Section 5
Audition

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COGS 17 A05

04/28/25

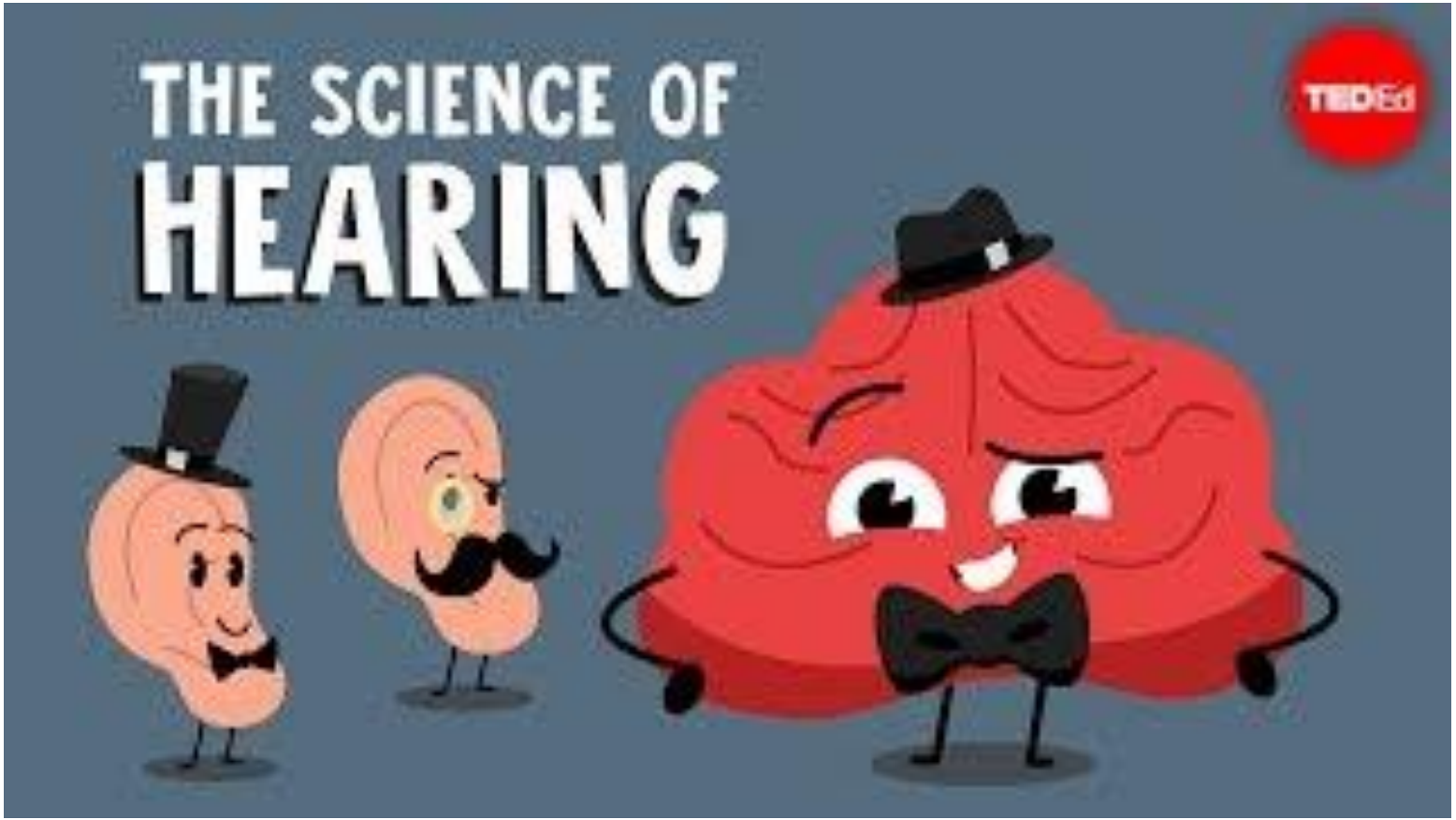
Notice

Online TA discussion section Next Week (05/05)

Will post Canvas notification for Zoom link

– same as office hour

Before we start…

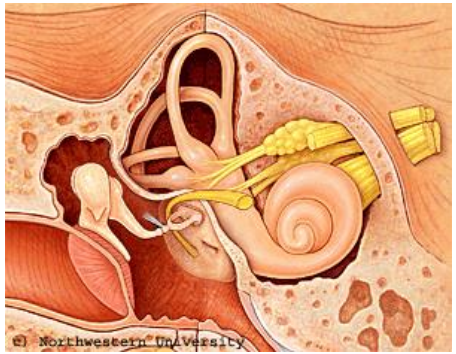


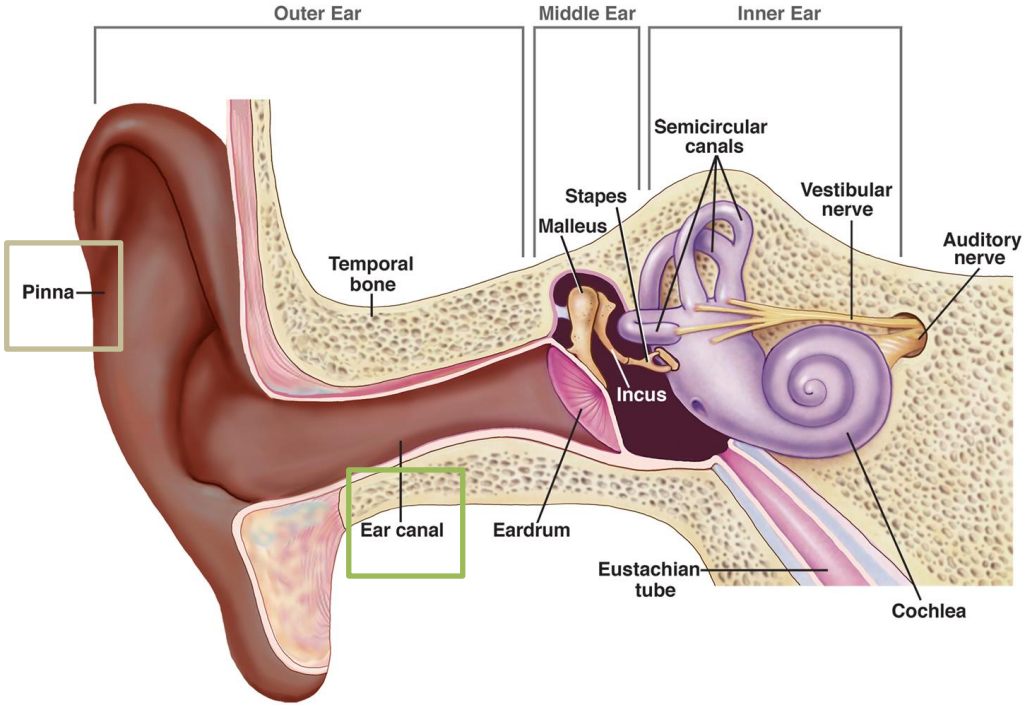
Anatomy of Auditory Reception

Outer Ear

- Pinna
  - The outer ear structure that helps localize sounds

- Auditory Canal
  - Channel that focuses sound waves and connects to the eardrum





