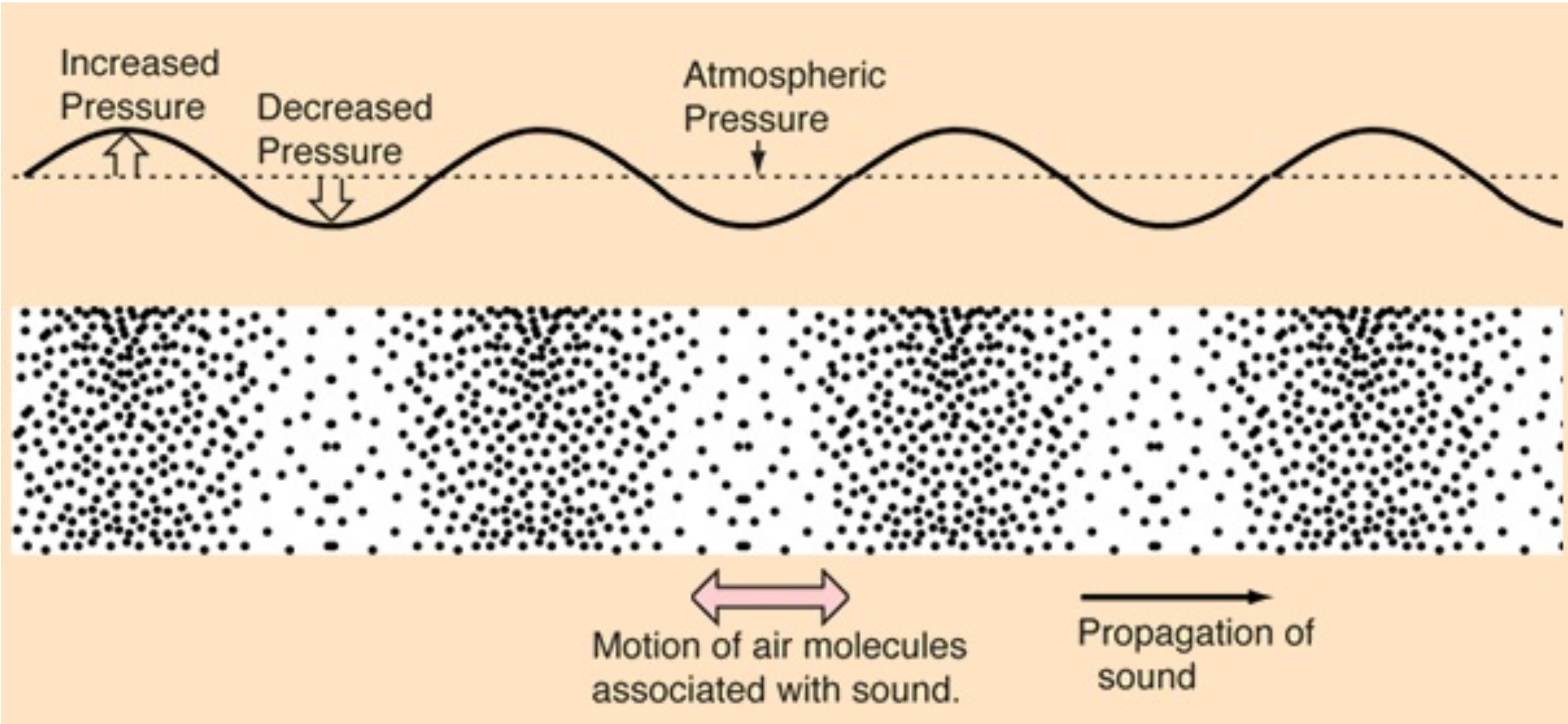
Lecture 5

Audition

Cogs17 * UCSD

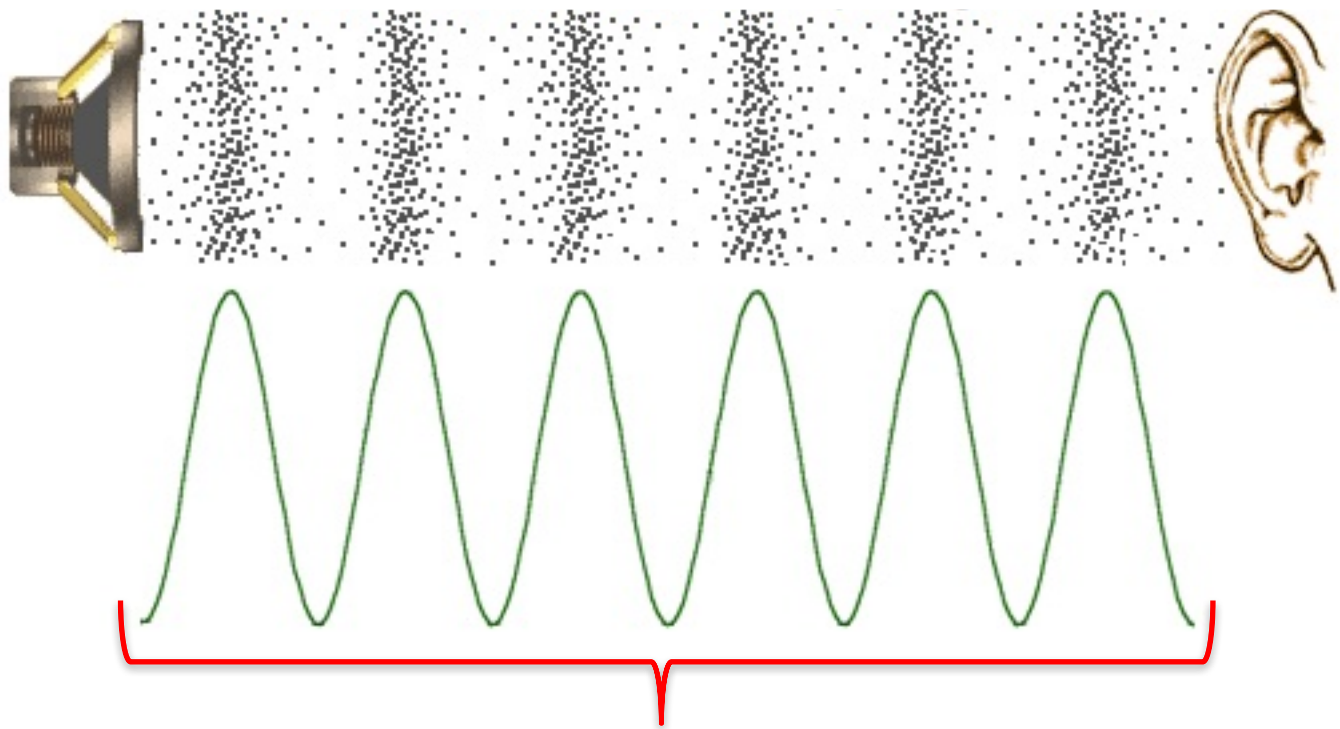
Sound Waves



Increased Pressure
Decreased Pressure
Atmospheric Pressure
Motion of air molecules associated with sound.
Propagation of sound

Frequency = # Cycles / Second = Hz

Per speed at which molecules of medium (air) ossicillate

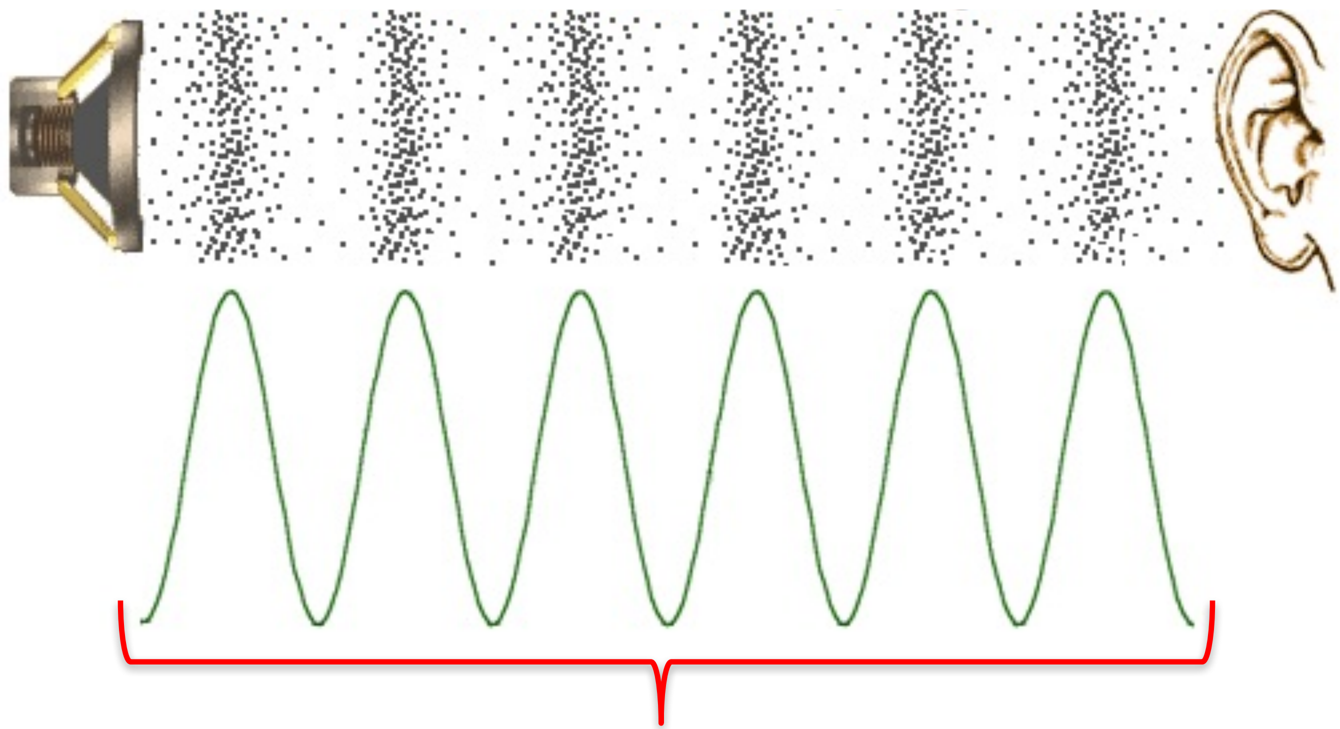


1 second

6 cycles / sec = 6Hz

Frequency = # Cycles / Second = Hz

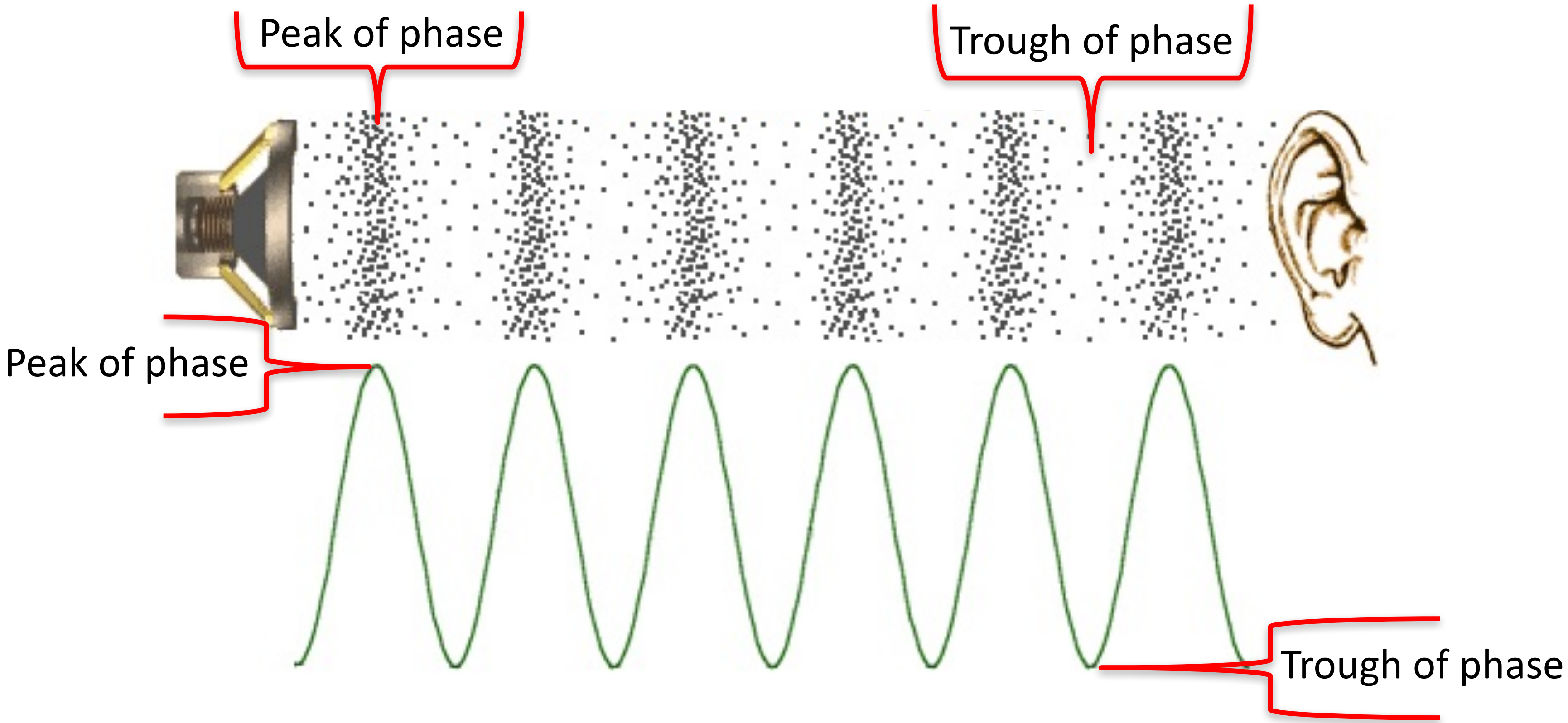
Per speed at which molecules of medium (air) ossicillate



