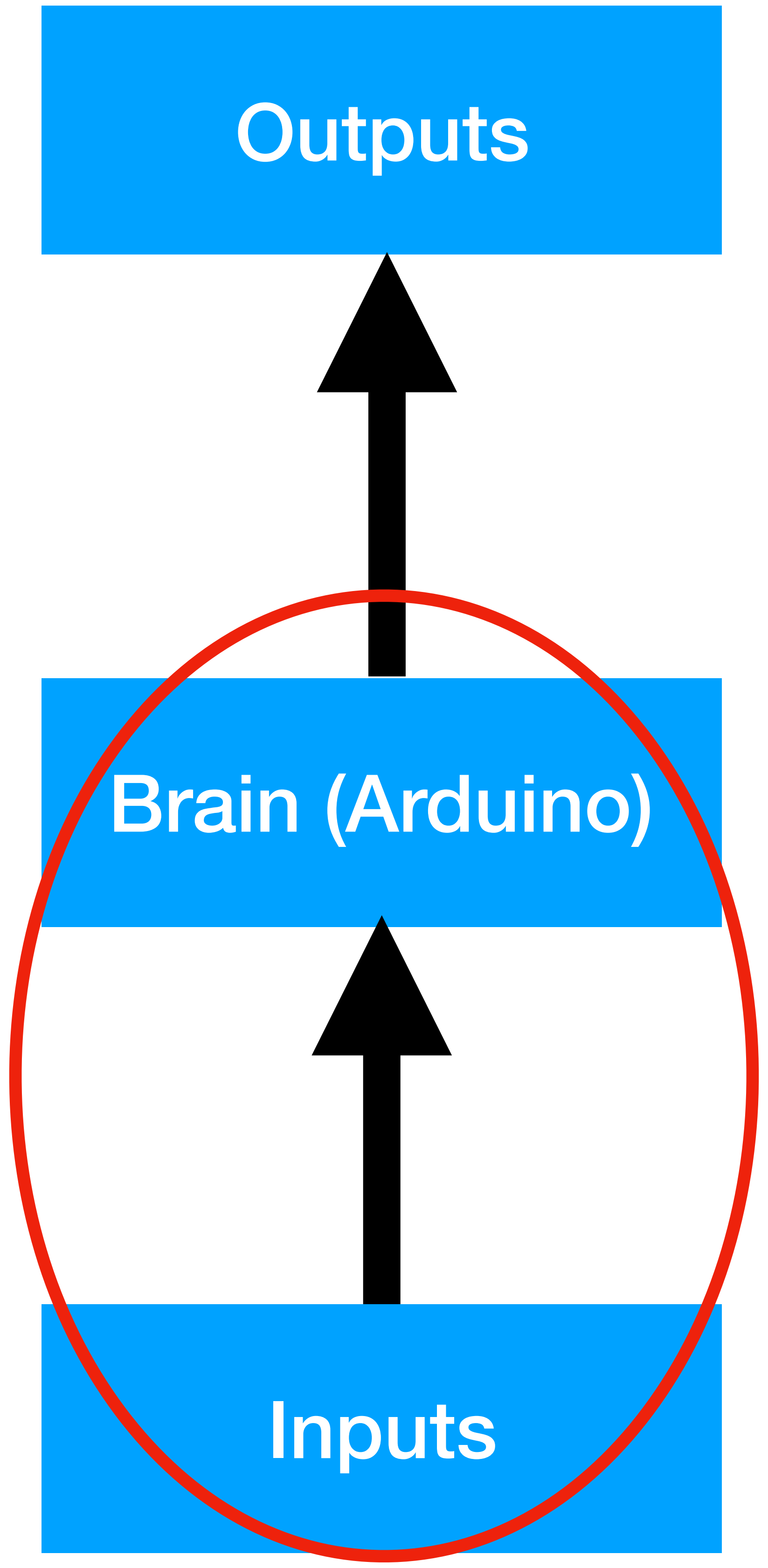
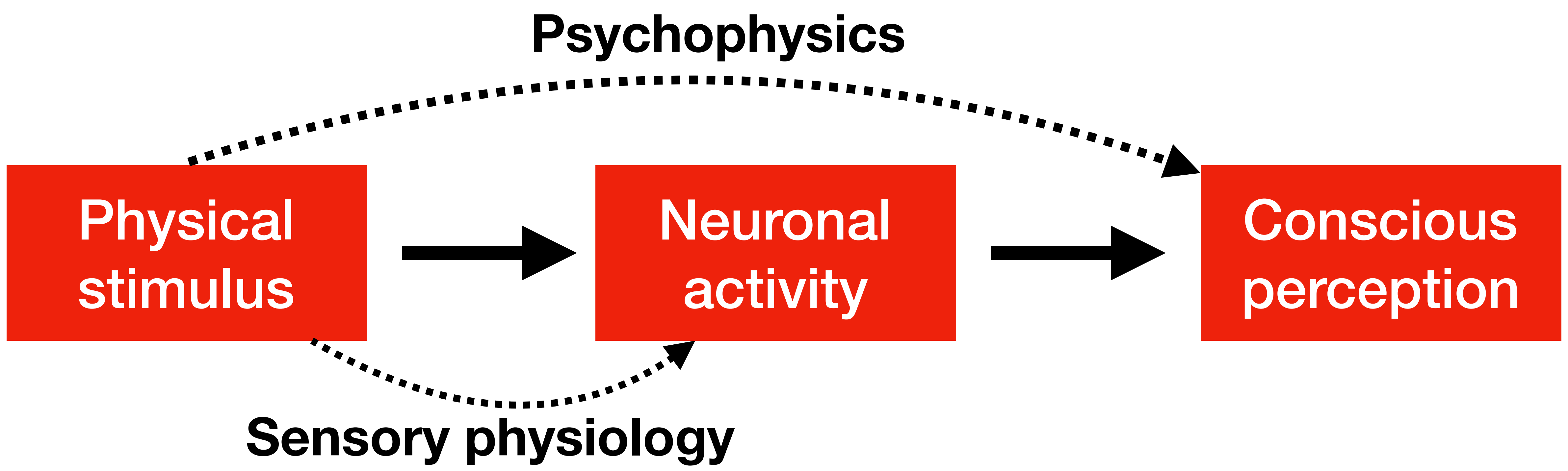
Introduction to sensory pathways

Gatsby / SWC induction week
25 September 2017

Studying sensory systems: inputs and needs

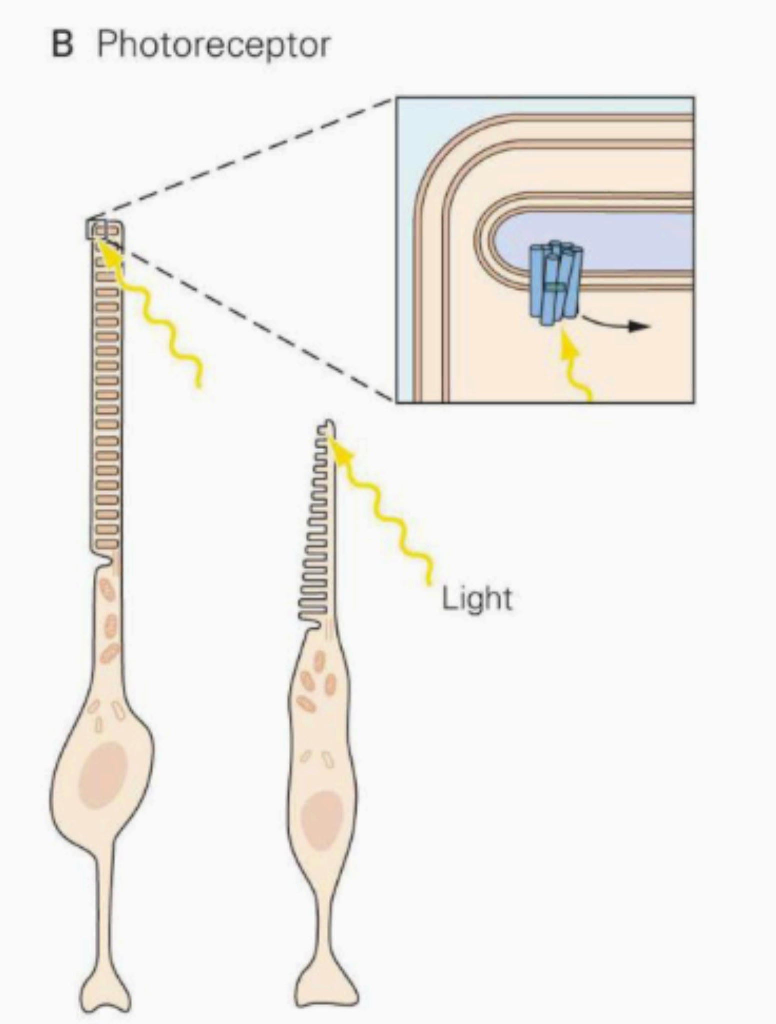


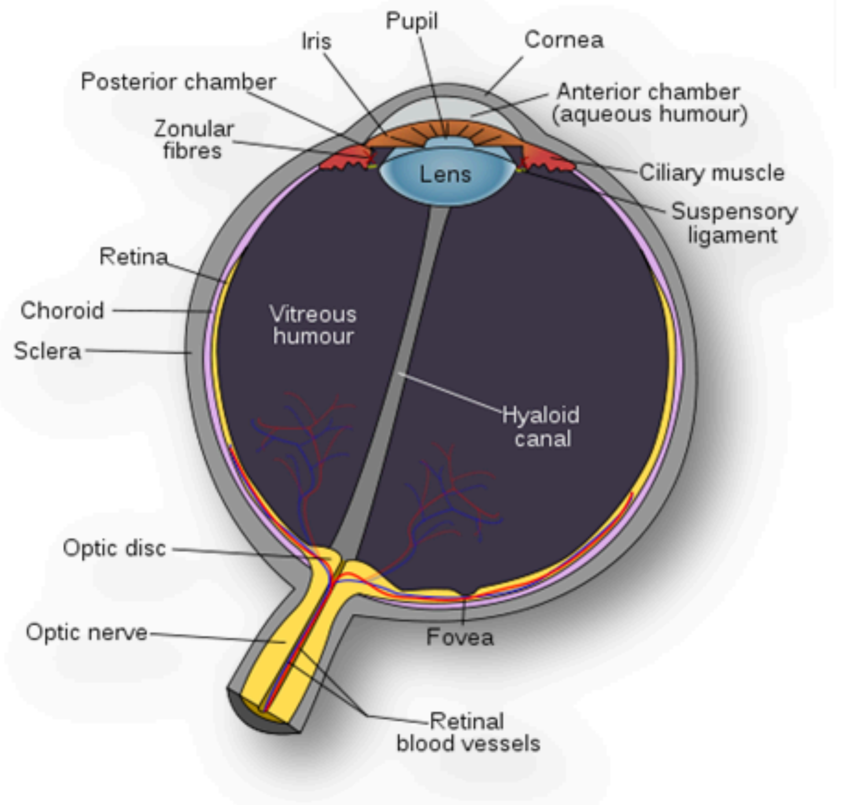
Stimulus	Modality	Robots' Sensors	Biological Sensors
Light	Vision	Photodiodes or CCD	Photoreceptors in the retina
Sound	Audition	Microphone	Hair cells in the cochlea
Pressure	Somatosensation	Pressure sensor	Cutaneous mechanoreceptor
Chemical	Smell and taste	Chemical sensor	Chemoreceptor
Gravity	Vestibular	Accelerometer	Hair cells in the vestibular labyrinth



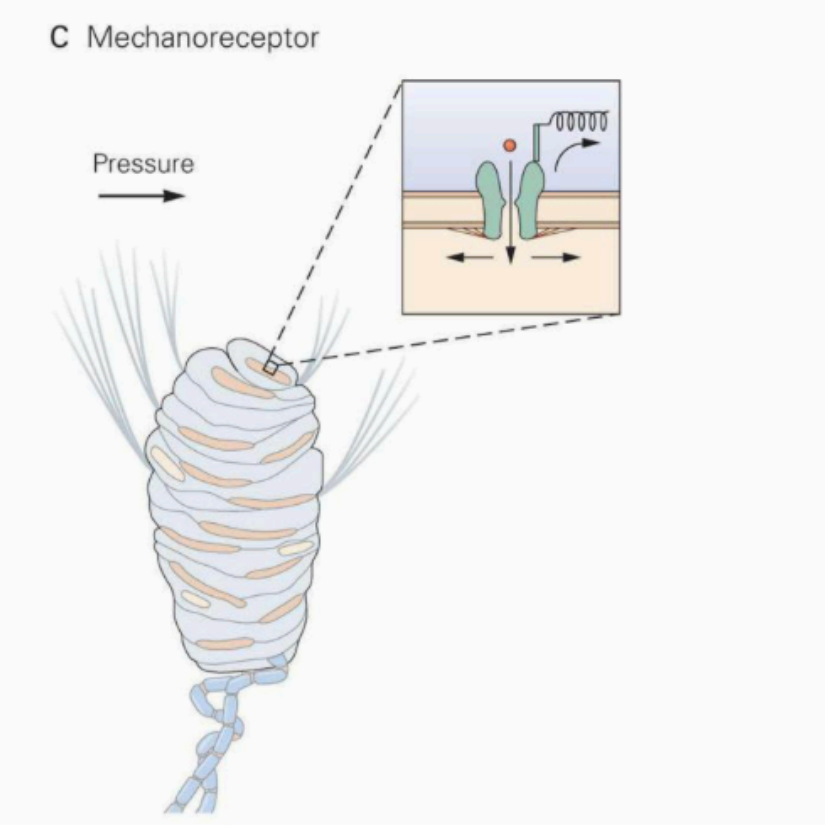
Overview: dealing with different types of input