Anatomy of Auditory Reception

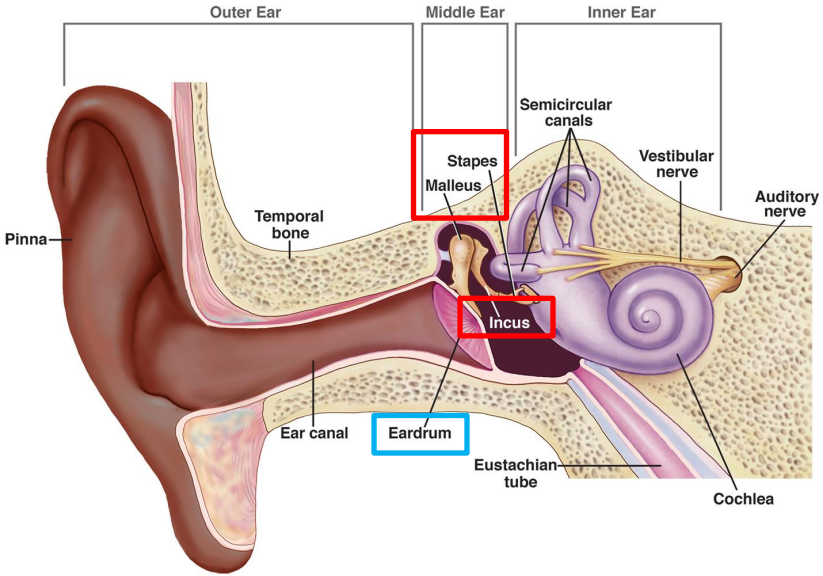
Middle Ear

- Eardrum
  - Membrane that helps convert air pressure into kinetic energy via the Ossicles
  - a.k.a. tympanic membrane

- Ossicles
  - Consists of **3** small bones: Malleaus, Incus, and Stapes

  - Overcomes impedance mismatch (easy to vibrate air molecules, but hard for cochlear fluid)

  - How? By amplifying vibrations of the eardrum (air pressure) to vibrations that can move fluid (kinetic energy)



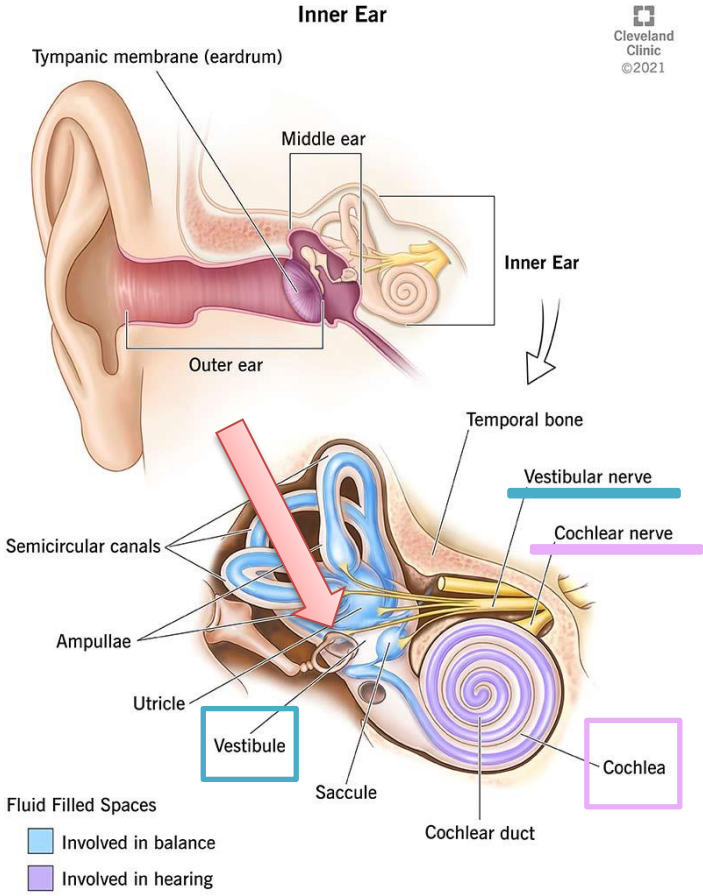
Anatomy of Auditory Reception

Inner Ear

- Oval Window
  - entrance point of sound waves in cochlea
  - A membrane at the Base of the upper chamber of the Cochlea
  - Ossicles act like an amplifying connection from the Eardrum to the Oval window

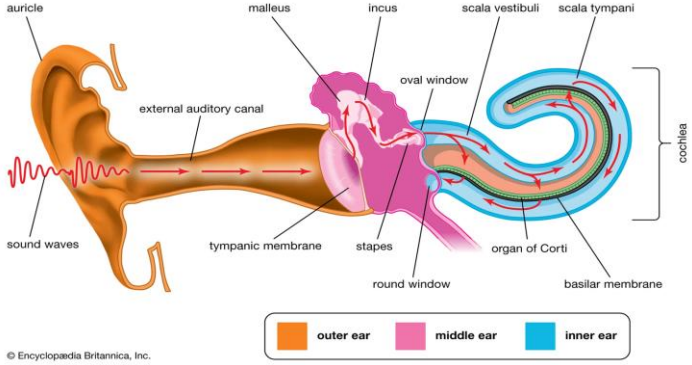
- Cochlea (hearing)
  - A snail-shaped coiled tube with 3 fluid-filled chambers

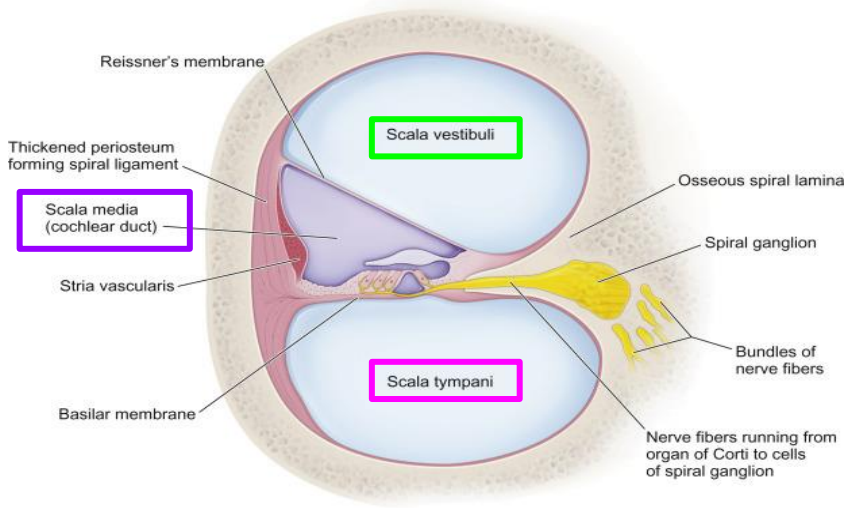
- Vestibule & Semicircular canal (balance)



Cochlea

- Converting sound waves → neural signals
- Vibrations from the **Oval Window** travel up from the base of the top chamber, to the **Apex** (end of the turns), then circle back to the base of the bottom chamber ending at the **Round Window**
- Consists of 3 chambers:
  - **Scala Vestibuli** (Upper)
  - **Scala Media** (Middle)
  - **Scala Tympani** (Lower)
- As the vibrations travel, they also vibrate the middle chamber S. Media

