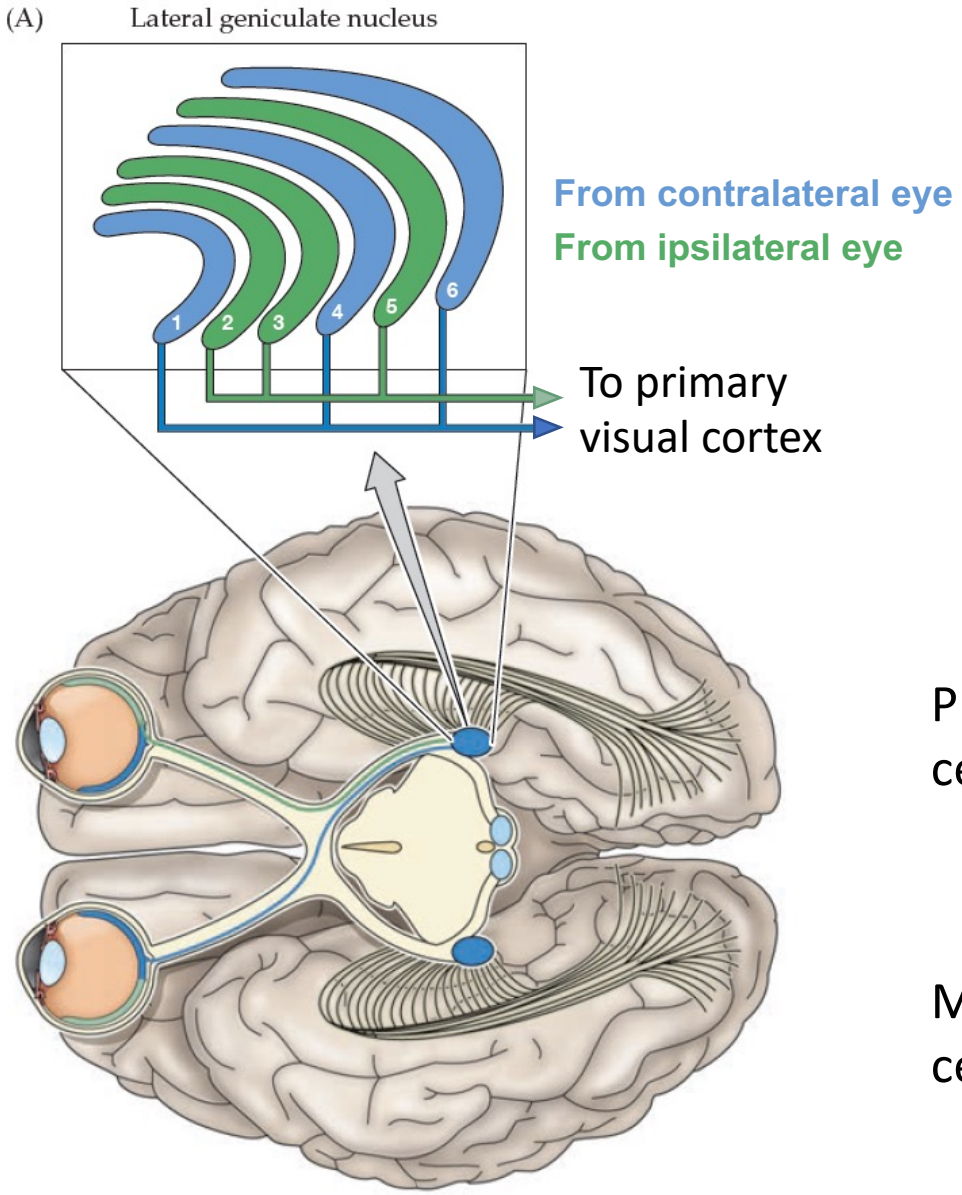

**Binocular visual field (B,C)** consists of two symmetrical visual hemifields

**Peripheral visual field (A, D)** is strictly monocular

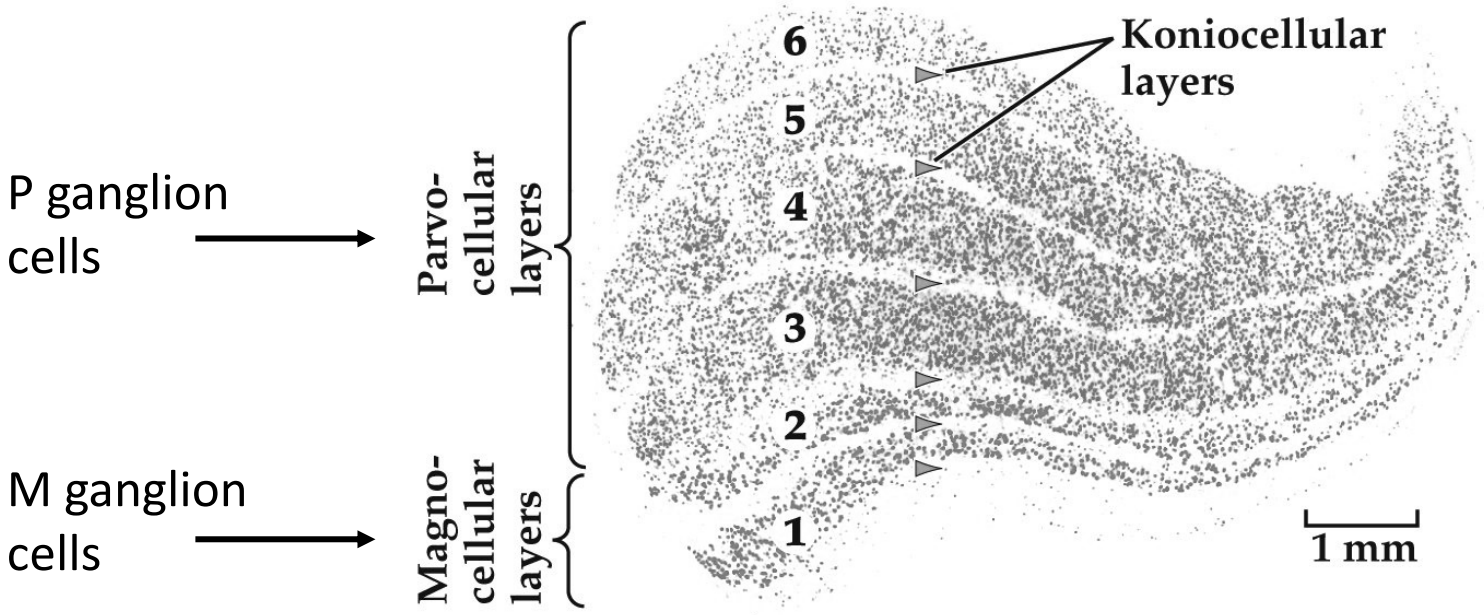
40% of axons project to the same side
60% cross the optic chiasm

**Purves Fig. 12.3 & 12.4**

# The Lateral Geniculate Nucleus (LGN)

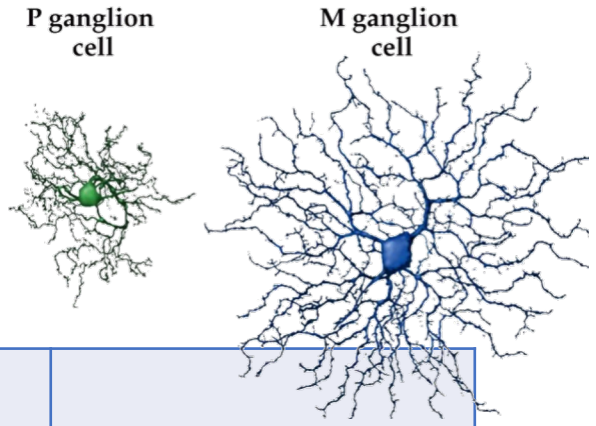



LGN neurons have similar receptive fields as retinal ganglion cells


Purves Fig. 12.11; 12.13

# Magno- and parvocellular pathways



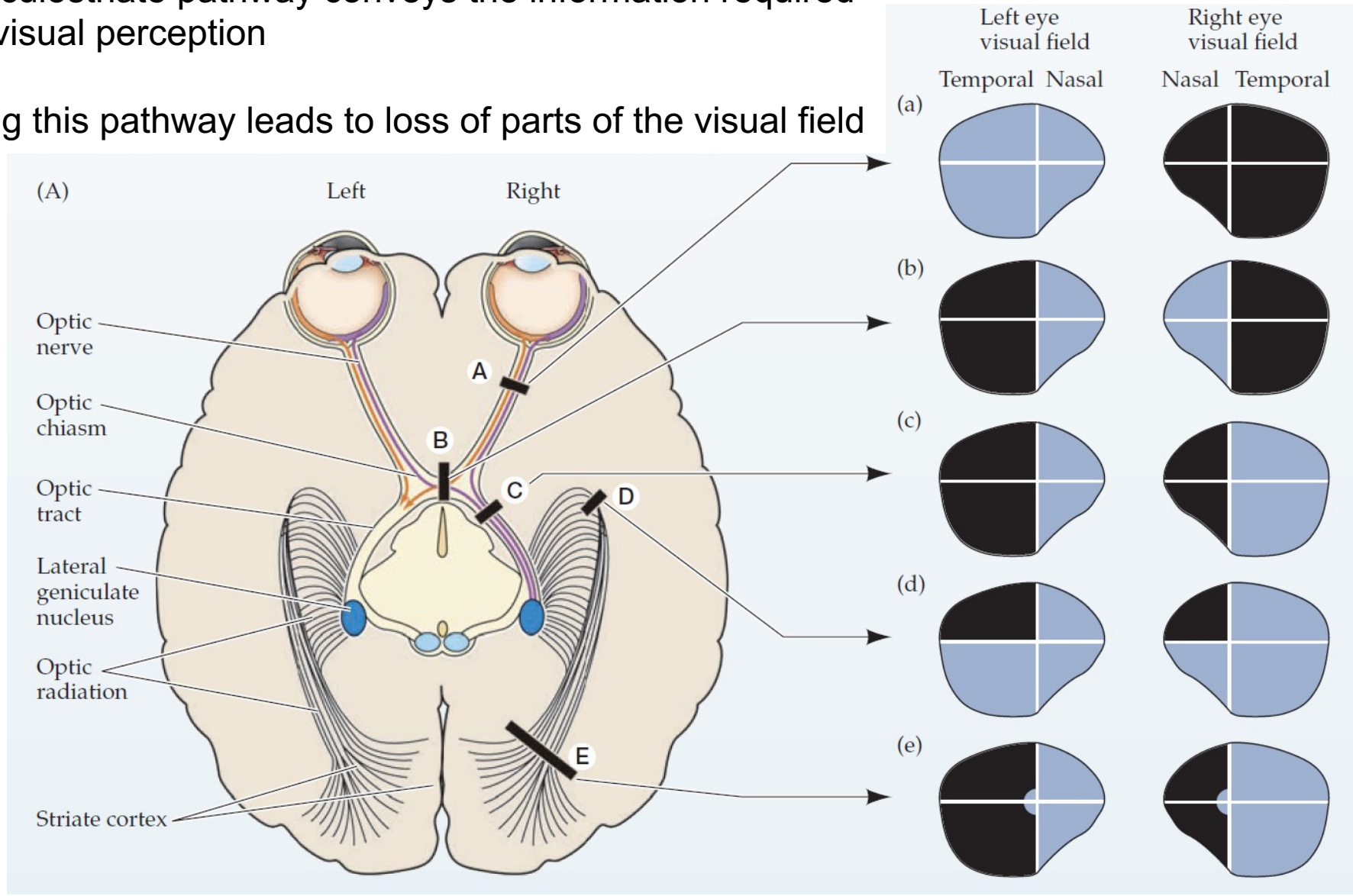

| Pathway | LGN layers | Size of cells and RF | Type of Information | Response |
|---|---|---|---|---|
| **Magnocellular pathway**<br>• M ganglion cells (RGC)<br>• Magnocellular cells (LGN) | Layers 1 and 2 | Large | Perception of **movement** and **location**<br>Colorblind | Rapid and transient |
| **Parvocellular pathway**<br>• P ganglion cells (RGC)<br>• Parvocellular cells (LGN) | Layers 3, 4, 5 and 6 | Small | Perception of **color** and **shape** in fine details | Slow and sustained |