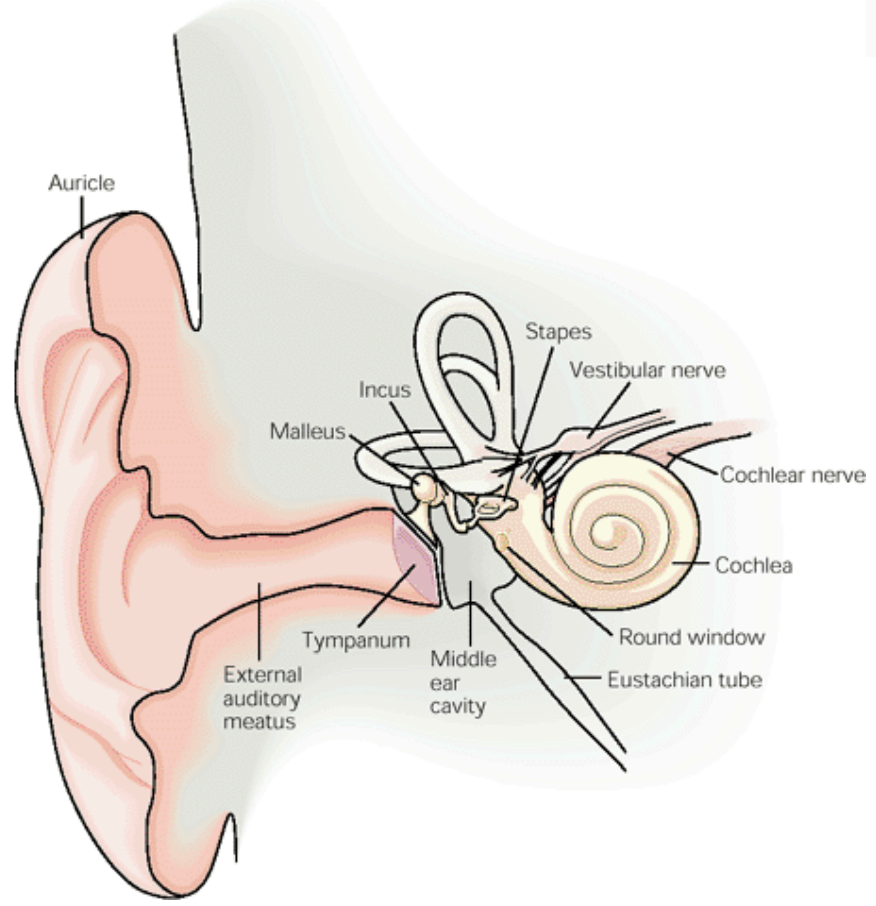
Vision



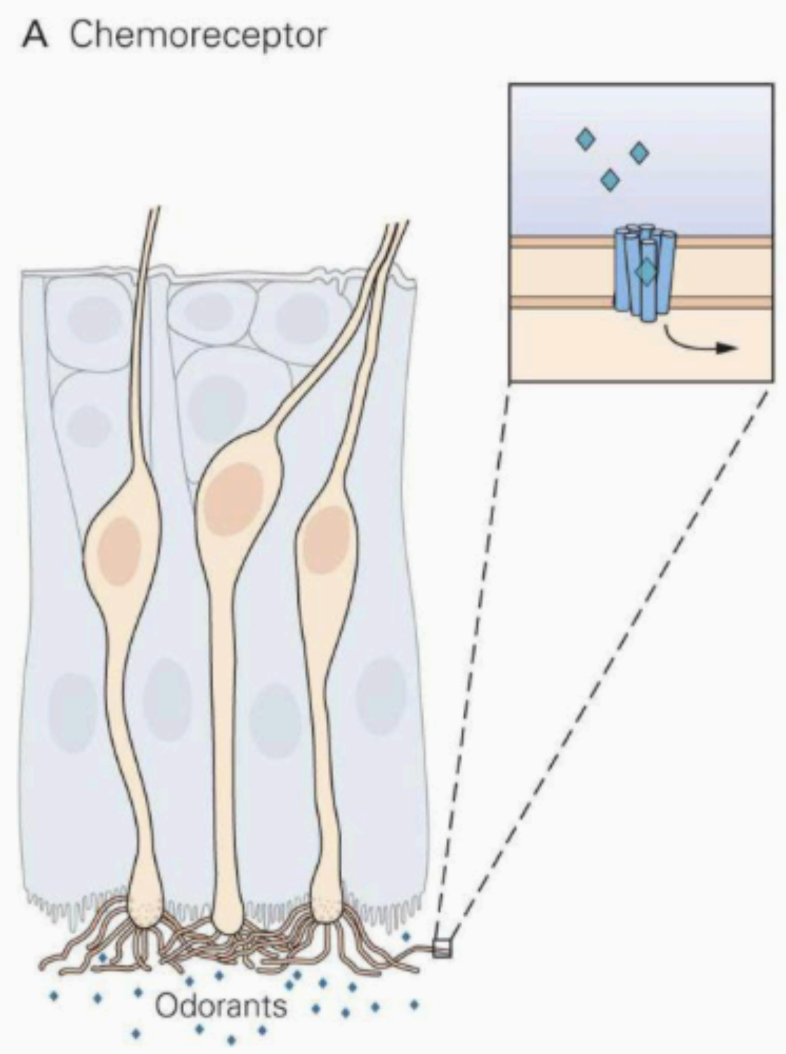


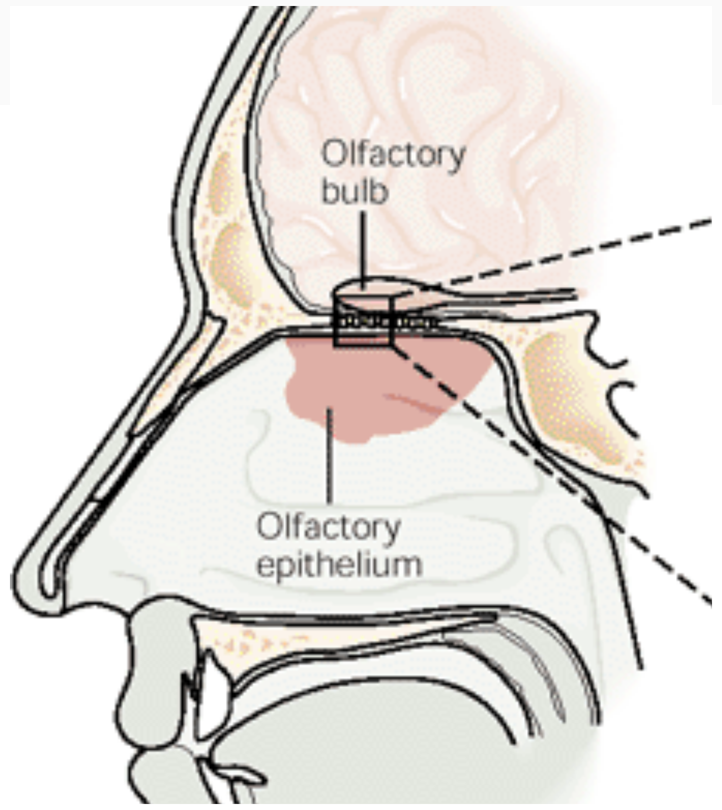
Audition





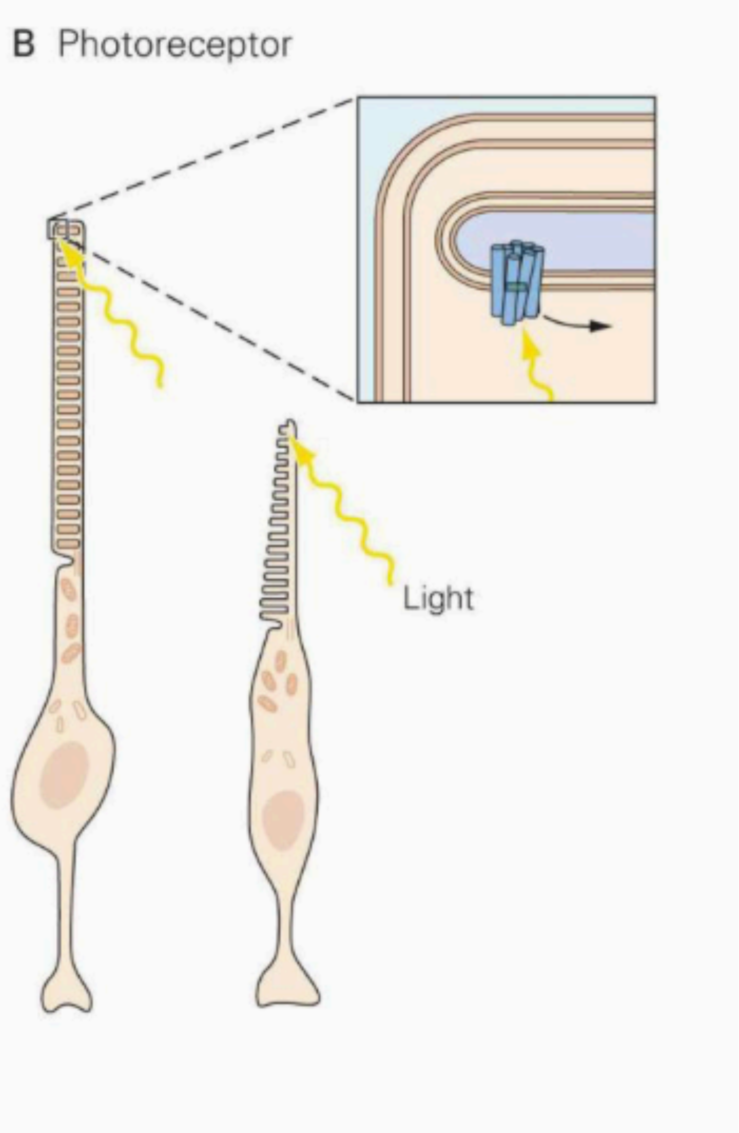
Olfaction

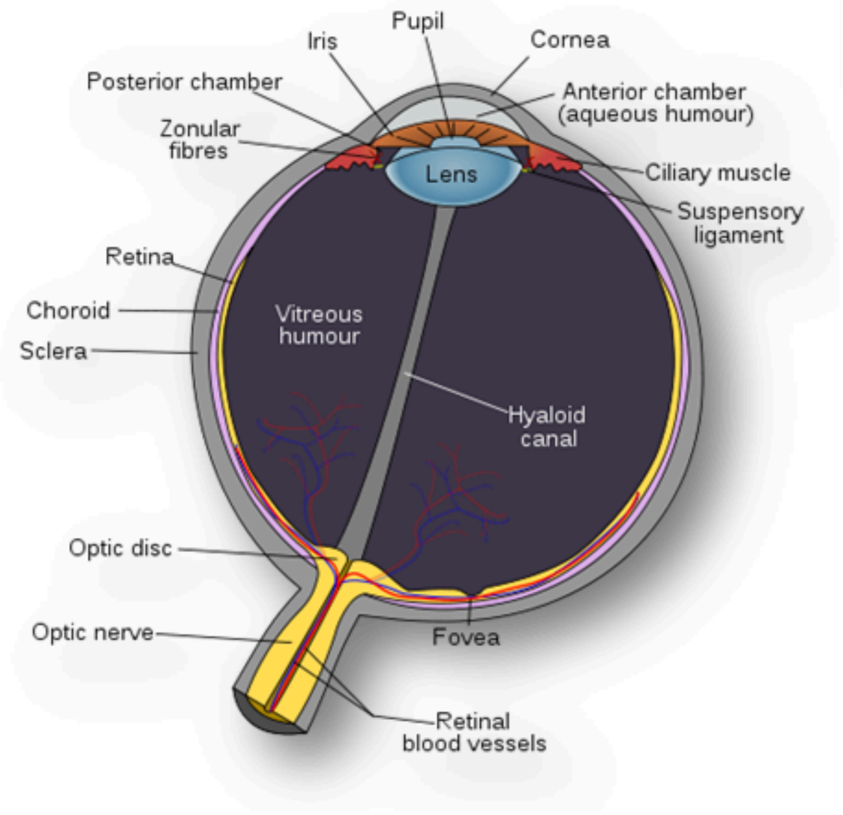




Overview: dealing with different types of input

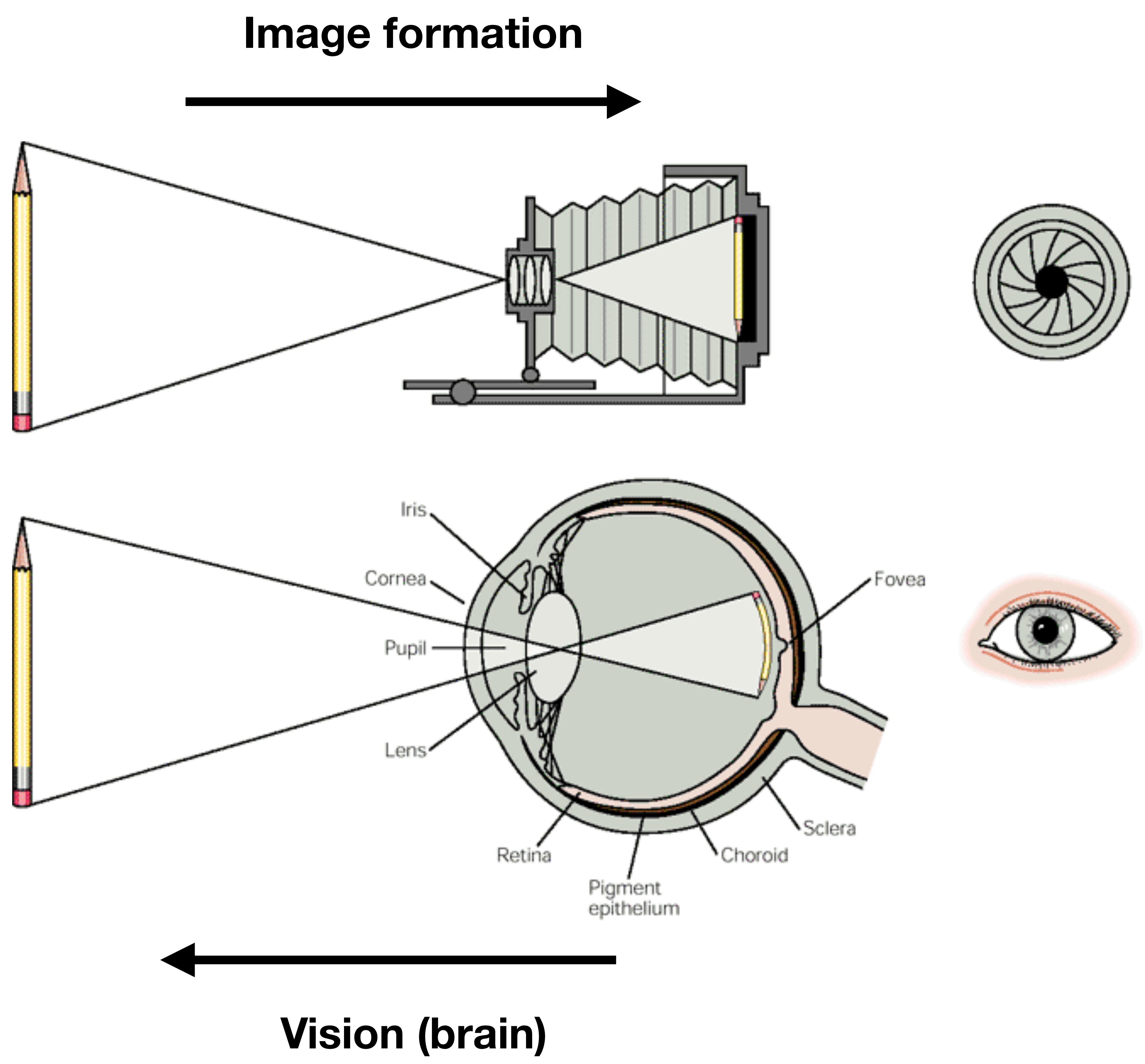
Vision



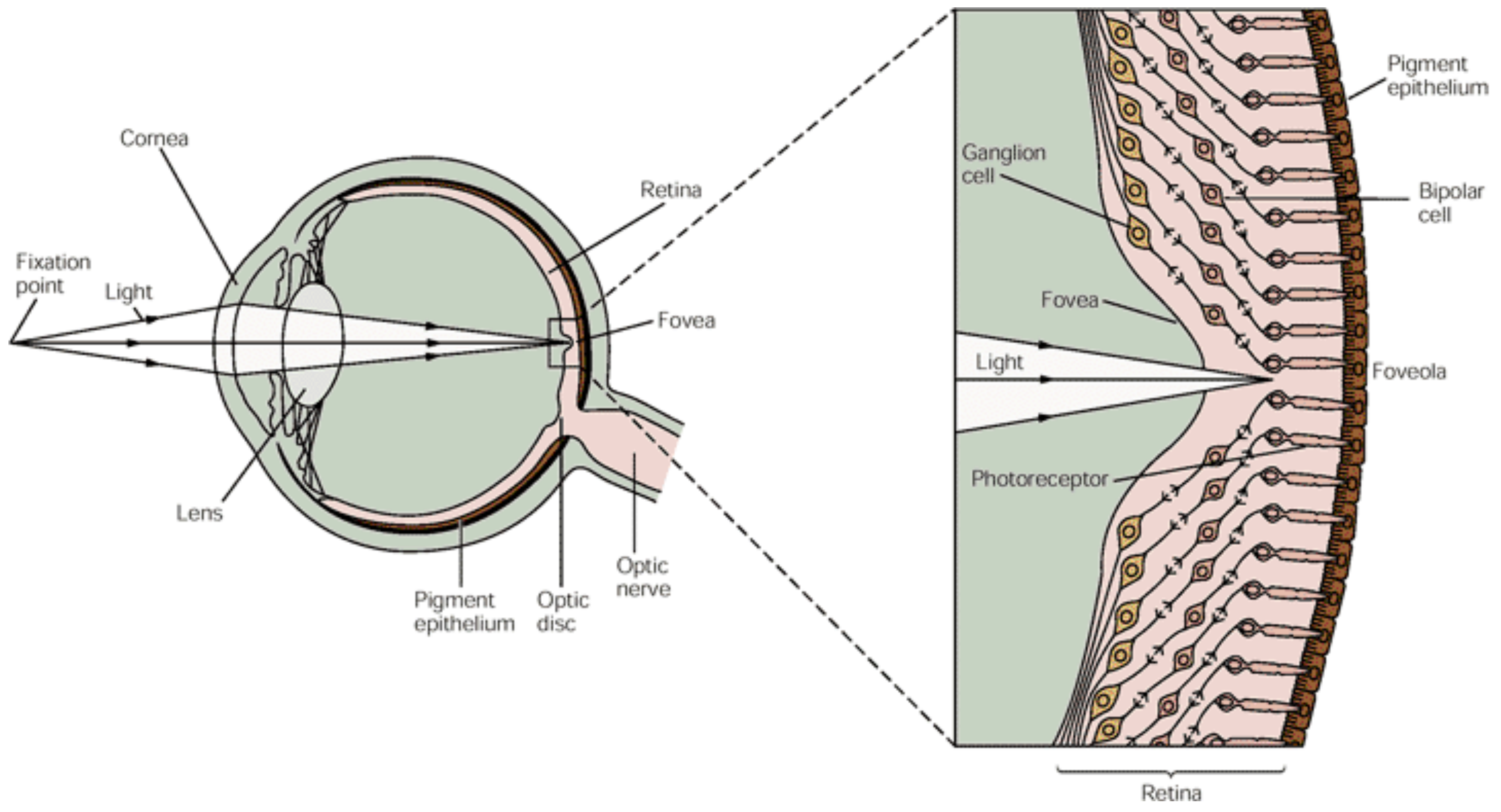


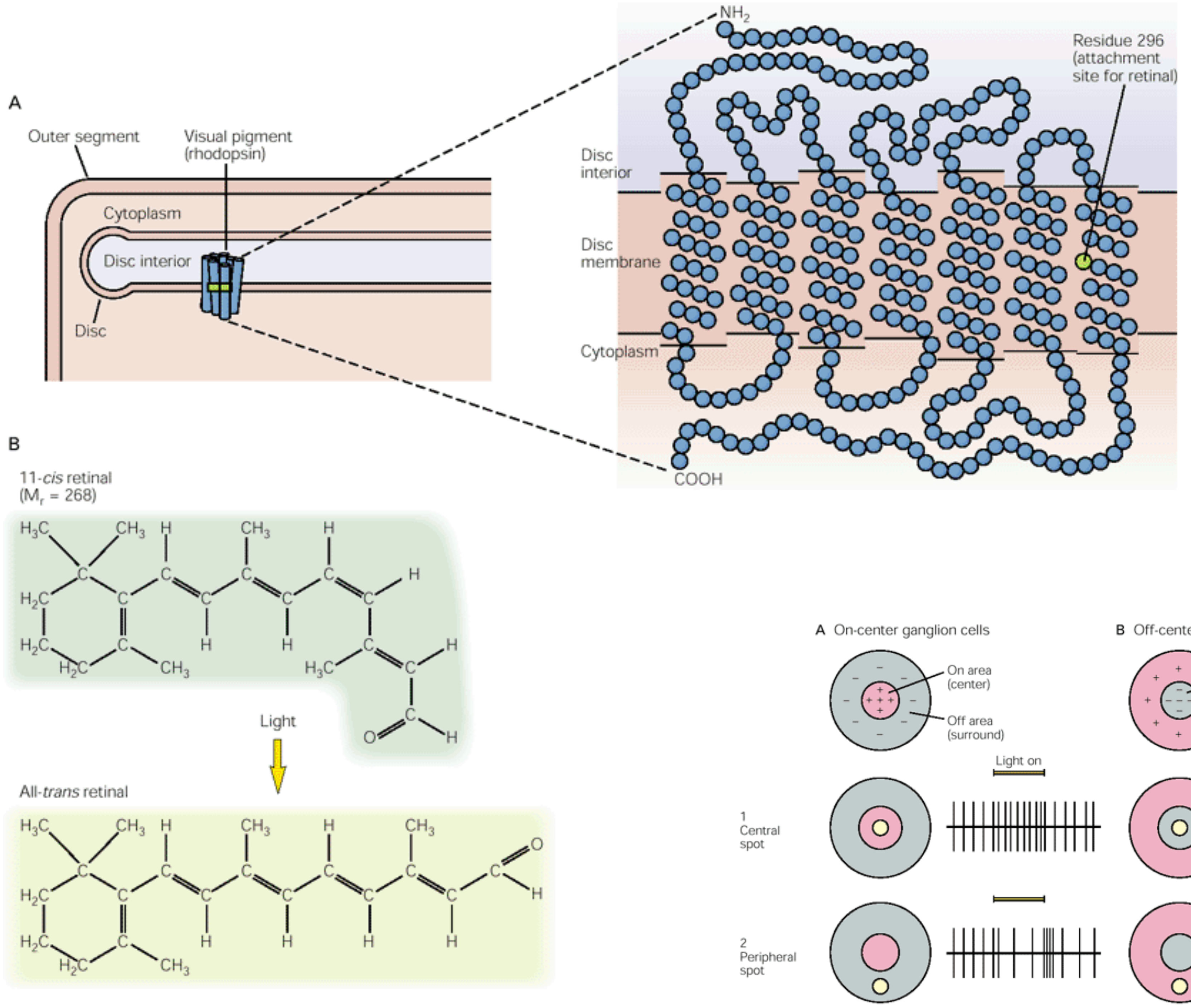
Introduction to the visual system

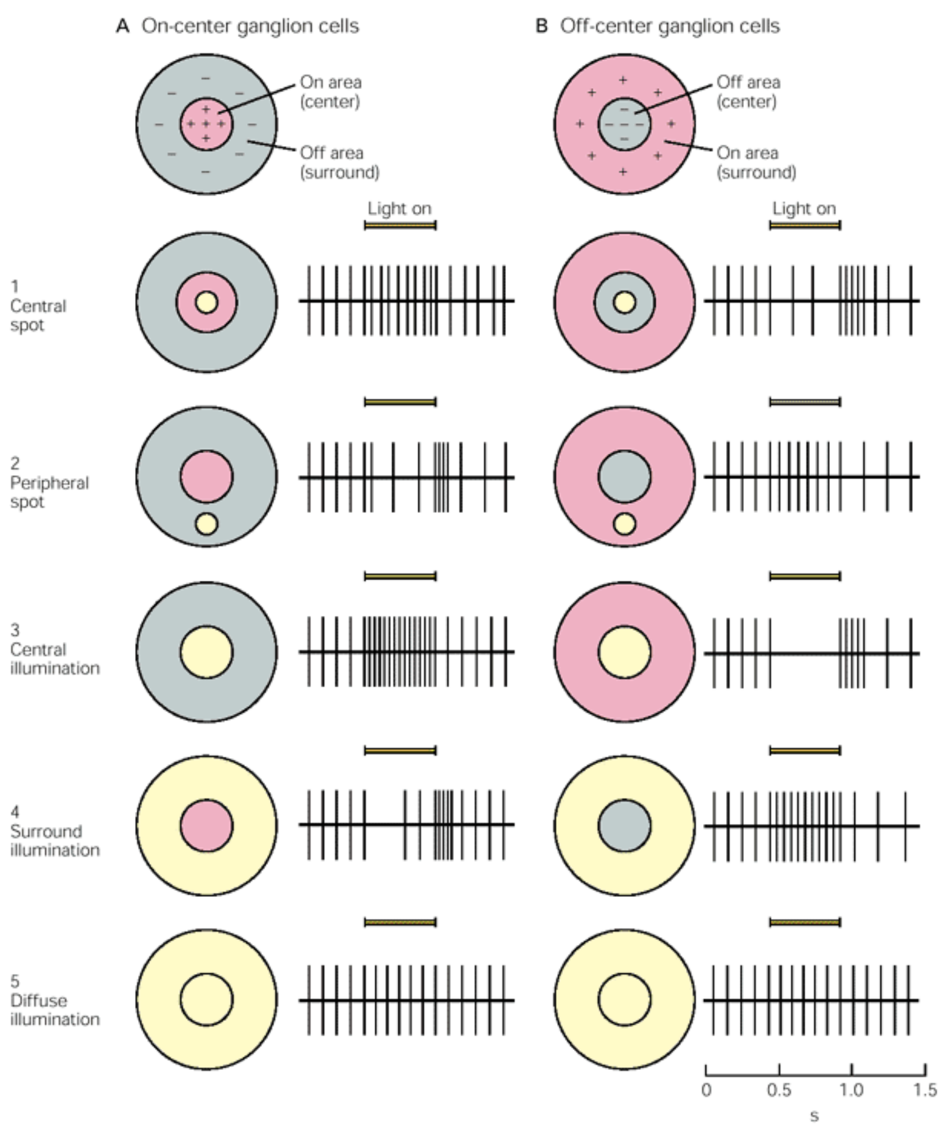
- Vision is one of the best studied systems in the brain
- The most important modality for us, and the most complex circuitry
- NOT a camera: the visual system solves the inverse problem

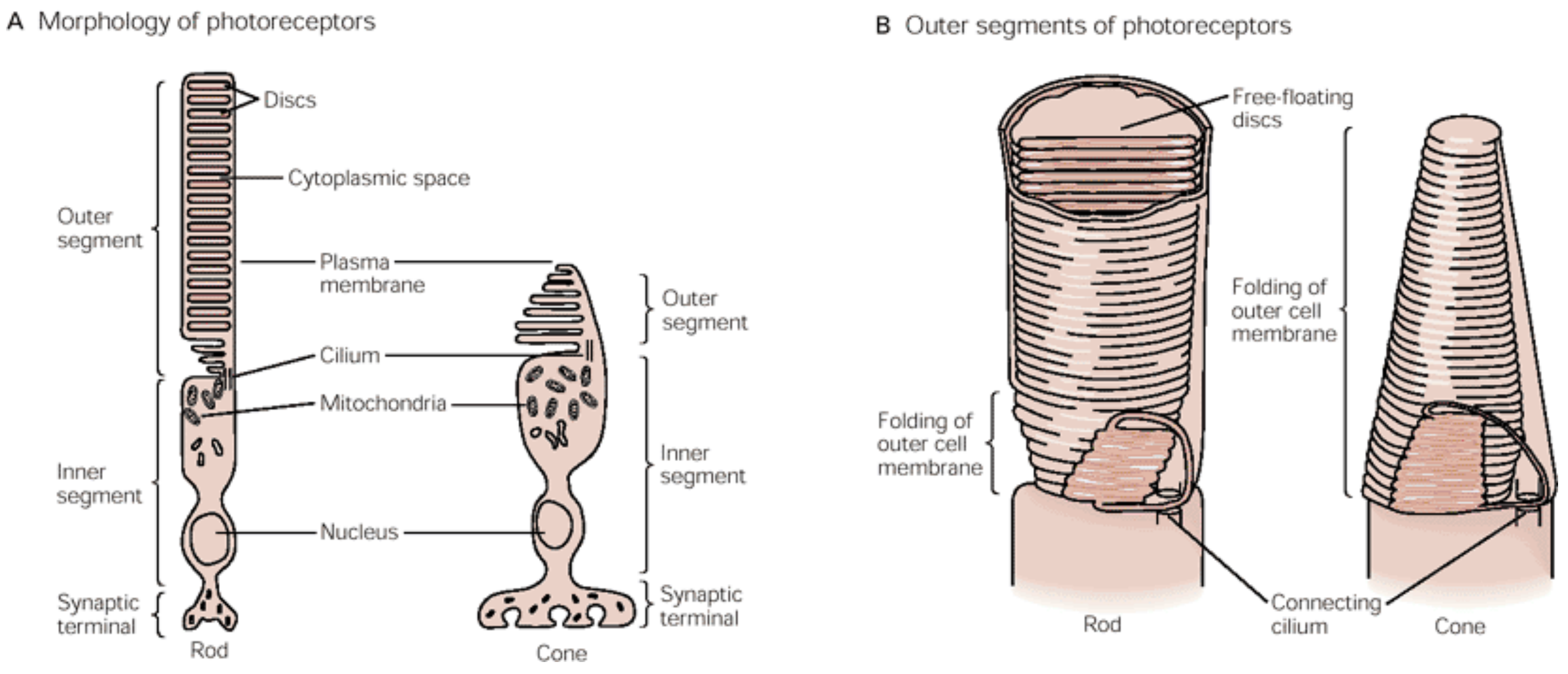


The retina: just a CCD?