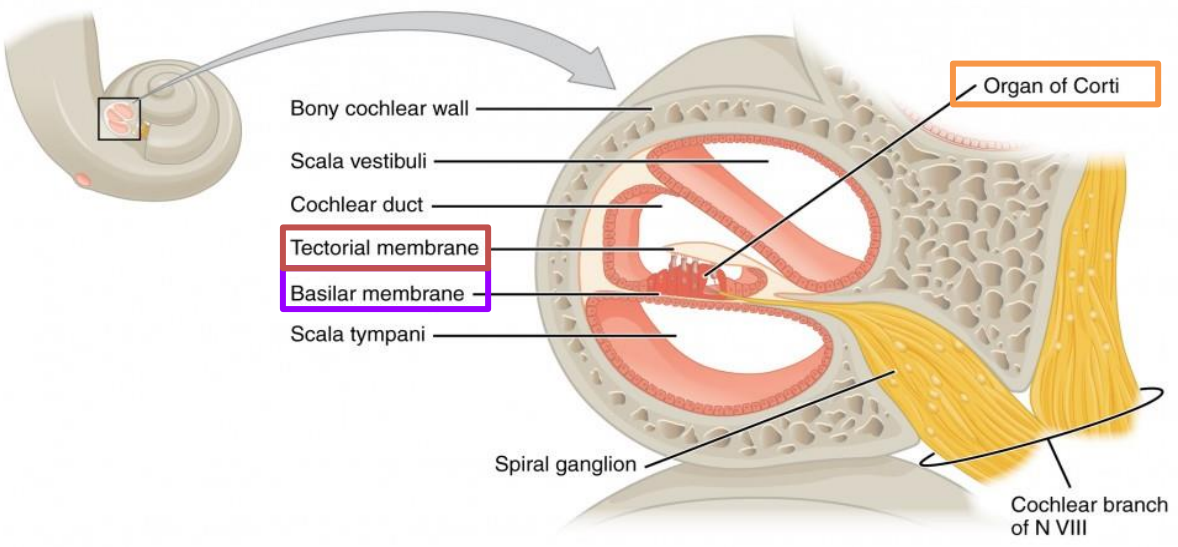




Cochlea

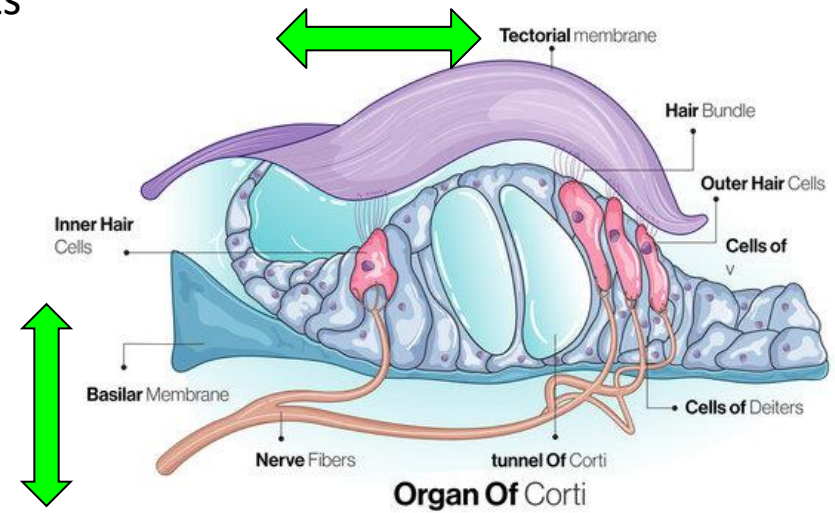
- Basilar Membrane – The floor of Scala Media

- Organ of Corti
  - Located on top of the Basilar Membrane
  - Contains specialized Neurons called **Hair Cells (auditory receptors)**
  - Covered by the Tectorial Membrane (roof) like a blanket



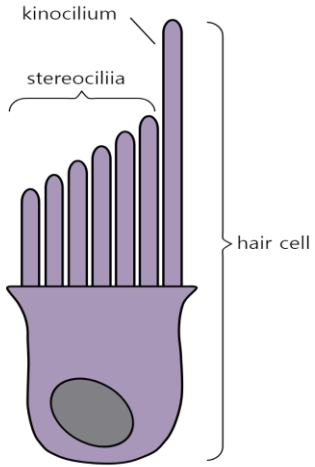
Organ of Corti

- Chambers are filled with a viscous, non-compressible K+ rich fluid called **Endolymph**
- Vibrations causes the Basilar Membrane to move **up and down** and the Tectorial Membrane to move **left and right**
- Cilia of Hair Cells are bent between these two membranes which triggers a cascade of downstream effects



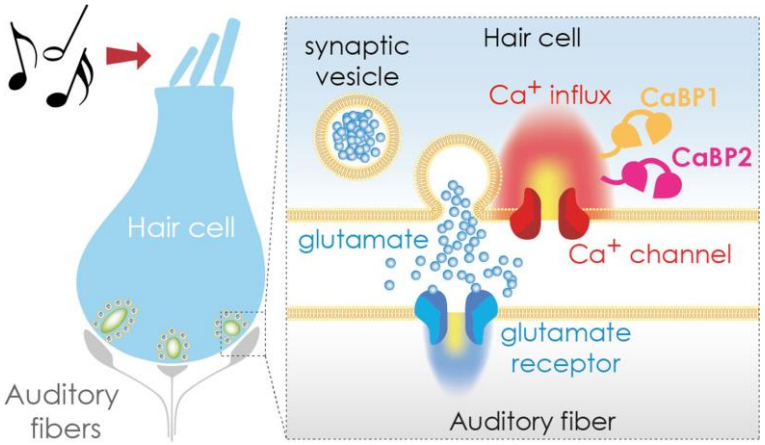
Hair Cell

- Auditory receptors that stand b/w Tectorial Membrane and Basilar Membrane
- Higher concentration of **K+** outside cell (cochlear fluid) → K+ enters (depolarization)
- This change in polarity opens Ca++ gates → Ca++ in, Neurotransmitter release