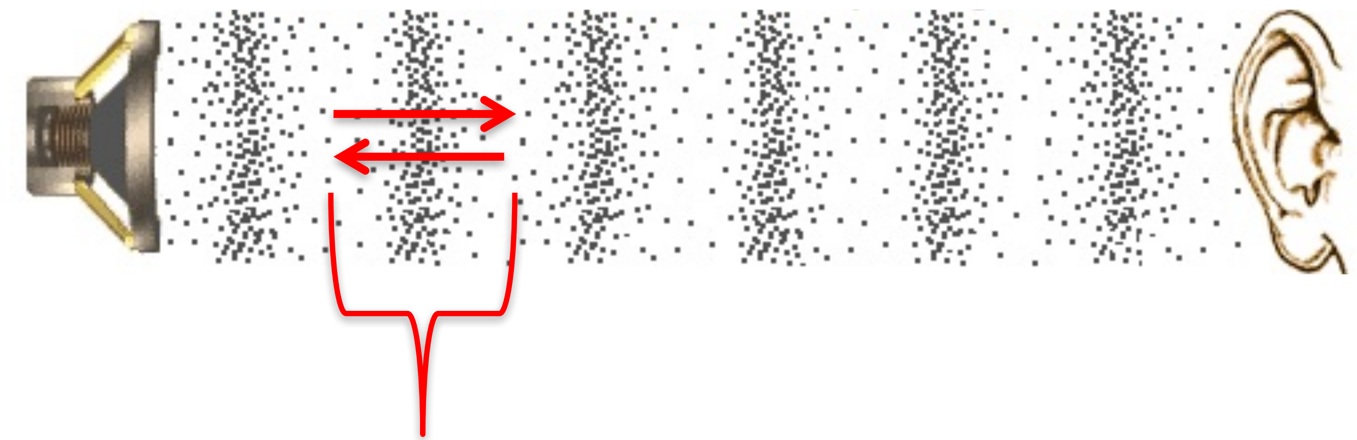
.001 second

6000 cycles / sec = 6000Hz = 6kHz

Phase = place in cycle of condensation & rarefaction



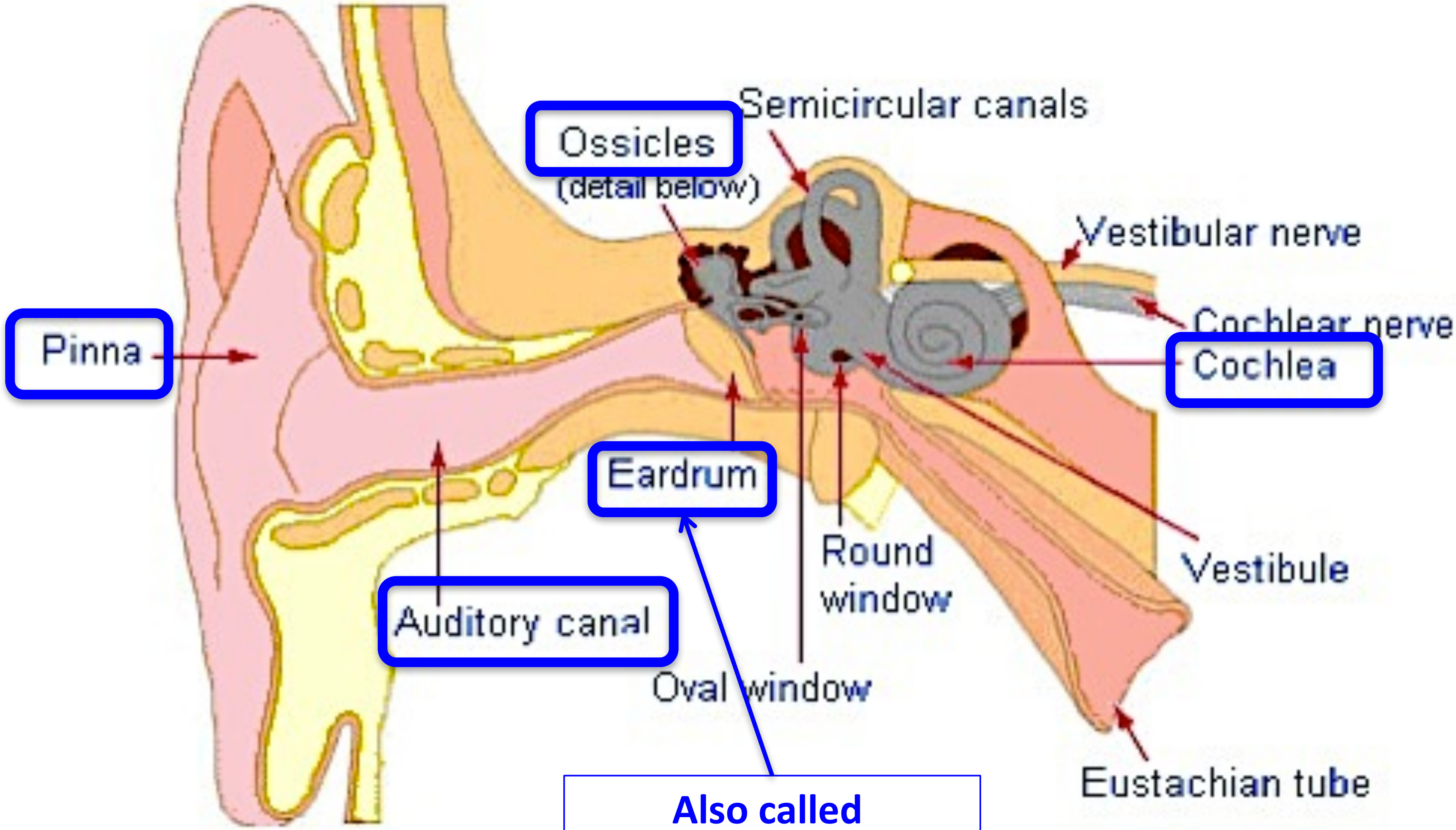
Amplitude = Distance a given molecule of medium (air) travels during its osscillation



If distance < x meters = Low Amplitude (soft sound)

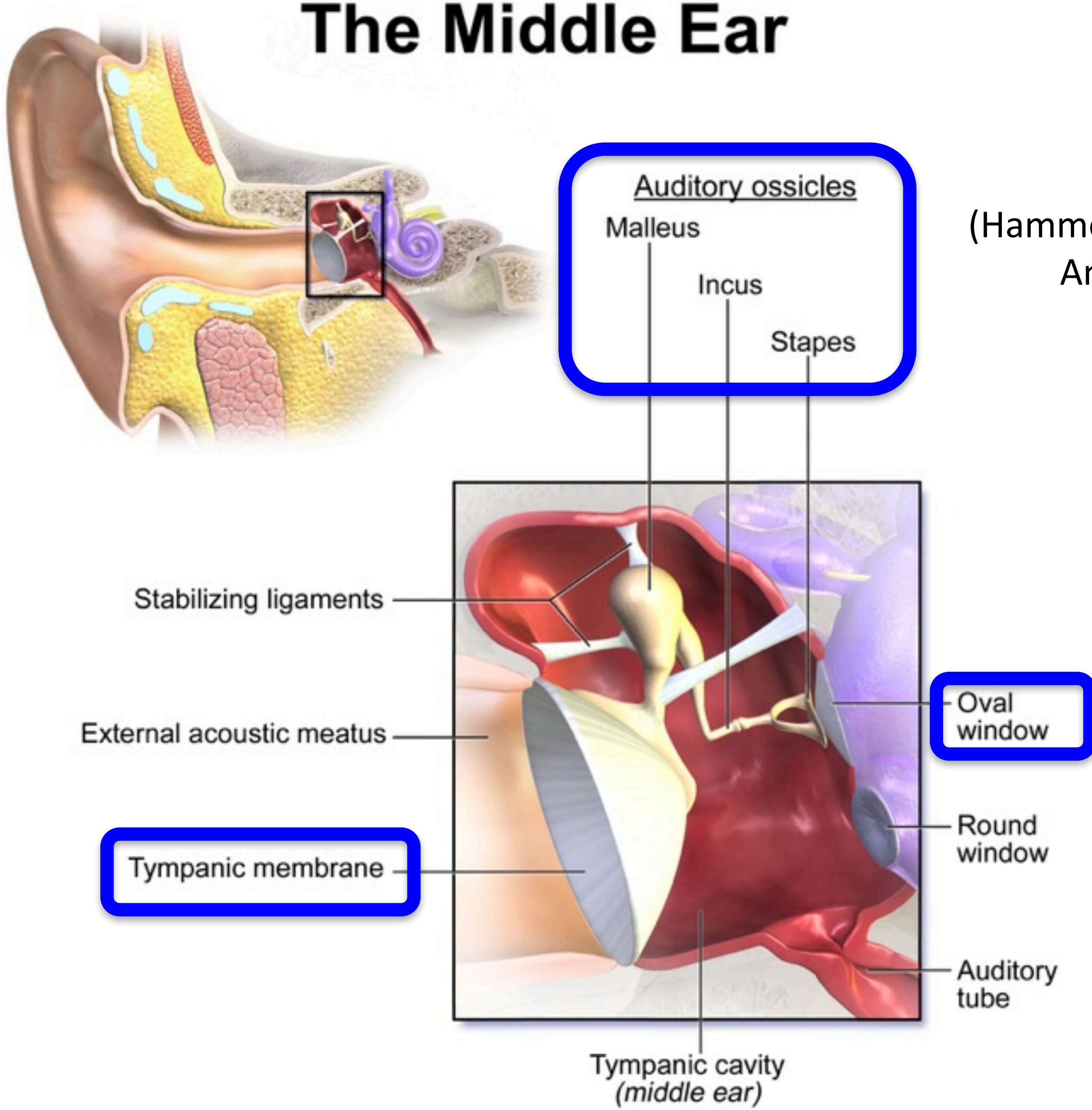
If distance > x meters = High Amplitude (loud sound)

Auditory Reception



Also called Tympanic Membrane

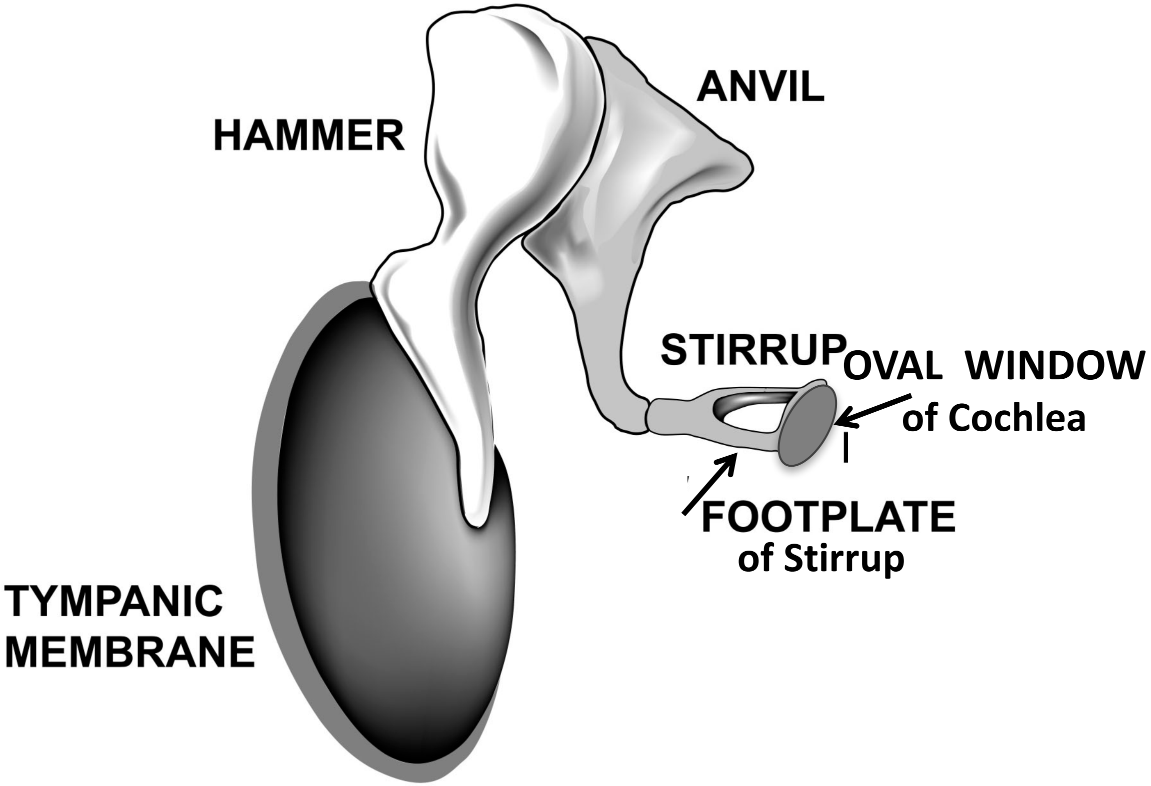
The Middle Ear



(Hammer
Anvil
Stirrup)

Ossicles

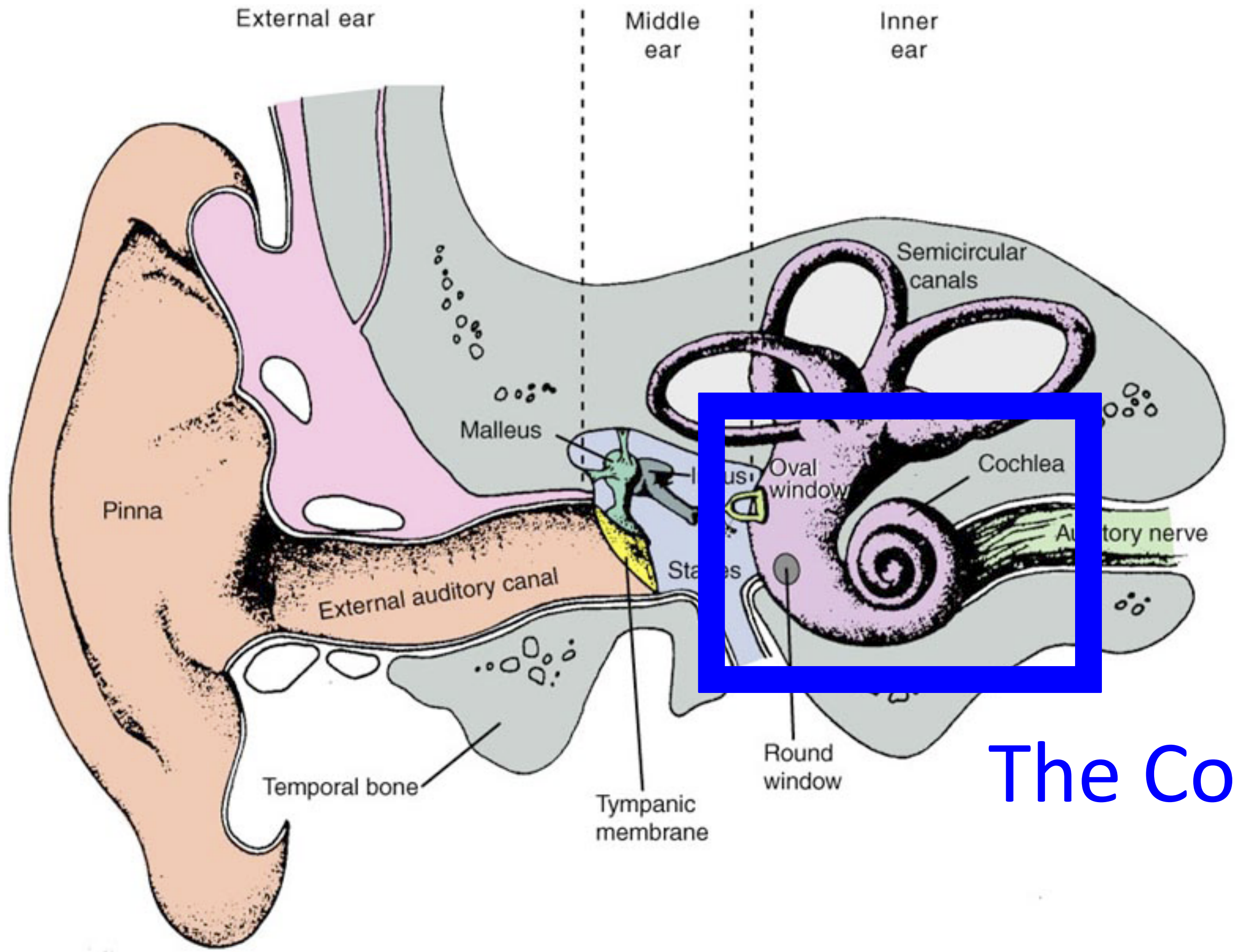
Convert large vibrations of big **Tympanic Membrane**
into smaller, but more powerful vibrations of **Oval Window**