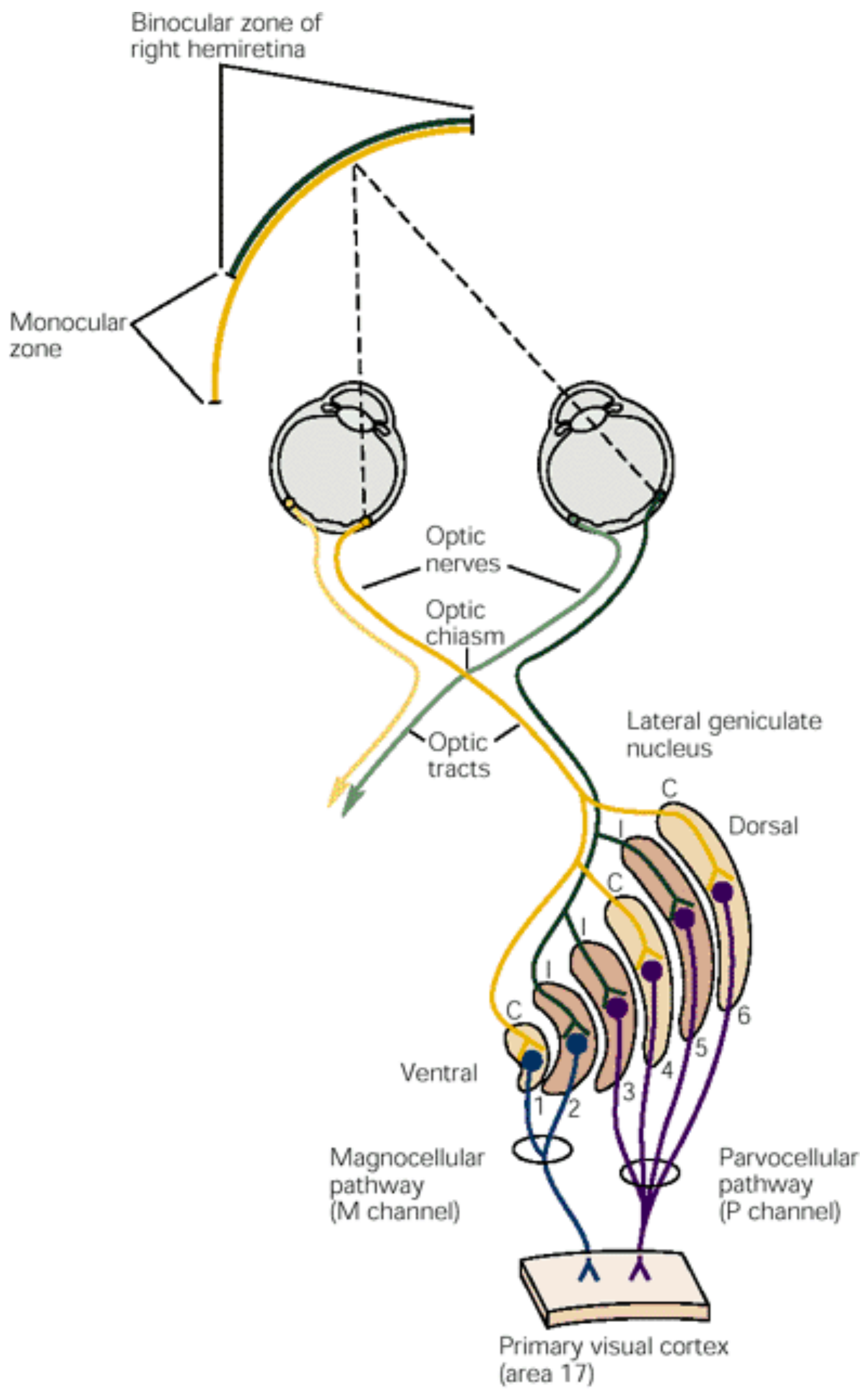


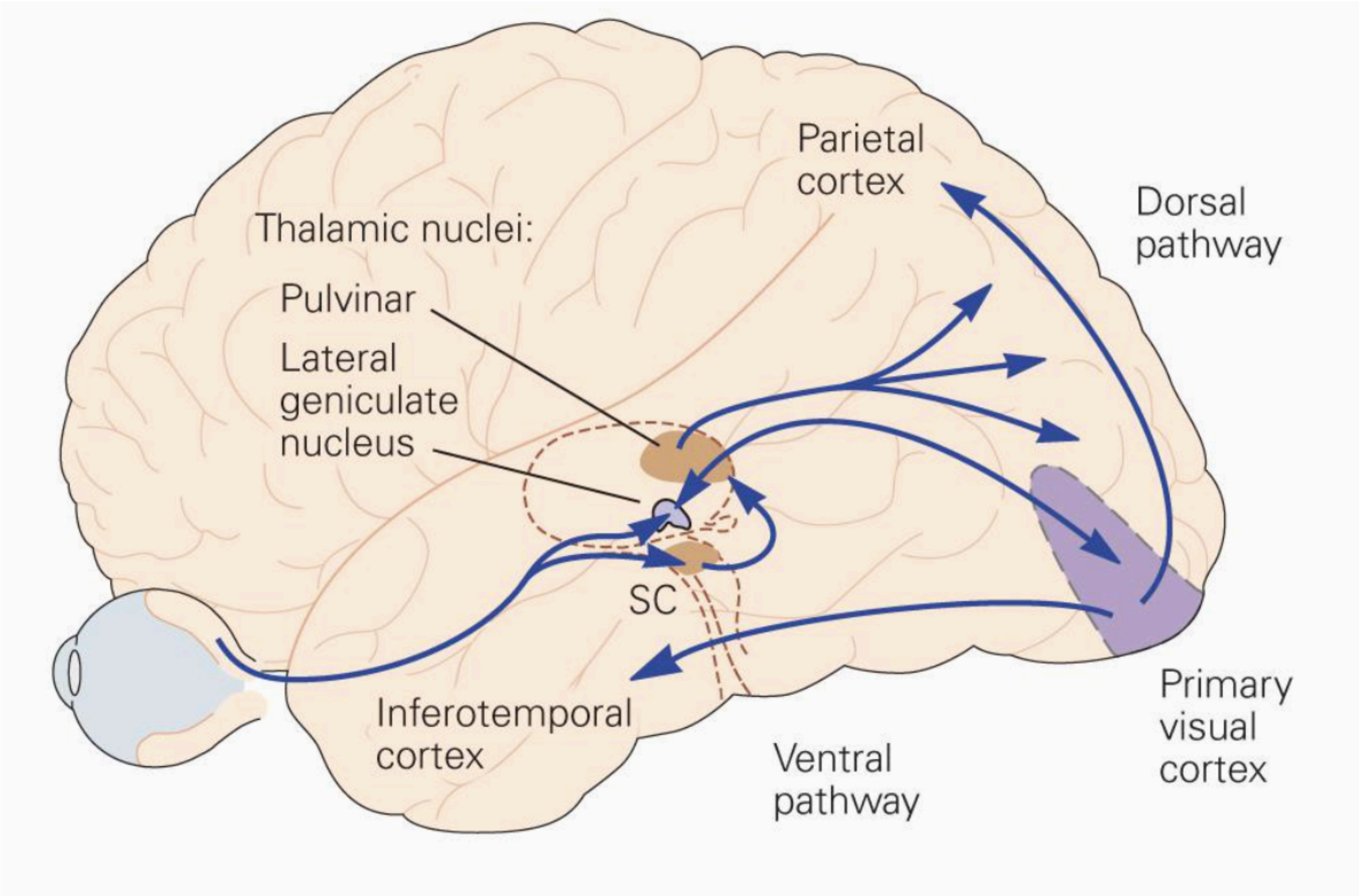




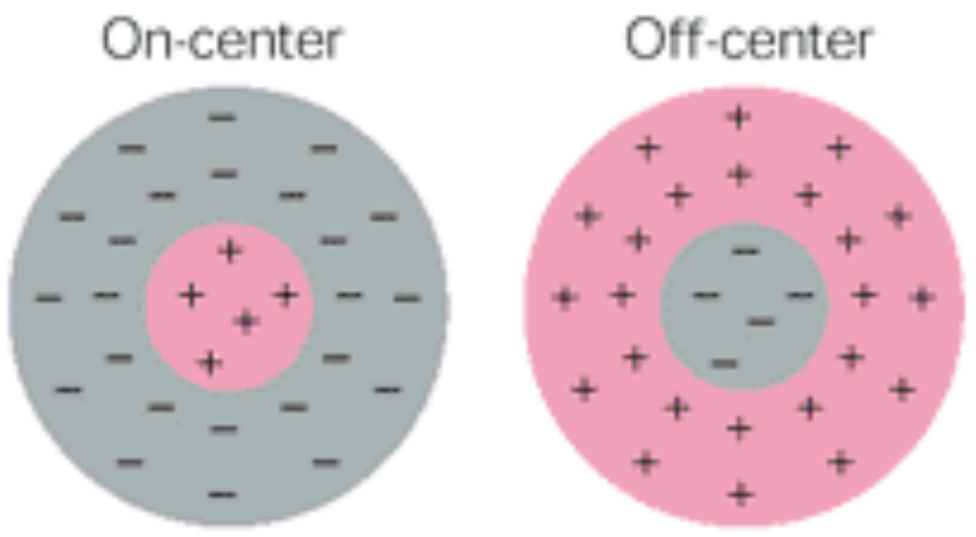
Receptive fields

Early visual processing: thalamic pathway

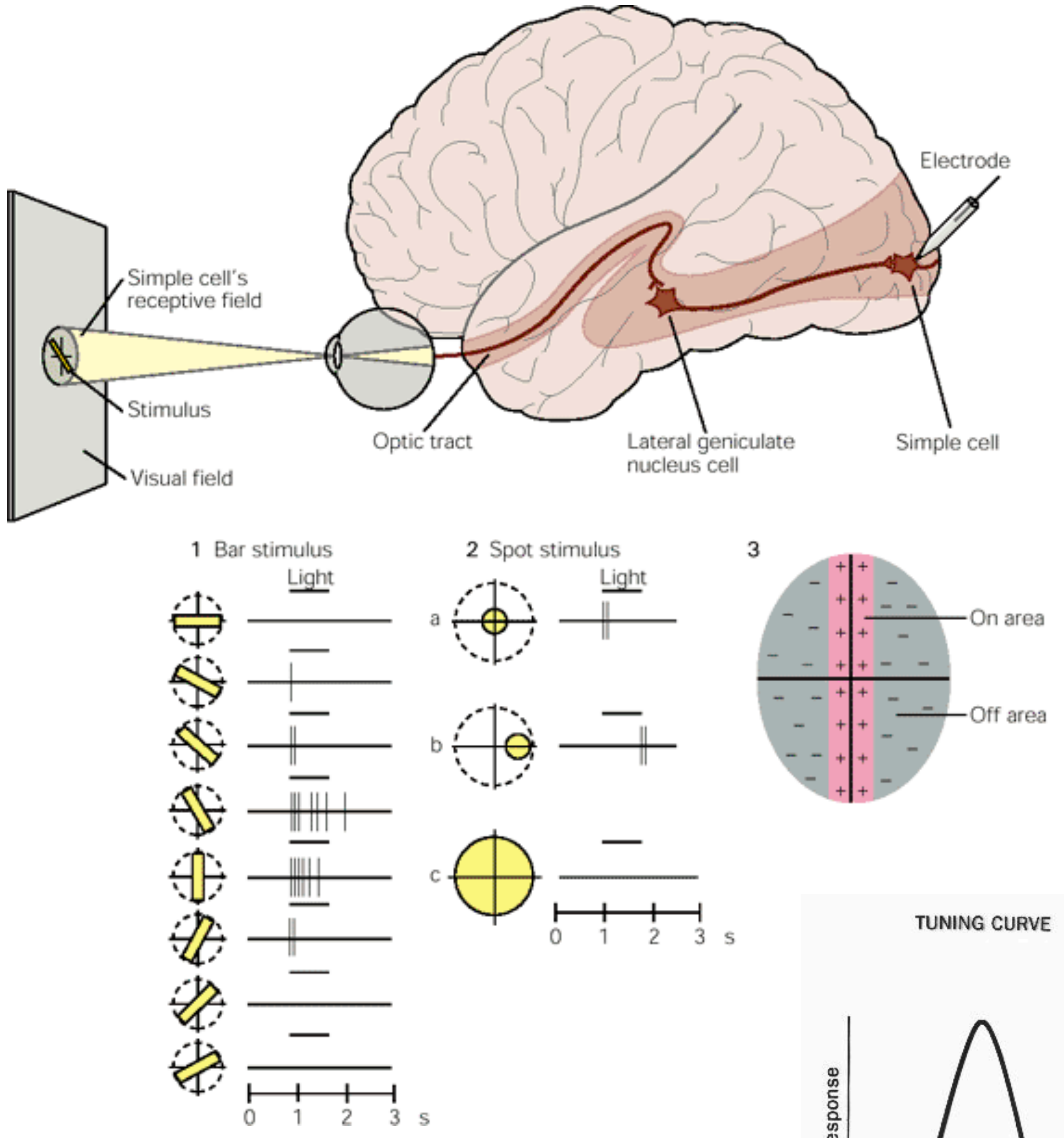


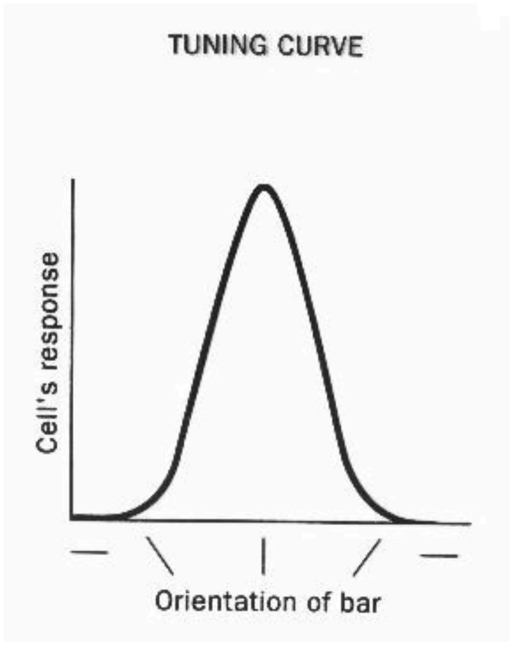


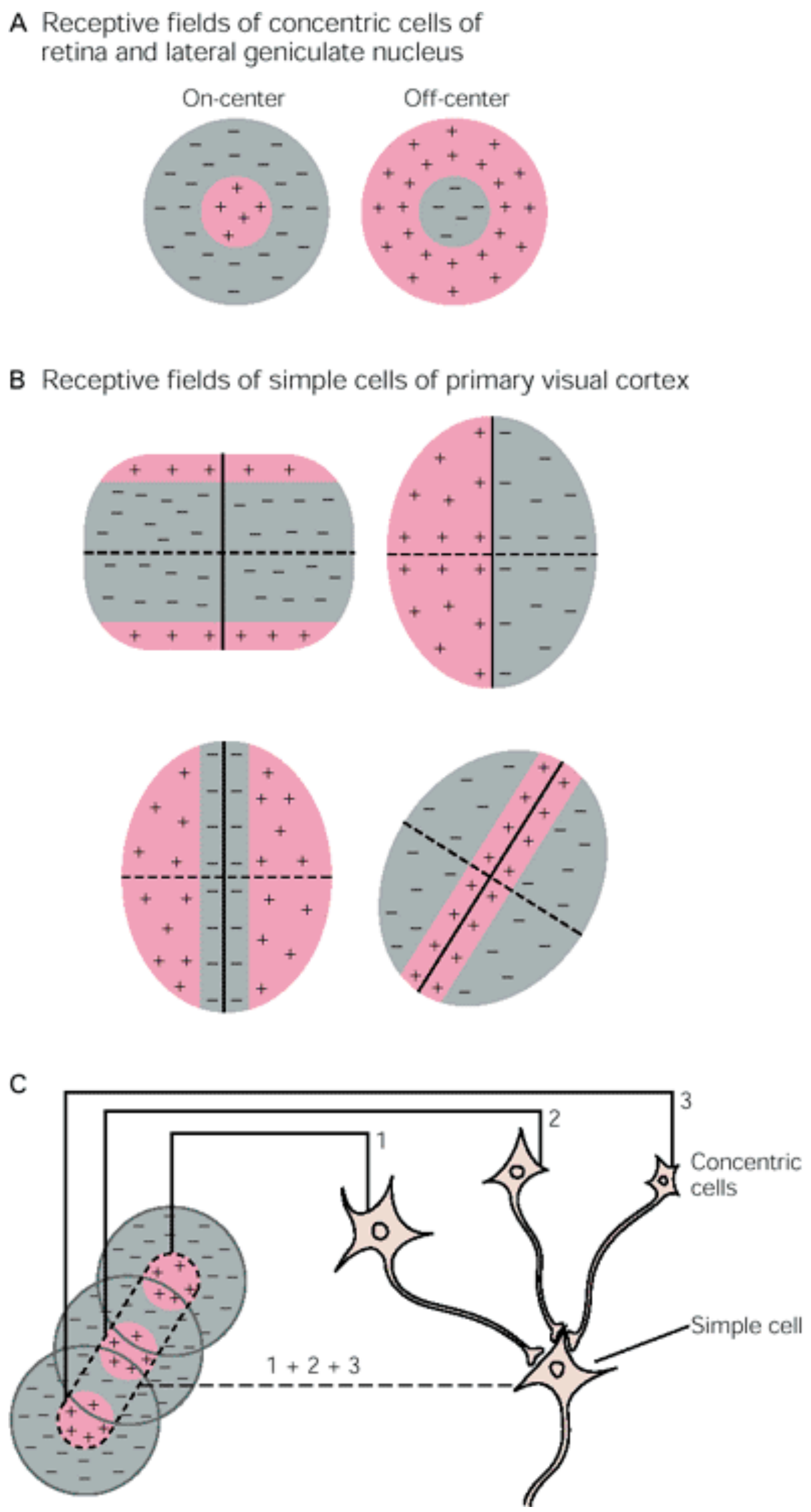
Receptive fields of concentric cells of retina and lateral geniculate nucleus

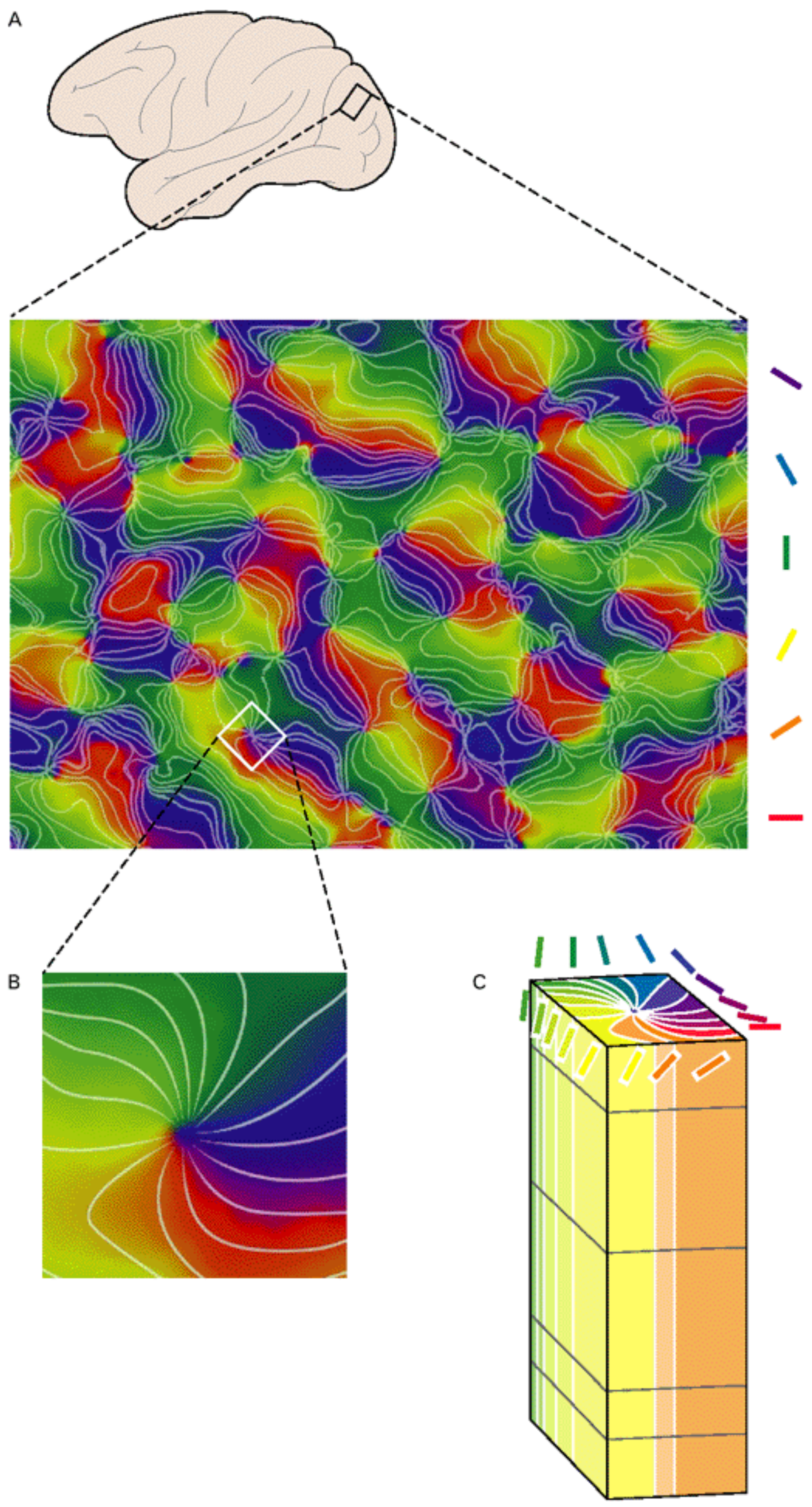


Primary visual cortex (V1) decomposes image into low-level features: bars with a specific orientation