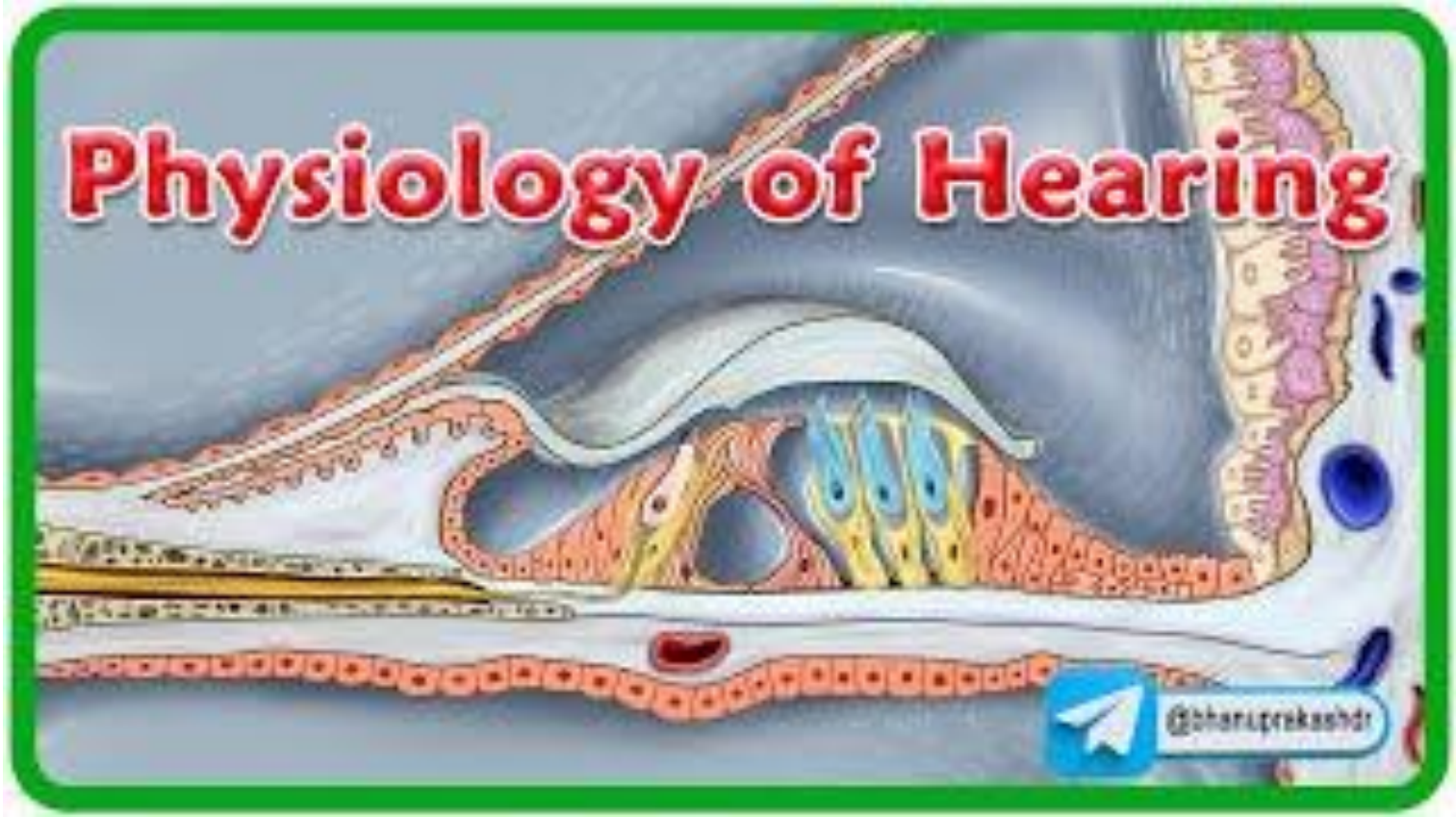


K+ gate open

K+ gate remain closed

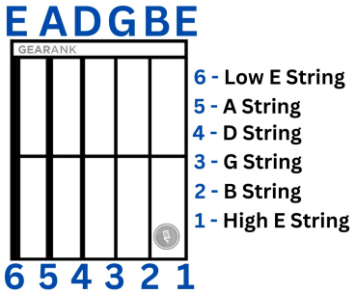


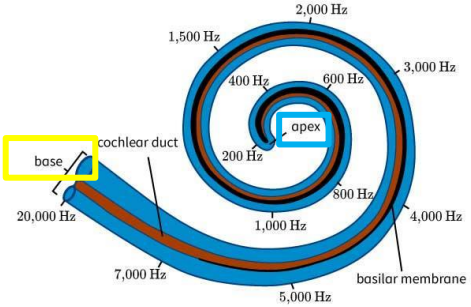
Hair Cell



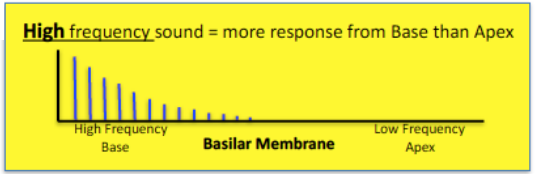
1. Place Coding

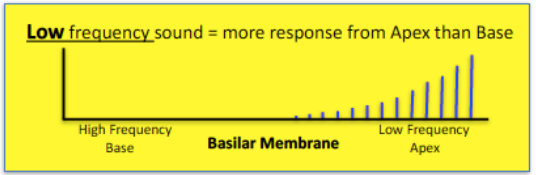
- The concept that specific frequencies are mapped to physical locations along the Basilar membrane

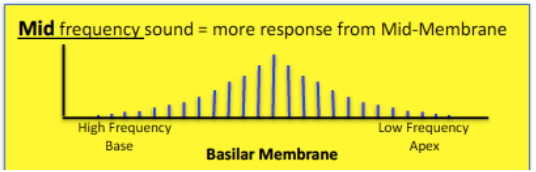




- **Base of the basilar membrane**
  - Closest to oval window
  - Narrow and Stiff fiber
  - Most responsive to high frequencies
- **Apex of the basilar membrane**
  - Far end of the Cochlea
  - Wide and Floppy fiber
  - Most displaced by low frequencies







- **Graded** response: The more the basilar membrane resonates, the farther it moves & the more the cilia of HCs are bent → more NT is released

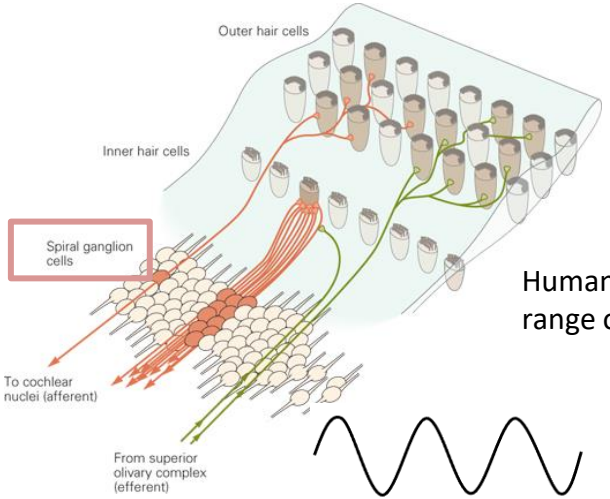
- It is the "**distribution**" of NT release in **group** of cells along the basilar membrane that encodes frequency information

2. Temporal Coding (Rate coding)

- In addition to different “places” resonating more than others, WHOLE Basilar M vibrates at the rate of input

- Hair Cells communicate to **Spiral Ganglions** (whose axons make up the Auditory nerve) which fire action potentials. However, SGs can only fire at a max rate of 1000 times/s (refractory period)

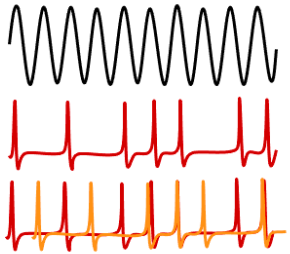
- SGs overcome this by “taking turns” and show coordinated pattern to encode higher frequencies → produce output along the auditory nerve that matches the incoming frequency



Humans can have a hearing range of 31 Hz to 19kHz!

200 Hz

A single neuron can encode low-frequency vibrations



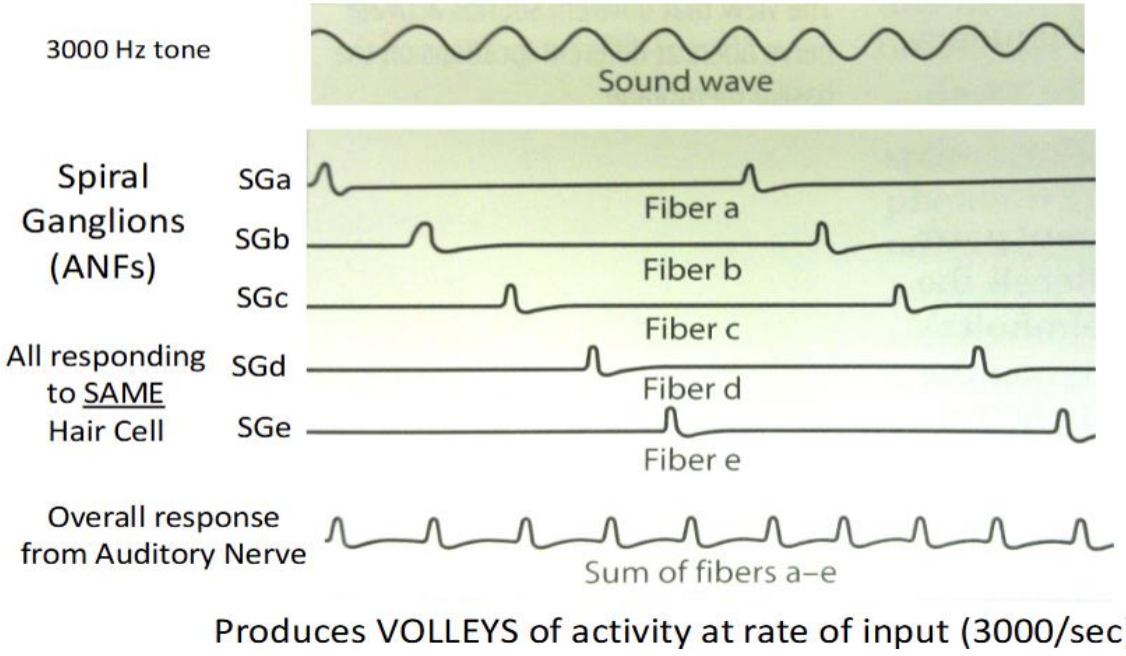
3000 Hz

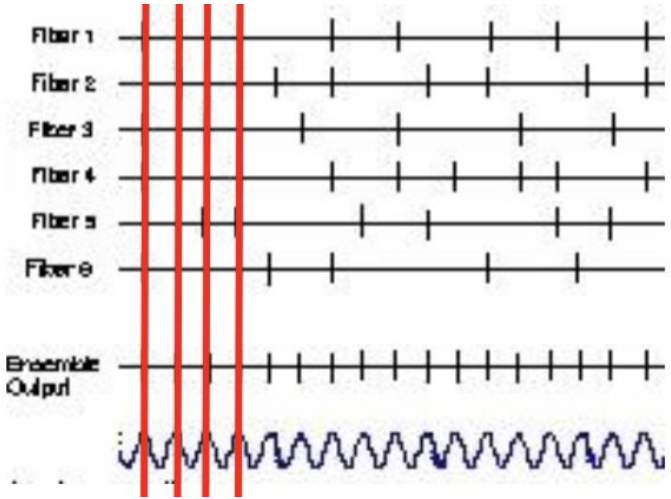
Individual neurons cannot keep up with high frequencies