Overcomes **IMPEDANCE MISMATCH**

Air molecules are easy to vibrate, but viscous COCLEAR FLUID molecules in Cochlea much harder to vibrate

The Cochlea

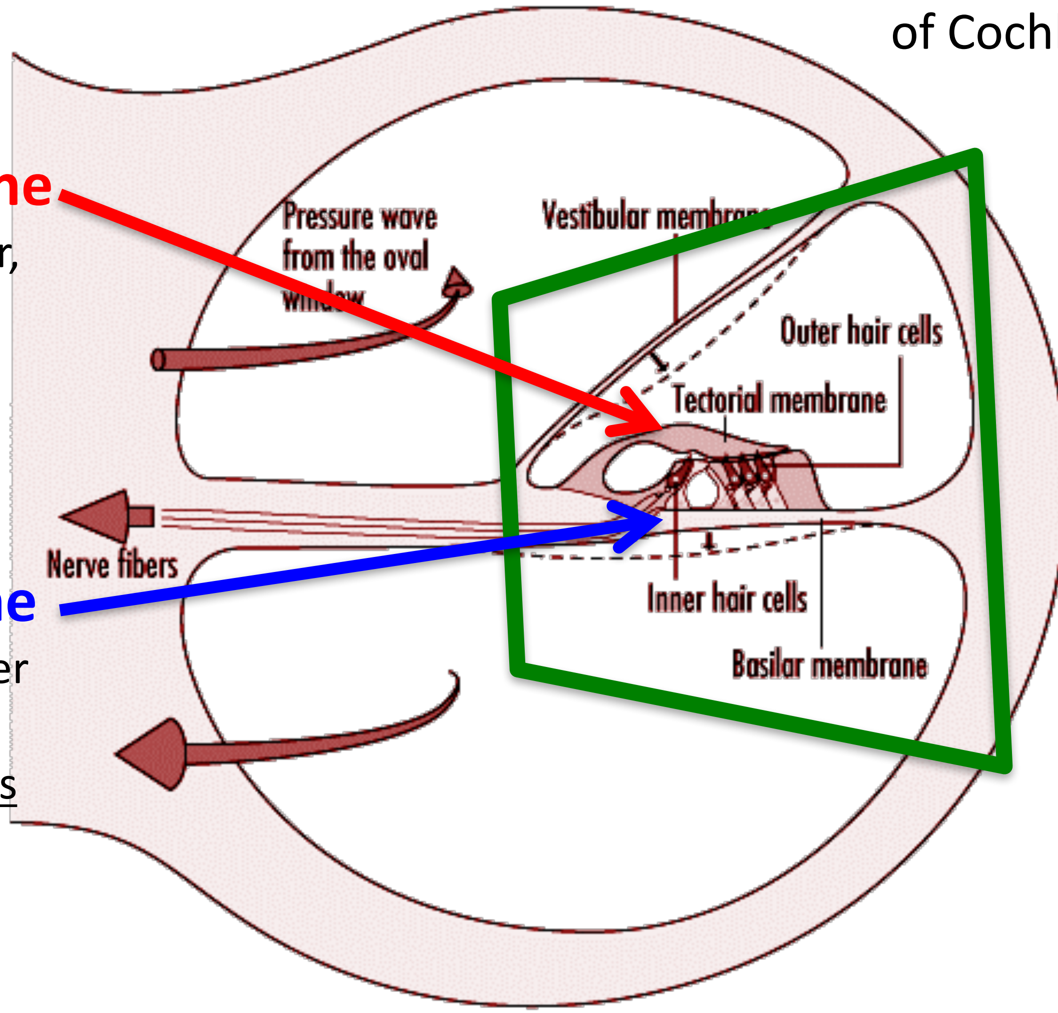

External ear
Middle ear
Inner ear
Semicircular canals
Malleus
Oval window
Cochlea
Pinna
External auditory canal
Temporal bone
Tympanic membrane
Round window

The Cochlea

Cross-Section of Cochlea

Tectorial Membrane
Within middle chamber, Top of Organ of Corti

Basilar Membrane
Floor of middle chamber & of Organ of Corti, on which the Hair Cells (Receptors) sit



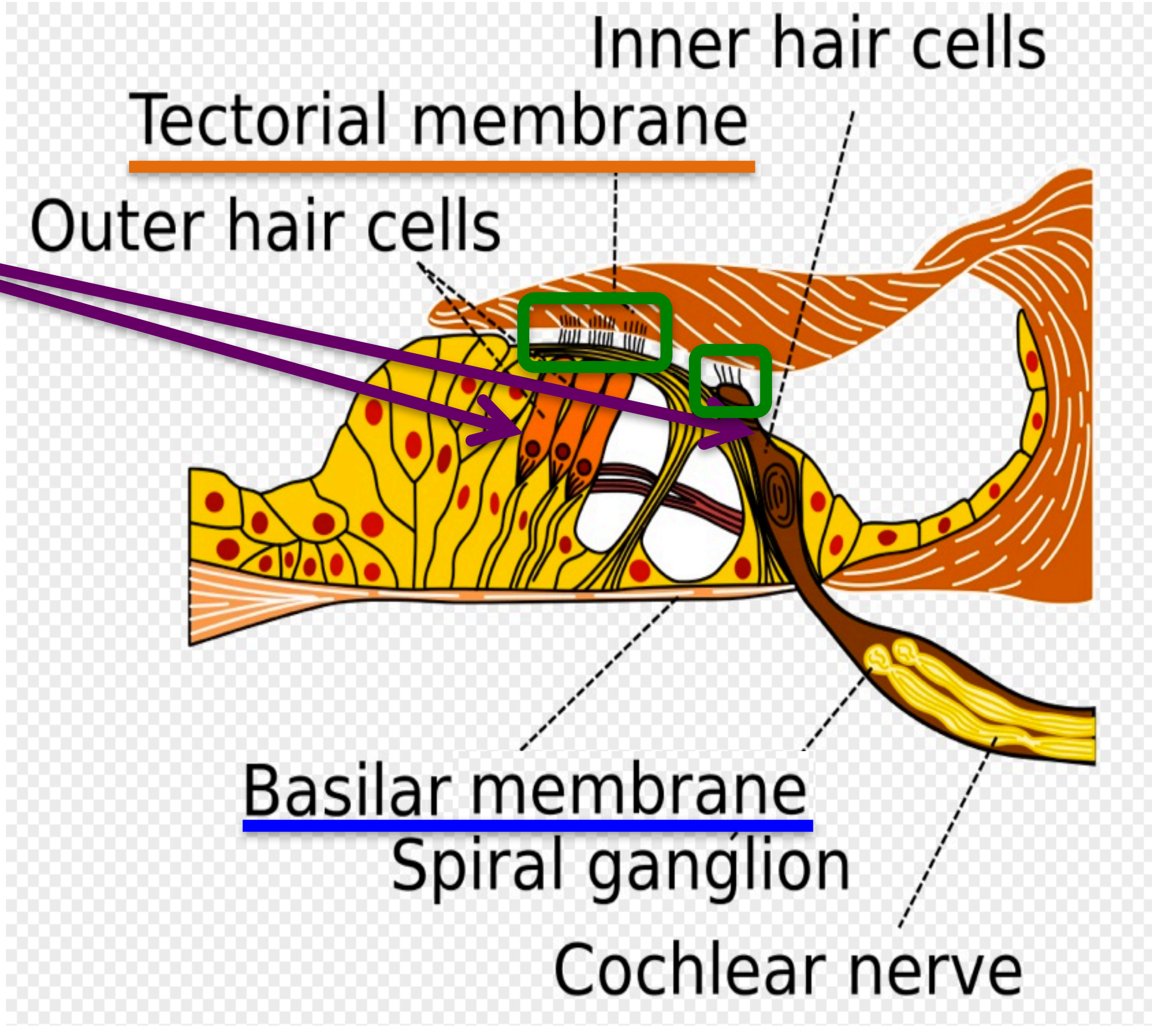
Organ of Corti

Source: Hohmann and Schmuckli 1989.

Organ of Corti

Hair Cells

Auditory Receptors

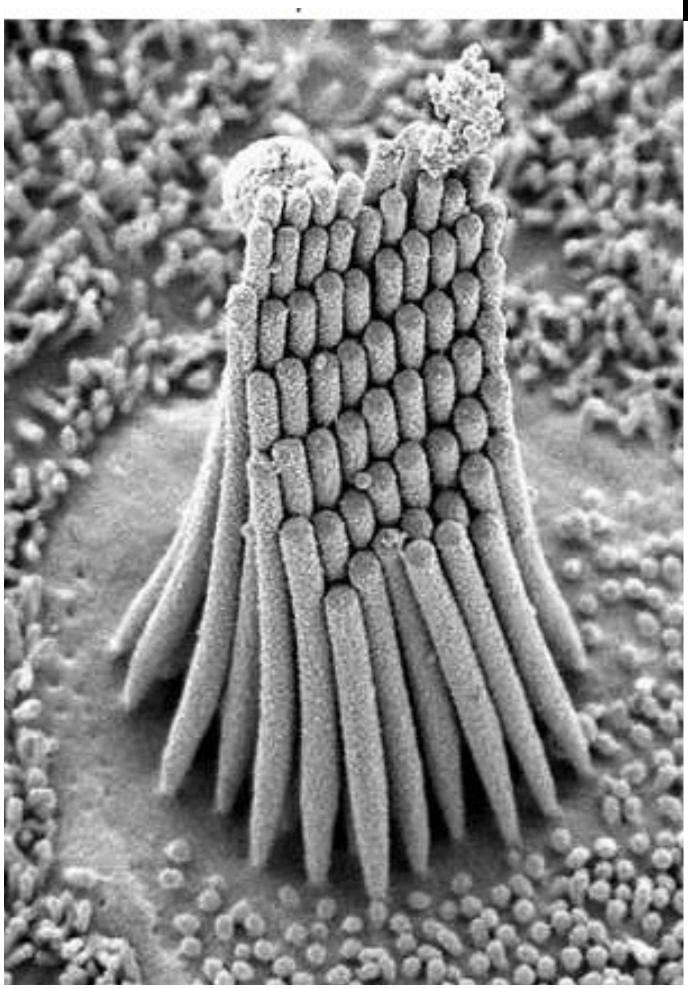


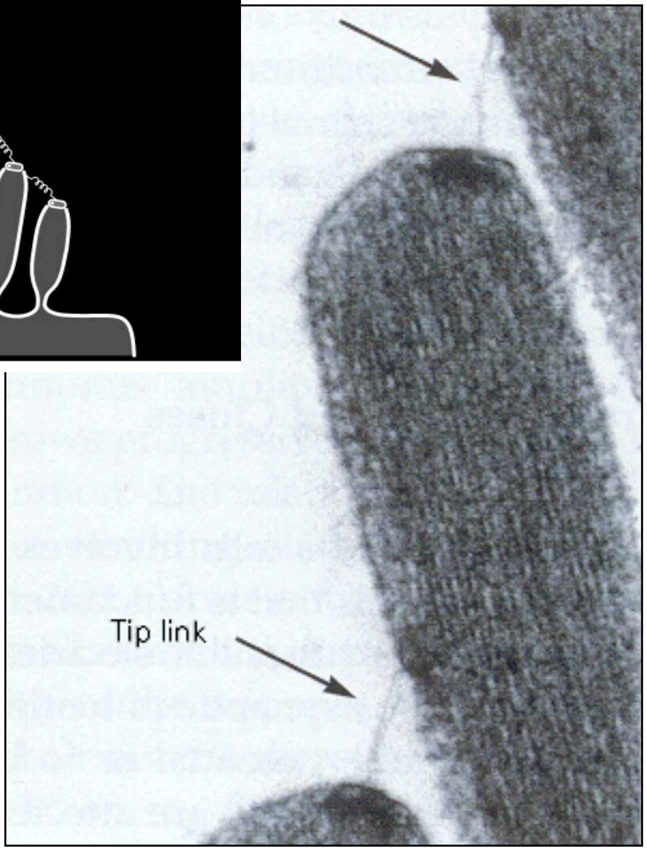
Stand between
Tectorial Membrane
above, and
Basilar Membrane
below.

As membranes vibrate
CILLIA (hairs) are
bent >>
release NT.