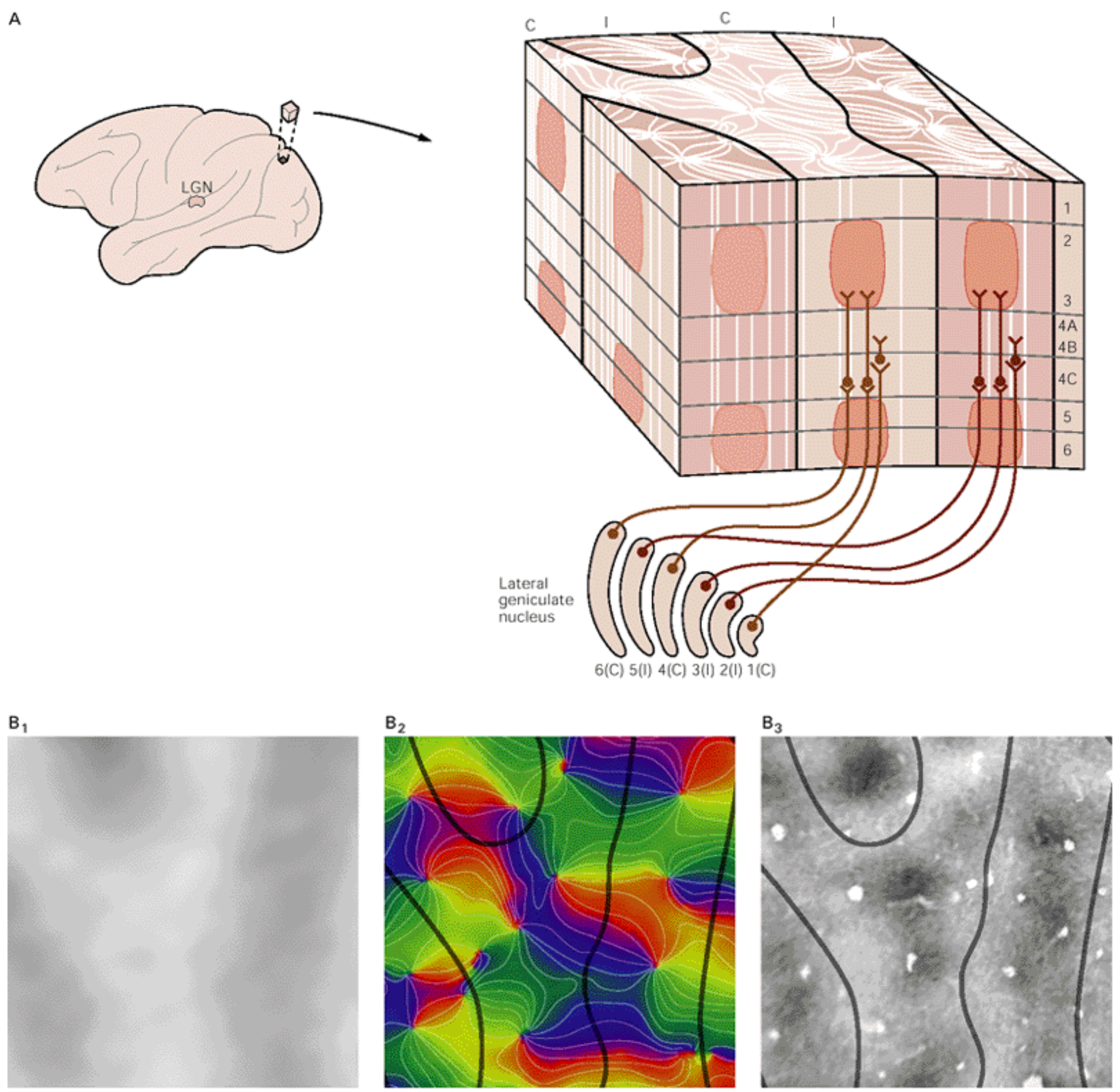






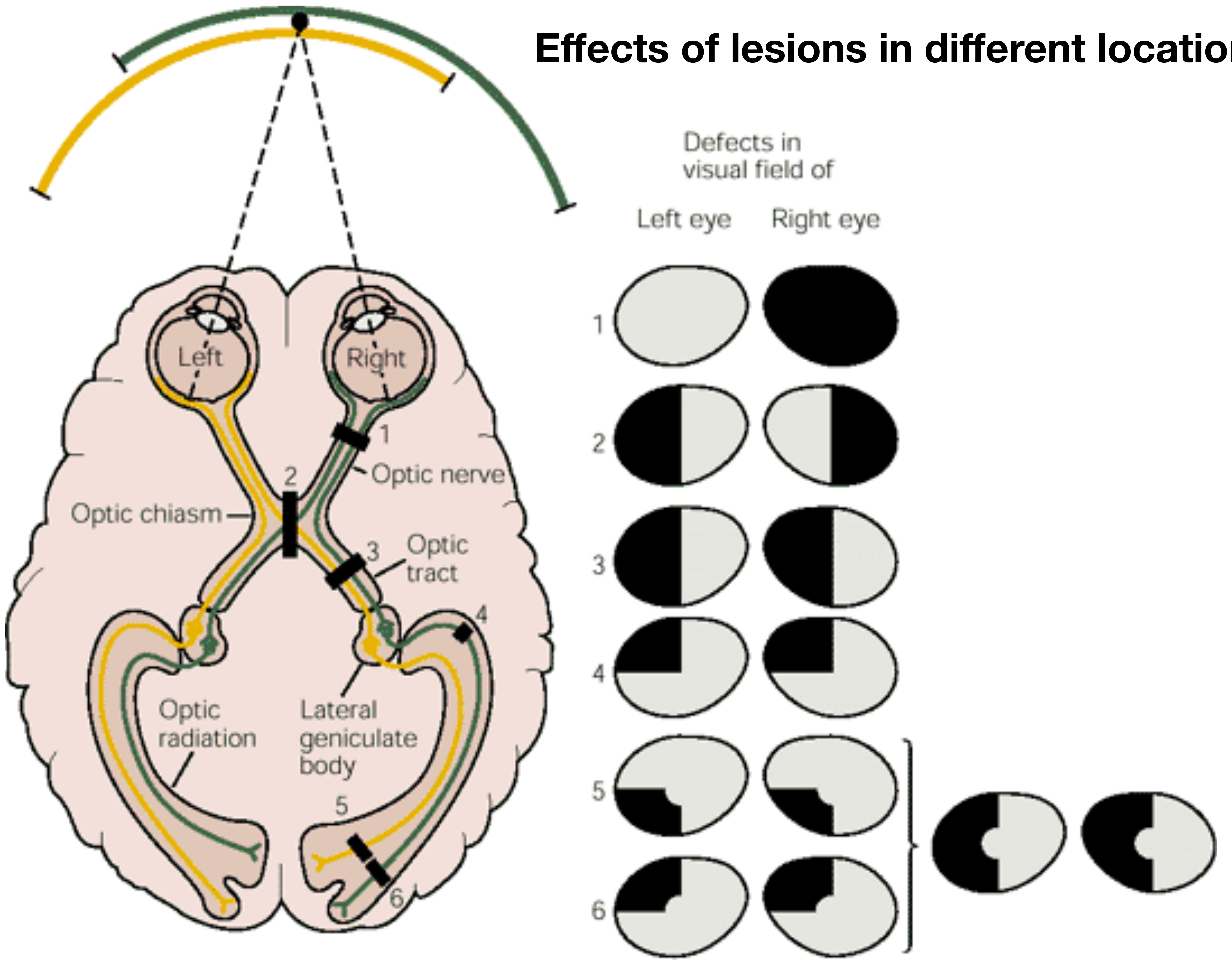


Functional organisation of V1

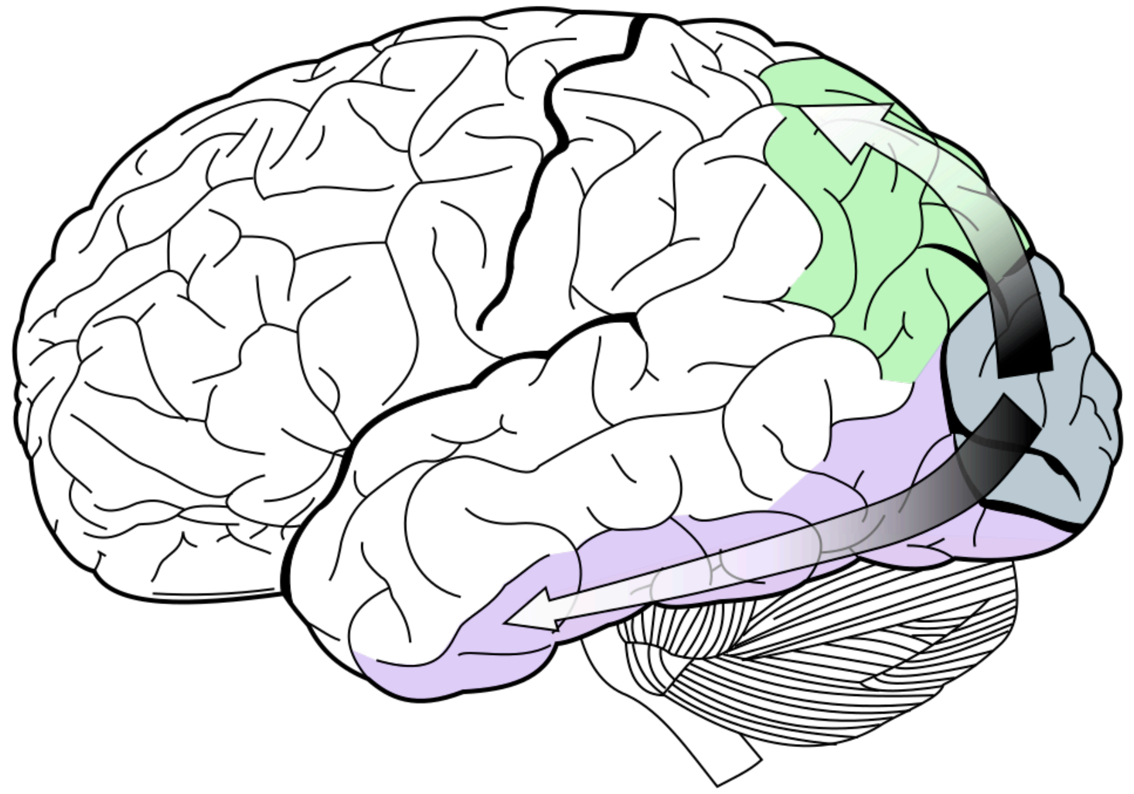


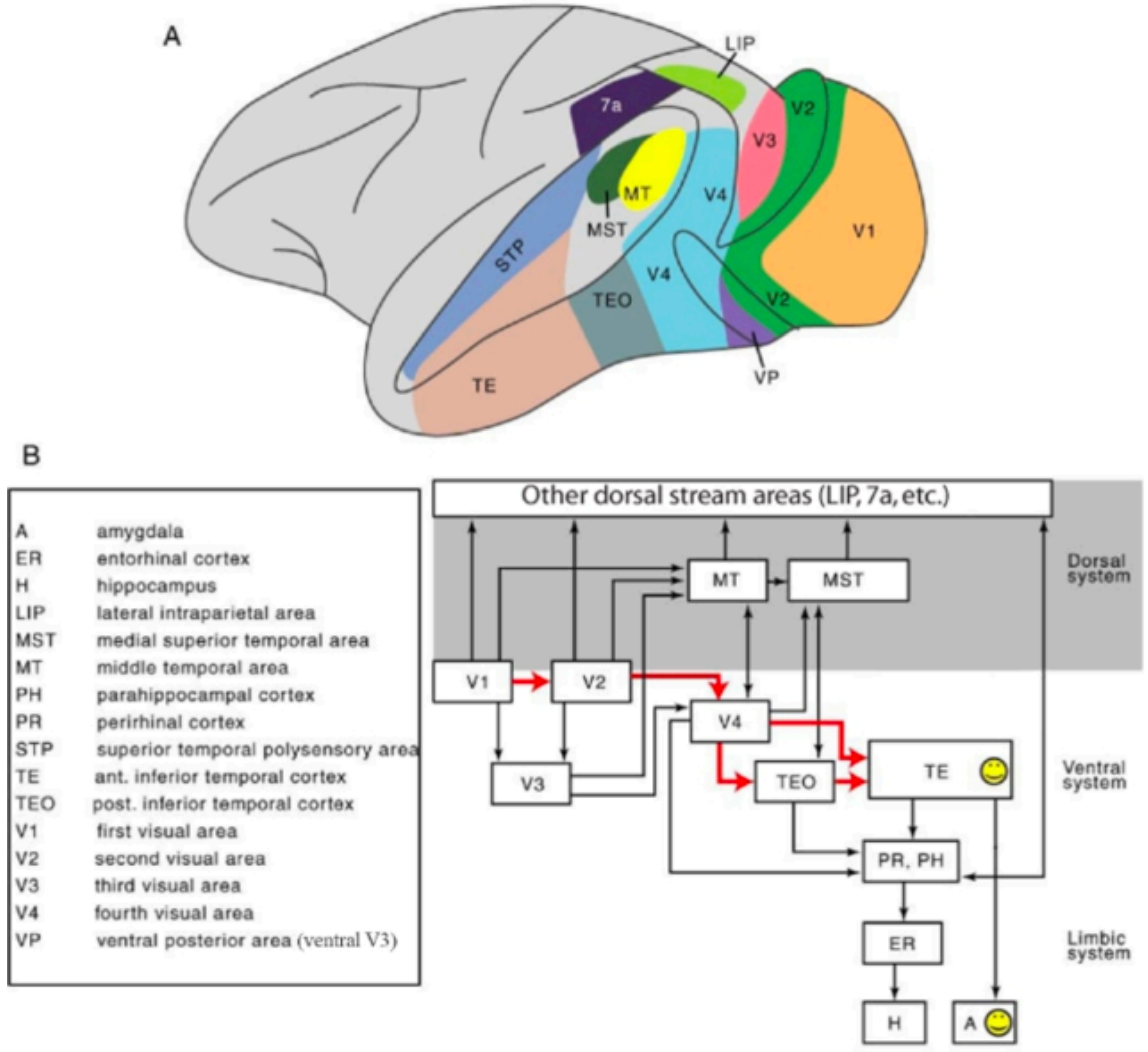
Ocular dominance **Orientation columns** **Color blobs**

Effects of lesions in different locations



Beyond V1: dorsal and ventral streams

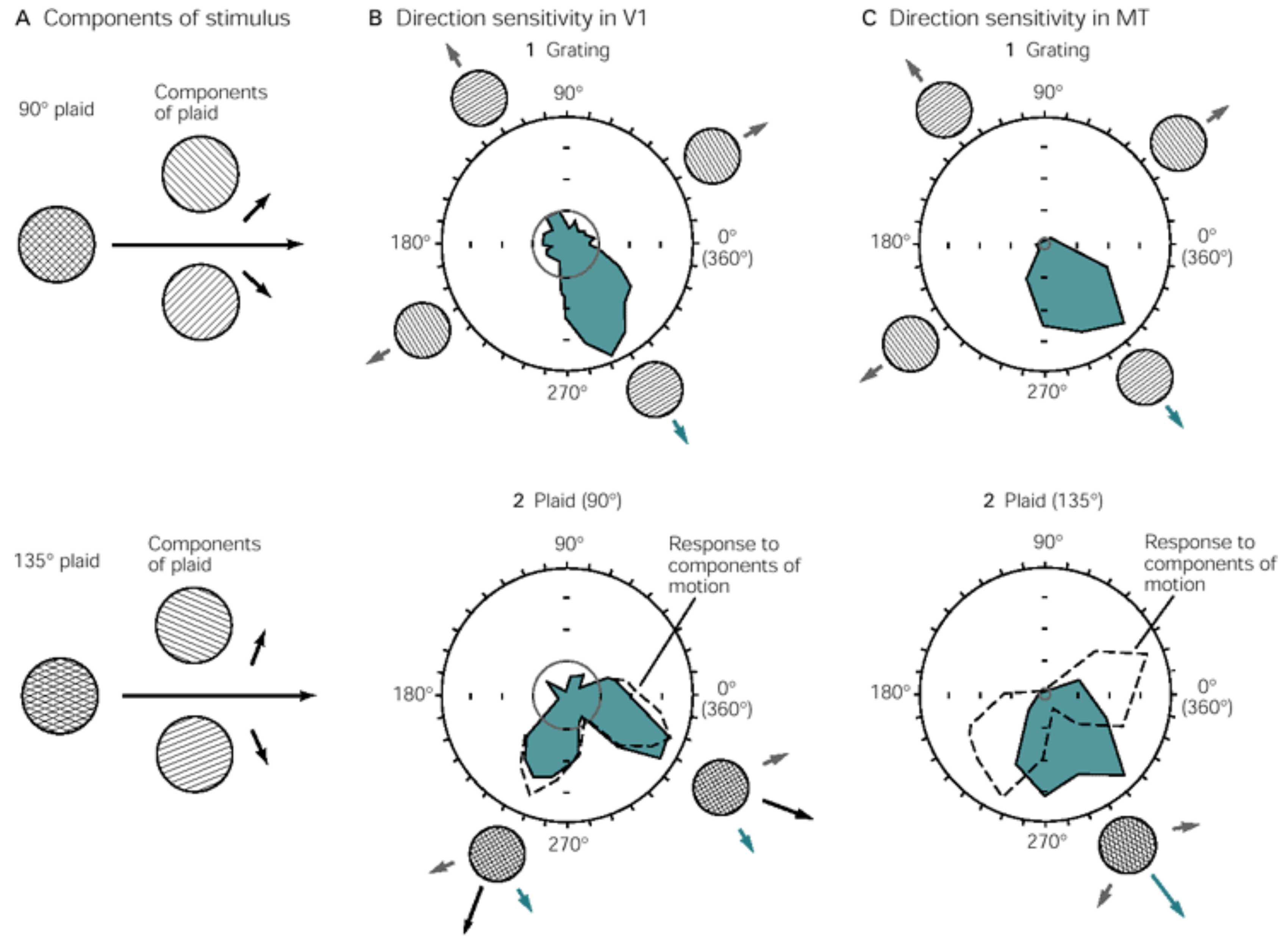




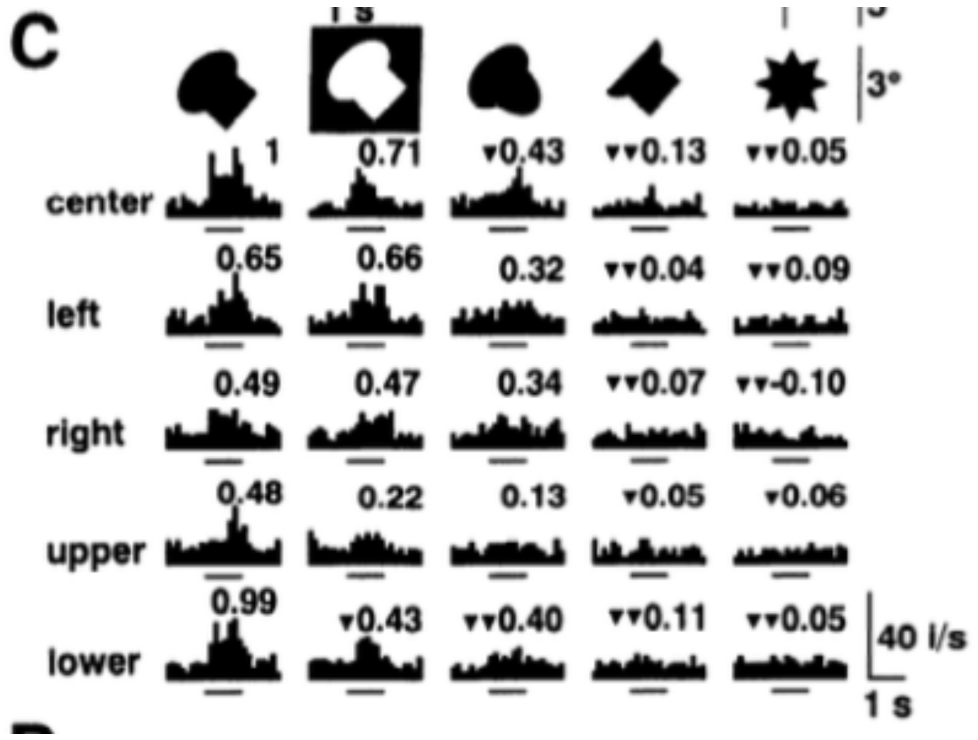
- **Ventral "what" pathway**
  - Specialises in object recognition
  - Includes areas V1, V2, V4 and inferior temporal areas
- **Dorsal "where" pathway**
  - Specialises in object localisation
  - Includes V1, V2, V3, MT (V5), MST and inferior parietal cortex
- Each functional area contains a full retinotopic map

Dorsal vs ventral: example

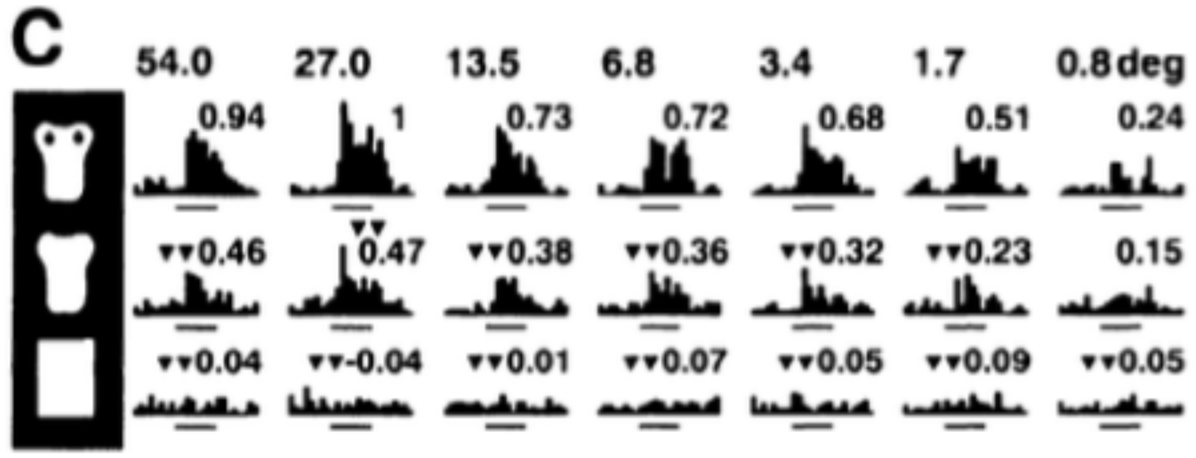
Motion perception in V5 (MT)