Phase locking enables a timing code in the local population

2. Temporal Coding (Rate coding)

Volley Principle (Across Fiber Coding): Only if the ganglions are "**phase locked**" will they produce volleys of activity at a rate that matches the incoming frequency





Produces VOLLEYS of activity at rate of input (3000/sec)

Problem Set

Fill in the blanks to complete each statement.

A) The **(base / apex)** end of the membrane is narrow and stiff.

B) Apex at the basilar membrane is most responsive to _____ frequencies.

C) When _____ enters the Hair Cells, the cells become depolarized.

D) Hair cells produce **(action / graded)** potentials.

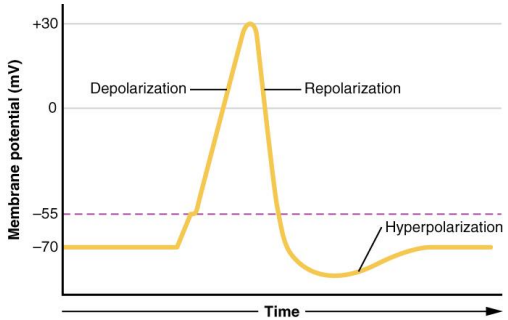
Problem Set

2) Fill in the blanks to complete each statement about <u>Place Coding</u> for frequency in audition

A) The __base__ end of the membrane is narrow and stiff.

B) Apex at the basilar membrane is most displaced by __low__ frequencies.

C) When ____potassium____ enters the Hair Cells, the cells become depolarized.

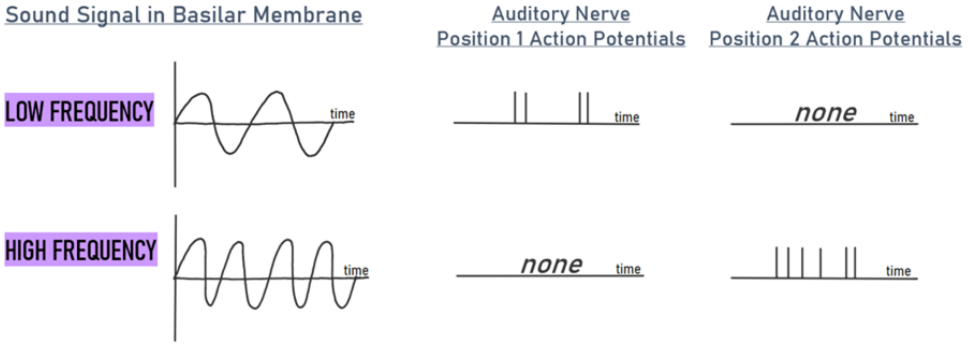


D) Hair cells produce ____graded____ potentials.

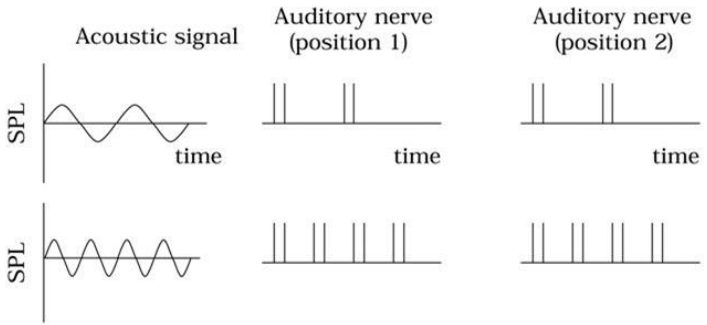
Problem Set

2) Which coding theory is this diagram for? Temporal or Place?

a. _____ coding



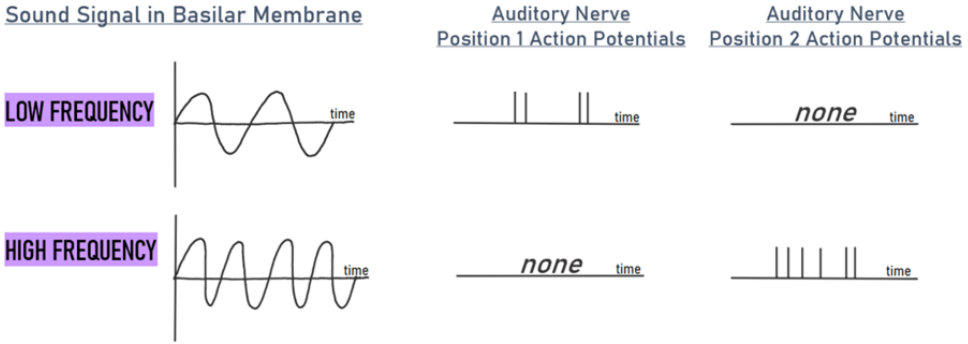
b. _____ coding



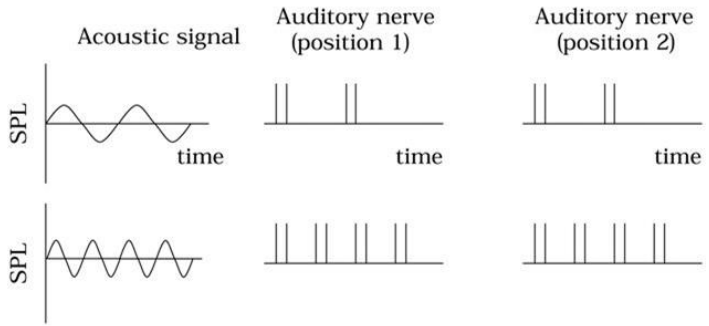
Problem Set

3) Which coding theory is this diagram for? Temporal or Place?

a. Place coding

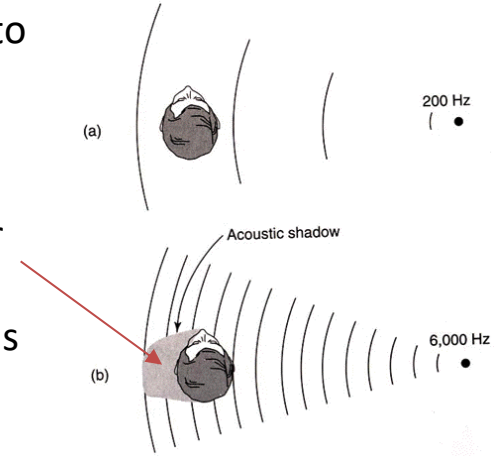


b. Temporal coding



Auditory Localization

- b/c sound is a physical pressure wave, binaural hearing allows us to localize the source of a sound based on:

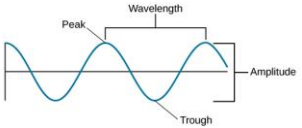


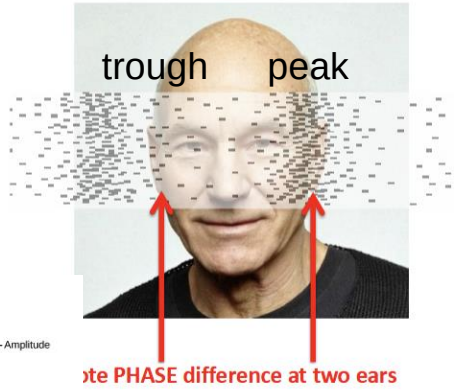
1. <u>Intensity</u>/<u>Amplitude</u> Differences:

- Sound at ear closer to source is louder/intense than at other ear, because of **head shadow**
- works best for **high** frequency sounds (b/c short wavelengths are more easily disrupted)

2. <u>Phase</u> Differences:

- For **lower** frequencies, the auditory system can detect differences in peak (oscillating molecules most condensed) vs. trough (spread out) of waves between the two ears
- One ear may pick up the peak, while the other picks up the trough, helping to determine the direction of the sound source
- Small-headed animals don't use this

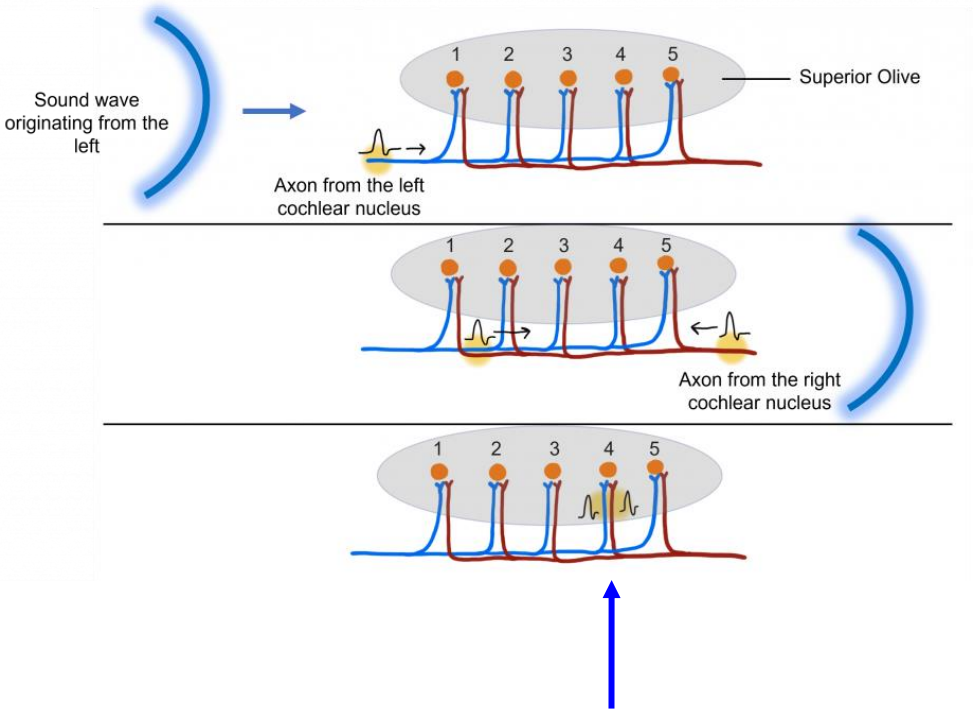




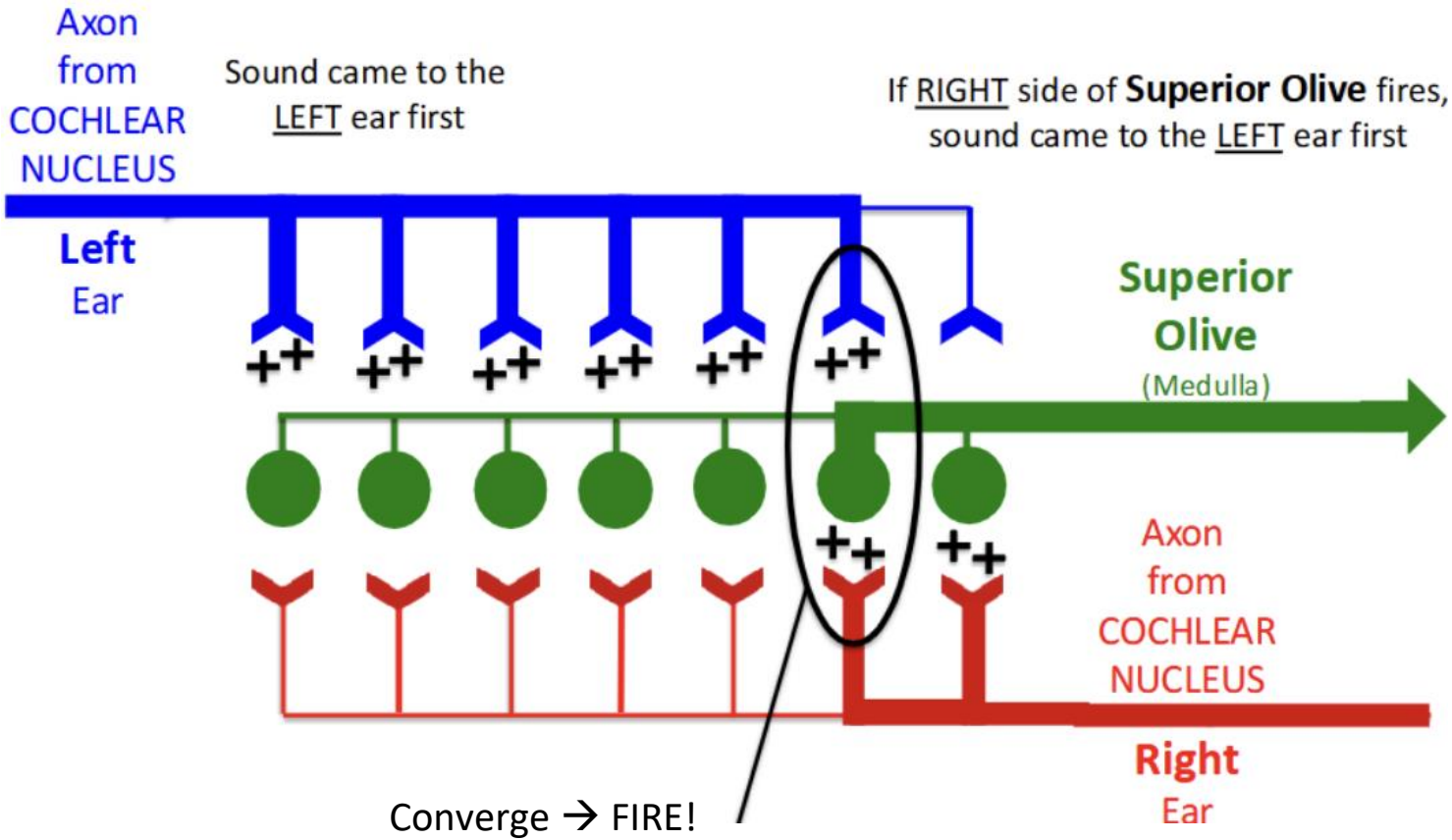
Auditory Localization

3. <u>Timing</u> Differences:

- "Interaural Time-Disparity Detectors" in the **Superior Olive (in medulla)** forms a competitive "racing" circuit
- If a sound is to the left, it reaches the left ear earlier than the right.
- Only when input from **BOTH** ears **converge** will Superior Olive fire → AP occurs at location farther from the left ear (vice versa)
- Superior Olive is first Binaural site along pathway → info from both ears is first combined here)