**Purves Fig. 12.13**

# Visual field deficits

The retinogeniculostriate pathway conveys the information required for conscious visual perception

Damages along this pathway leads to loss of parts of the visual field

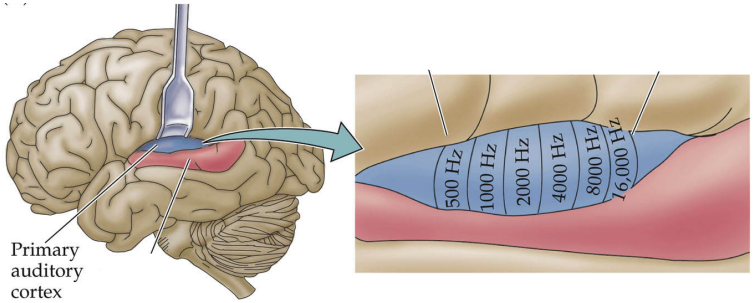


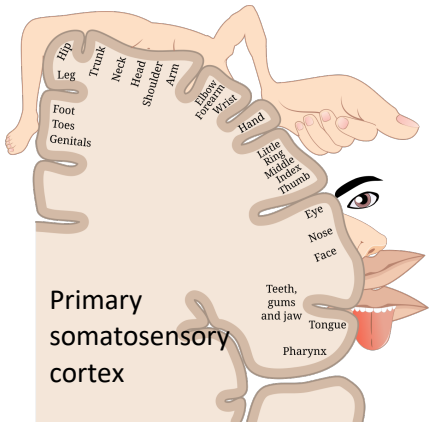

Purves p. 263

# Topographic maps of sensory modalities

For most sensory modalities, there is a direct mapping between the organization of the physical world and the organization of the brain area(s) that process it:

- **Tonotopy**: Neurons in the auditory cortex are organized based on the frequency of sound they process



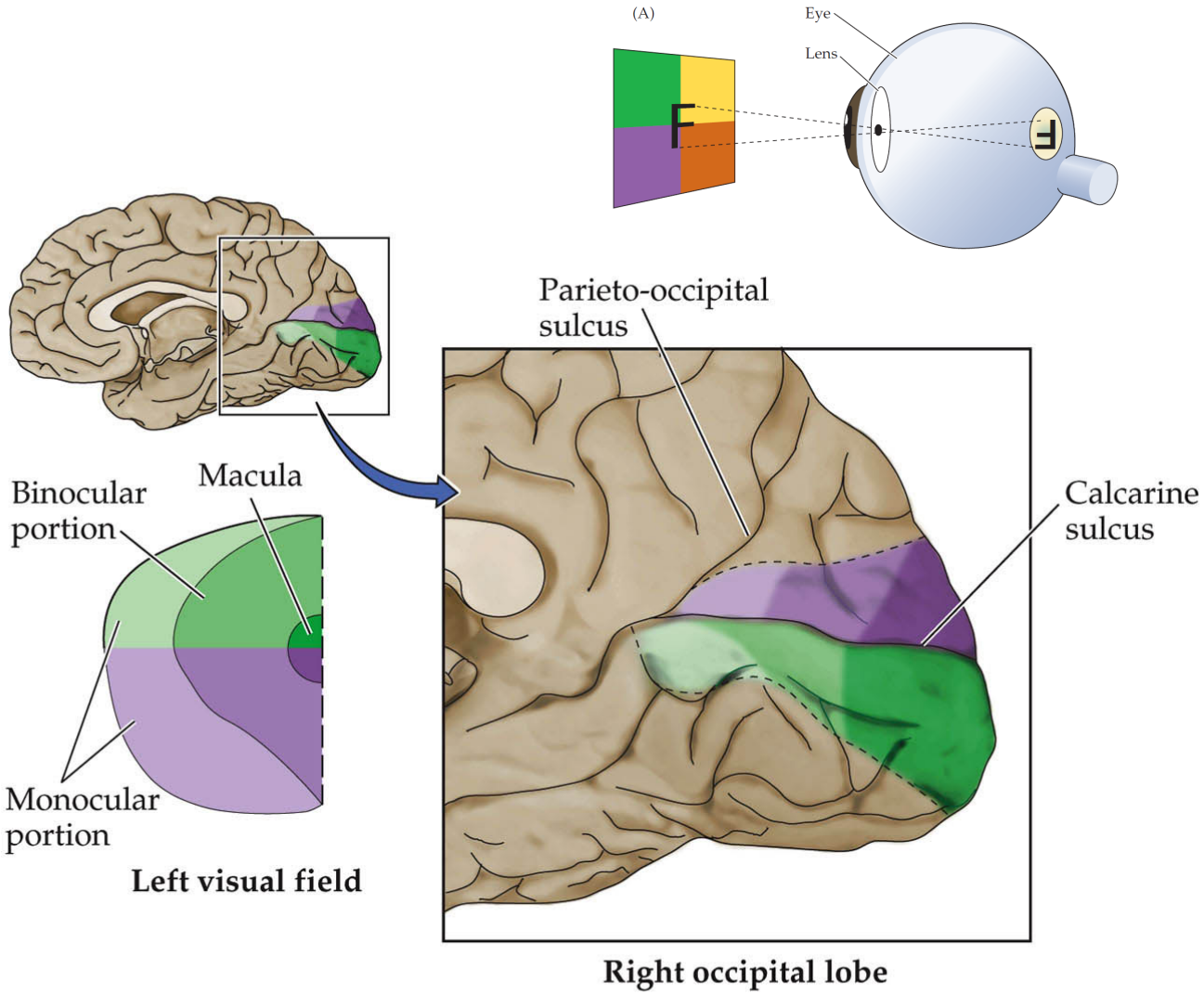

- **Somatotopy**: Neurons in the somatosensory cortex are organized based on the physical organization of body parts

- **Retinotopy**: Neurons in the visual cortex are organized based on the spatial arrangement of the visual field

Primary
visual
cortex

**Purves (older version) Fig. 13.16; wikipedia: somatotopic arrangement; Wandell et al. 2007 Neuron**

# The Primary Visual Cortex (V1) and Retinotopic map




**Cortical magnification**: the dedicated brain surface area is proportional to the density of receptors

- Fovea for the visual system
- Hands and lips in the somatosensory system

Left visual field is processed in the right hemisphere

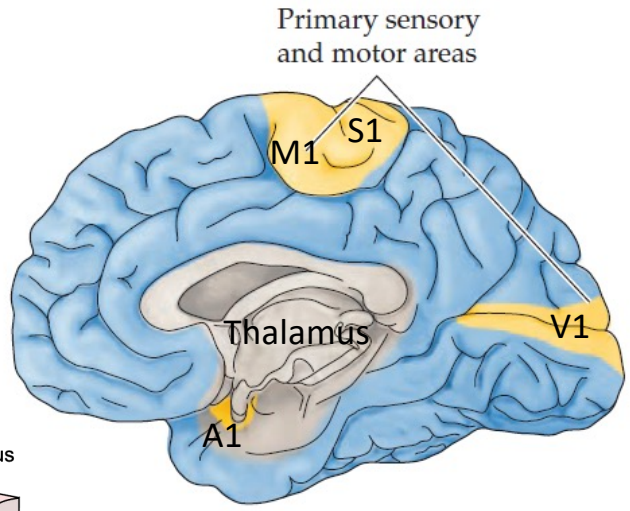
The primary visual cortex is also sometimes called the striate cortex or V1

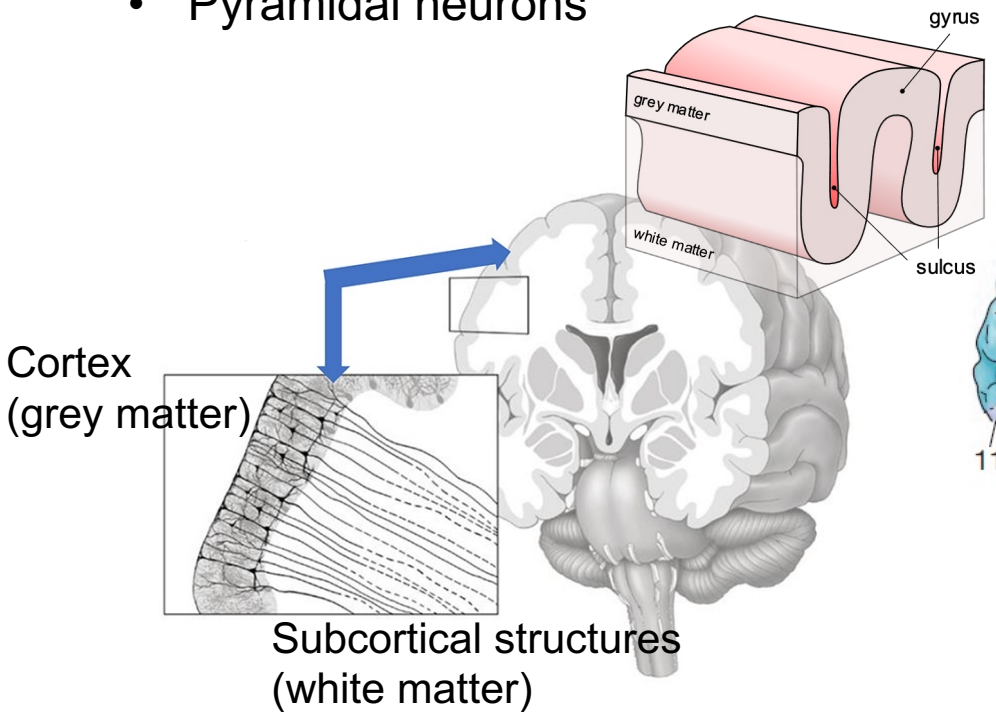
**Purves Fig. 12.3; 12.5; Wandell et al. 2007 Neuron**

# General organization of the cerebral cortex

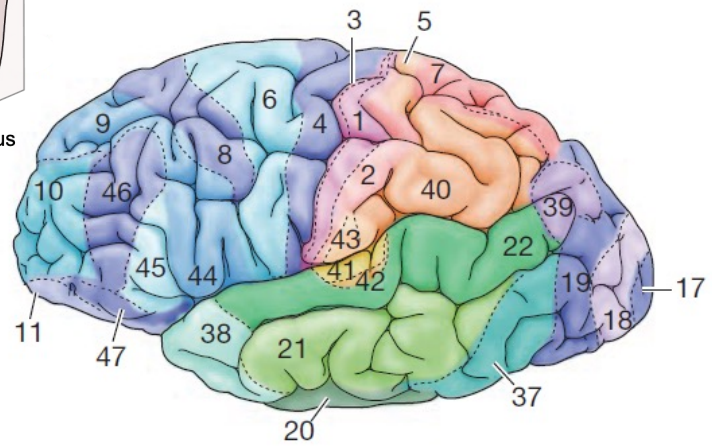
**Important terms**:

- Cortex
- White matter and grey matter
- Gyrus and sulcus
- Broadman areas
- Cortical layers
- Primary sensory cortices
- Pyramidal neurons