Perception of shapes in IT



Position invariance



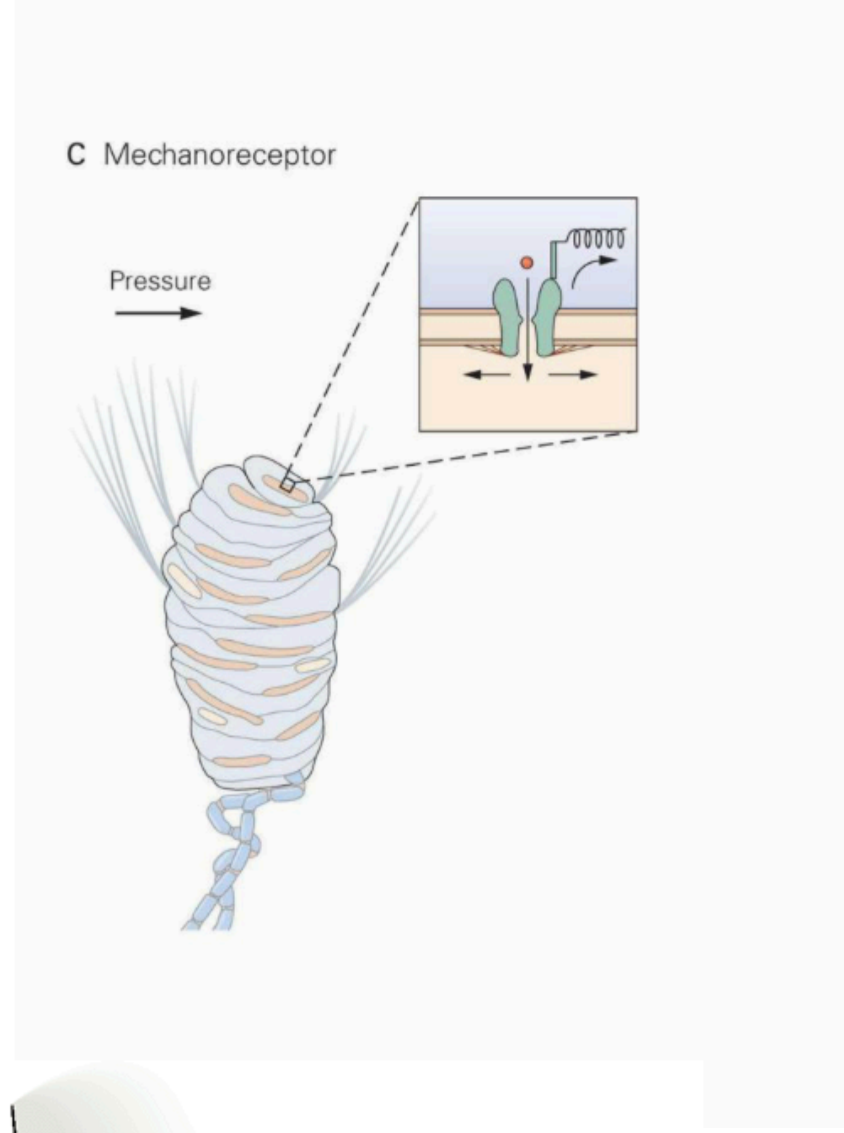
Size invariance

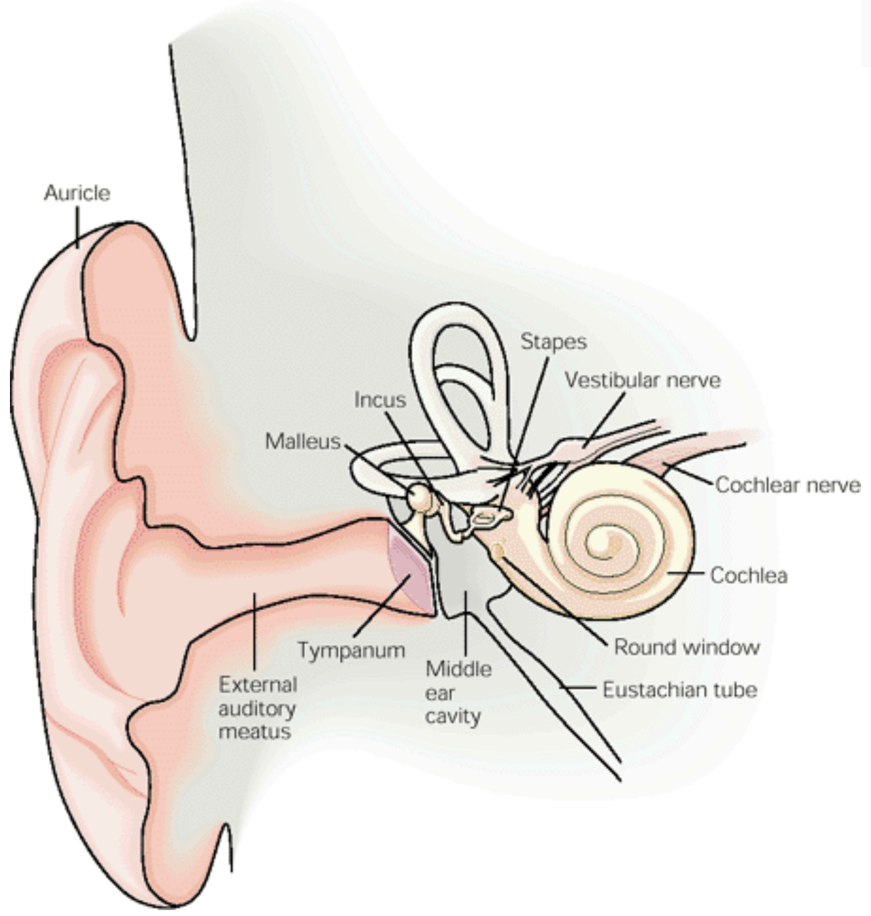
Take-home messages from the visual system

- Retinotopic mapping: geometric placement of neurons follows organisation in the retina
- The processing hierarchy: lower order areas encode lower order features of the image. Higher order areas encode higher order features
- Receptive fields grow when you ascend the hierarchy
- The dorsal stream tells you “where”, the ventral stream tells you “what”

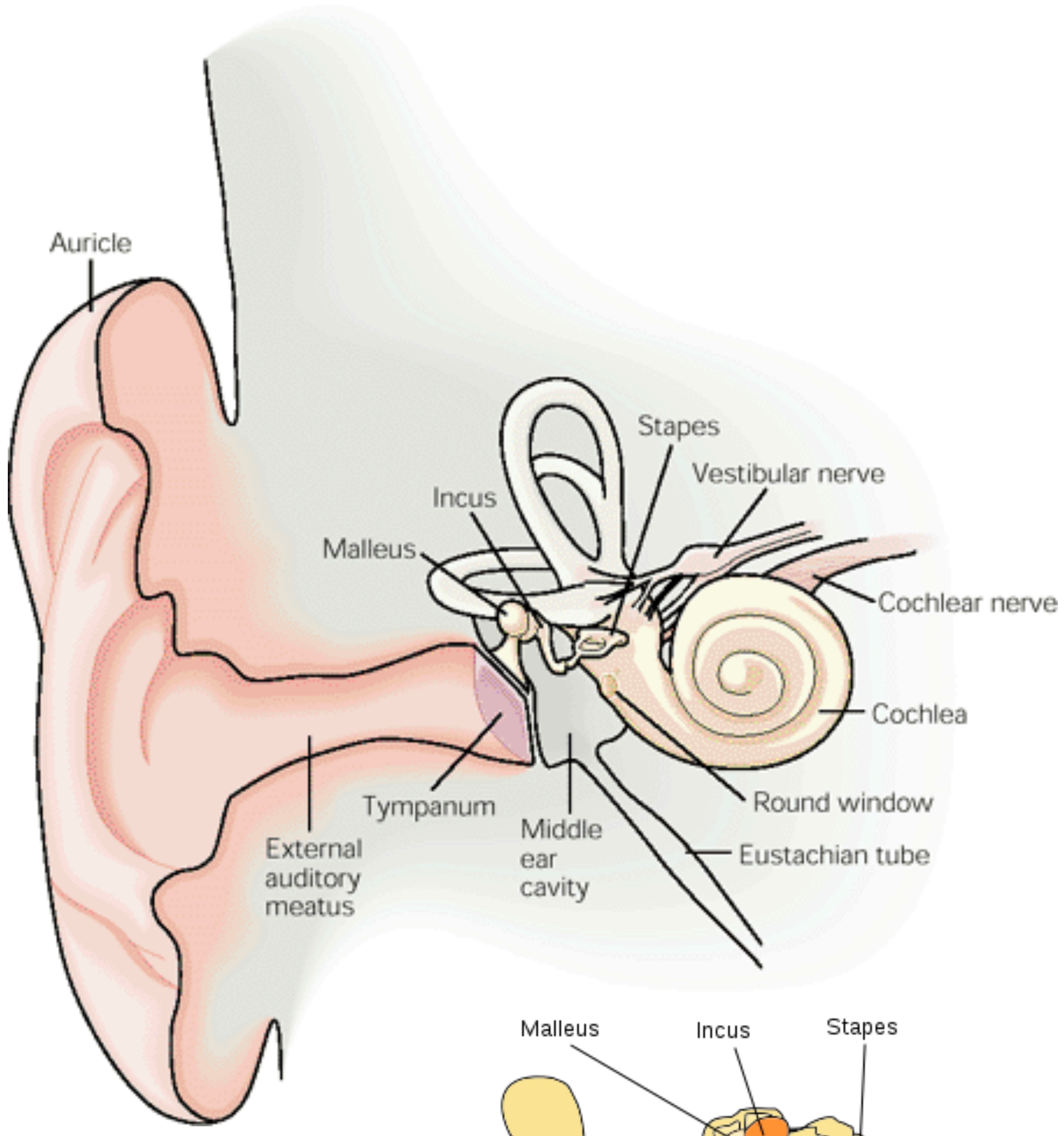
Overview: dealing with different types of data