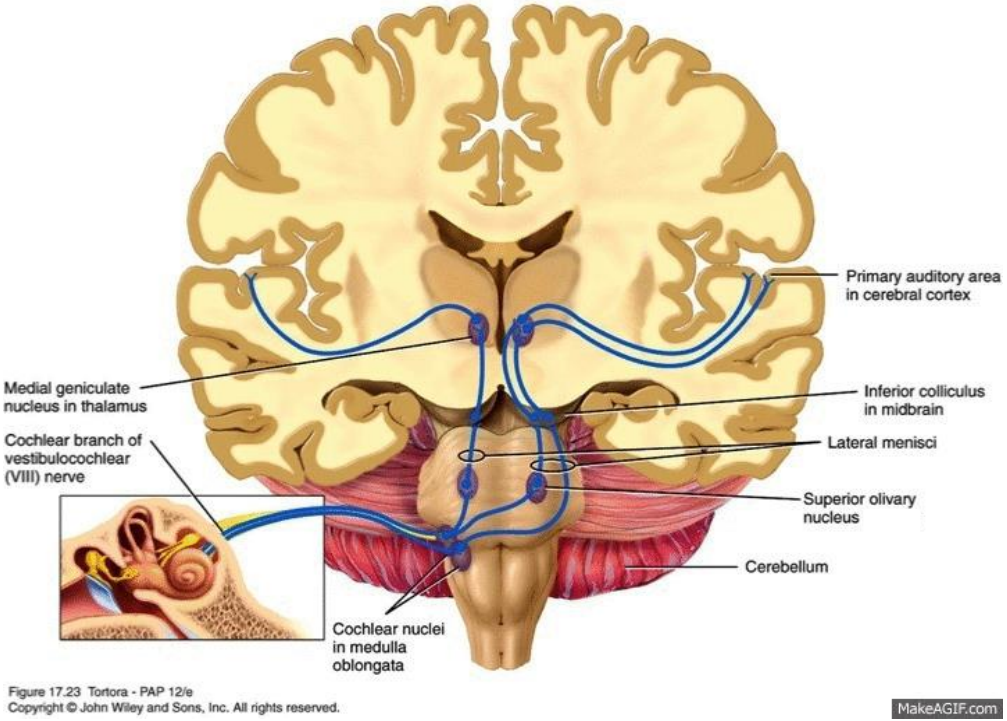


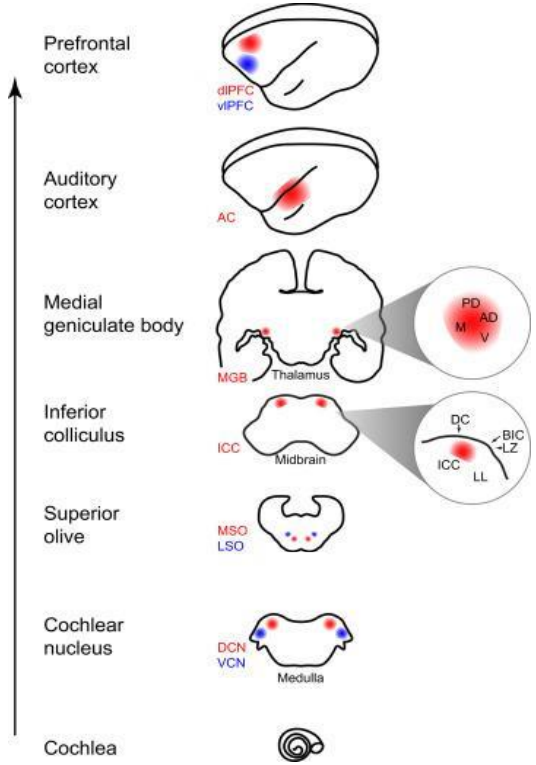
Auditory Localization



Auditory Pathway

Starts with two types of Hair Cells in Cochlea → starts at the cochlear nucleus in medulla → the superior olive in medulla → the inferior colliculus in tectum, midbrain → medial geniculate nucleus (MGN) in thalamus → primary auditory cortex (A1) and secondary auditory cortex (A2) in Temporal Lobe





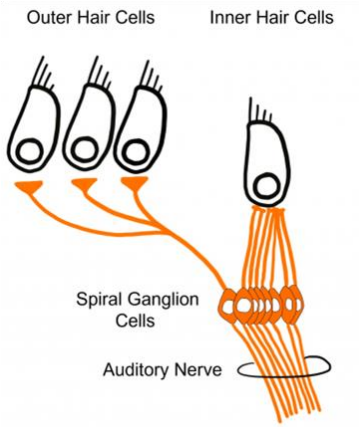
Auditory Pathway

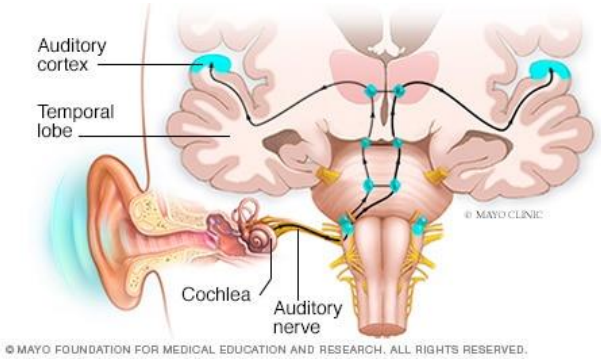
- Starts with 2 types of Hair Cells in Cochlea

- **Inner Hair Cells (IHC)** (like Cones)
  - ~3500 per ear, **Divergent** connectivity → 1:8 = IHC : Spiral Ganglions
  - Responsible for encoding frequency information
  - High **detailed** with little loss of information

- **Outer Hair Cells (OHC)** (like Rods)
  - ~12000 per ear, **Convergent** connectivity → 20:1 = OHC: Spiral Ganglion
  - Lose details, but good for **amplitude** information

- **Spiral Ganglion (SG)**
  - Specialized neurons whose axons form the **Auditory Nerve** (part of the 8th Cranial Nerve) → Feeds into Cochlear Nucleus in the Medulla

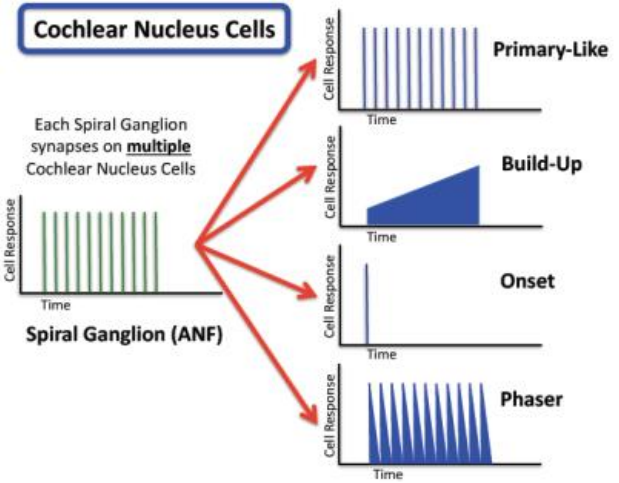




Auditory Pathway

- Each SG synapses on multiple Cochlear Nucleus cells in medulla

- **Cochlear Nucleus:** first brainstem structure that receive input from the auditory nerve
    a. L cochlear nucleus receives from L ear only, R from R only (monaural site)
    b. Cell types: responds to sound in distinct ways
        c. Primary–Like Cells
            i. Reproduces SG firing patterns
            ii. Preserves the tonotopic map
        d. Build–Up Cells
            i. Create continually increasing **graded** responses
        e. Onset Cells
            i. Single onset signal ("Starting Now!")
            ii. And adapt right after that
            iii. Goes to S. Olive to determine which ear received sound first
        f. Phaser Cells



- Some Cochlear Nucleus axons cross-over to contra-lateral Superior Olive, others to ipsi-lateral

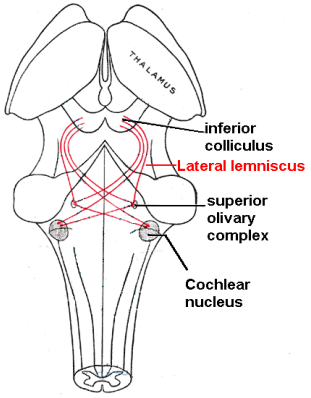
Auditory Pathway

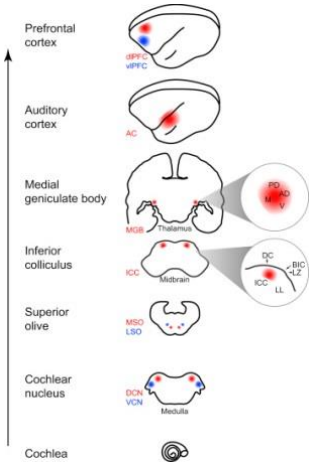
- **Superior Olive** is the first **Binaural** site along the path
  - Localize the source of a sound by integrating signal from both ears