Hair Cells

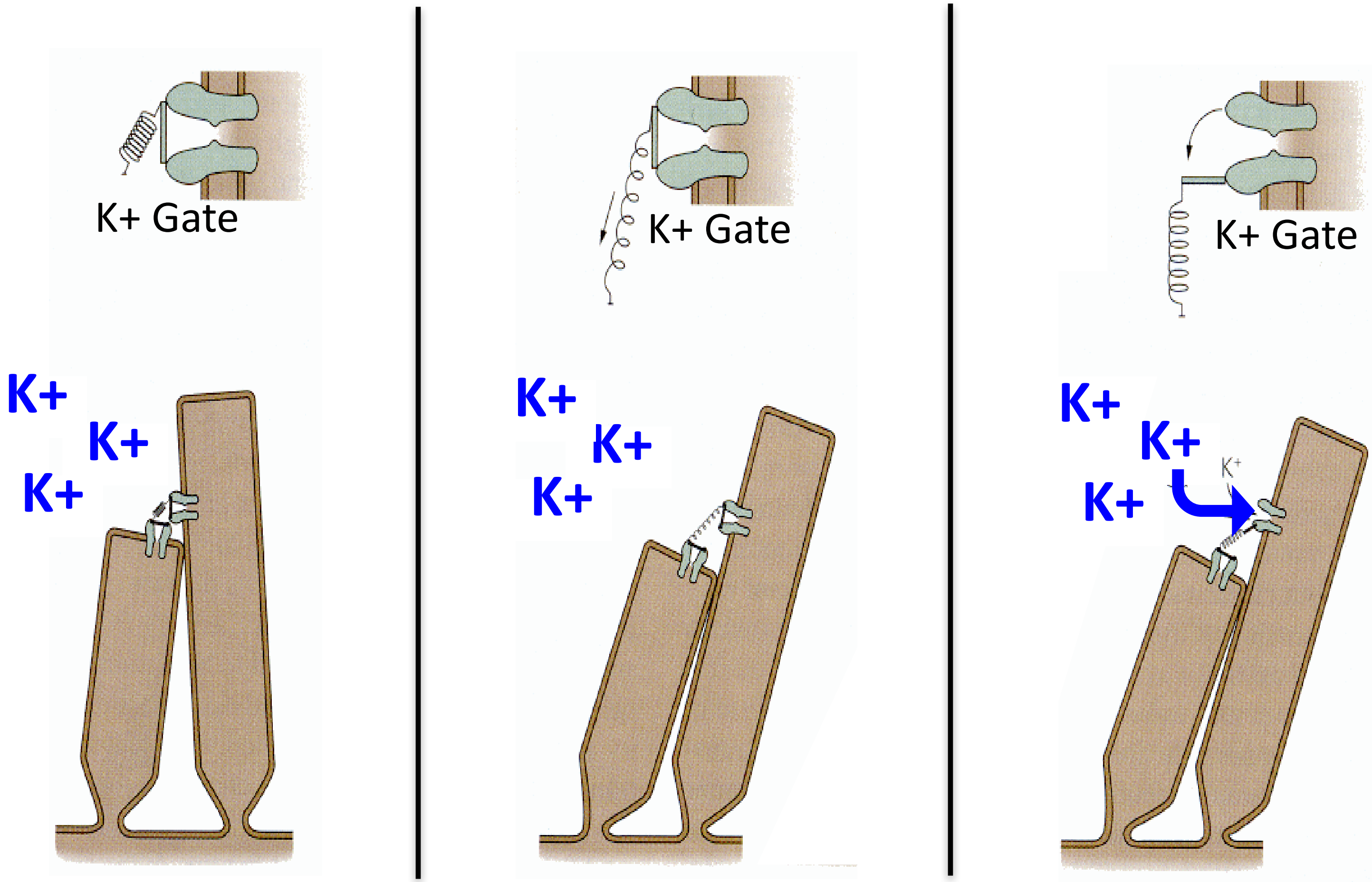
Cillia





Transduction in Hair Cells is **Potassium (K+)** based (No Na+)

Cochlear Fluid is rich in Potassium



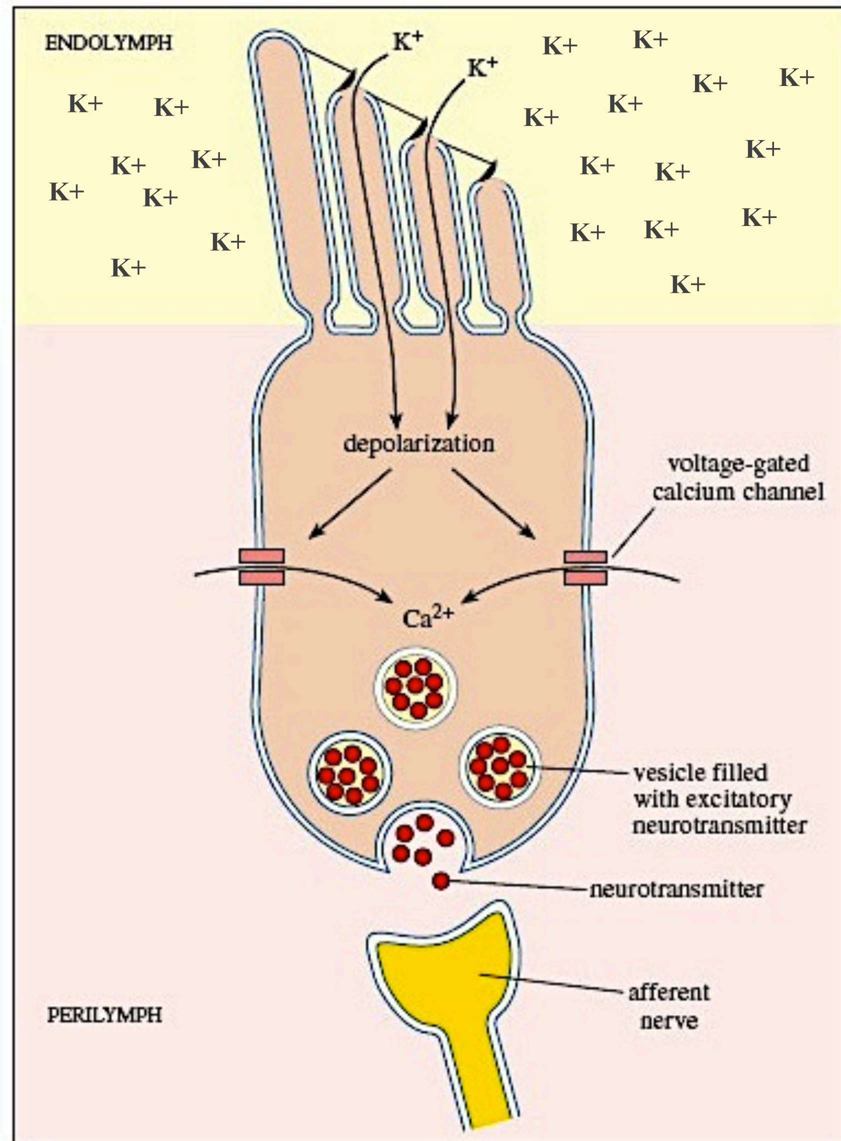
When Cillia are bent, K+ gates are pulled opened

Hair Cells

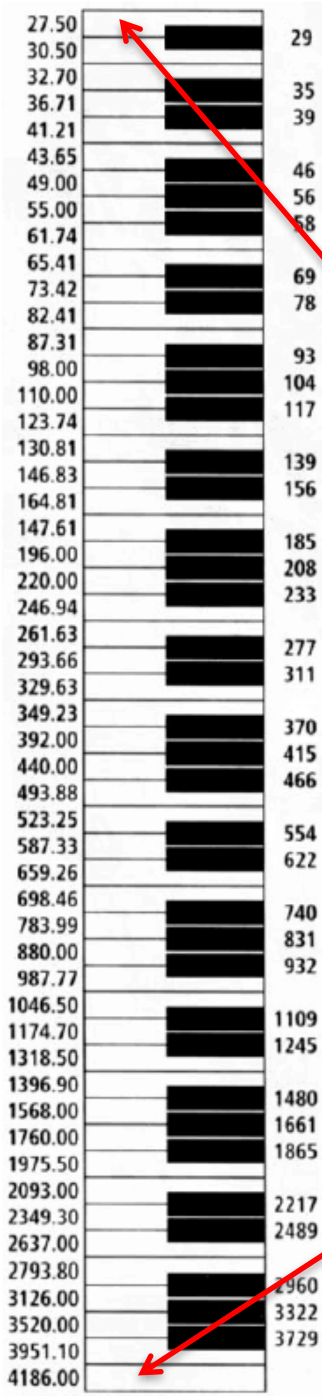
Higher Concentration of K+ OUTSIDE cell >>
so K+ enters

This change in polarity opens Ca++ gates

Ca++ in,
Neurotransmitter out



...a Graded response



Frequency (Pitch)

Humans hear from 20 Hz to 20,000 Hz (or 20 kHz)