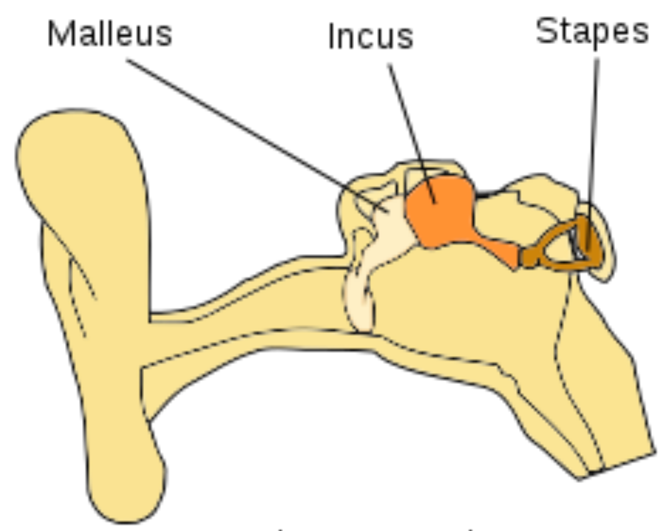
Audition





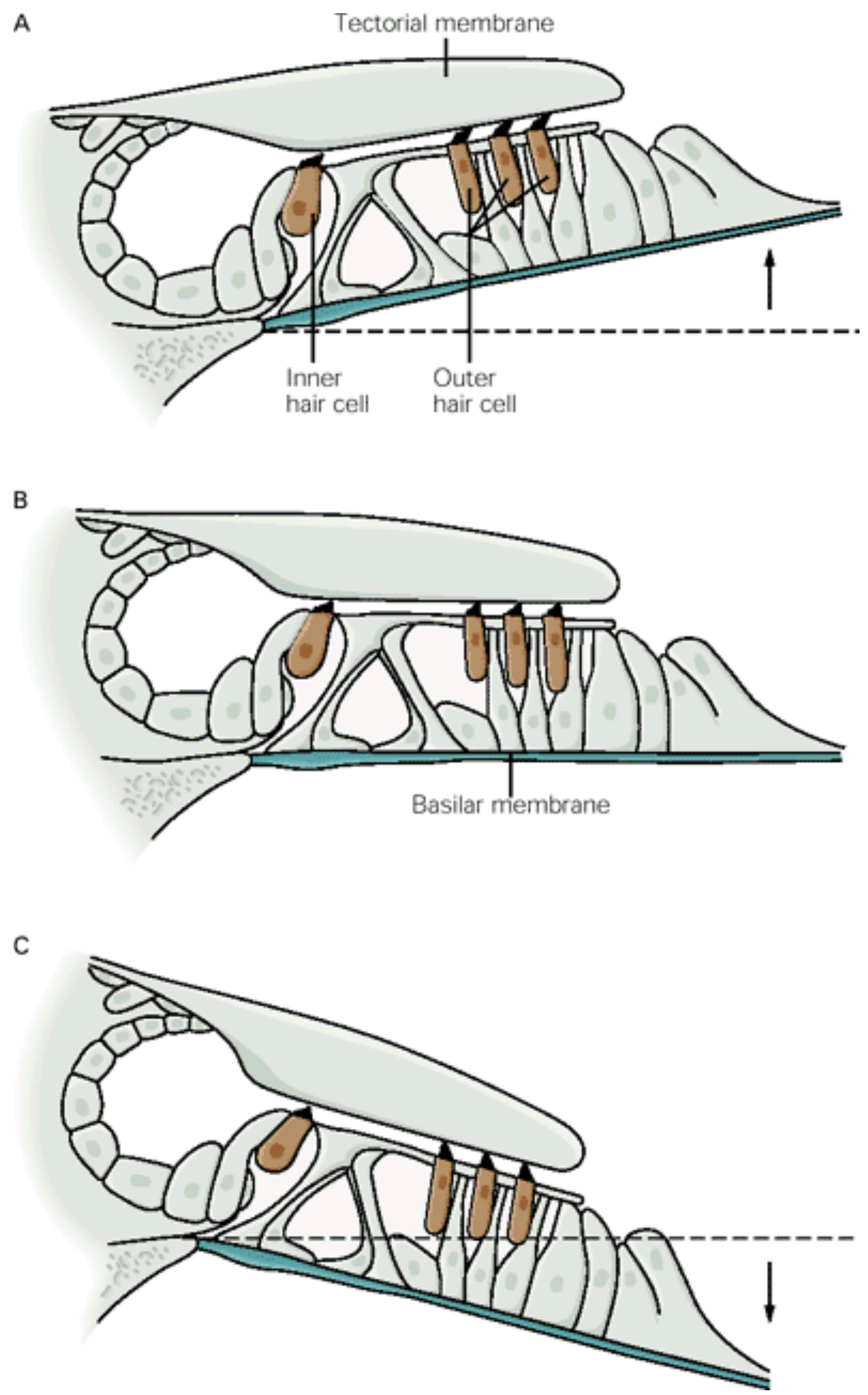
Introduction to the auditory system





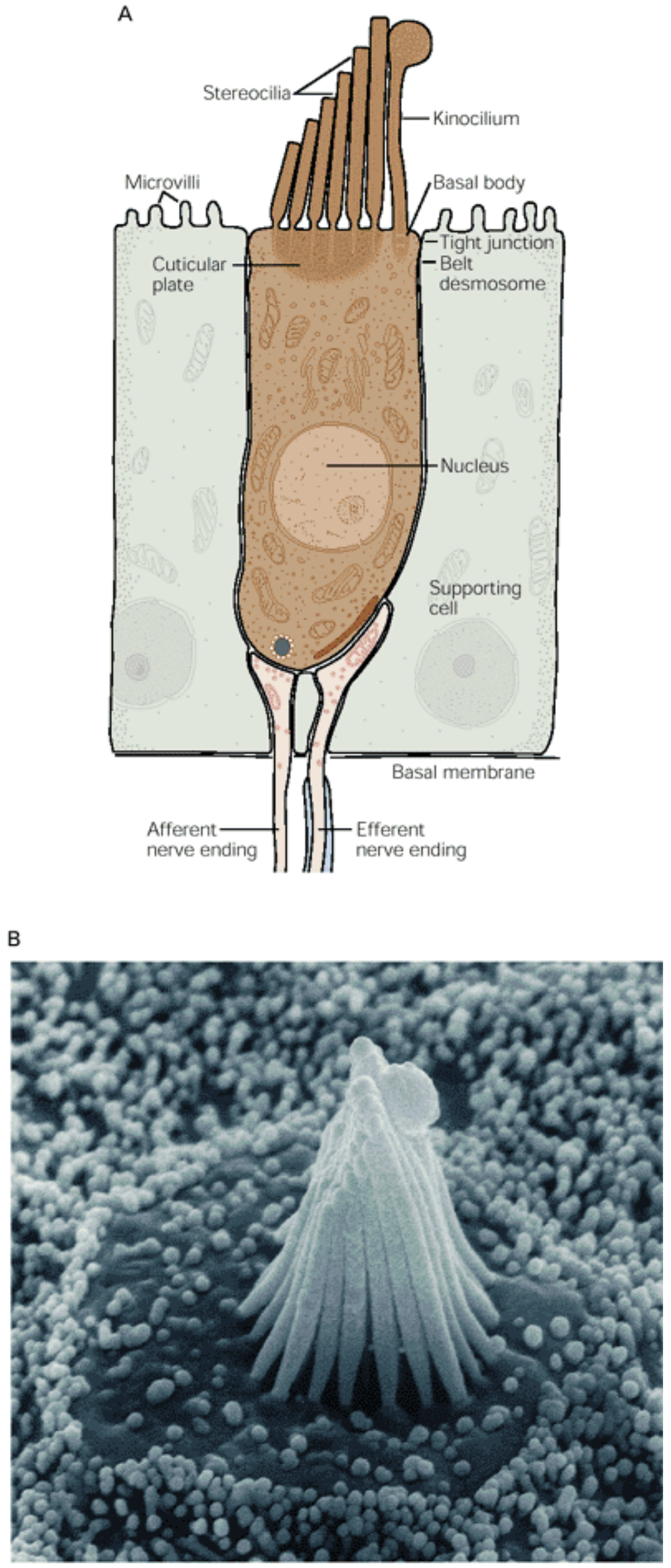
Auditory ossicles

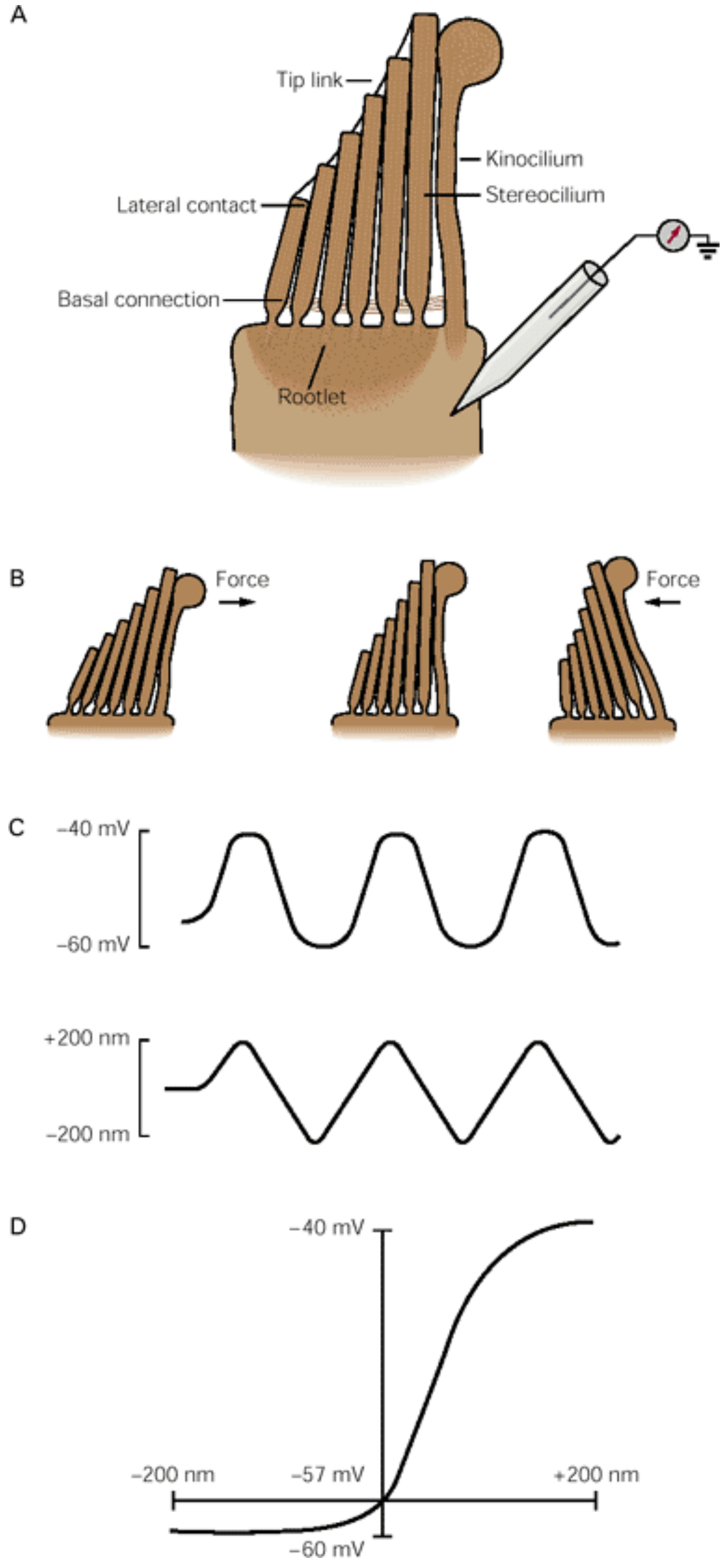
hammer, anvil and stirrup

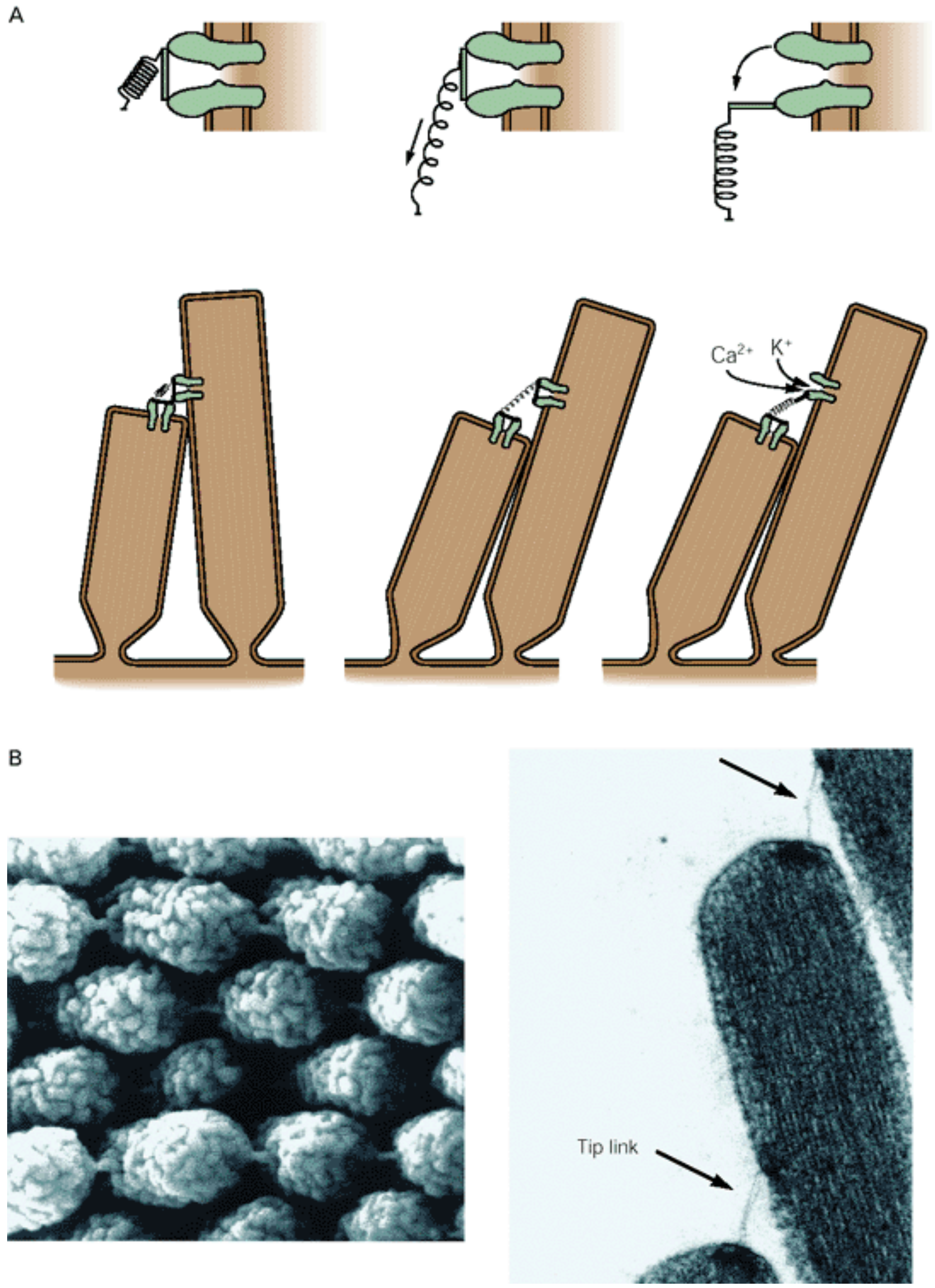


16,000 hair cells

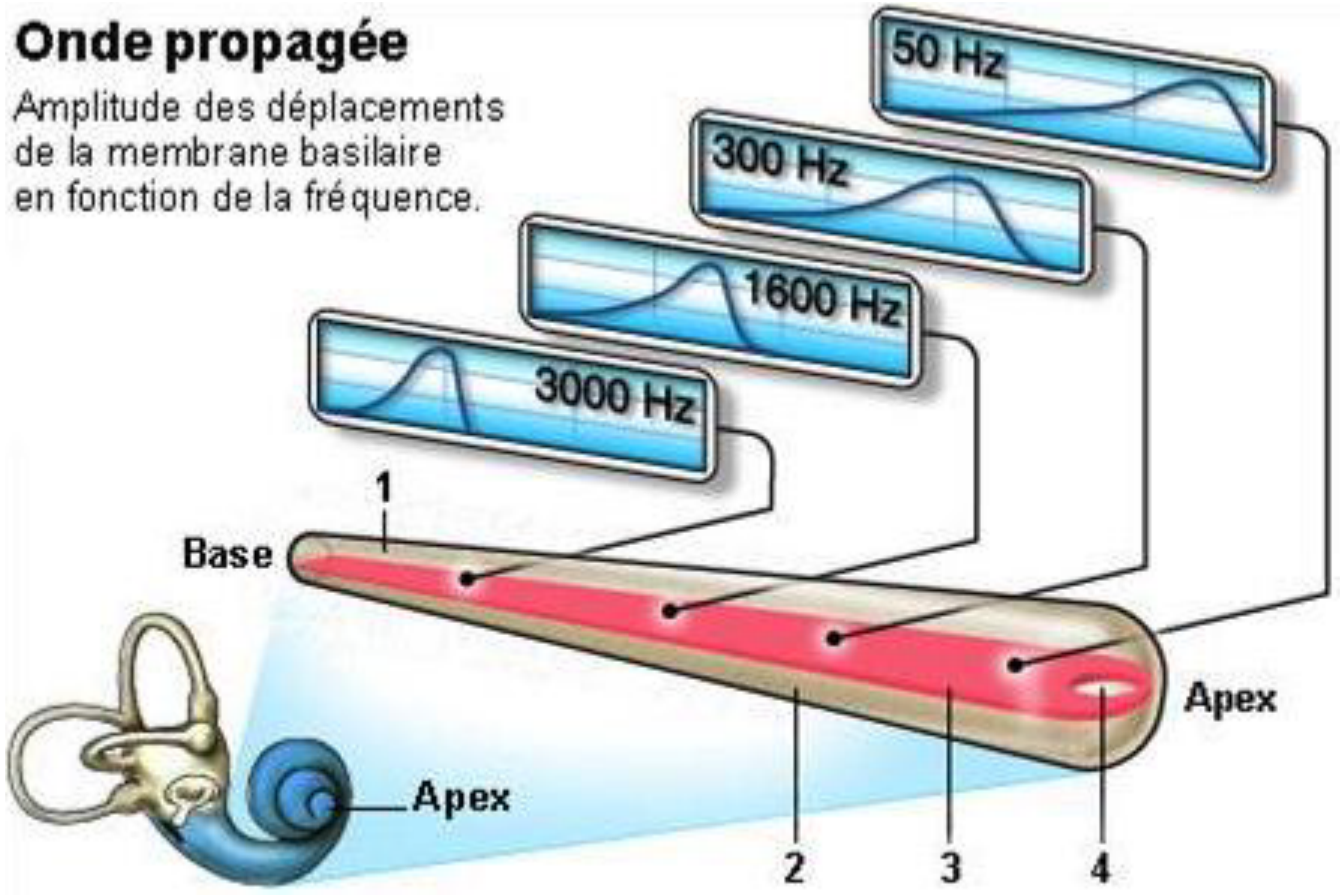
Hair cells: mechanoreceptors in the ear



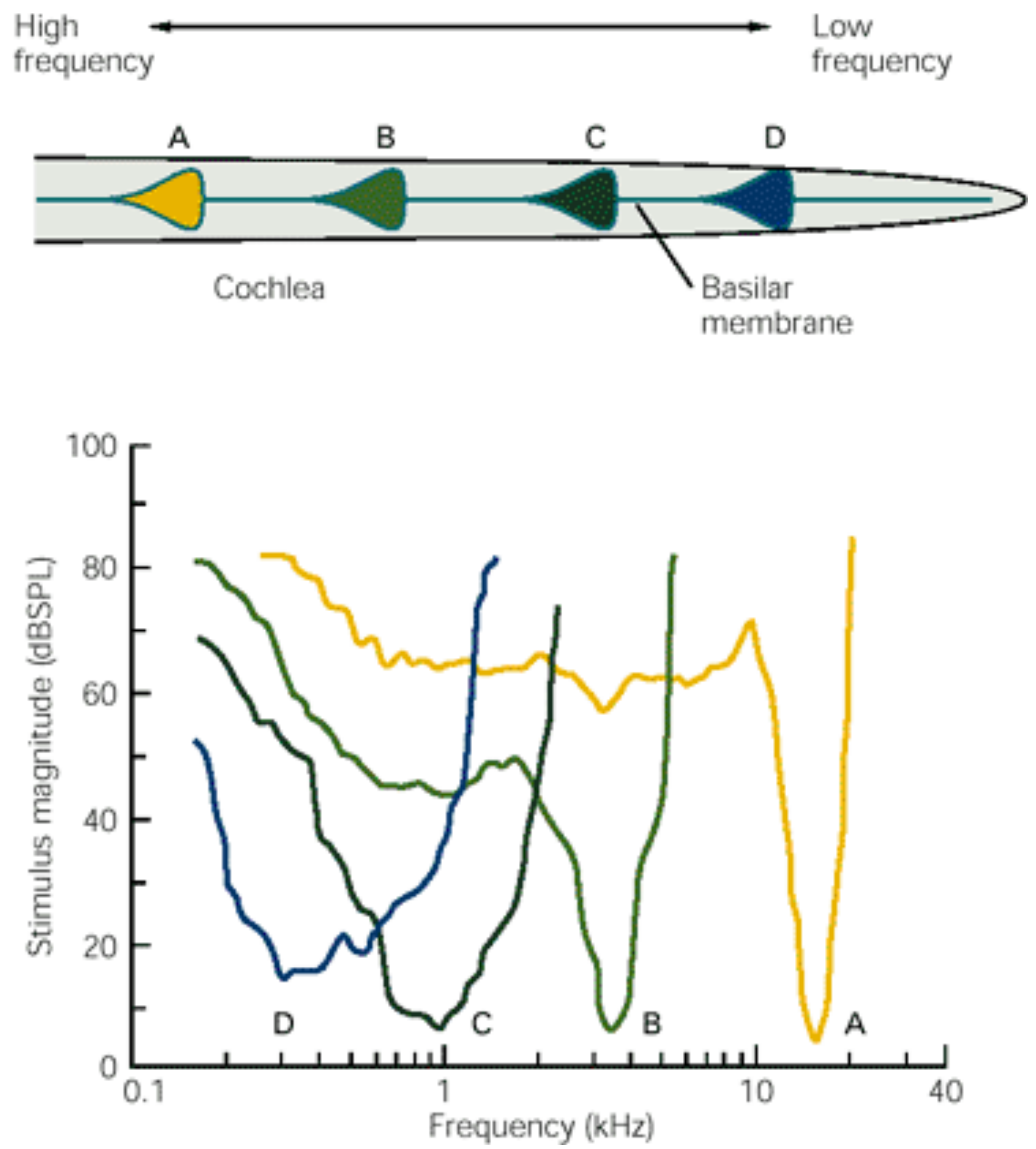




Tonotopy in cochlear hair cells



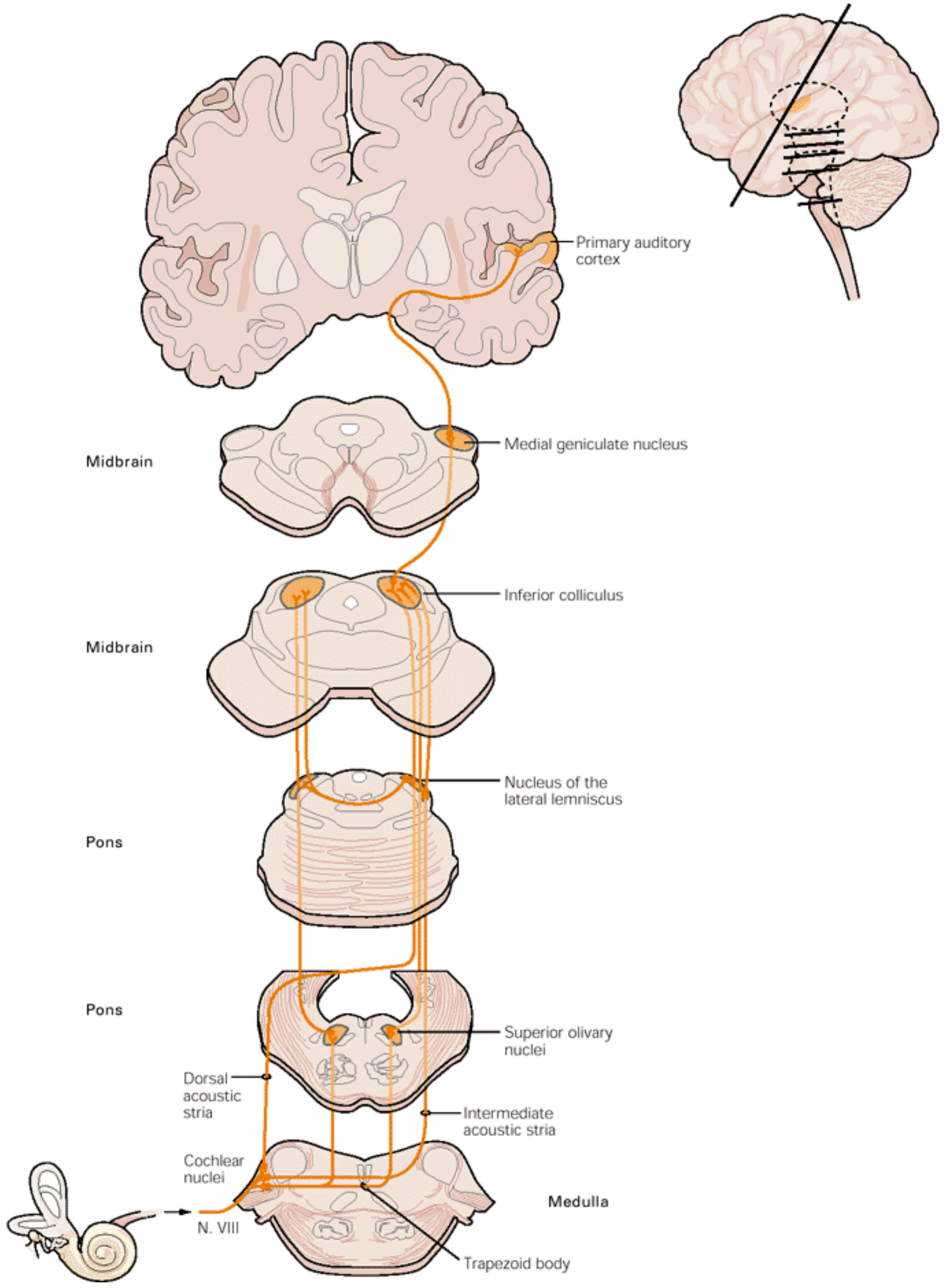
Tonotopic organisation



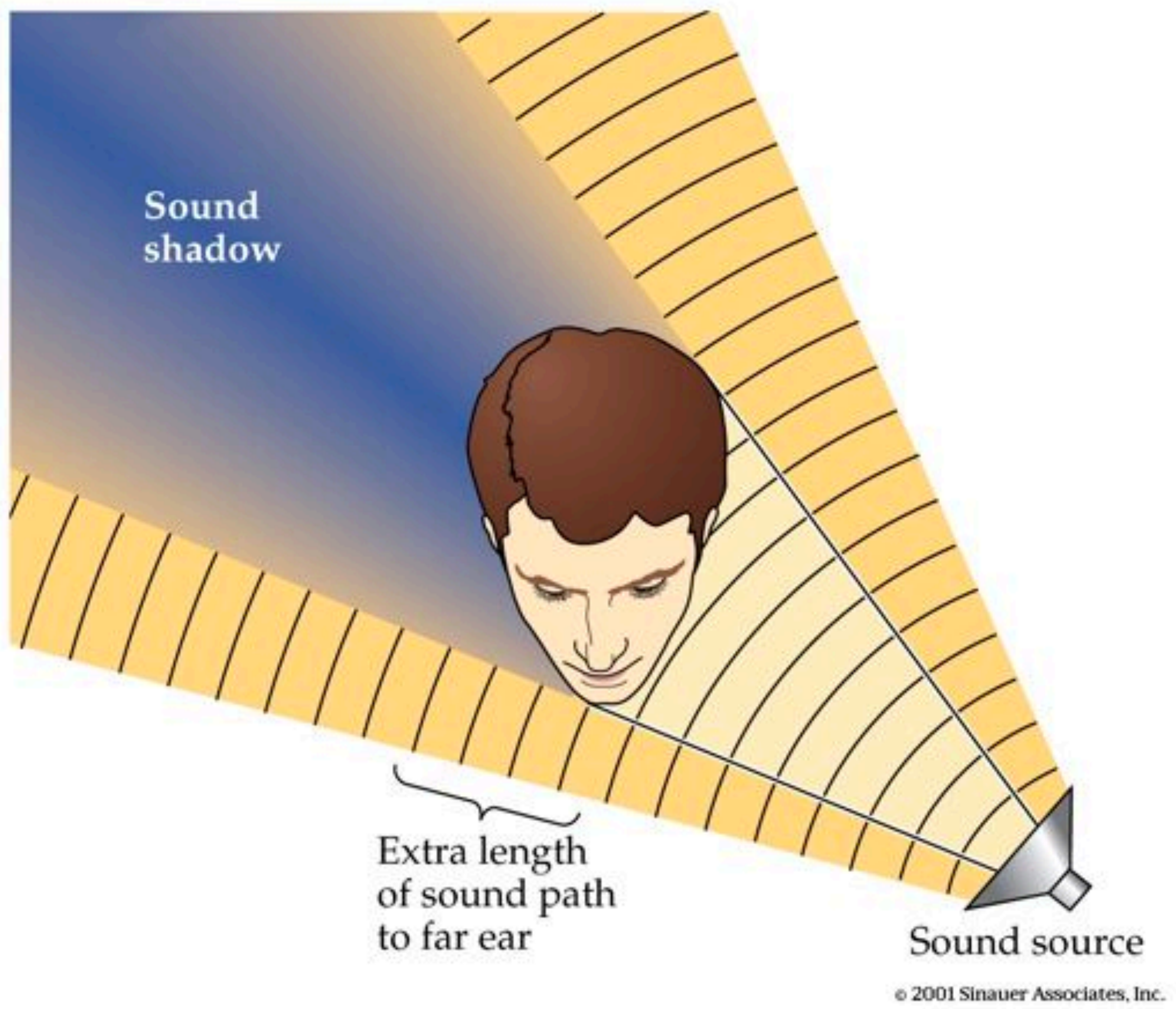
Tuning curves for cochlear hair cells

The auditory pathways: structure and function

- Auditory information is much more transient than vision
- Picking up on small temporal differences is important
- Extensive subcortical structures implement much of this quickly before information has reached cortex
- Not one, but three pathways from cochlea to cortex

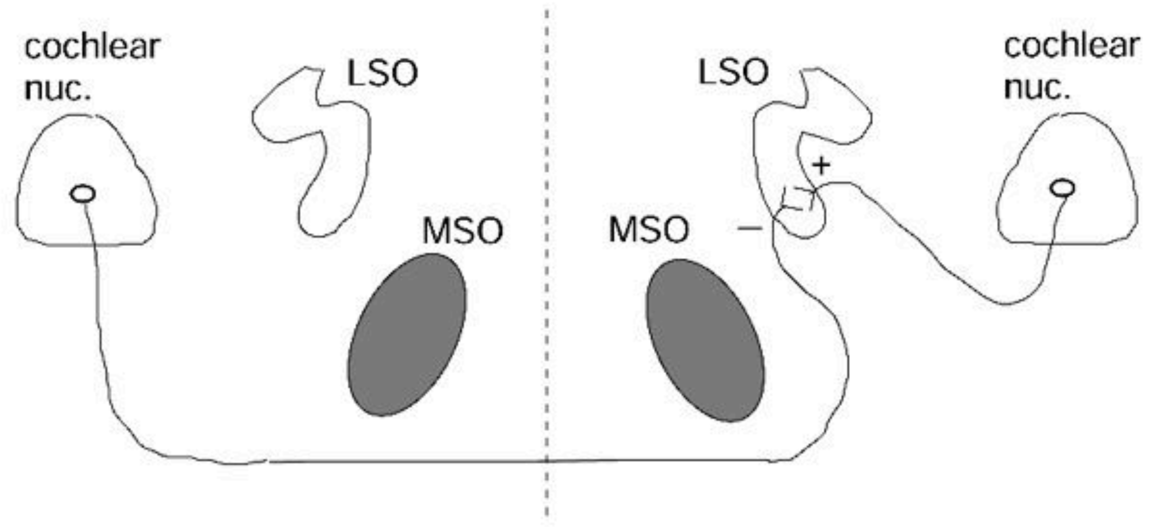


Sound localisation in the superior olive



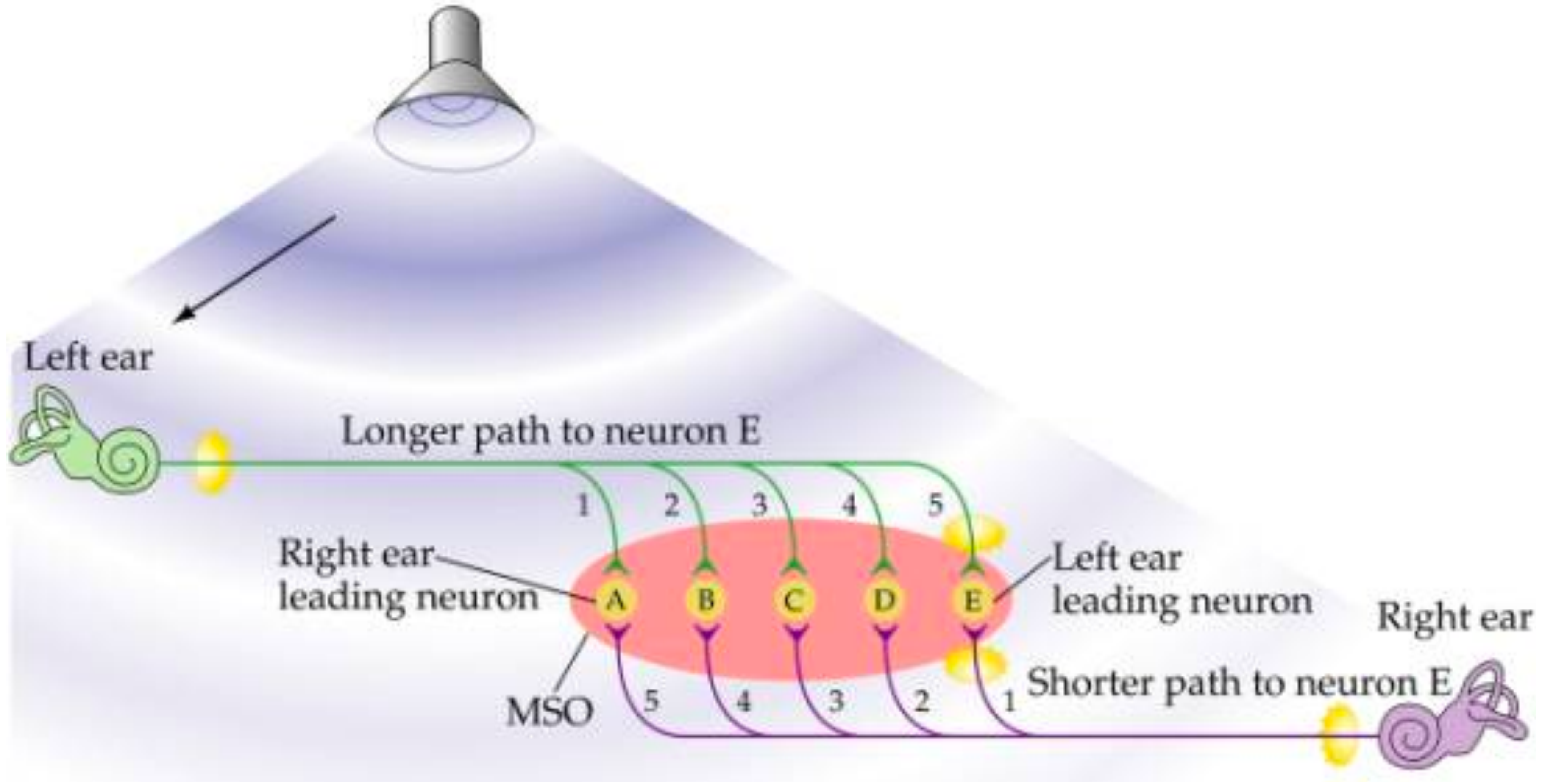
IID: Interaural Intensity Difference
ITD: Interaural Time Difference