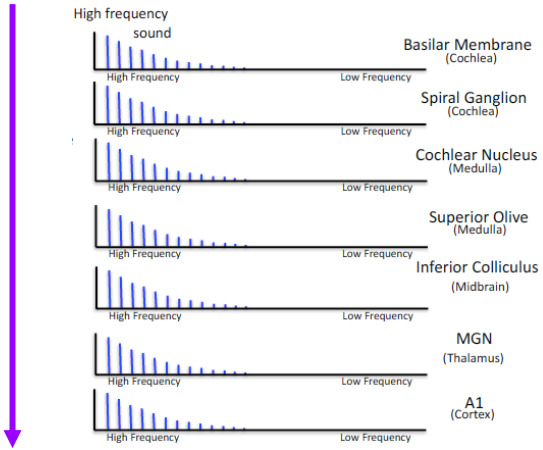
- **Inferior Colliculus** in midbrain receives some input from contra-lateral Cochlear Nucleus & and most from ipsi-lateral Superior Olive
  - integrates with visual info in Superior Colliculus, help map source of sight/sound

- Pathway continues up to the **Medial Geniculate Nucleus (MGN)** in the Thalamus which processes tonotopic maps

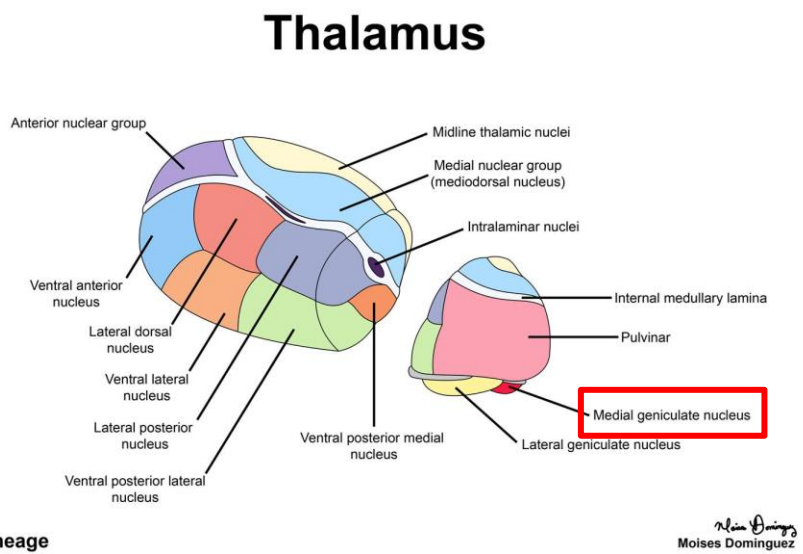
- **Tonotopic** Maps in Auditory System
  - At each point along the pathway, primary-like cells re-represent the same pattern to preserve the topological map created by the distribution of activity across BM







Medial Geniculate Nucleus (MGN)



LGN (Lateral Geniculate Nucleus) • **L** is for Light (Visual)

MGN (Medial Geniculate Nucleus) • **M** is for Music (Auditory)

VPN (Ventral Posterior Nucleus) • **VP** is for Very Personal (Touch)

DMN (Dorsal Medial Nucleus) • **DM** is for Dog Muzzle (Smell)

VLN (Ventro Lateral Nucleus) • **VL** is for Victory Lap (Motor)

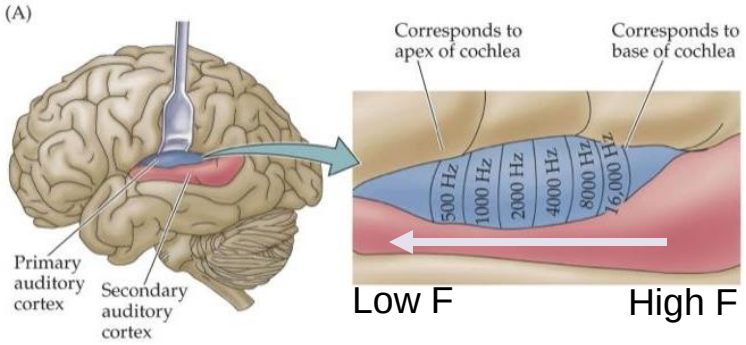
MDN (Medial Dorsal Nucleus) • **MD** is for Memory Doctor

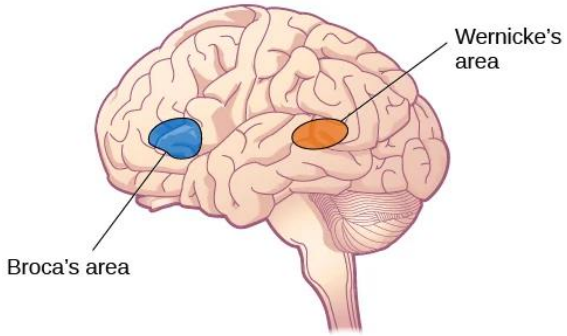
Auditory Cortex

- Fibers from MGN synapse to A1 and A2 Cortices

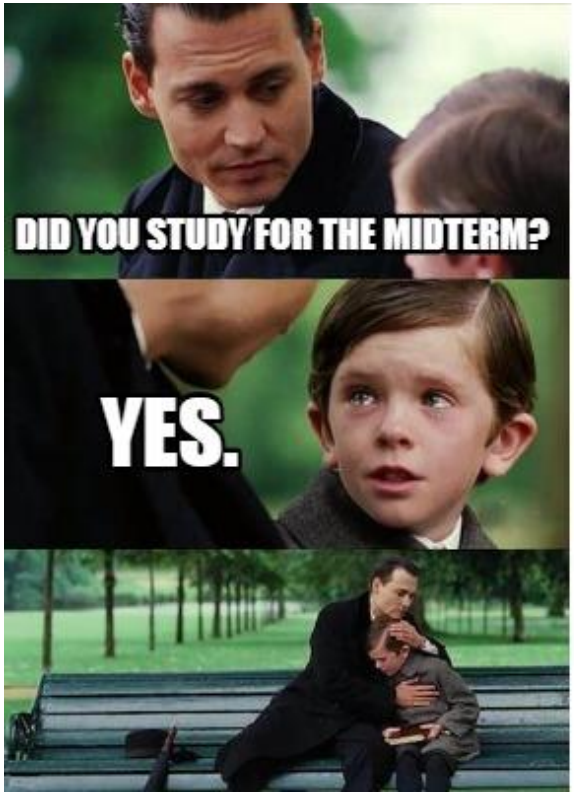
- **Primary Auditory Cortex (A1)**: primary projection area
  - Tonotopic/Amplitude map is preserved and represented along the lateral axis (High to low frequency: posterior to anterior; High to low amplitude : medial to lateral)
  - Cells within each layer are attuned to various attributes
    - Some cells respond best to **simple** tones
    - Some to more complex sounds
  - Other areas respond to the location of the sound source
- **Secondary Auditory Cortex (A2)**
  - Responds best to **changing/complex** sounds (familiar noises, speech sounds, etc)
  - Damage to A2 not necessarily result in deafness, but Auditory Agnosia (= inability to recognize or identify familiar sounds)

- **Higher Auditory Cortex**: processes complex patterns, integrates auditory input w/ other perceptual & cognitive activities
  - e.g., speech comprehension (Wernicke's Area in L hem)





Beyond human


DID YOU STUDY FOR THE MIDTERM?
YES.