But, we make our most detailed discrimination between frequencies up to ~ 5kHz

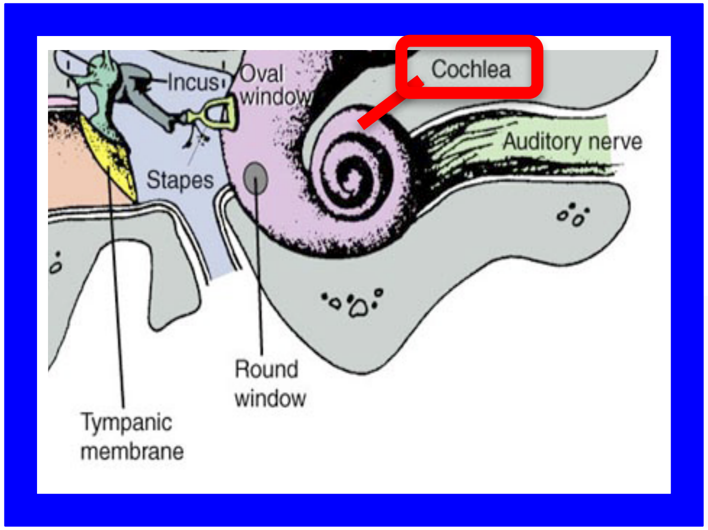
The piano keyboard

ranges from 27.5 Hz at low end

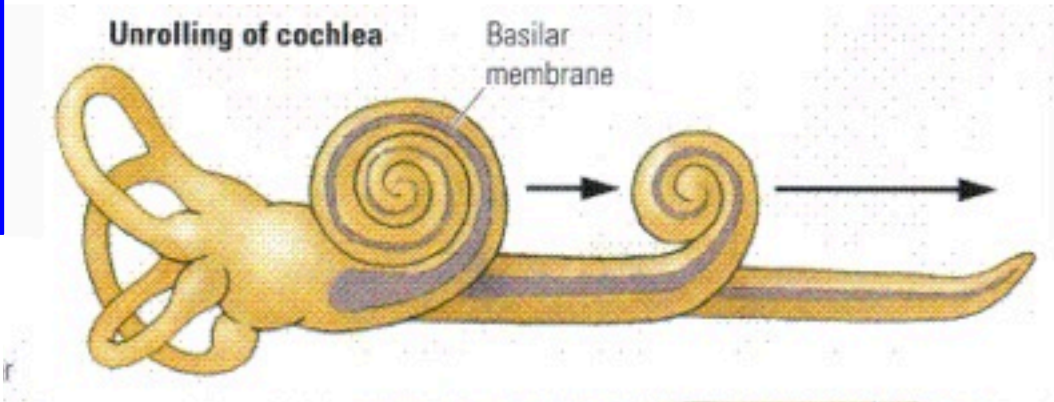
to 4,186 Hz (~4.2 kHz) at high end

Coding for Frequency

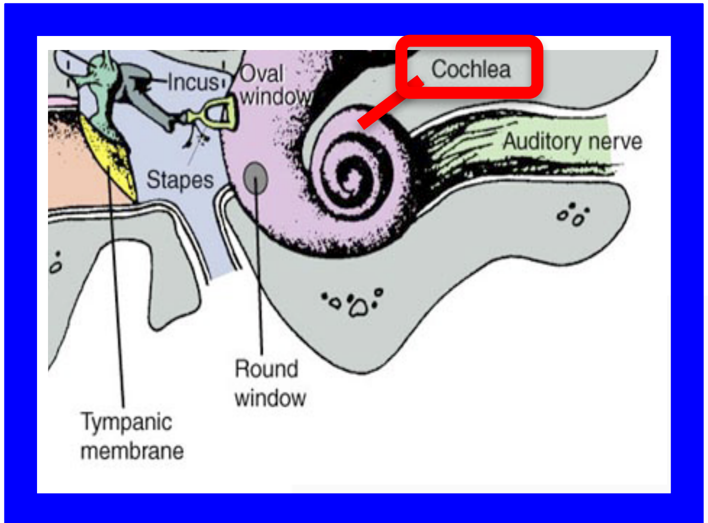
- Place Coding
- Temporal (Rate) Coding

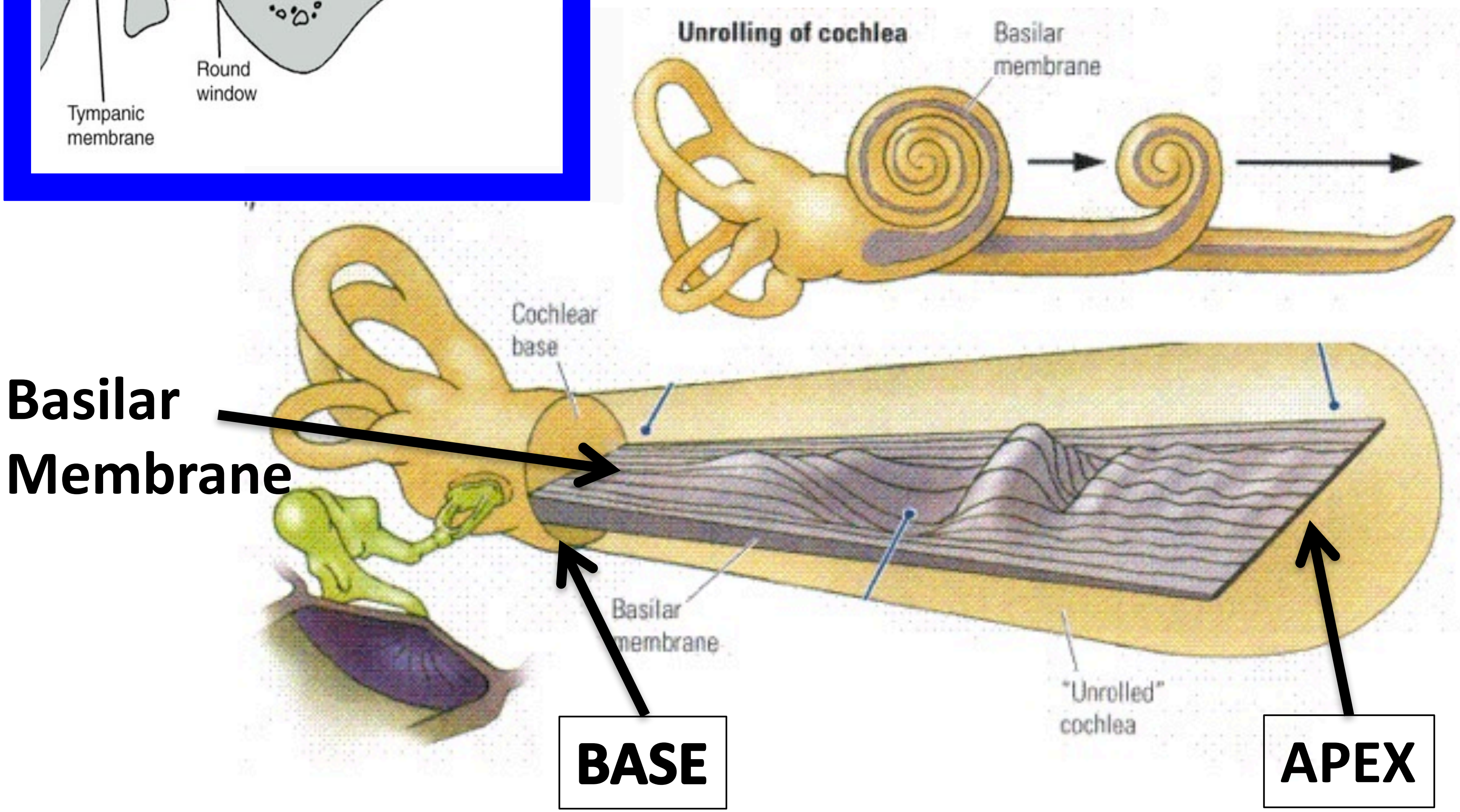


Place Coding



Place Coding



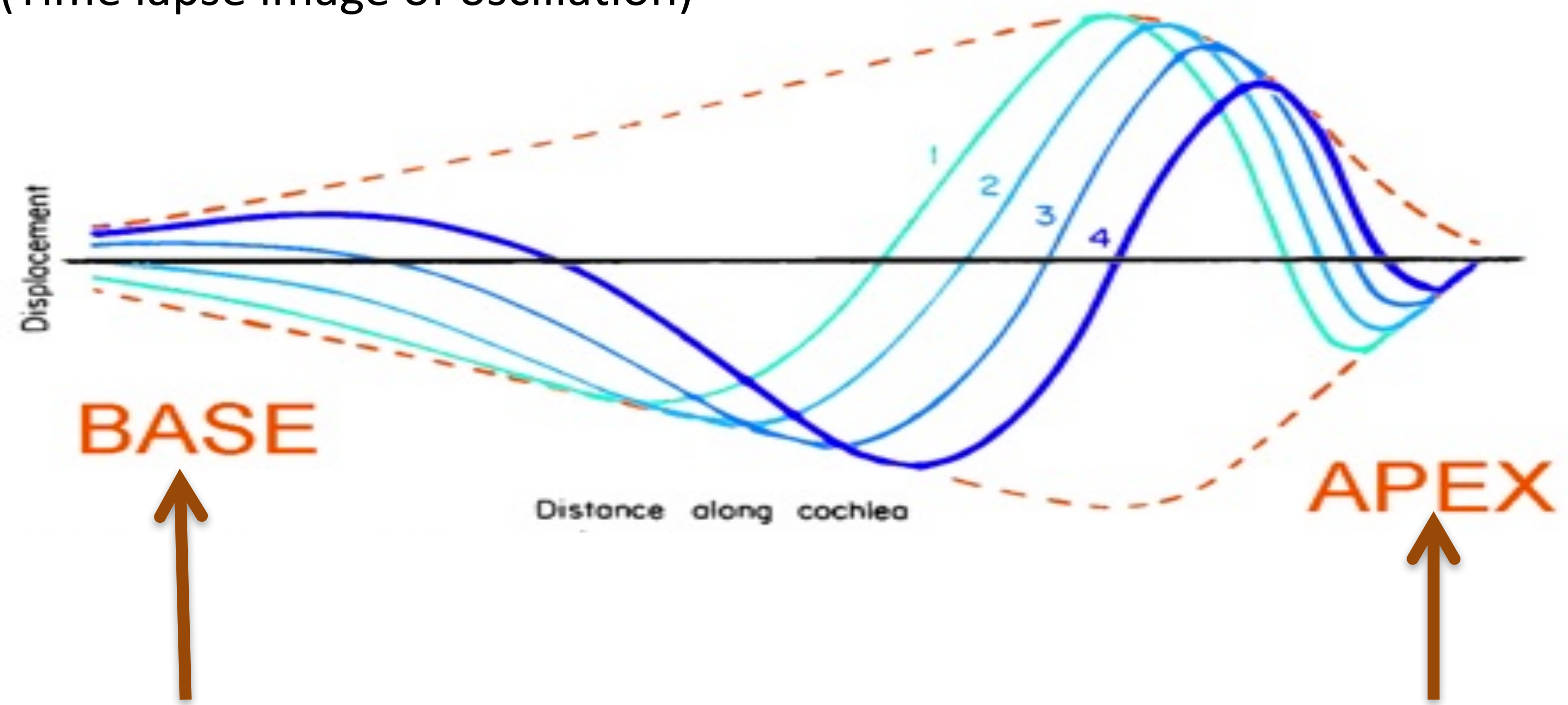


Narrow & Stiff

Wide & Floppy

Place Coding

Basilar Membrane
(Time lapse image of oscillation)

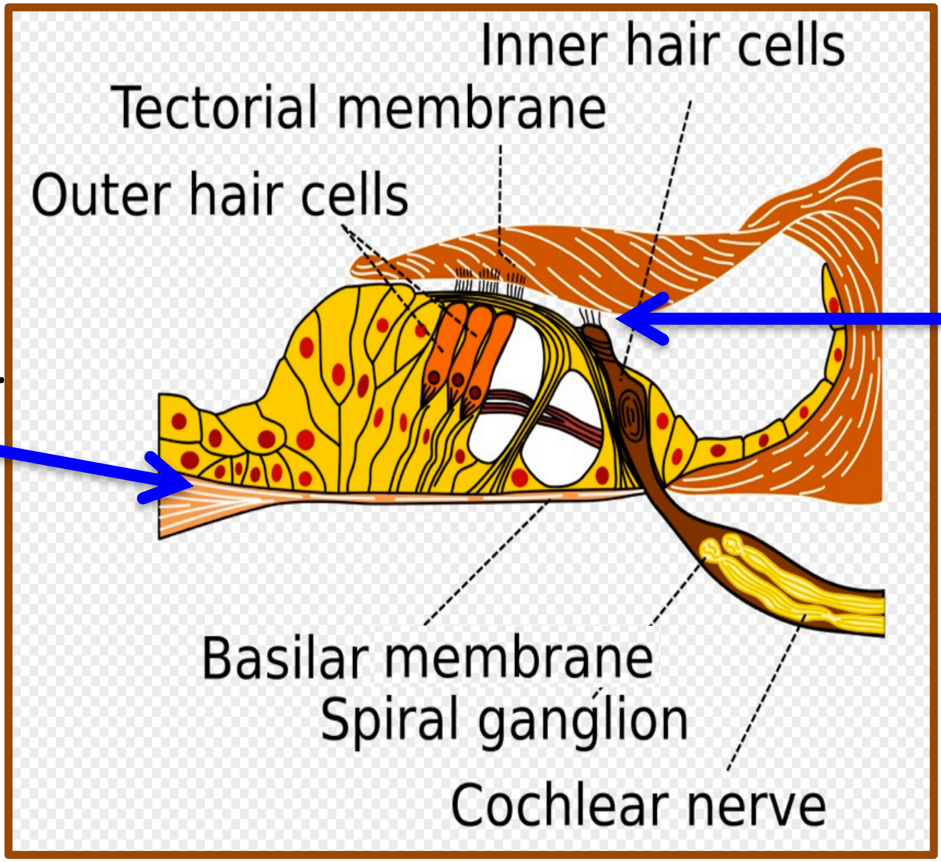


Narrow & Stiff
resonates
to <u>HIGH</u> Frequencies

Wide & Floppy
resonates
to <u>LOW</u> Frequencies

Place Coding

The more the
Basilar Membrane
resonates,
the farther it moves...

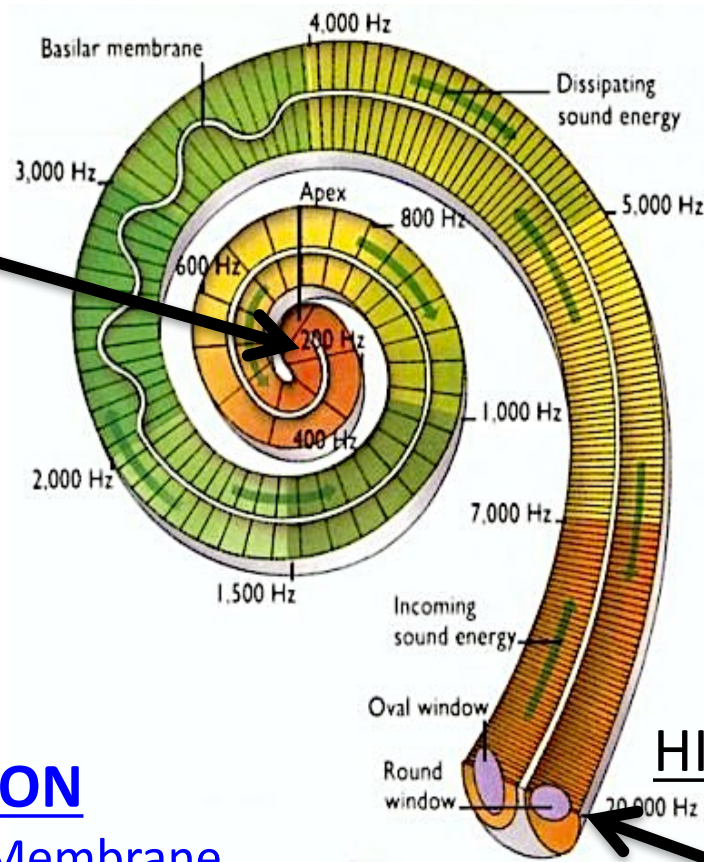


...the more the
Cillia of the
Hair Cells are
BENT
against the
Tectorial Membrane...

...the more Neurotransmitter
the Hair Cells release.

Place Coding

<u>LOW</u> Frequencies
resonate
APEX of cochlea

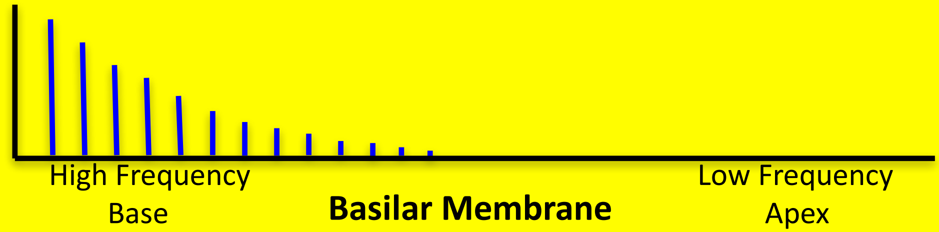


<u>HIGH</u> Frequencies
resonate
BASE of cochlea

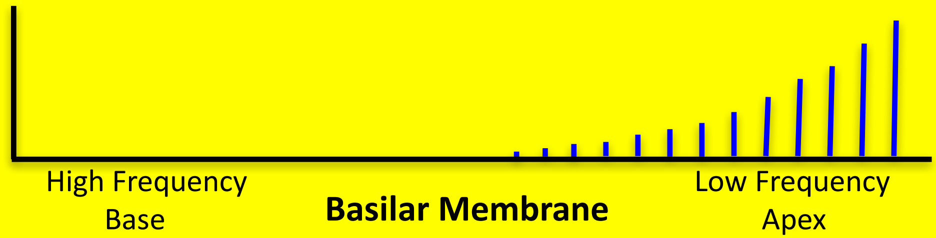
So, it is **<u>DISTRIBUTION</u>**
of NT release along Basilar Membrane
that codes for Frequency

Place Coding

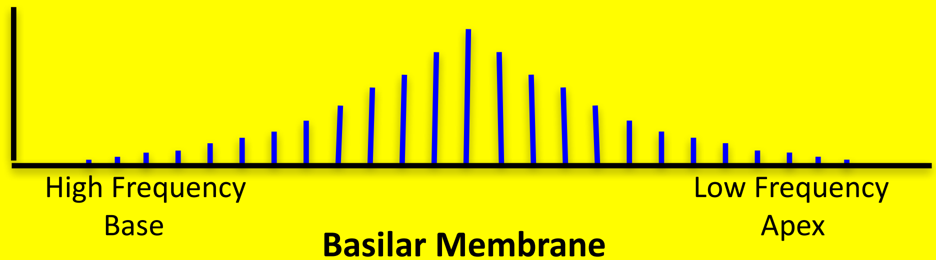
<u>High</u> <u>frequency</u> sound = more response from Base than Apex



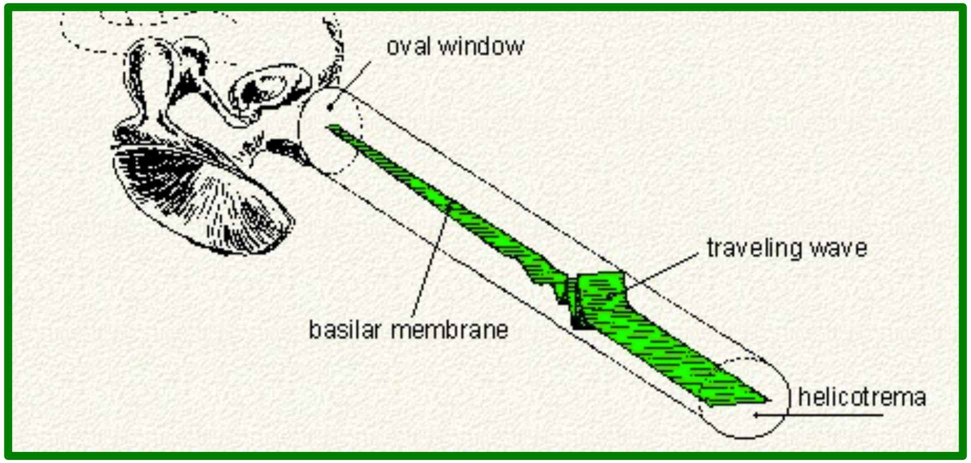
<u>Low</u> <u>frequency</u> sound = more response from Apex than Base



<u>Mid</u> <u>frequency</u> sound = more response from Mid-Membrane



Temporal Coding (Rate Coding)



In addition to different "places" resonating more than others, **WHOLE** Basilar Membrane vibrates at rate of input (e.g. 3000 Hz >> 3000 oscillations/sec)

Hair Cells accomodate this with a graded response, responding to relative amounts of vibration along Basilar Membrane

BUT Hair Cells communicate to **Spiral Ganglions** (whose axons make up the Auditory Nerve) which fire **Action Potentials**

Refractory Period for Action Potentials limit how frequently Spiral Ganglions can fire!