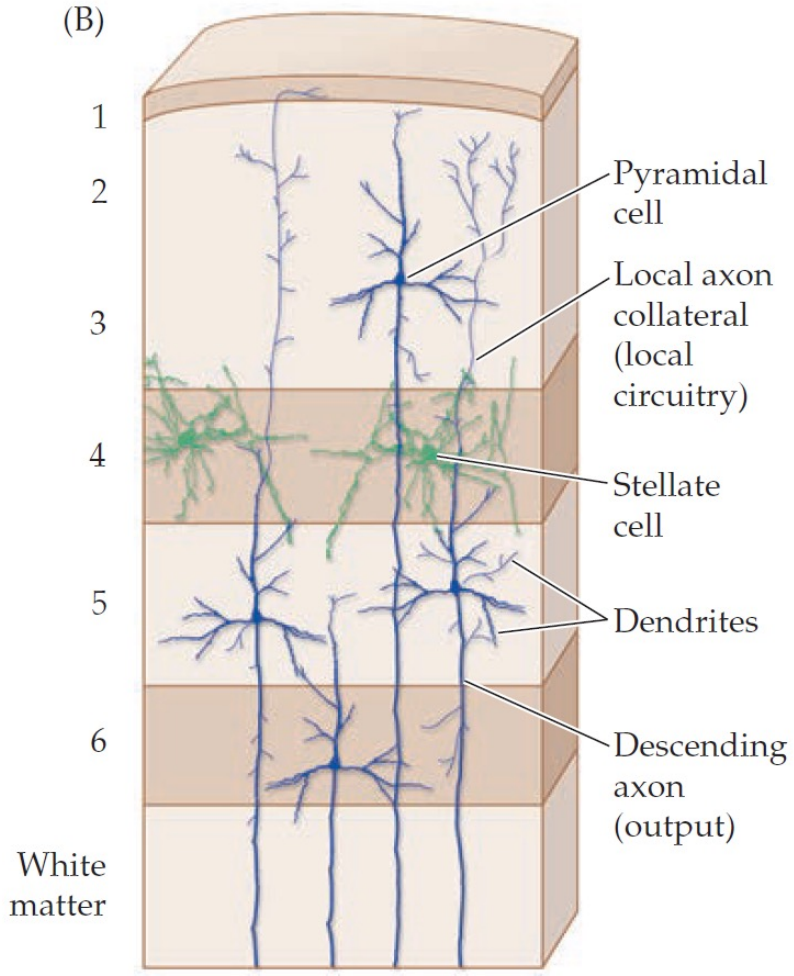




Broadman areas



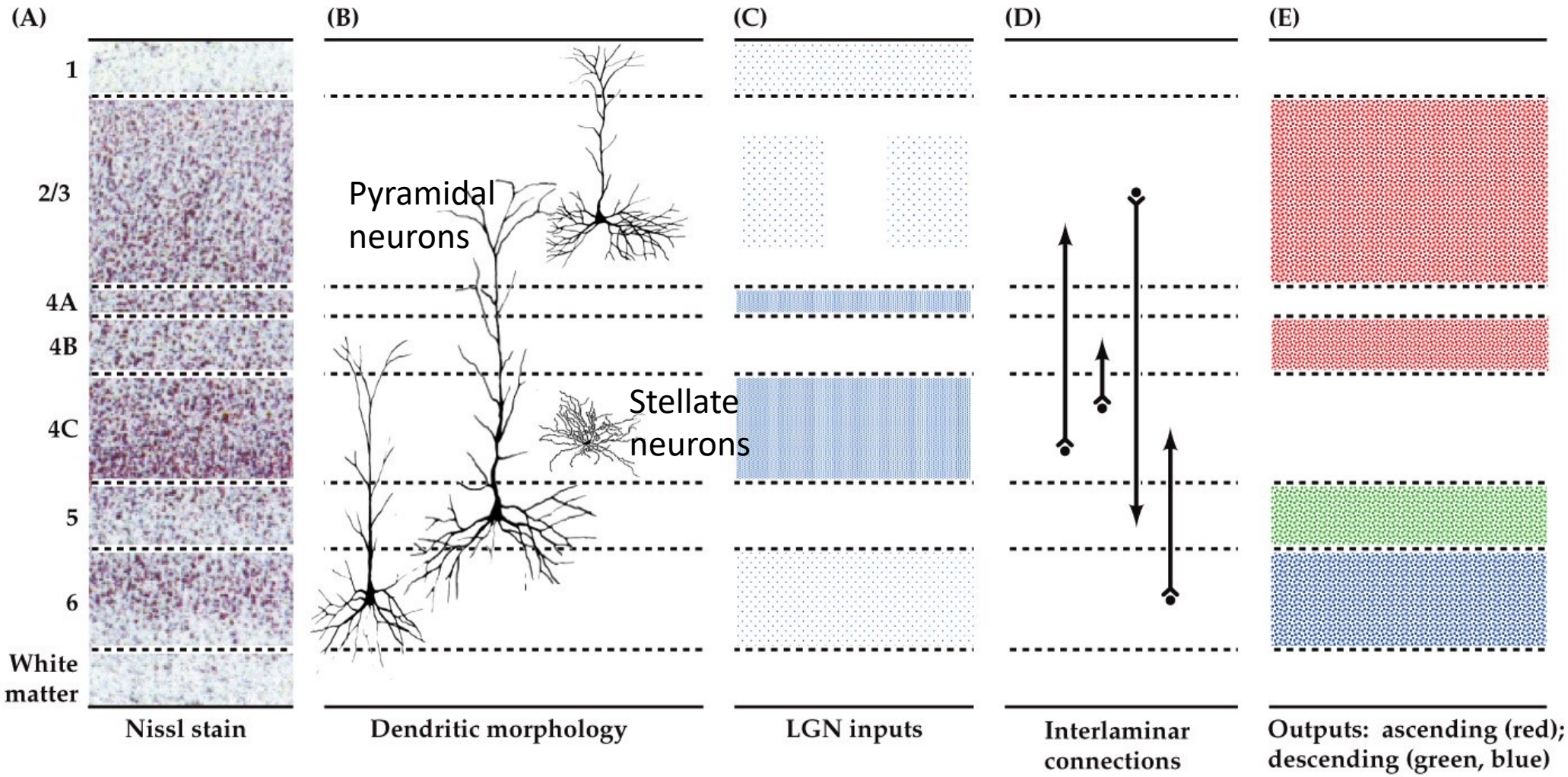

V1 = Broadman area 17

Cortical layers




**Purves Fig. 27.1**

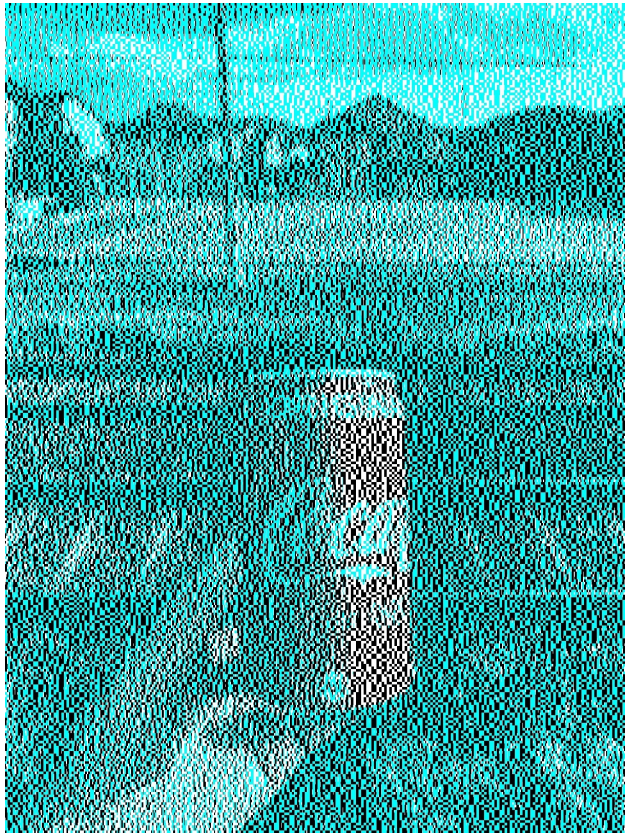
# Organization of the primary visual cortex cortical layers




- Distinct layers have distinct composition and connectivity patterns
- Input from LGN arrive primarily in layer 4C and is then sent to the other cortical layers via stellate neurons axons
- Superficial layers preferably send projections to other cortical areas while deeper layers send their axons to subcortical areas