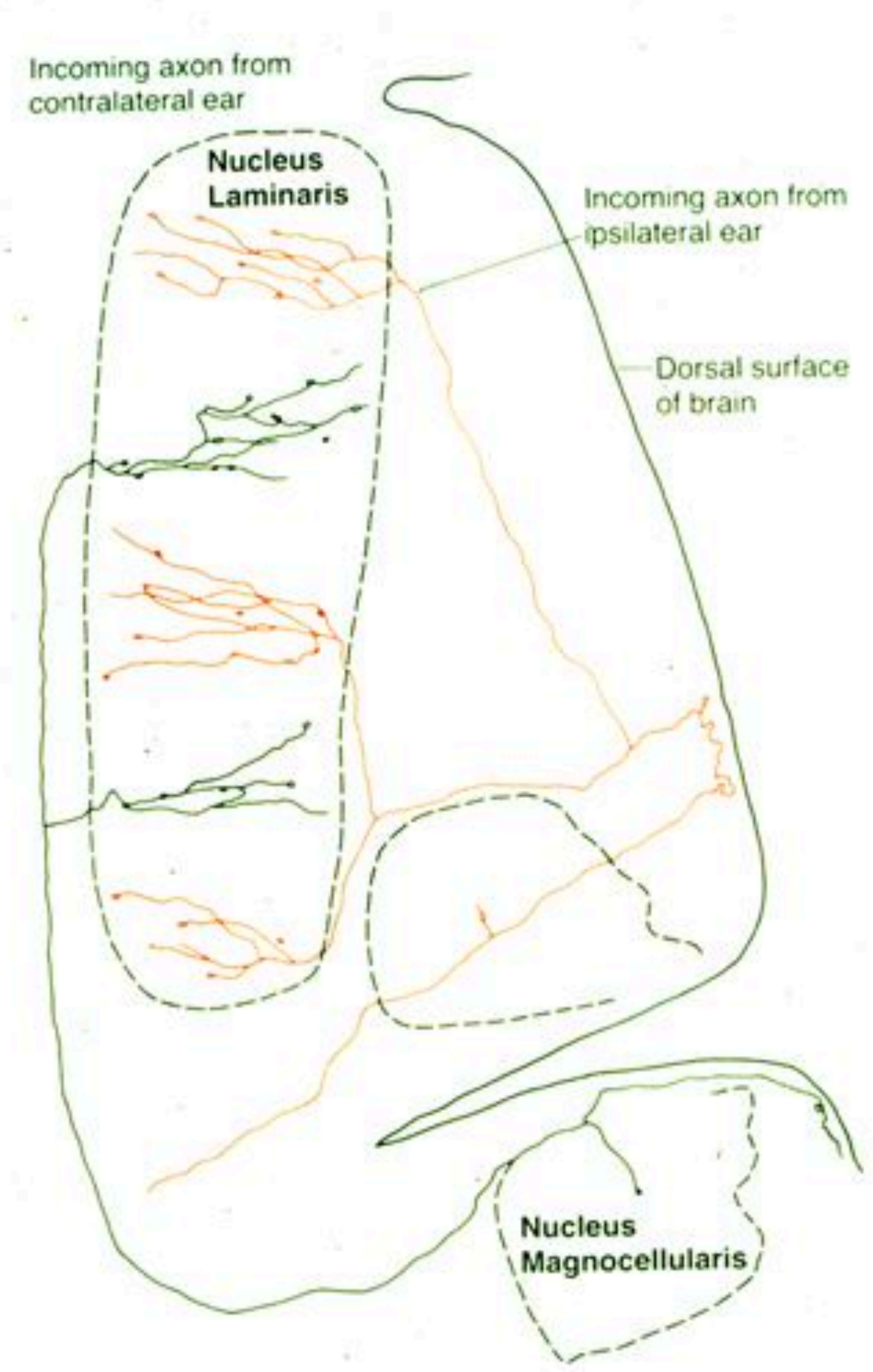
Sound localisation based on intensity difference



LSO neurons compute the difference between inputs coming from the two ears

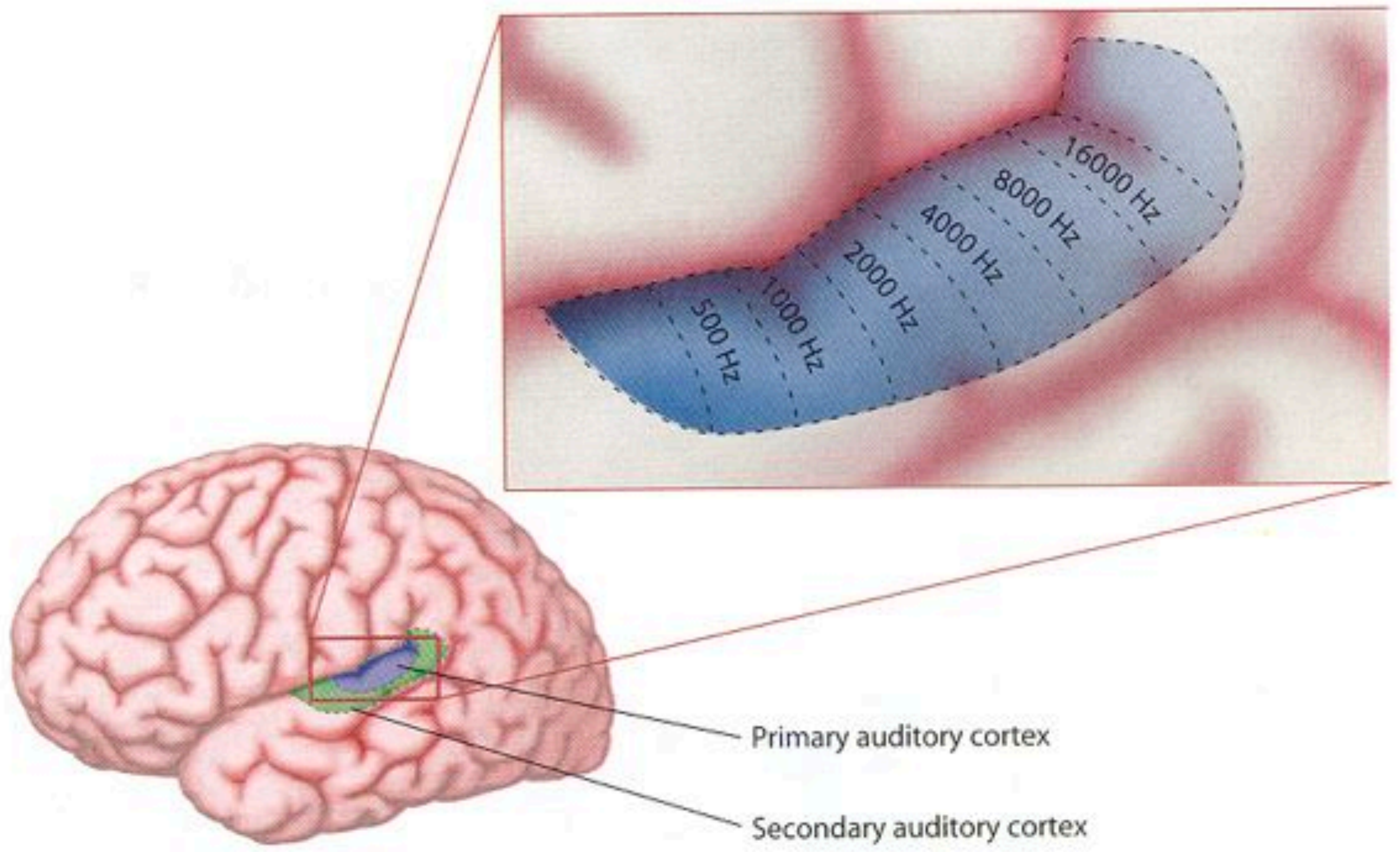
Sound localisation based on time difference

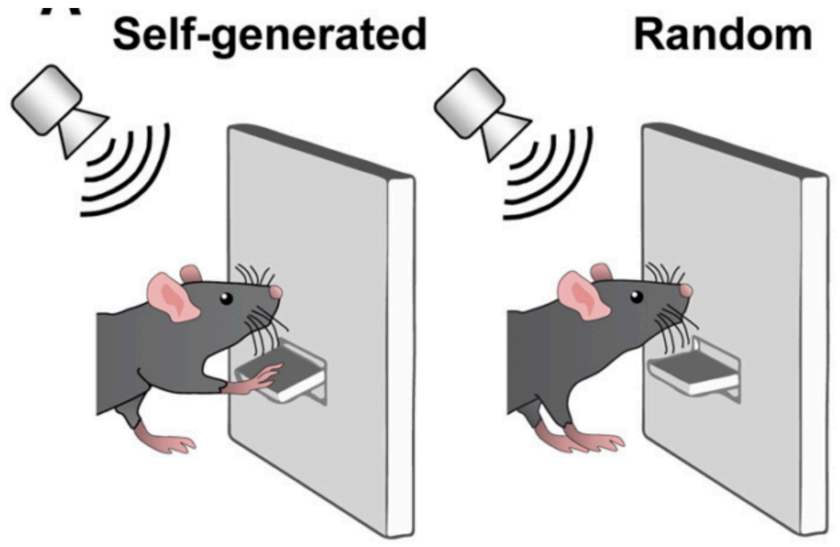


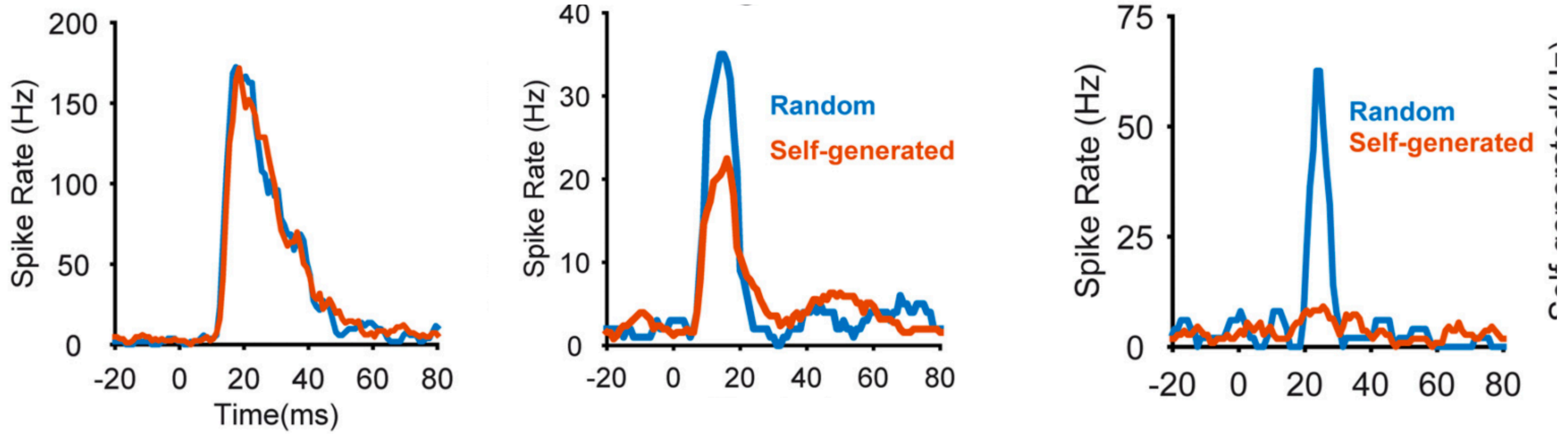


Auditory cortex

- Auditory cortex consists of multiple areas and maintains a tonotopic mapping
- There are cells that respond to either ear (EE) and cells that respond to one ear, inhibited by the other (EI)
- Its function is more ambiguous than visual cortex. Does it predict future events?







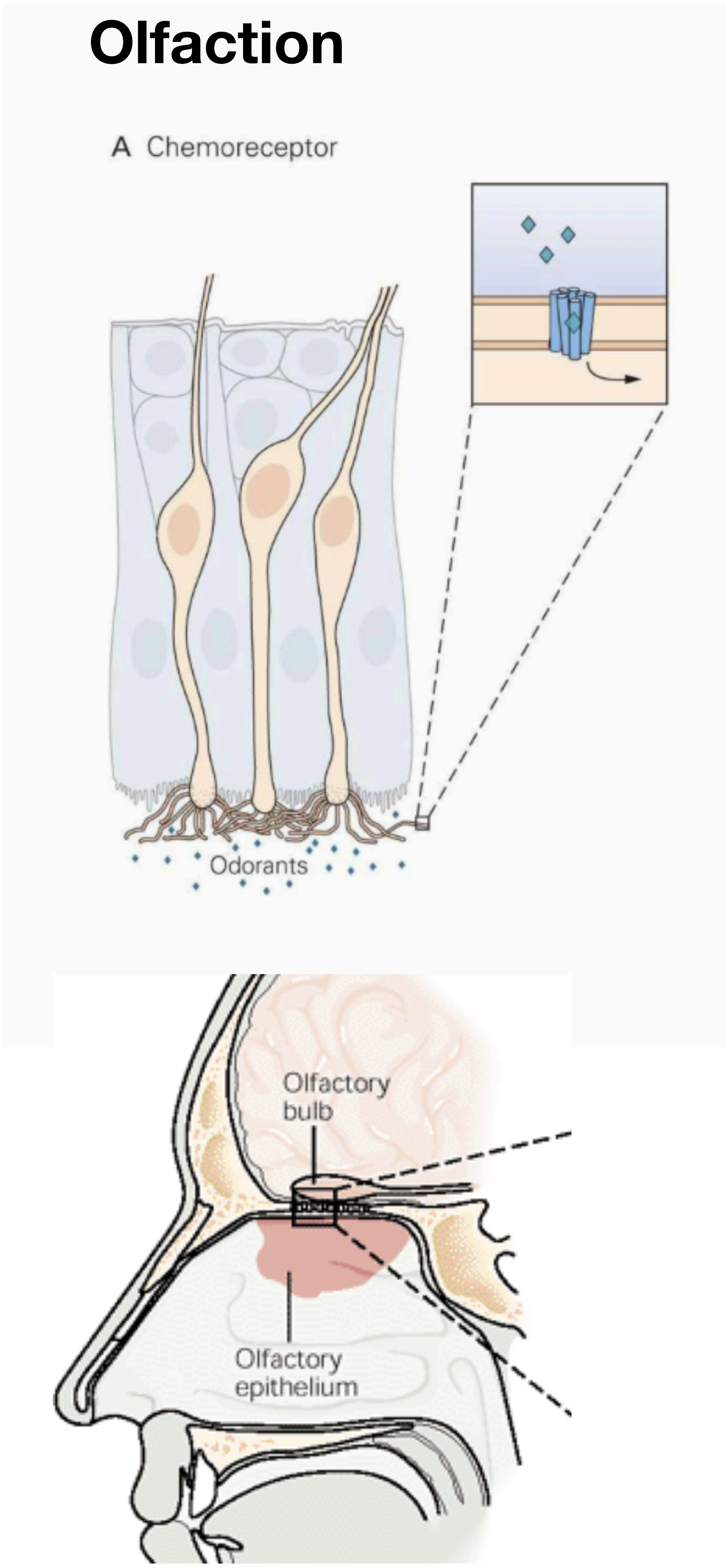
Thalamus   Auditory cortex   Hippocampus

Rummell et al. 2016, JNeurosci

Take home message for audition

- The auditory system retains tonotopic mapping
- A lot of of auditory processing happens subcortically
- Sound localisation in the superior olive: structure serves computation

Overview: dealing with different types of input

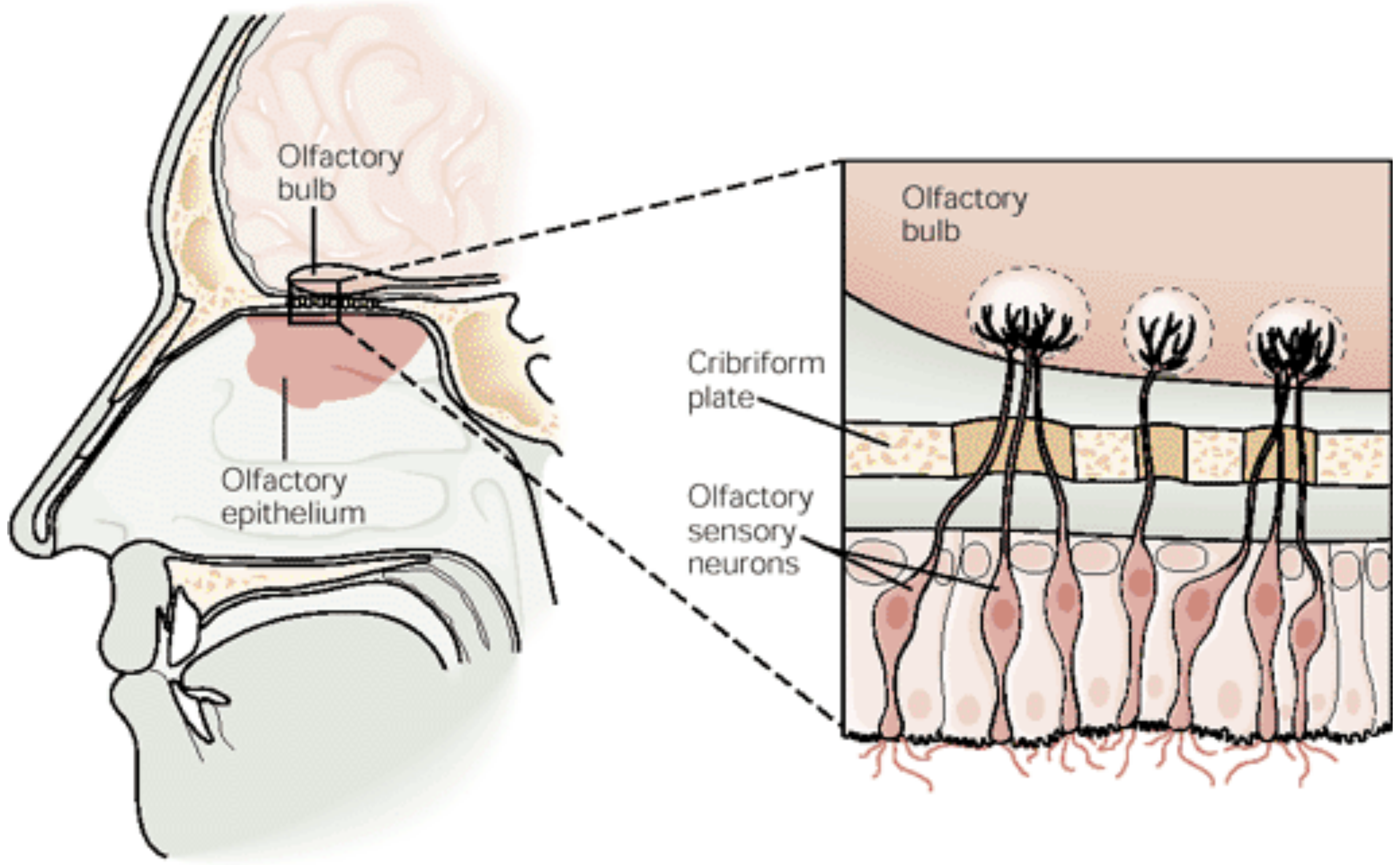


Introduction to olfaction

- The olfactory system processes information about chemicals in the environment: a specific mix of chemicals constitutes an *odour*

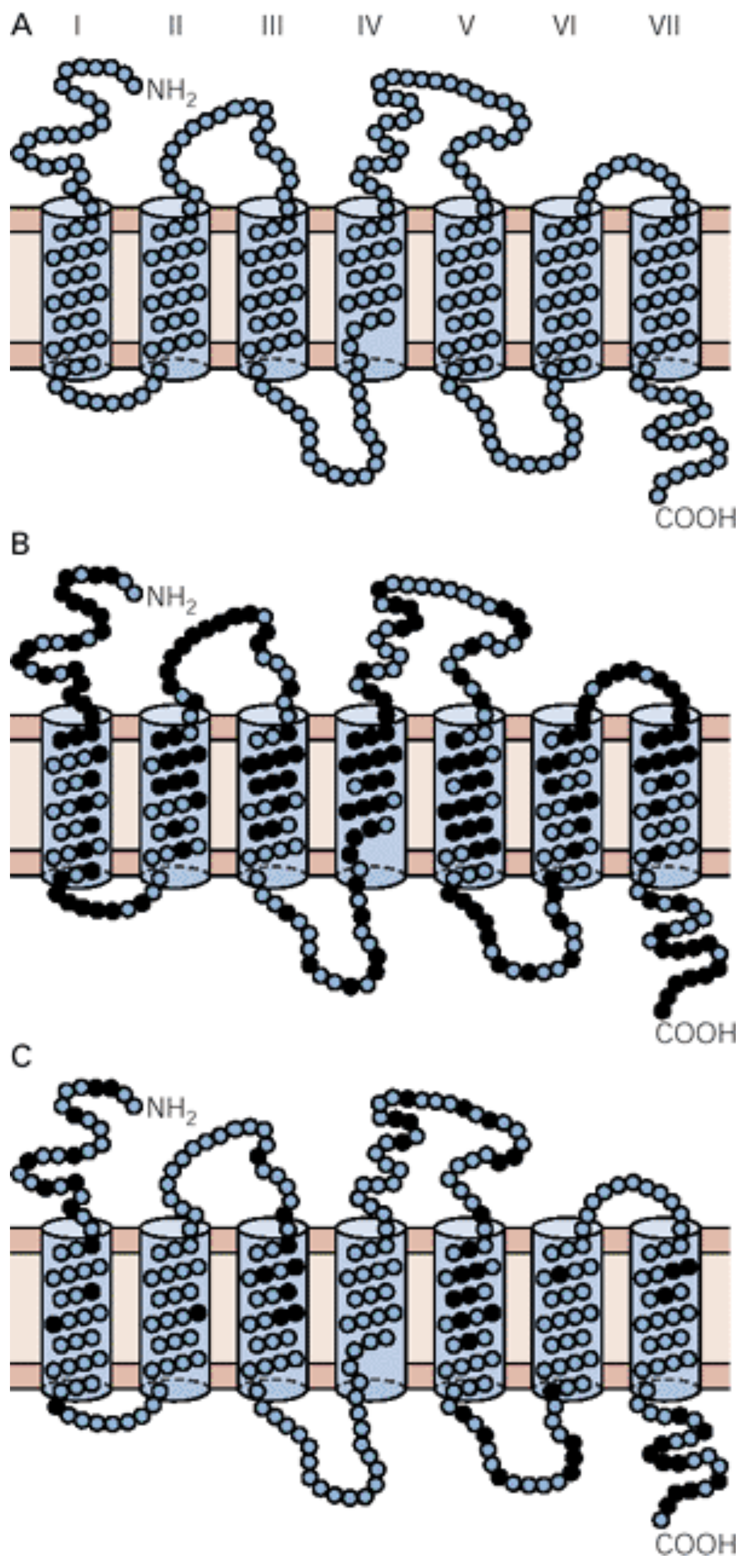
- Molecules bind to Olfactory Sensory Neurons in the nose