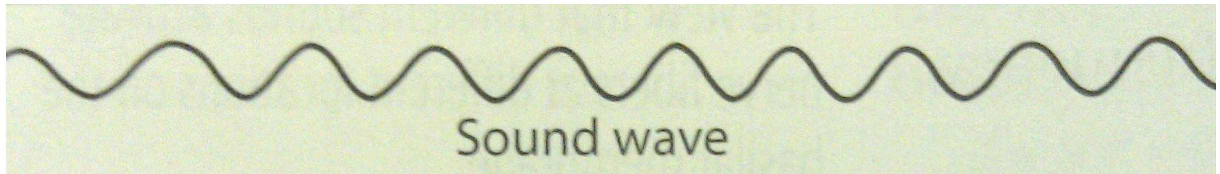
Maximum ~ 1000/second

So how can they code for a 3000 Hz tone?!!

Temporal Coding (Rate Coding)

ANSWER: No single Ganglion cell can! But a <u>group of them working together</u> CAN!!

3000 Hz tone

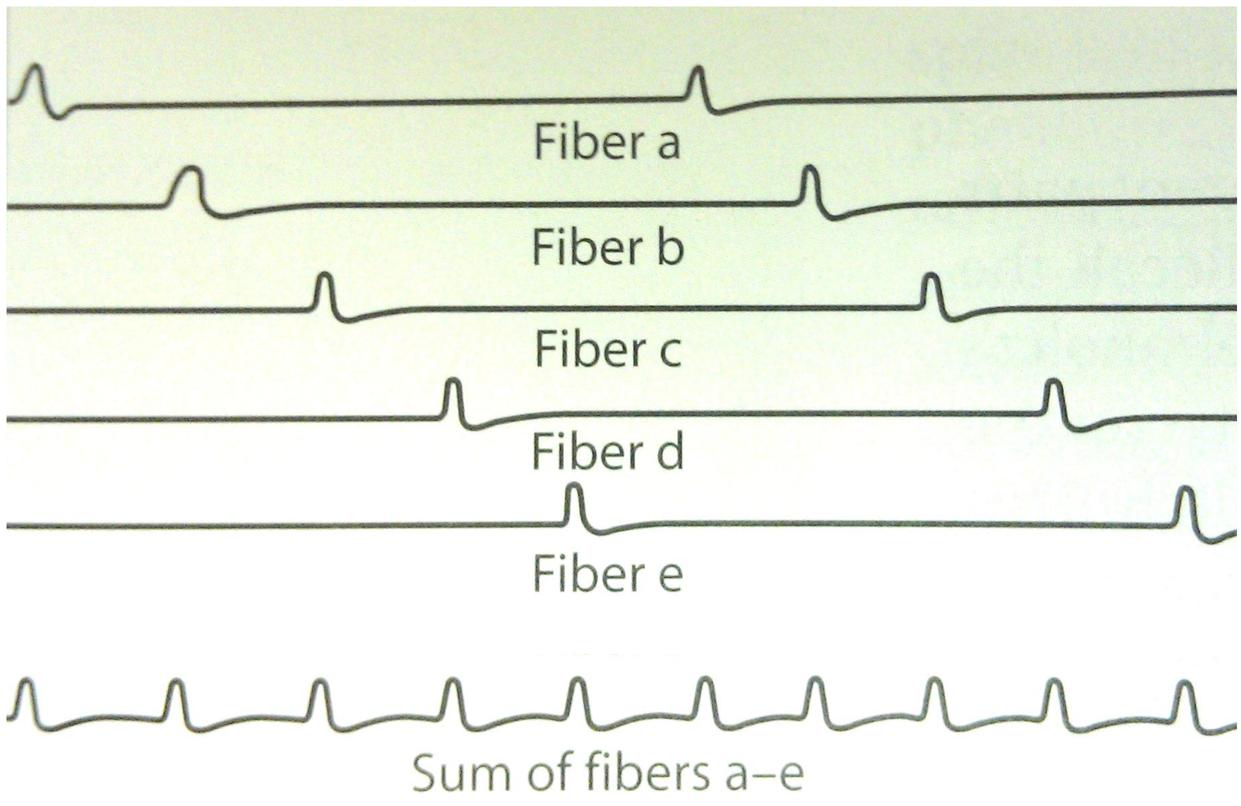


Spiral Ganglions (ANFs)

All responding to <u>SAME</u> Hair Cell

SGa
SGb
SGc
SGd
SGe

Overall response from Auditory Nerve



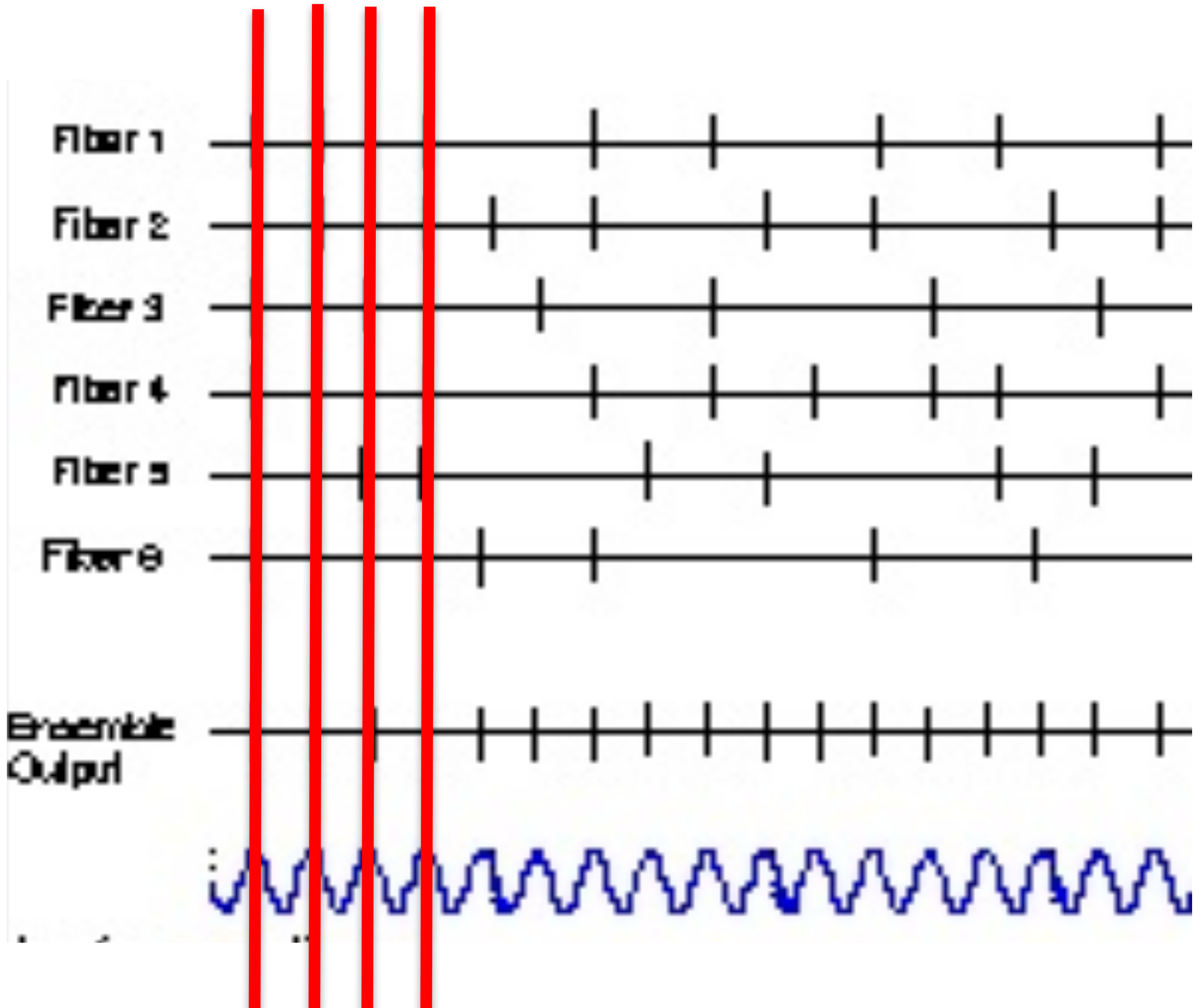
Produces VOLLEYS of activity at rate of input (3000/sec)

Temporal Coding (Rate Coding)

Volley Principle – Depends on Ganglions being **Phase Locked**

Spiral Ganglions
do not just fire when
they are ready,
but are locked to the
PHASE of input
(only fire ~PEAK)

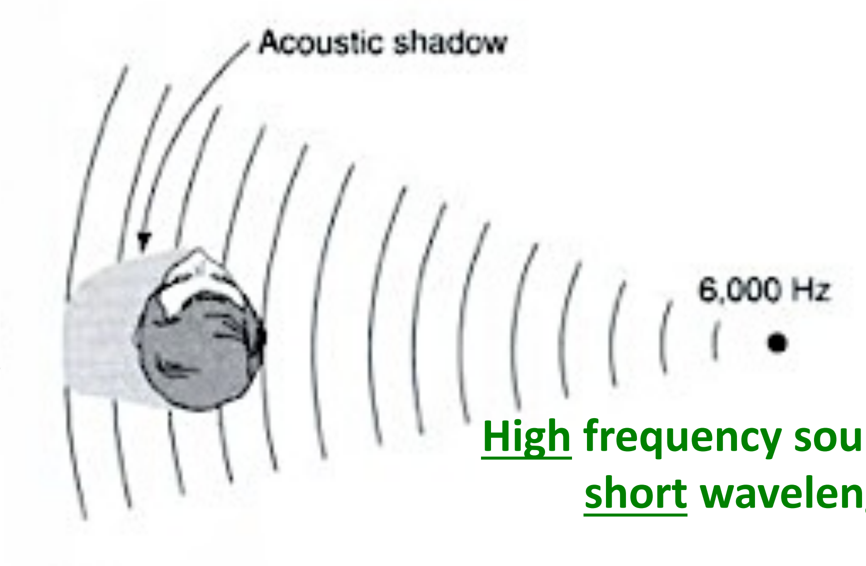
In this way,
Auditory Nerve
produces
VOLLEYS of activity
at correct intervals



Localization - via <u>Amplitude</u> differences

"Head Shadow"

Head absorbs some of sound energy, so sound is louder at ear closer to source.



<u>High</u> frequency sounds have <u>short</u> wavelengths

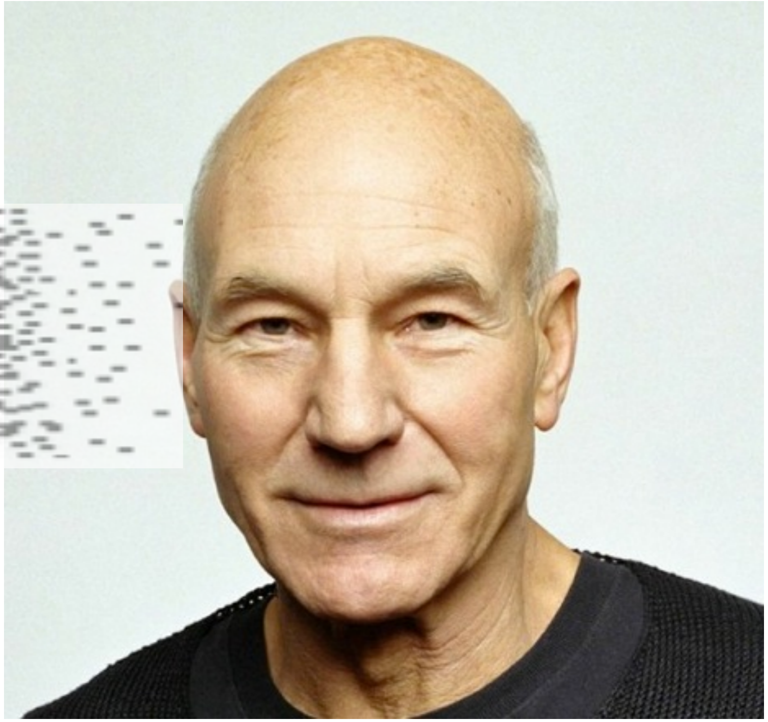
Works best with

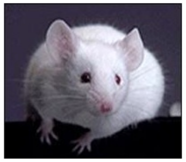
Higher Frequencies

(shorter wavelengths) since lower frequencies pass around head, less likely to be absorbed.