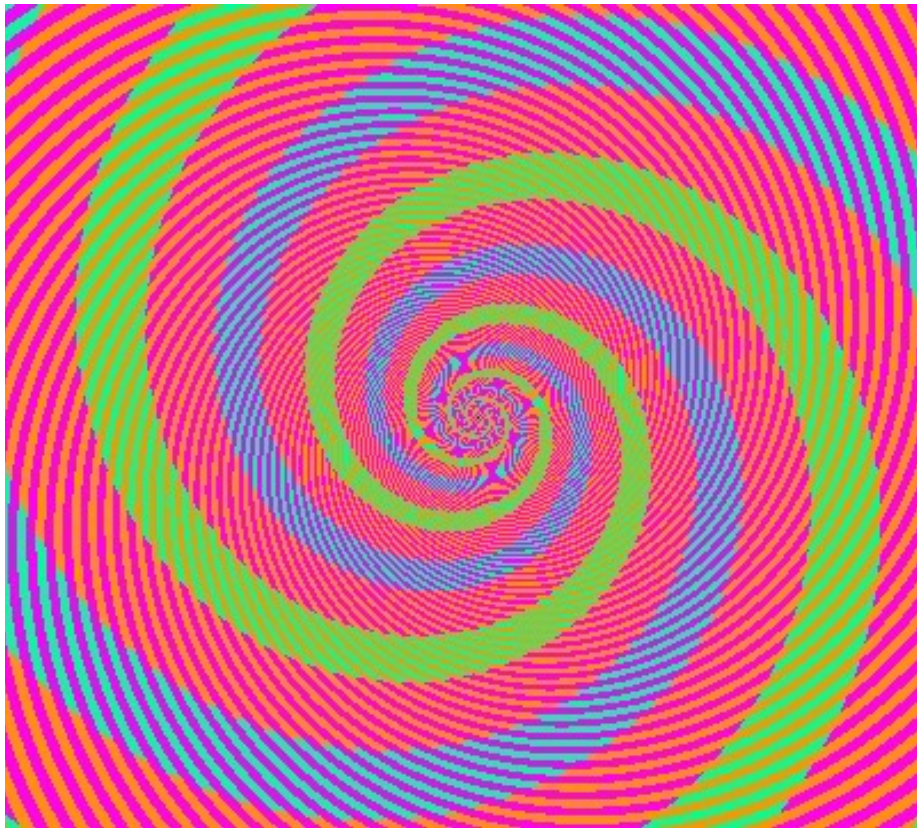
**Purves Fig. 12.8**

# Break: please enjoy some cool visual illusions !

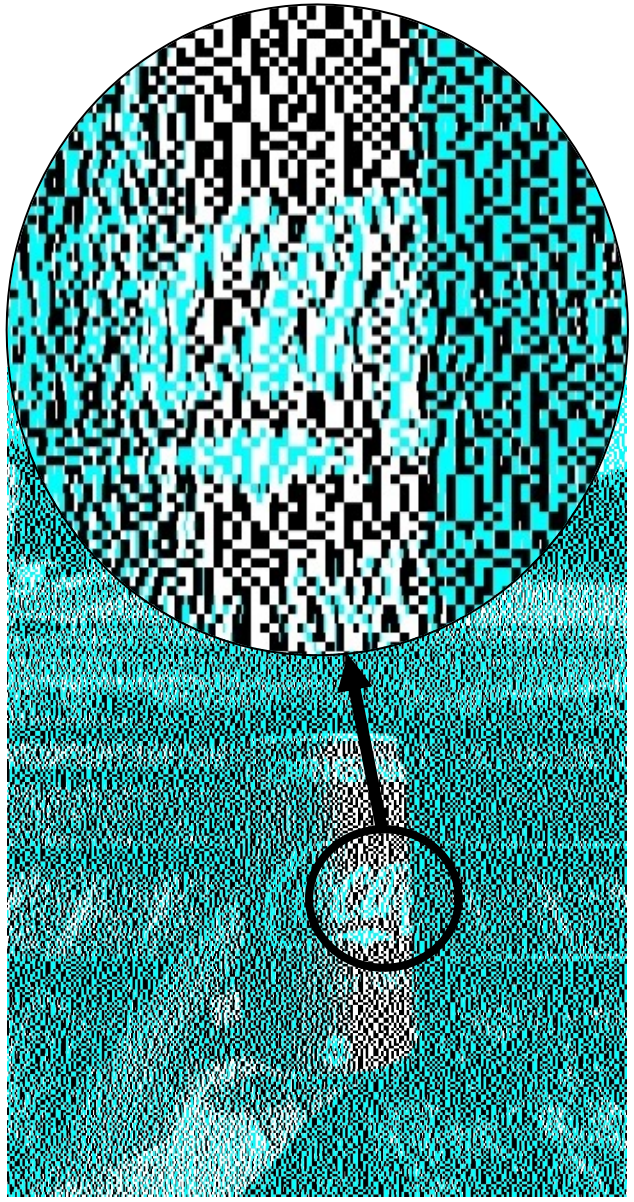


**Is there any red in this image ?**

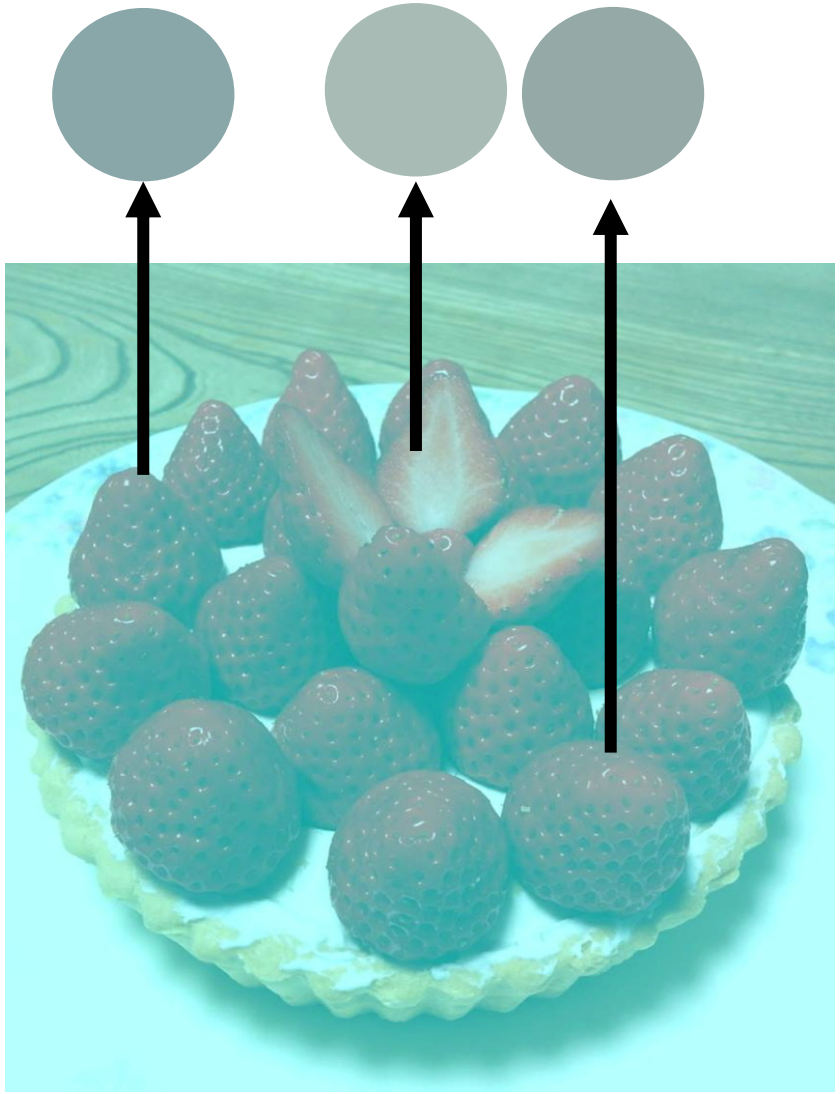
**And in this one ?**



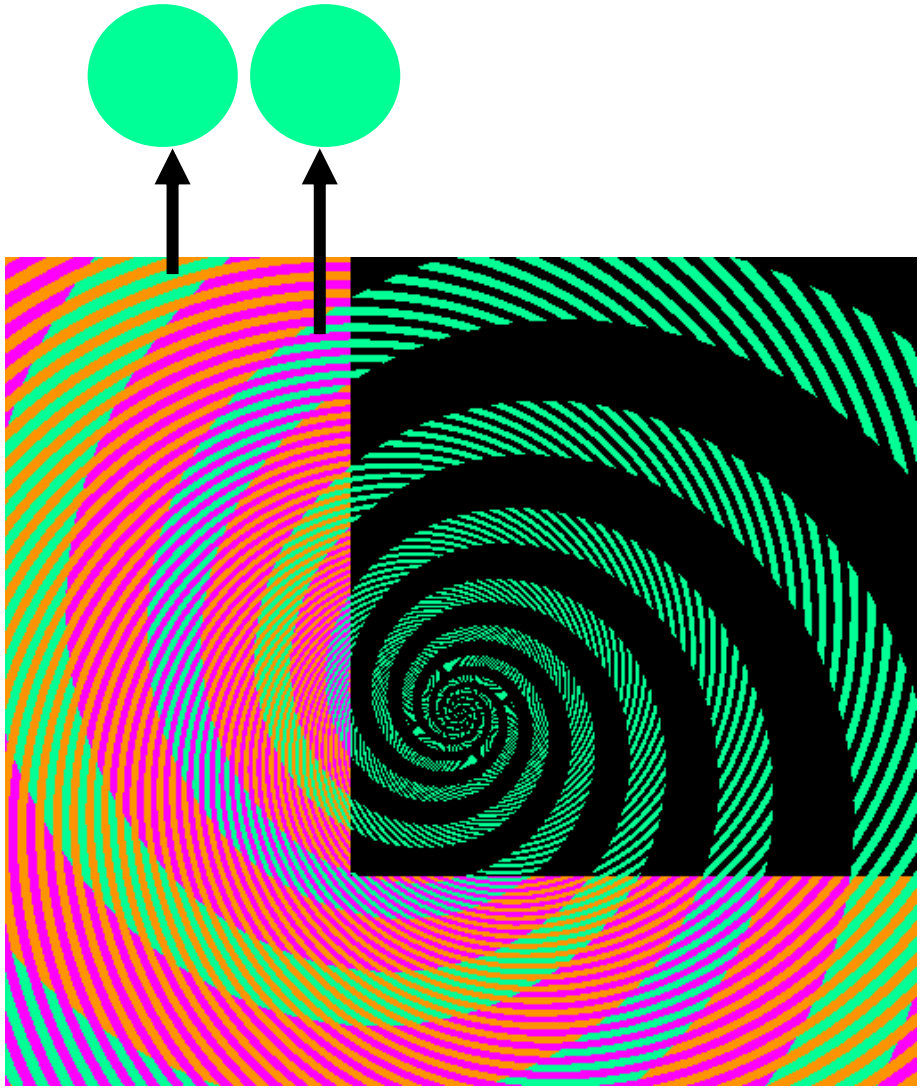
**How many colors do you see ?**



There is no red. Only blue, white & black.

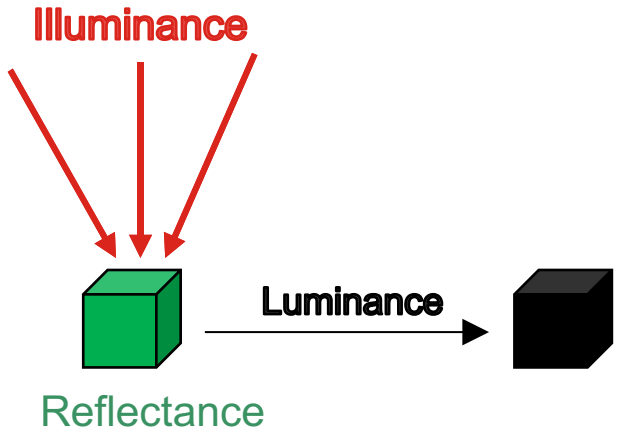


There is no red, only different shades of gray.



There are only 3 colors in the spiral: pink, orange and turquoise.

# Color perception is dependent on context

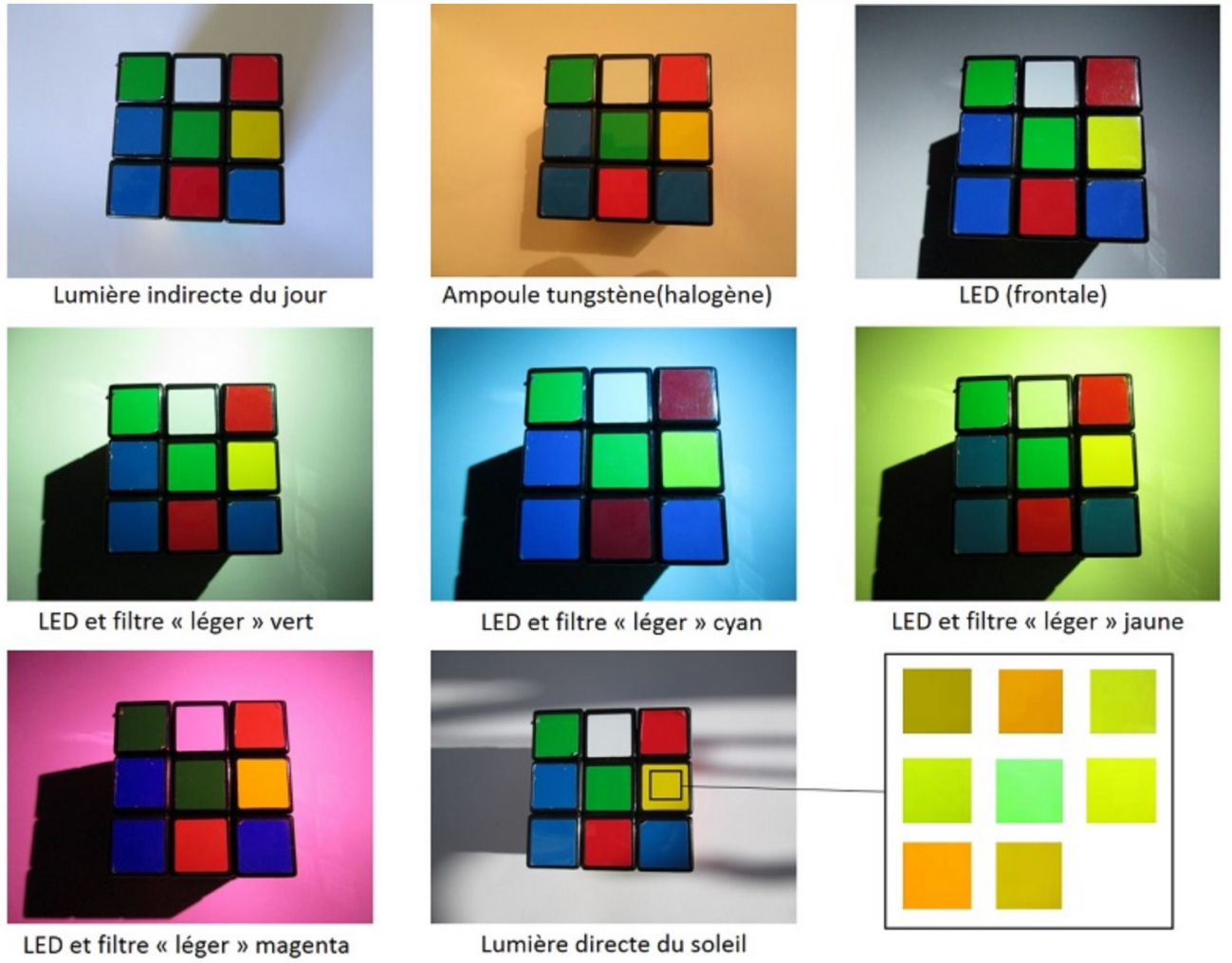



**Luminance** = **Illuminance** x Reflectance

Well-lit blue and black dress ?

Or backlit white and yellow dress ?