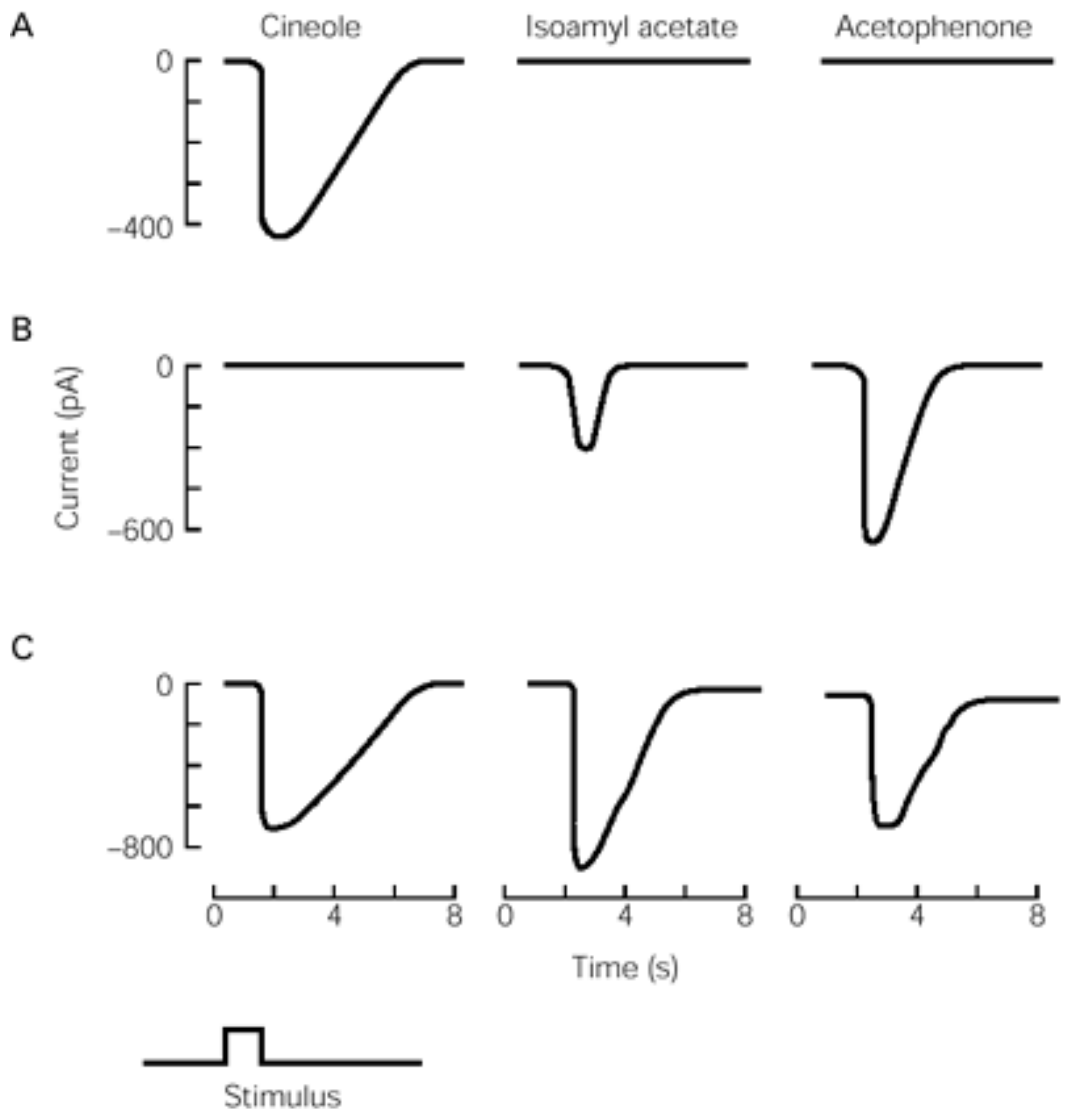
- Given the complex mixture of chemicals, which odours are present?



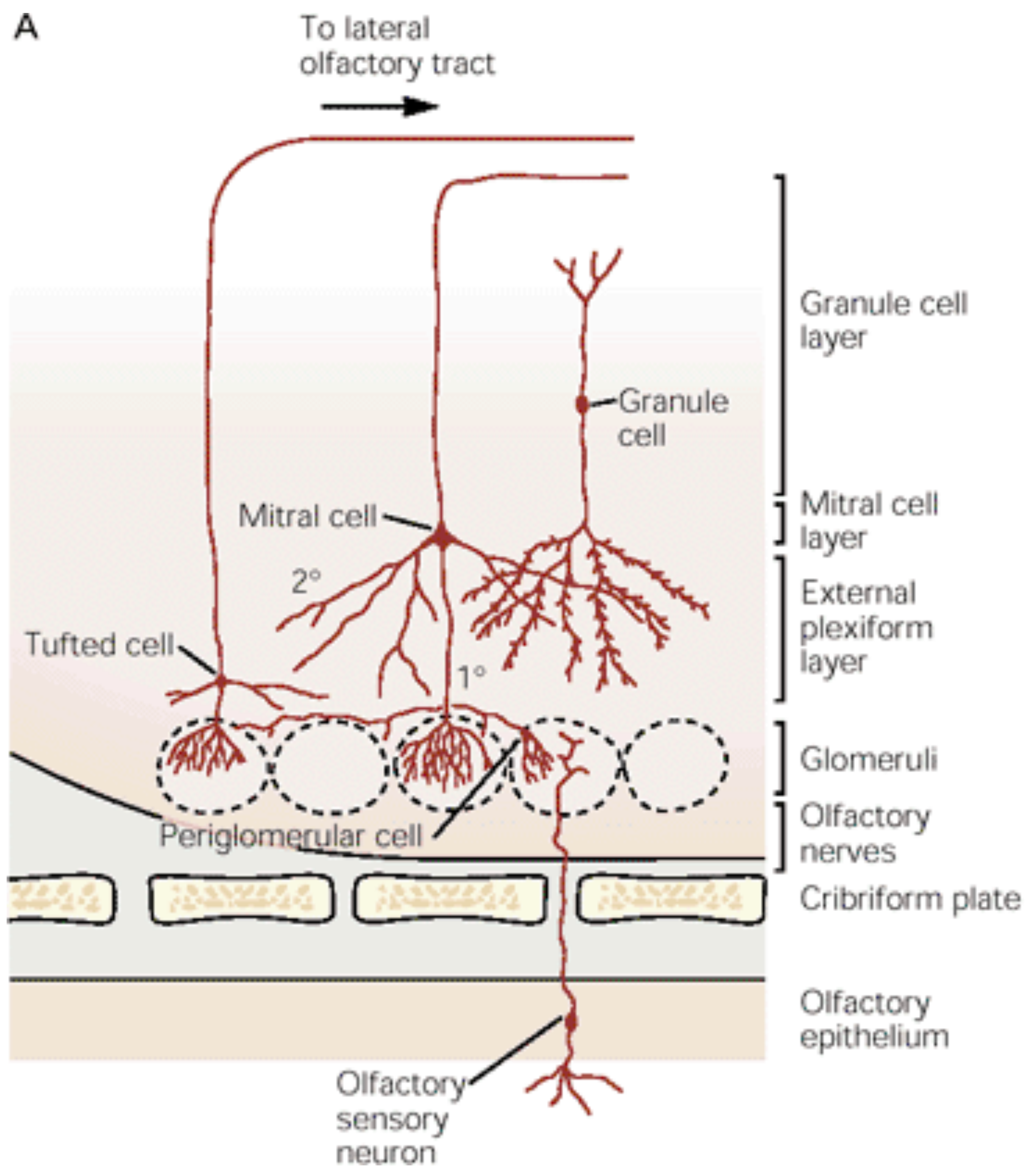
Diversity in olfactory receptors

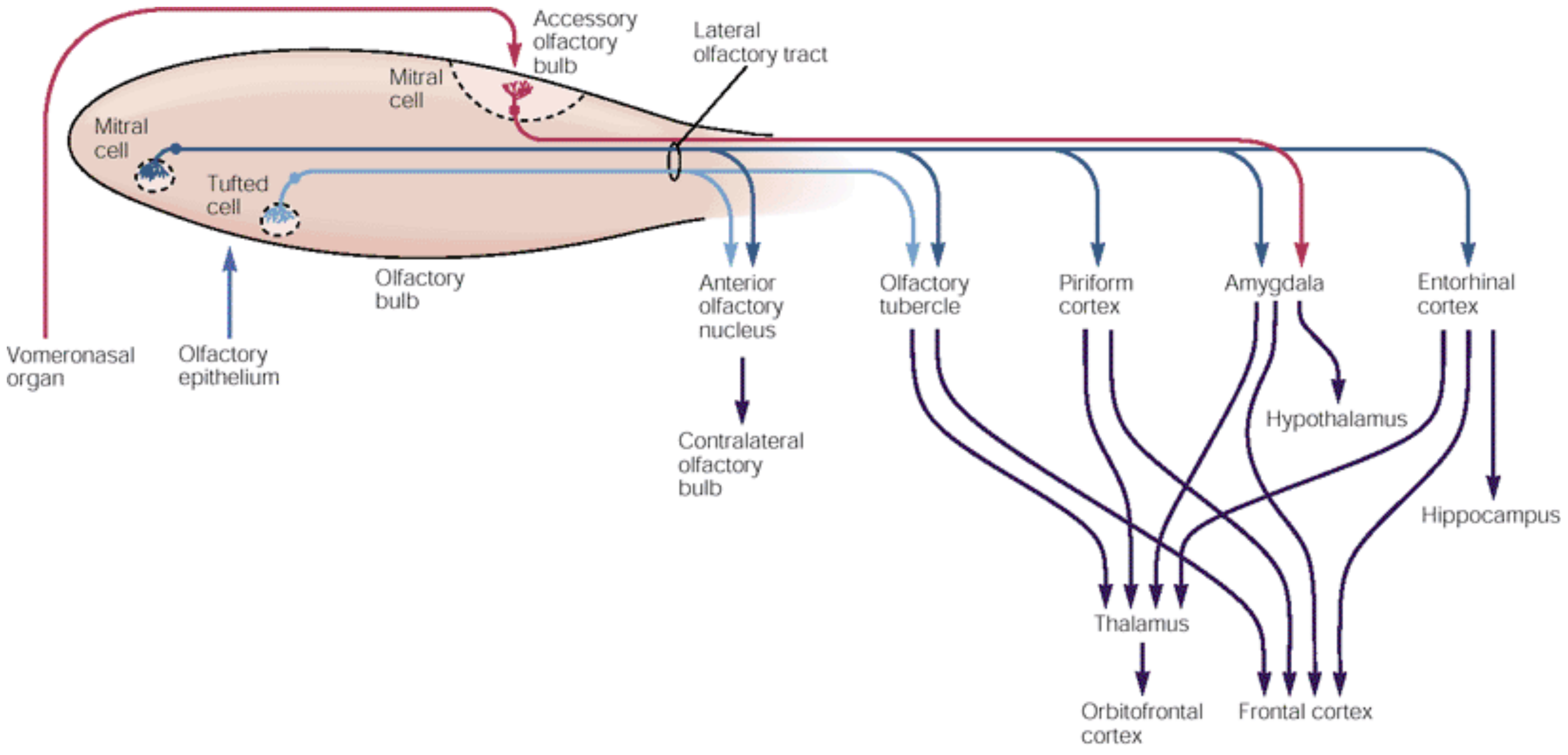
- Different olfactory sensory neurons have different kinds of receptors with different sensitivities to certain odours
- Genes in humans and rodents code for 1000 different types of odourant receptors
- Each neuron expresses only one kind of receptor





The olfactory pathways





Take home messages olfaction

- There are 1000+ receptor types in the nose
- Glomeruli in the olfactory bulb get input from a specific type of olfactory sensory neuron
- The relative location of these different glomeruli is highly genetically preserved across species

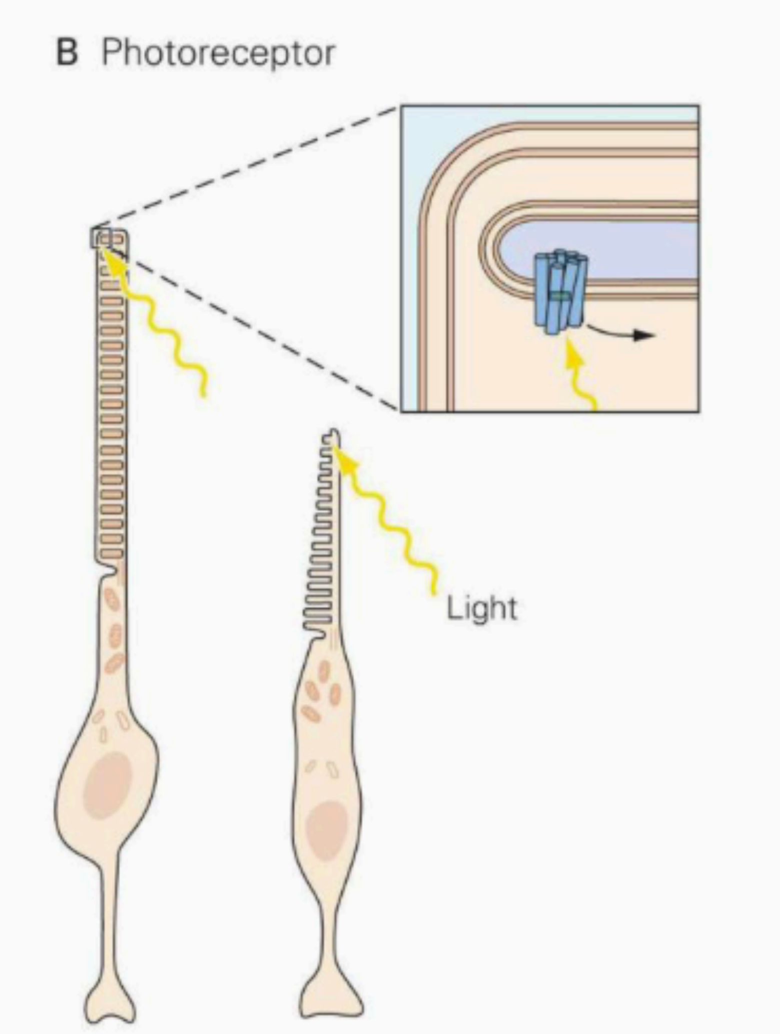
nature neuroscience

A probabilistic approach to demixing odors

Agnieszka Grabska-Barwińska[1,2], Simon Barthelmé[3], Jeff Beck[4], Zachary F Mainen[5], Alexandre Pouget[1,6–8] & Peter E Latham[1,8]

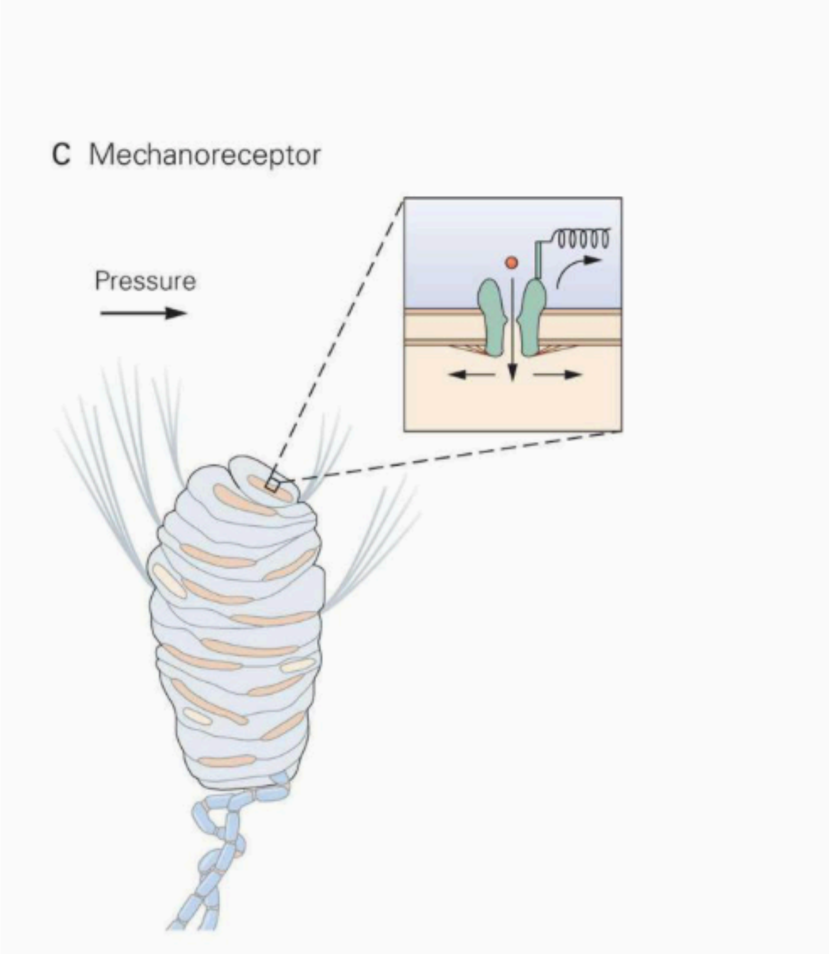
Overview: dealing with different types of inputs

Vision



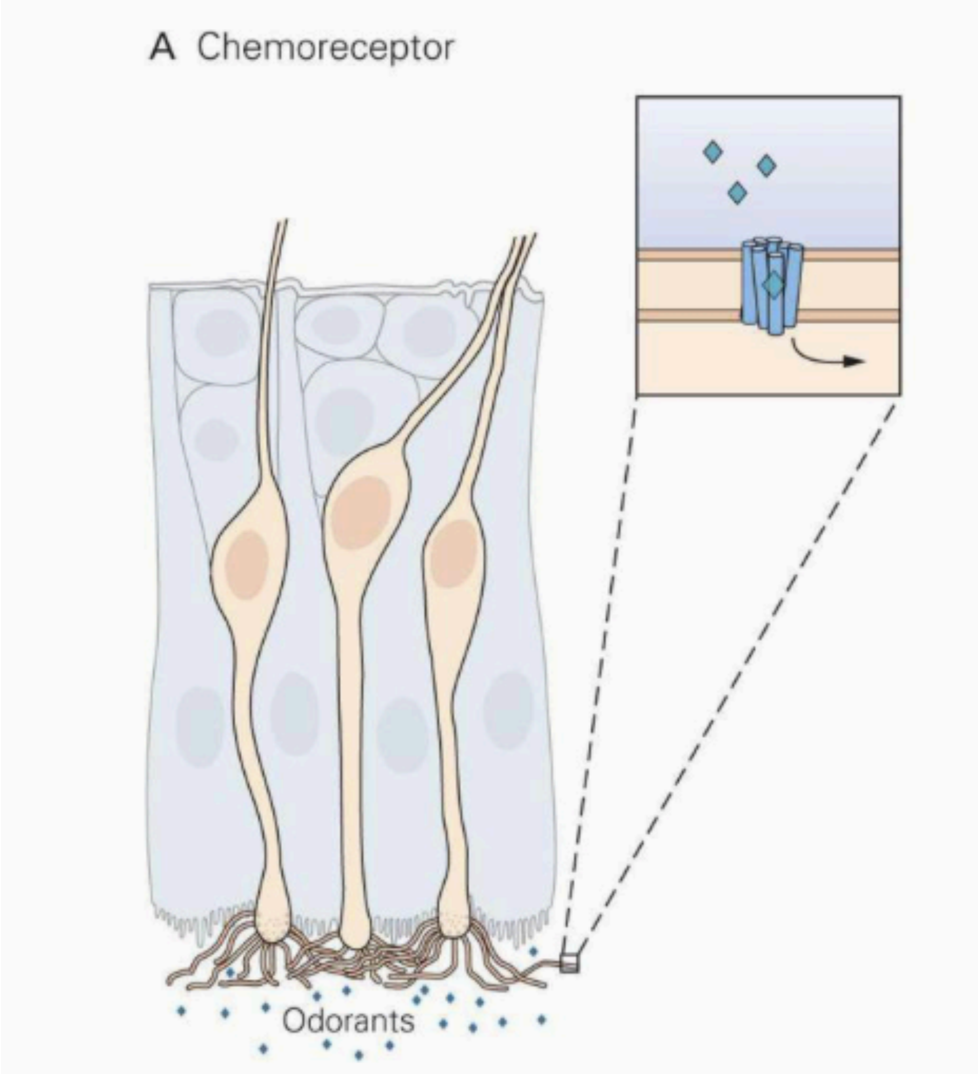
- Goal: reconstruct 3D world from 2D image
- Most complex system: mostly cortical processing
- Functional specialisation in *what* and *where*
- Retinotopic mapping

Audition



- Goals: identify and localise sounds, speech comprehension, etc.
- Timing is crucial: extensive subcortical processing
- Tonotopic mapping

Olfaction



- Goal: demix odours to identify source
- Direct connections from olfactory bulb to many areas
- Preserved spatial organisation of odours