<u>Low</u> frequency sounds have <u>long</u> wavelengths

Localization - via <u>Phase</u> differences

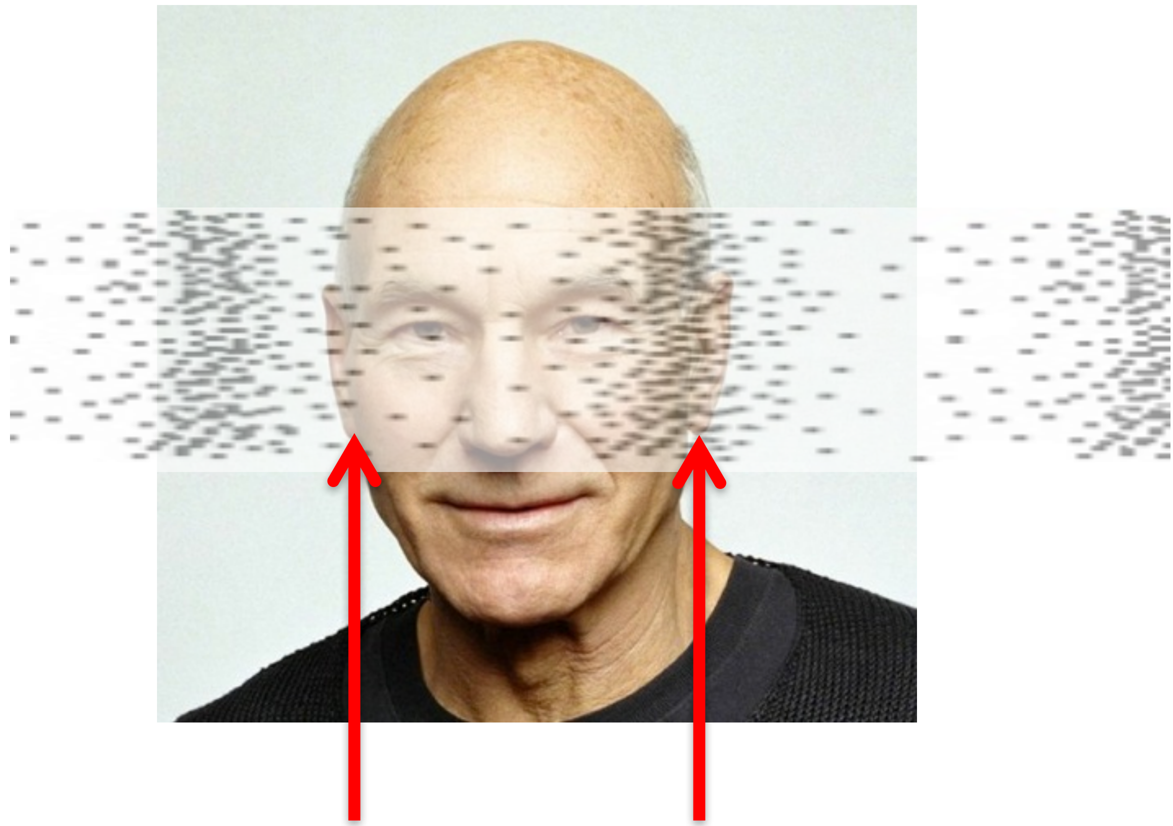




Localization - via <u>Phase</u> differences

<u>Works best with</u>
<u>Lower Frequencies</u>
(longer wavelengths)

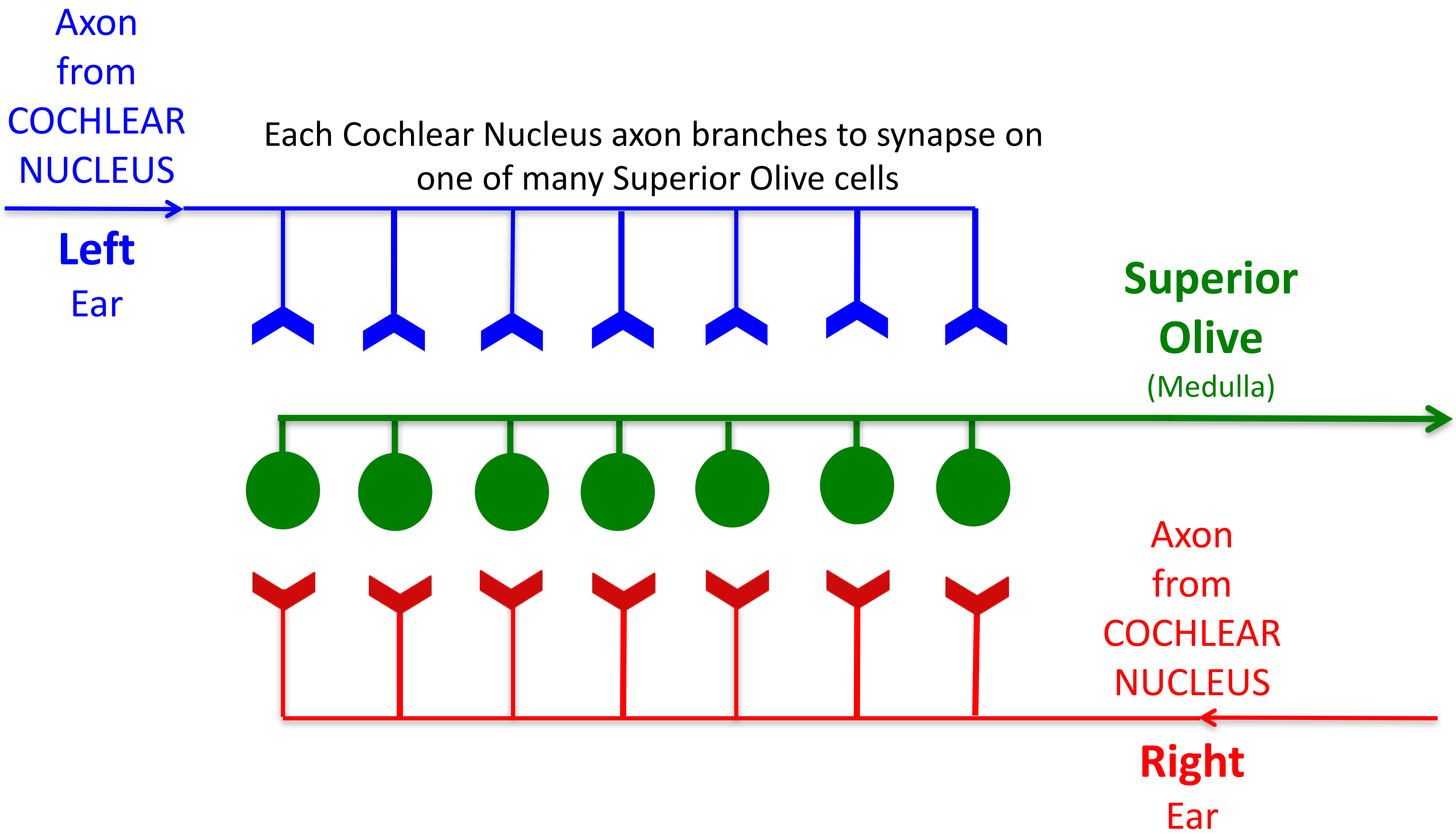
Small-headed animals
do not use phase,
since often ambiguous



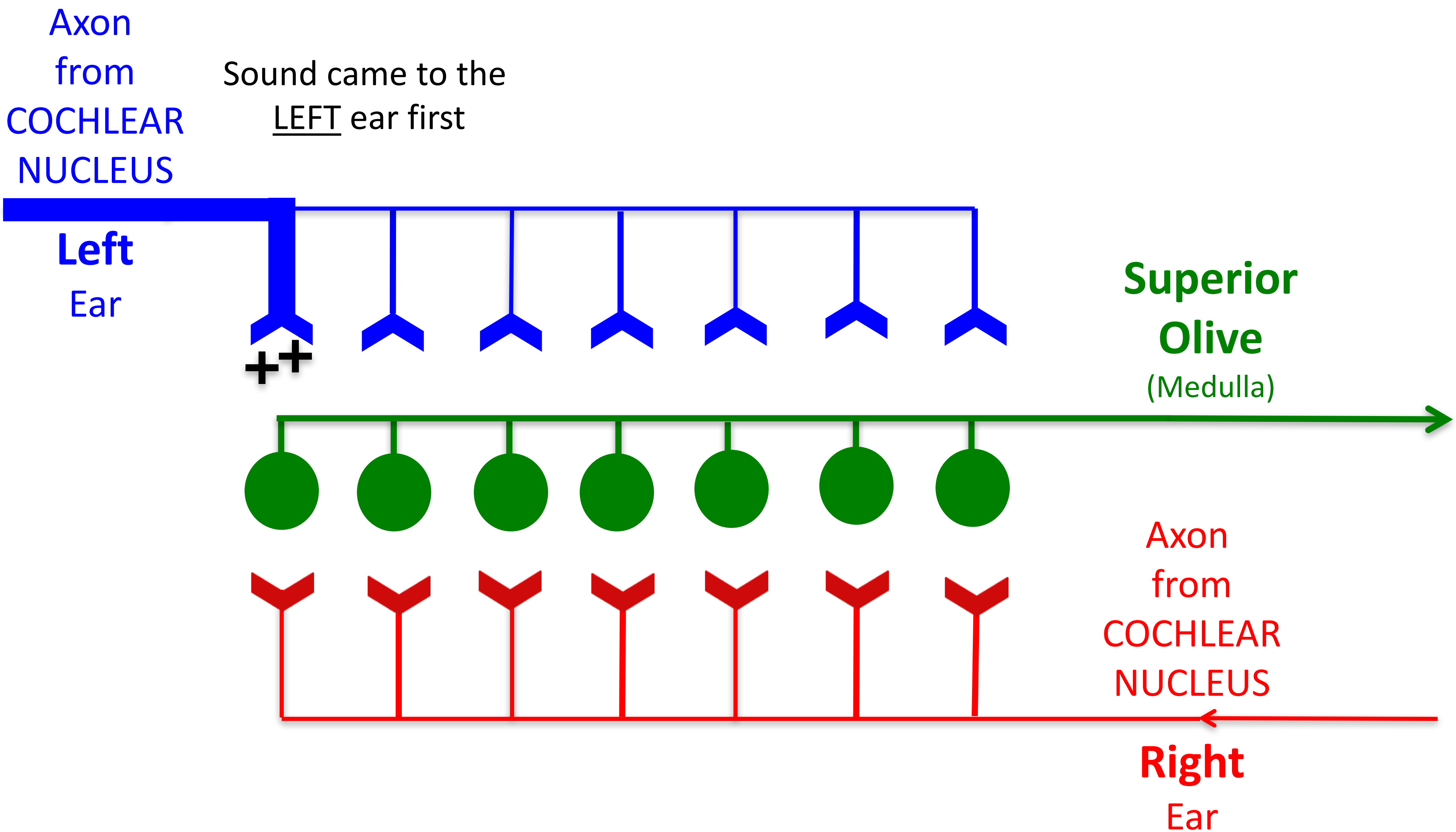
Note PHASE difference at two ears

Localization - via Timing Differences

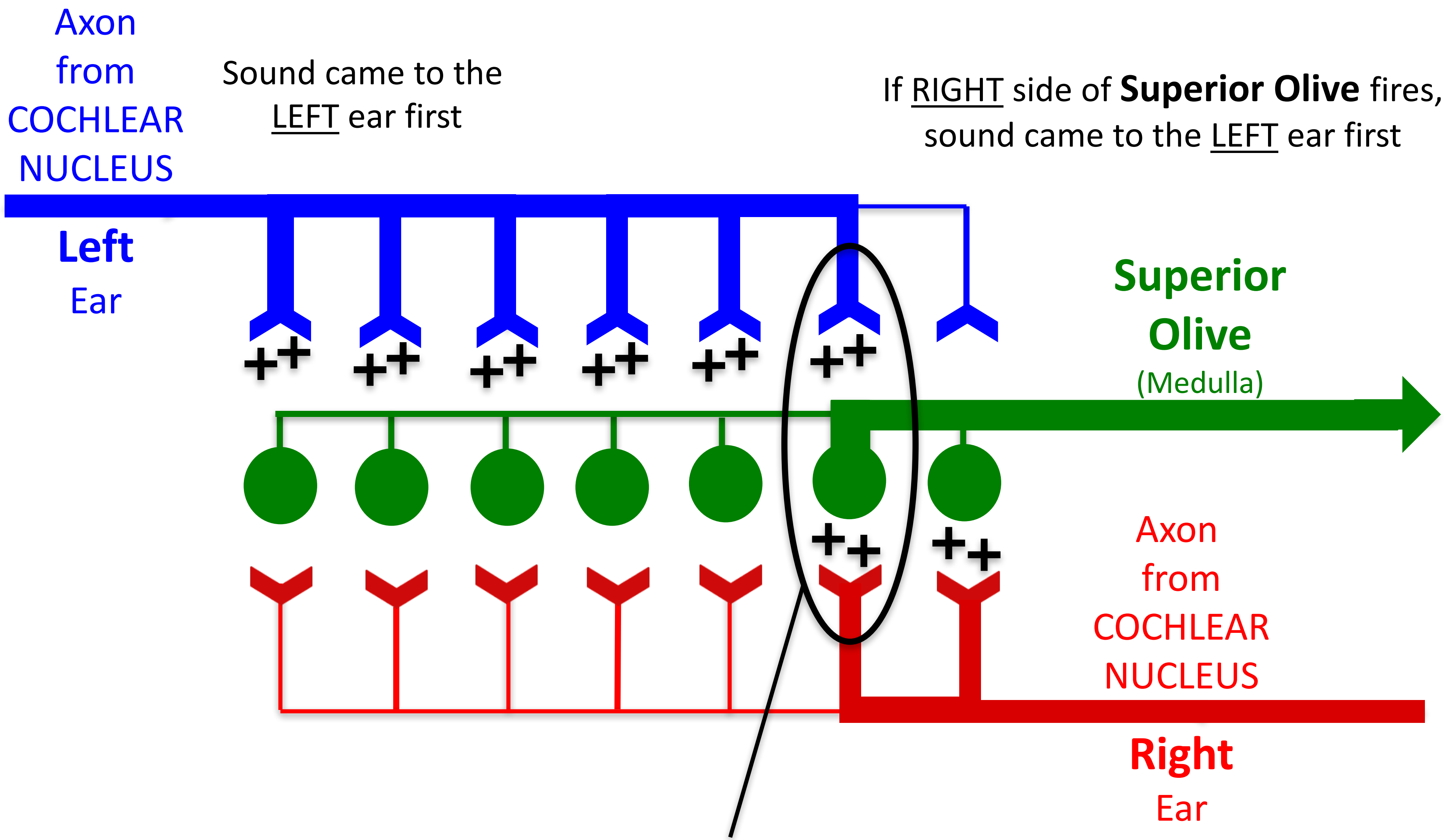
Each Cochlear Nucleus axon branches to synapse on one of many Superior Olive cells