## Color constancy

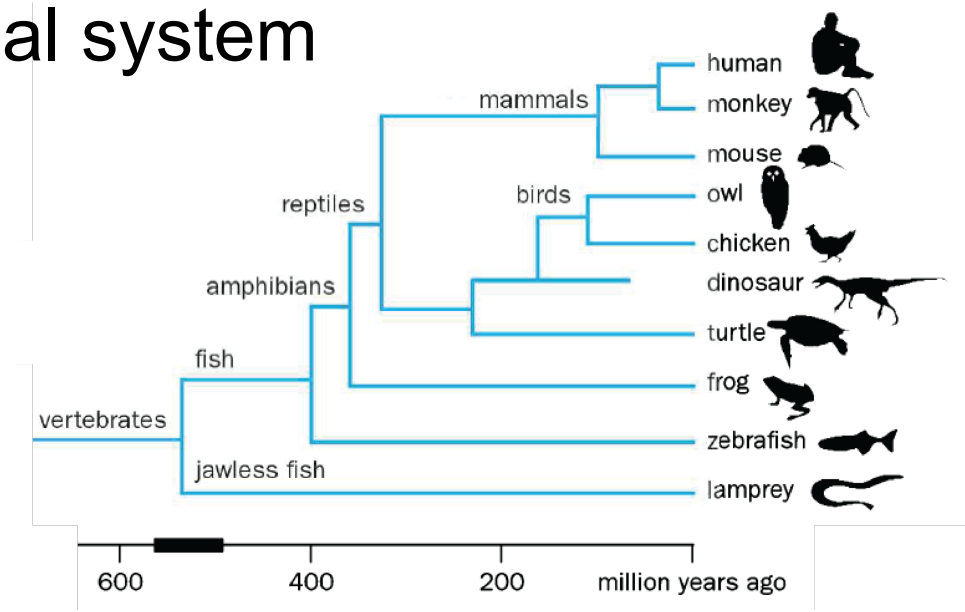


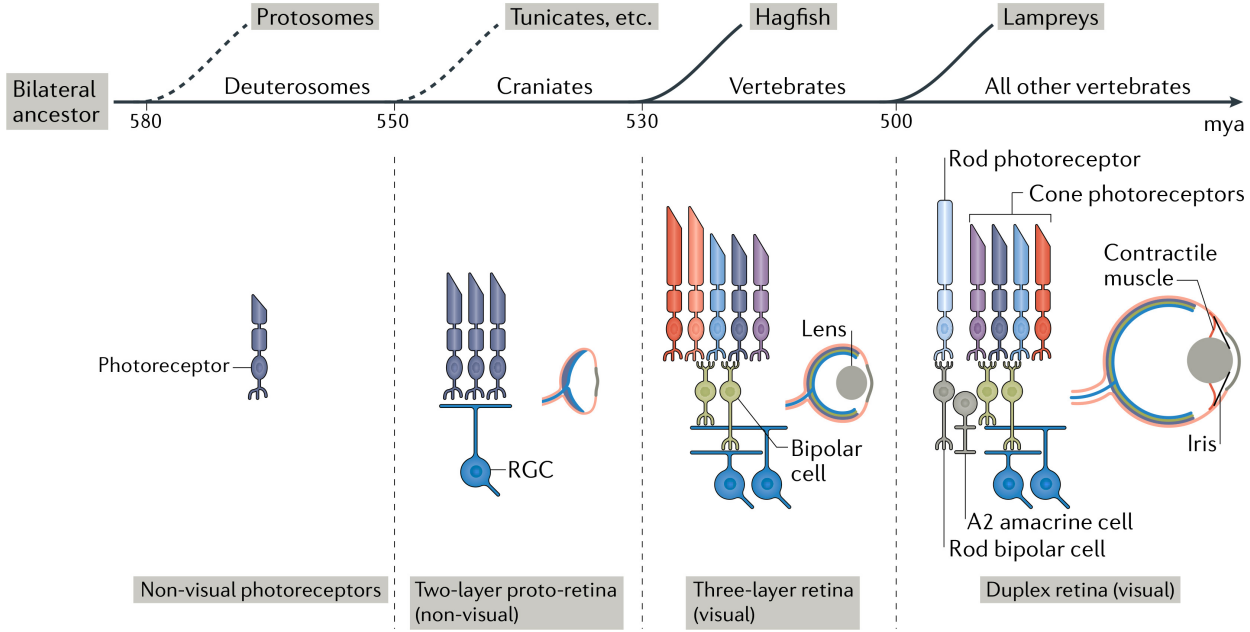
# Using animal models to investigate the visual system

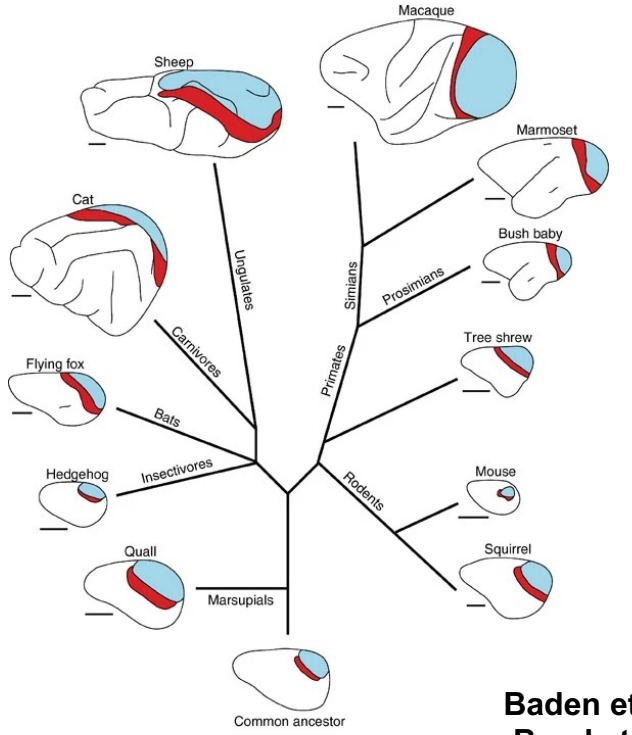
The three-layered retina has evolved in the predecessors of fish and vertebrates around 500 million years ago

The organization and function of cortical visual areas (especially V1 and V2) are similar across mammals

Trichromatism evolved in primates, possibly to facilitate frugivory



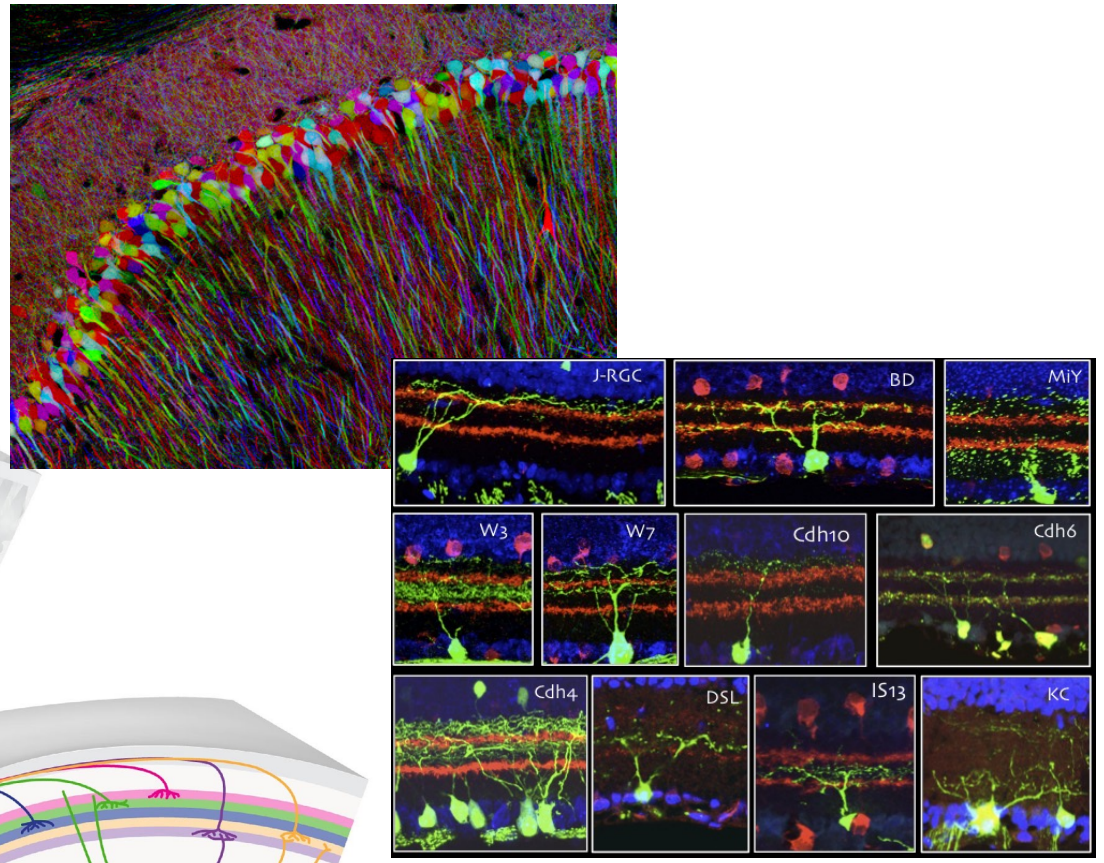




**Luo, Fig. 12-2**
**Baden et al. 2020 Nature Reviews Neuroscience**
**Boyd et al. 2024 Encyclopedia of Neuroscience**

# Using mice to study the types and targets of Retinal Ganglion Cells (RGC)

Different types of RGCs innervate different targets of the visual system and provide different information

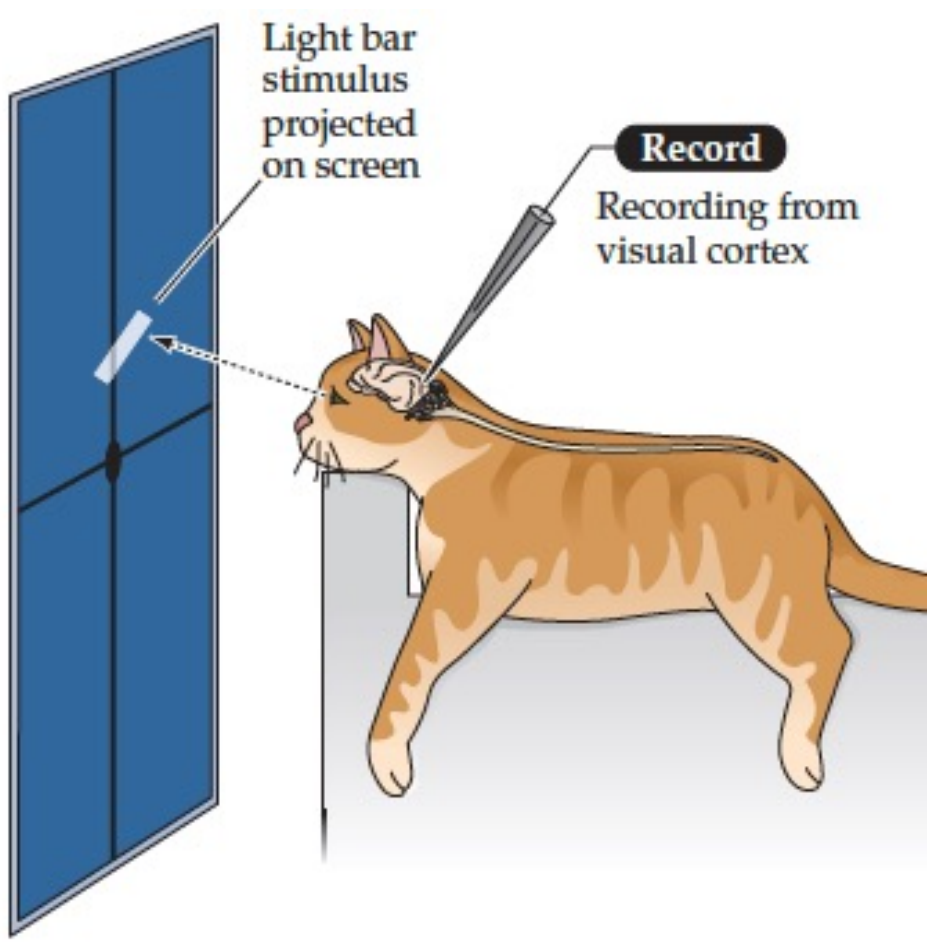
Transgenic mice have been critical to investigate the different types and targets of RGCs

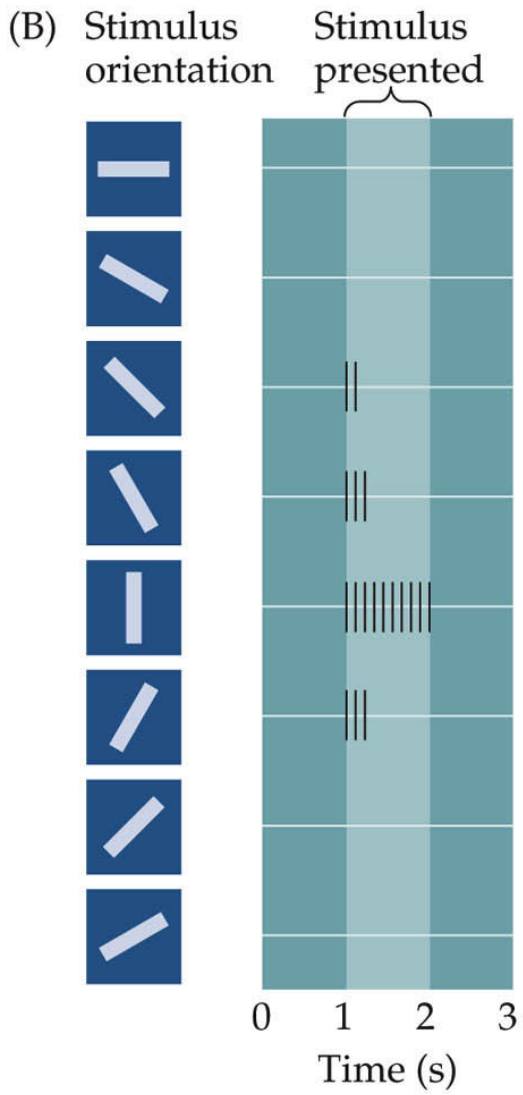


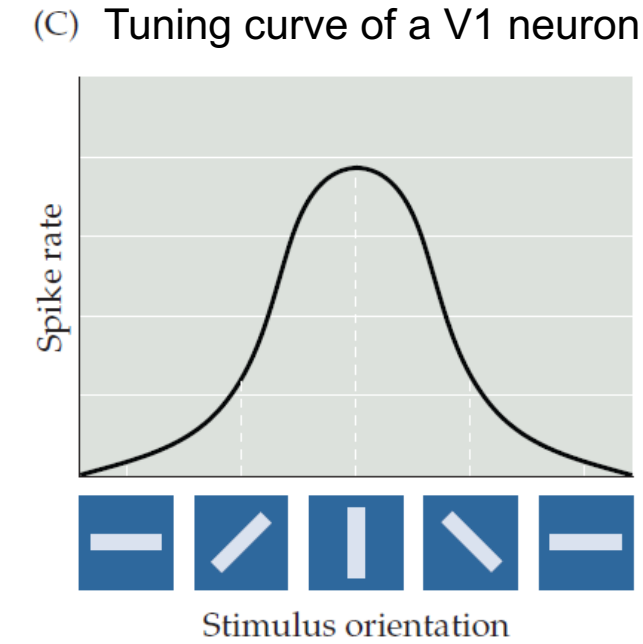

There are at least 30 morphologically and physiologically distinct retinal ganglion cell types

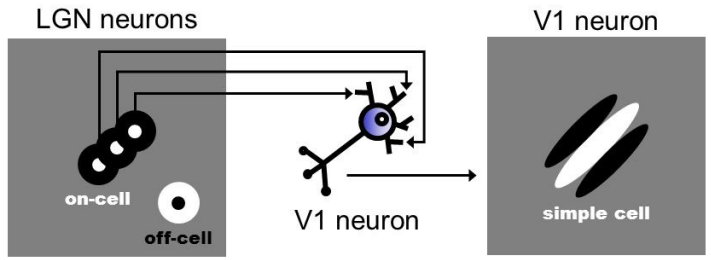
**Prof. Josh Sanes**

# Receptive field of neurons in the primary visual cortex




Example for a V1 neuron with a bar-like receptive field (“simple cell”)

**Purves Fig. 12.7**

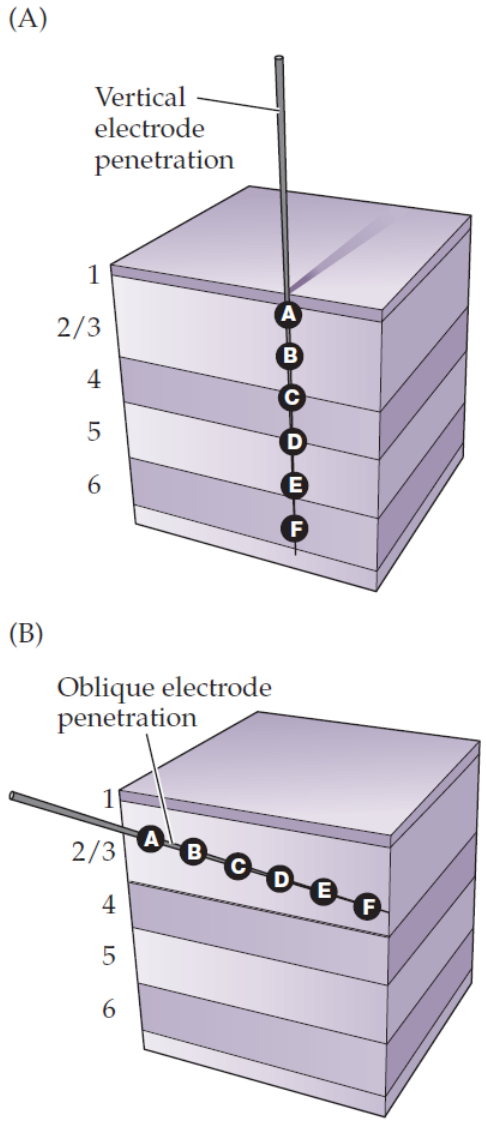

Hubel & Wiesel 1964

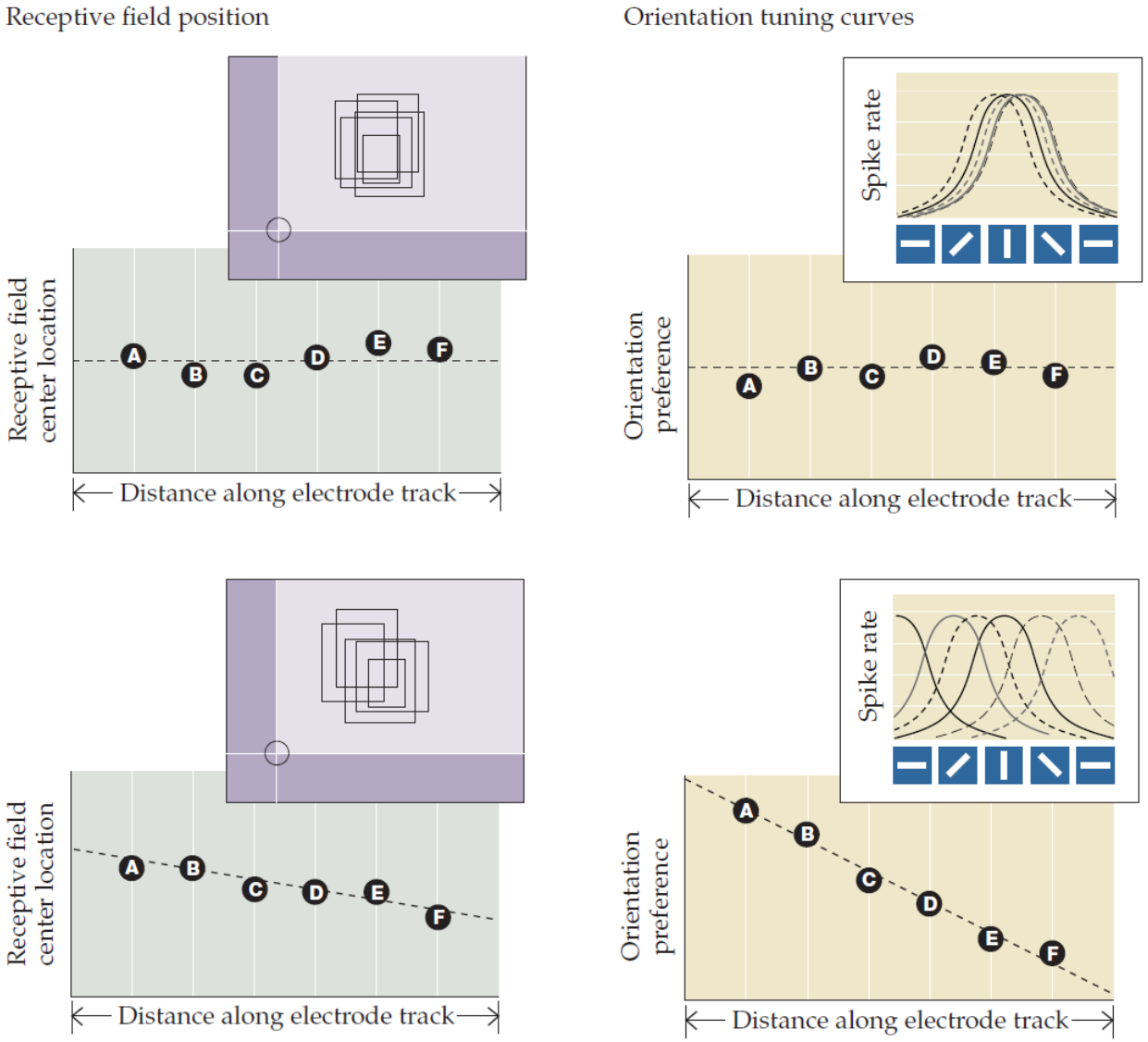
# Columnar organization in the primary visual cortex

**The sensory cortices are organized in 6 layers:**

- The 6 layers typically have highly similar receptive fields
  → **Organized in columns**

- Adjacent columns typically have adjacent receptive fields
  → **Organized in maps**



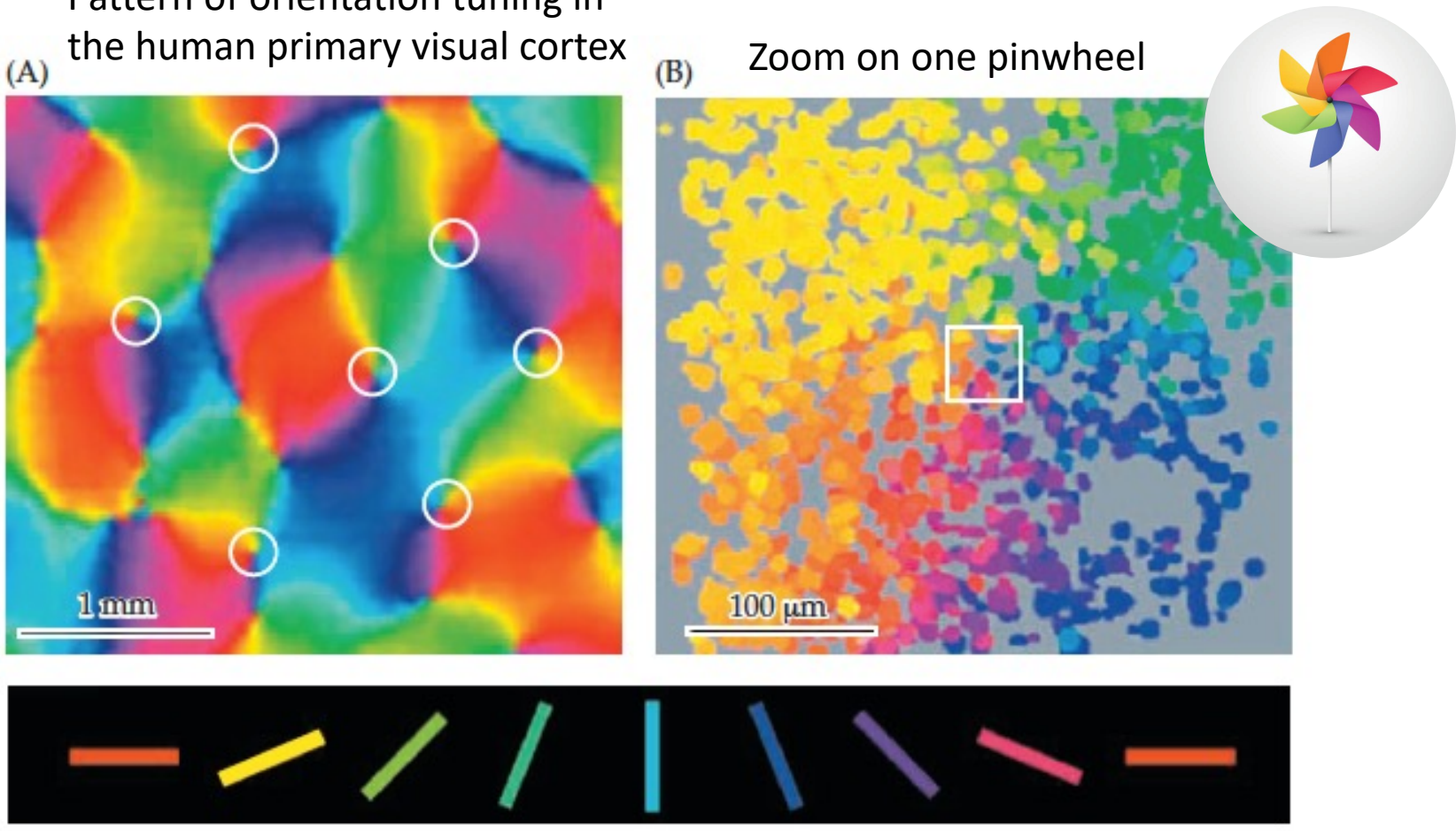




**Purves Fig. 12.9**

# Organization principles in the primary visual cortex

Pattern of orientation tuning in the human primary visual cortex

Zoom on one pinwheel



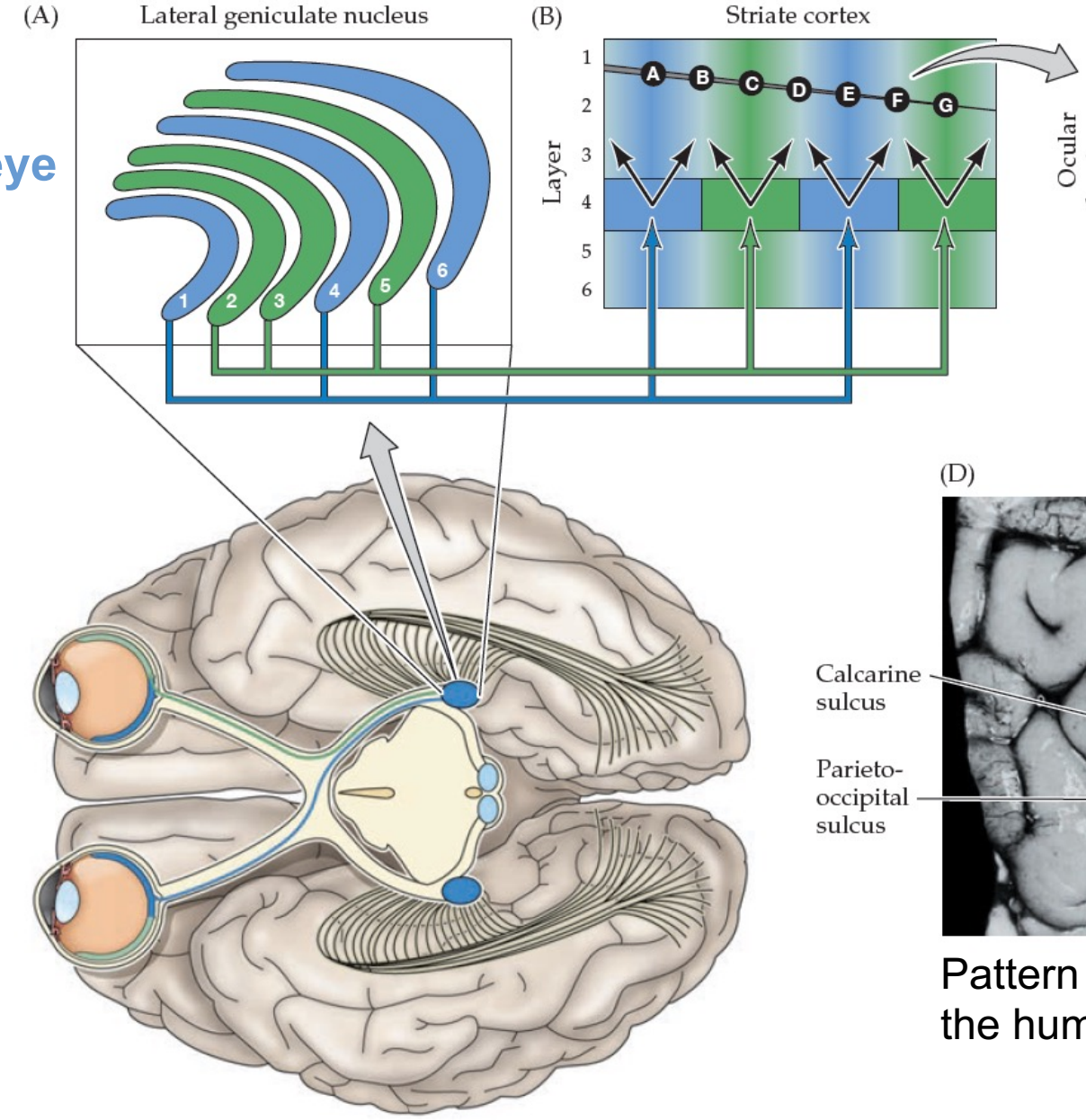

Orientation tuning is color-coded

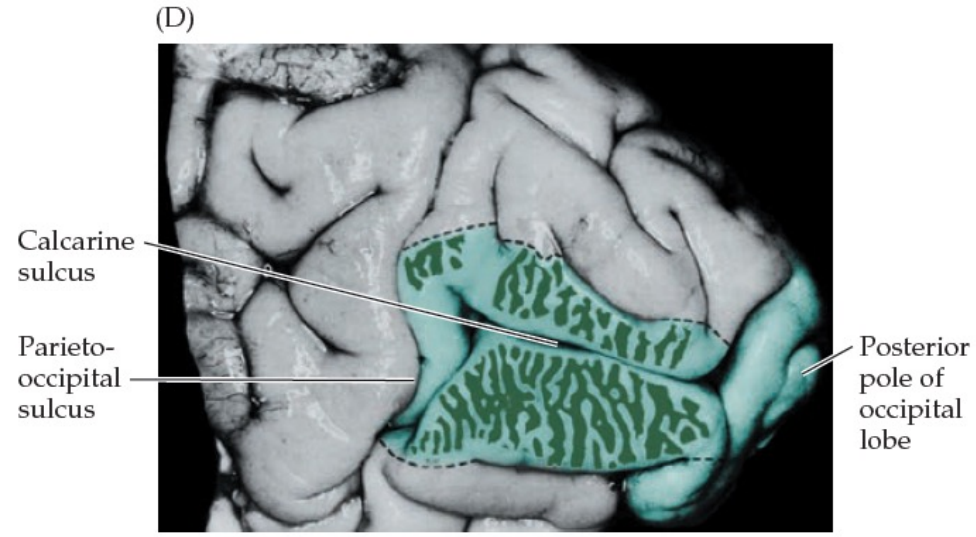
**Purves Fig. 12.10**

# Ocular dominance columns

From contra- eye

From ipsi- eye

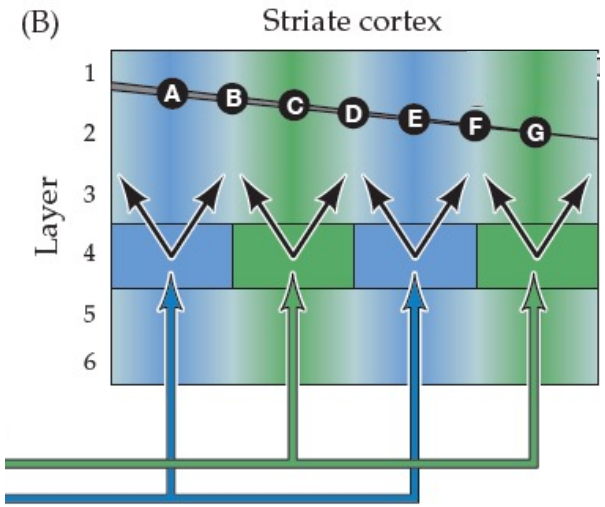



Pattern of ocular dominance in the human primary visual cortex

**Purves Fig. 12.11**

# Depth perception

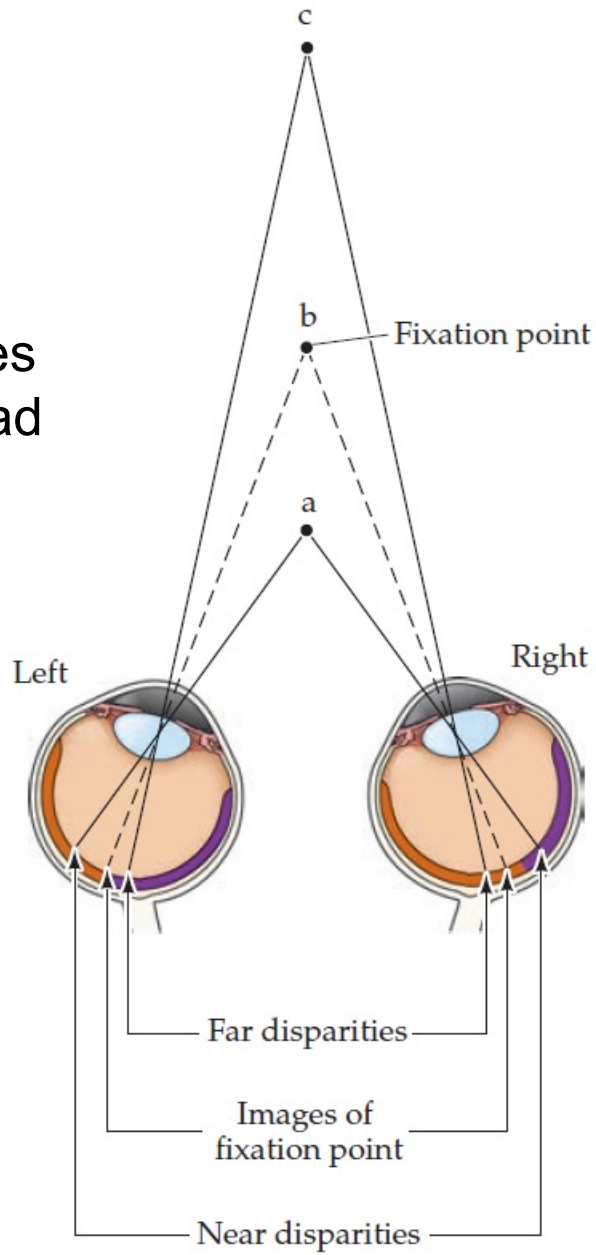



Input from LGN

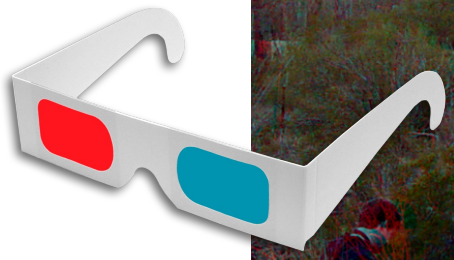
From contralateral eye

From ipsilateral eye

**Stereopsis**: sensation of depth that arises from viewing objects with two eyes instead of one.

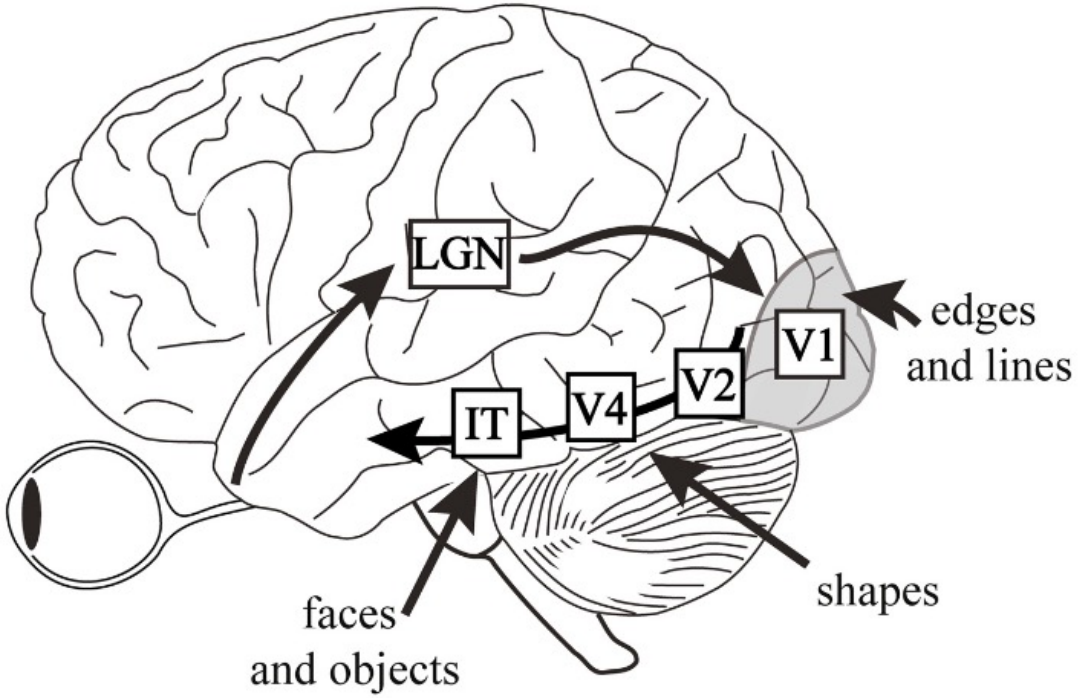


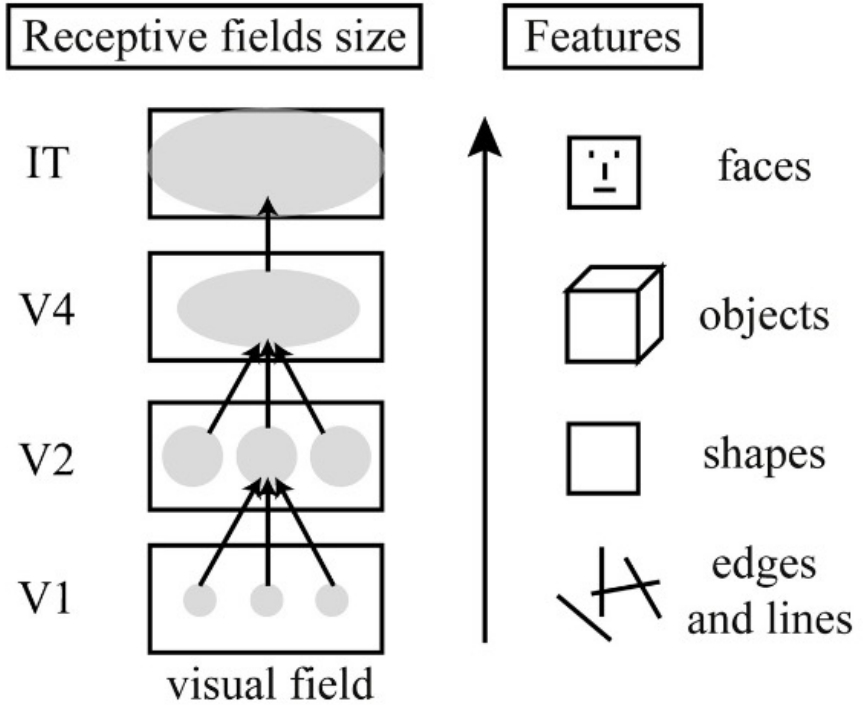

Ocular dominance columns in primary visual cortex



**Purves Fig. 12.11; 12.12**

# The visual pathway does not end in V1 !




Neurons in V1 are selective to basic features:

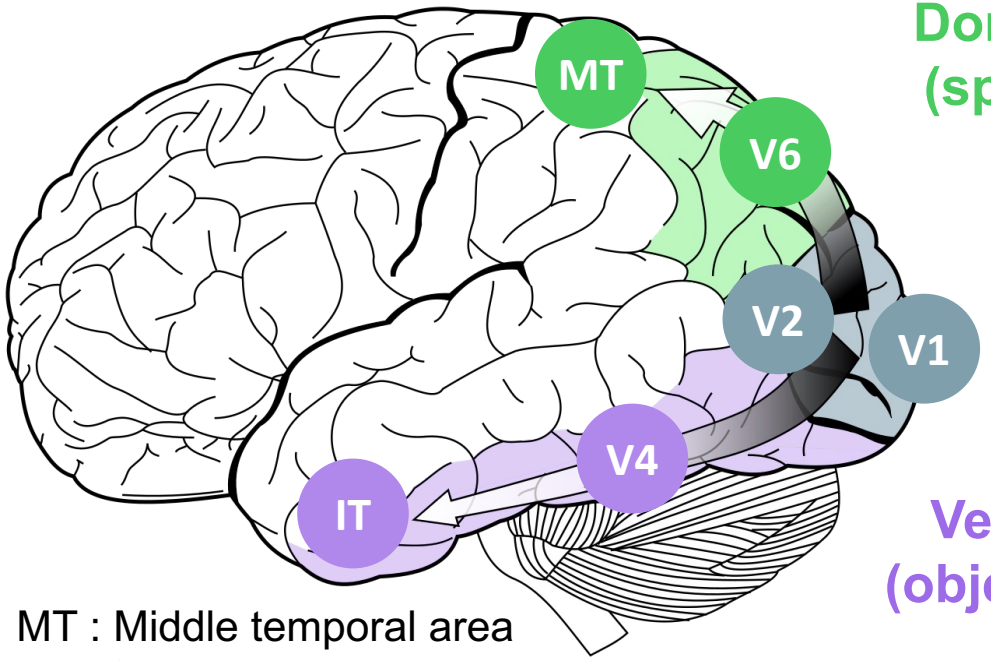
- Edge orientation
- Movement direction
- Rate of change (speed)
- Spatial frequency (texture)

The further we go along the visual pathway, the larger and more complex the receptive fields

Visual processing is not purely feedforward

**Herzog & Clarke 2014 Frontiers in Computational Neuroscience**

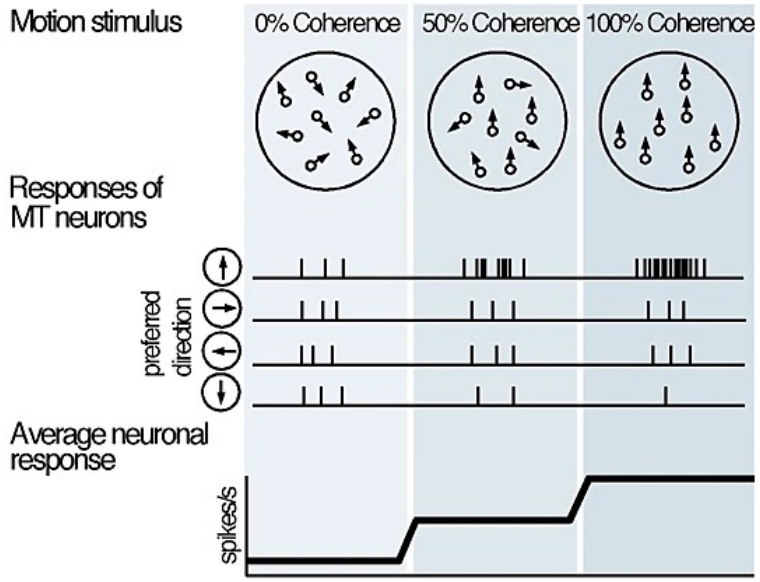
# The ventral and dorsal streams



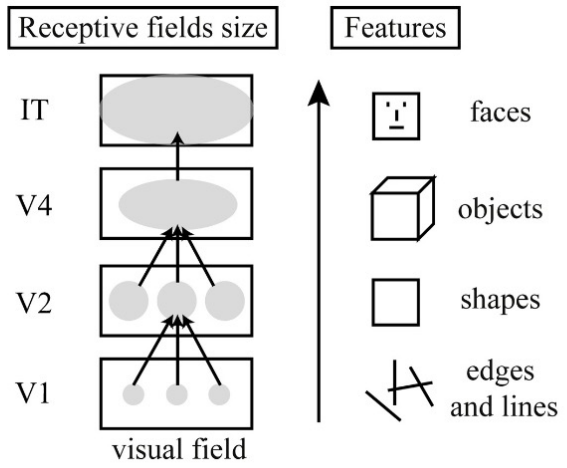

MT : Middle temporal area
IT: Inferior temporal area
FFA: Face fusiform area

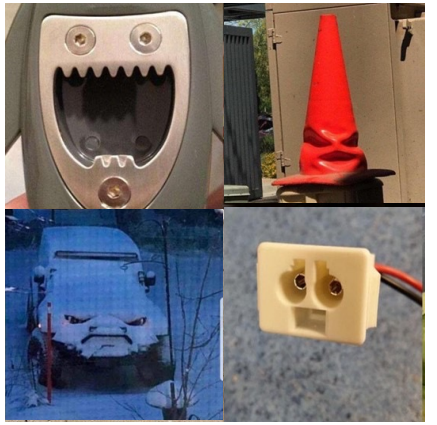
**Dorsal pathway (spatial vision)**
«How?»

**Ventral pathway (object recognition)**
«What ?»




MT neurons are selective to motion direction



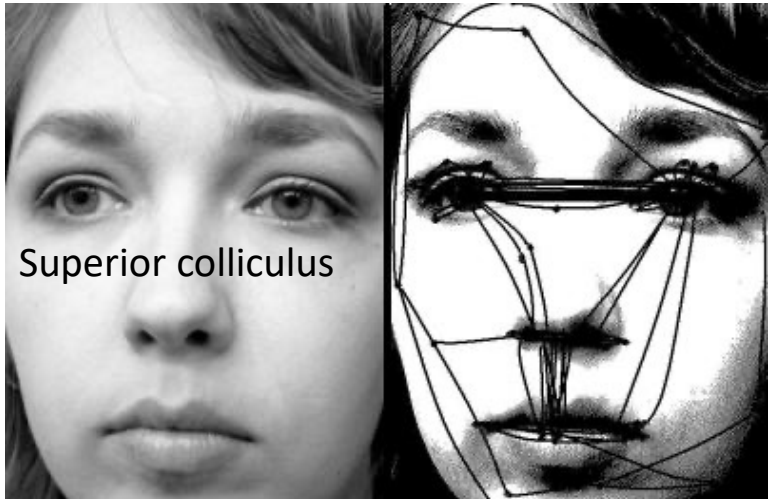
Face-like stimuli activate FFA

**Wikipedia: Two-stream hypothesis**
**Heeger et al. 2000 Nature Neuroscience**
**Wardle et al. 2022 PNAS**

# Functions of the visual system


Regulation of light entering the eye

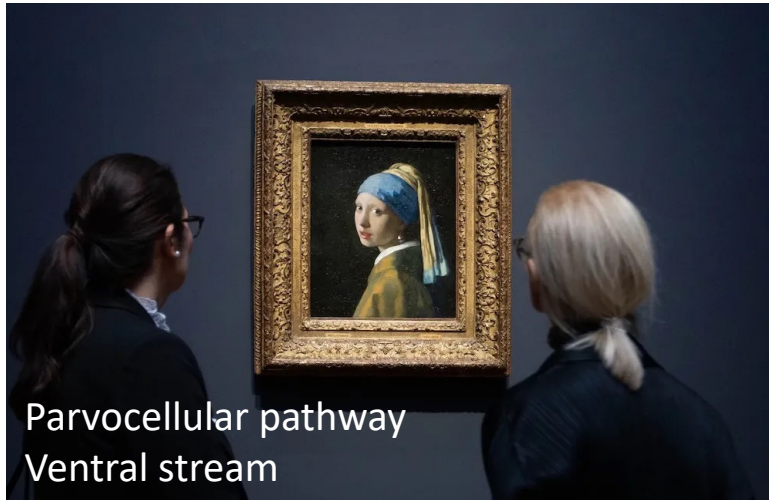

Regulation of the night-day cycle




Regulation of eye movements and attention


Perception of motion and distance


Color perception




Object and face recognition

Summary

Important concepts and keywords

- The different targets of the retinal ganglion cells and their functions
- The retinogeniculostriate pathway (from the retina to V1)
- Binocular vision
- Lateral geniculate nucleus (LGN) organization
- Retinotopic map
- General organization of the cortex (layers,…)
- Receptive fields in the visual system
- Columnar organization of V1 (orientation, ocular dominance)