Localization - via Timing Differences

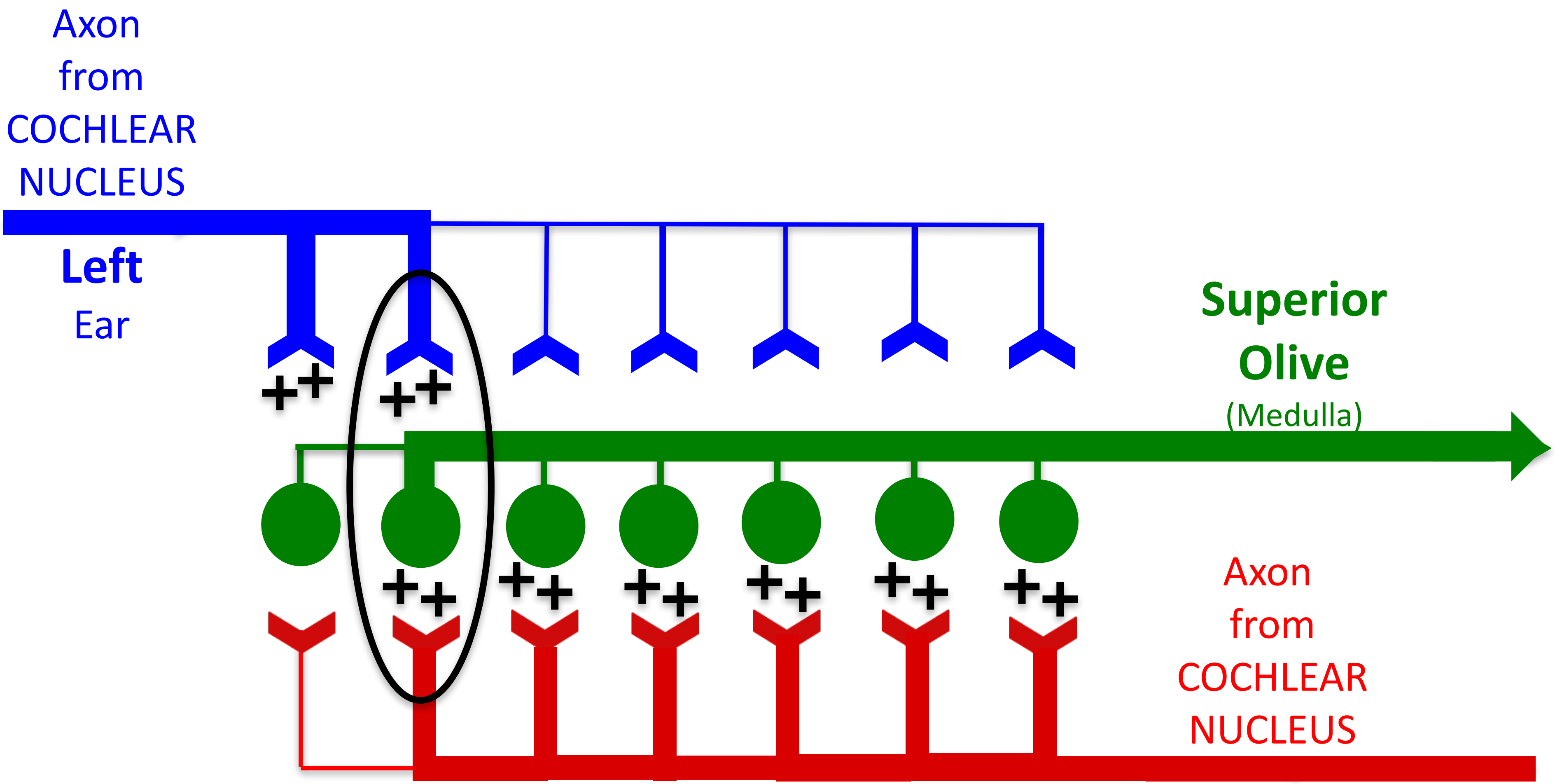


Localization - via Timing Differences



Only when input from BOTH ears converges
will Superior Olive fire

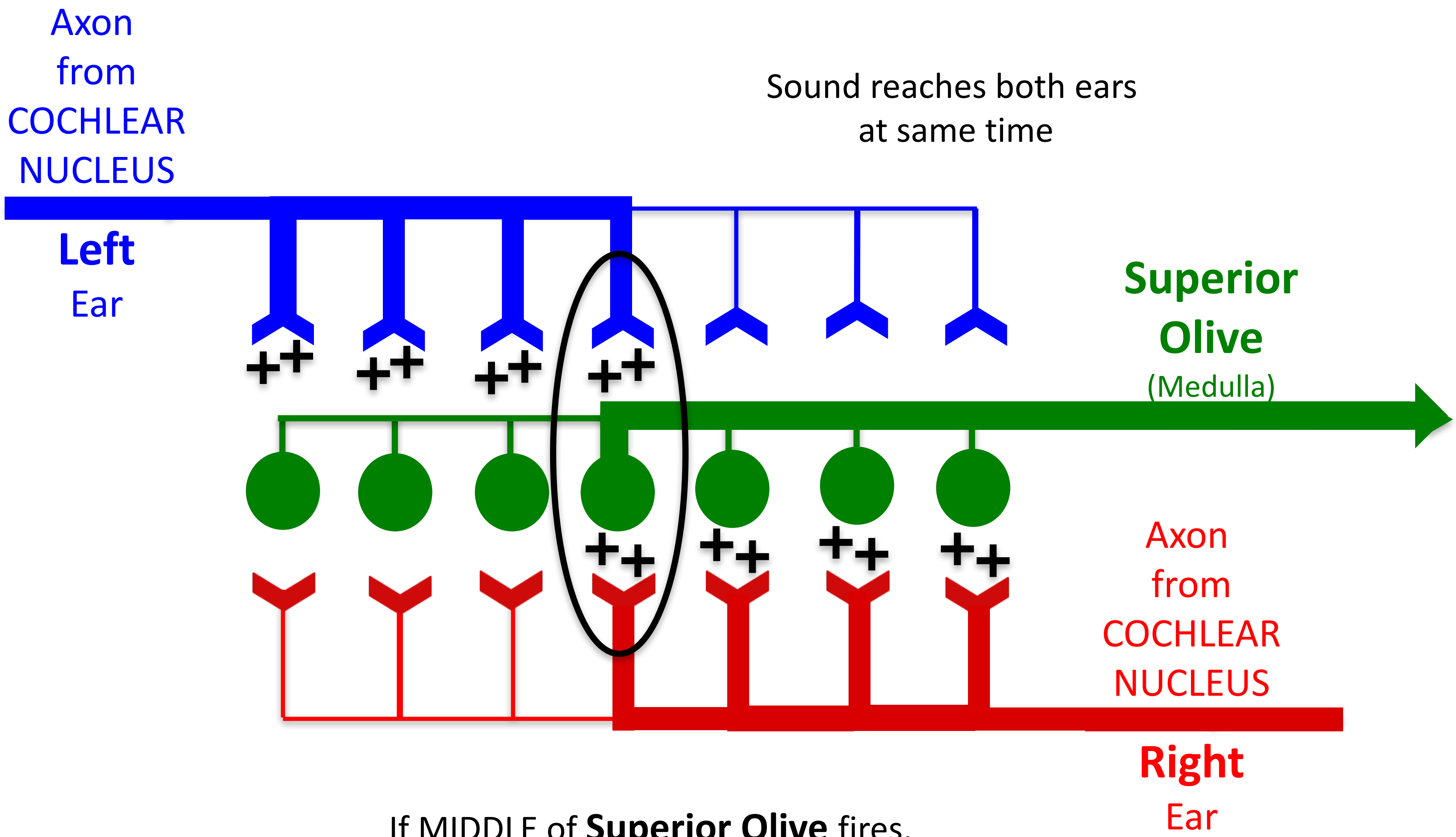
Localization – via Timing Differences



Sound came to the RIGHT ear first

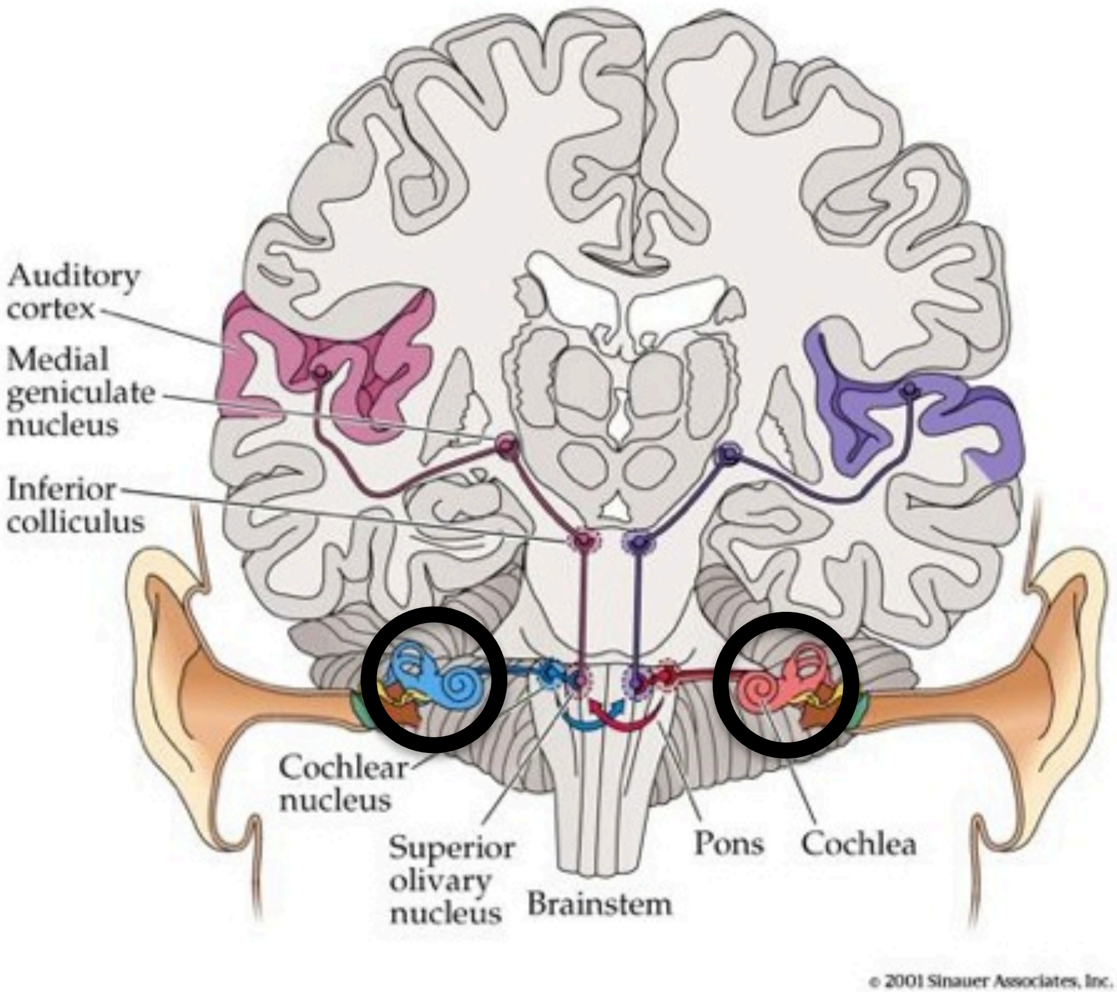
If LEFT side of **Superior Olive** fires, sound came to the RIGHT ear first

Localization – via Timing Differences



If MIDDLE of **Superior Olive** fires,
sound came to BOTH ears at same time

Auditory Pathways



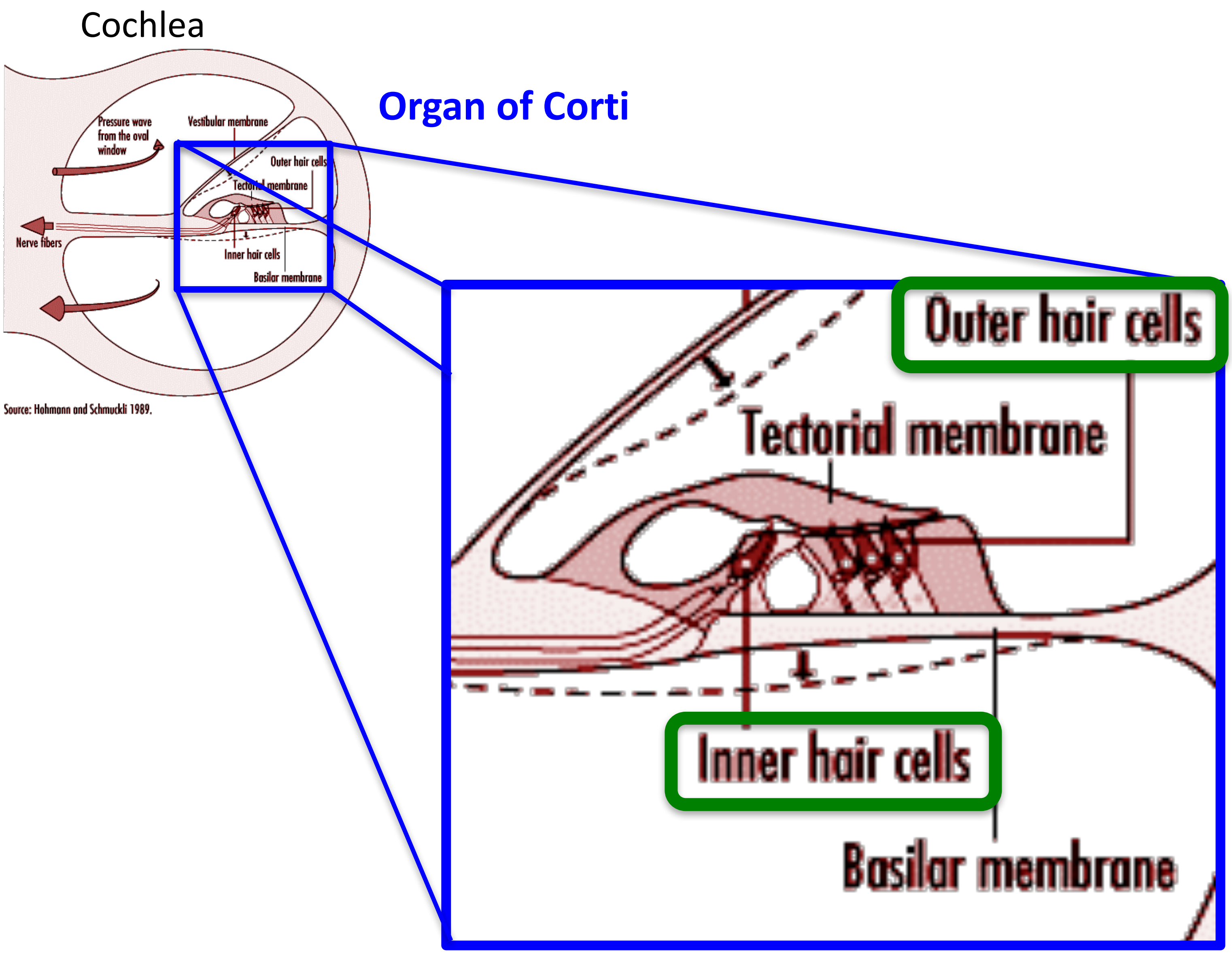
Begin with

Hair Cells

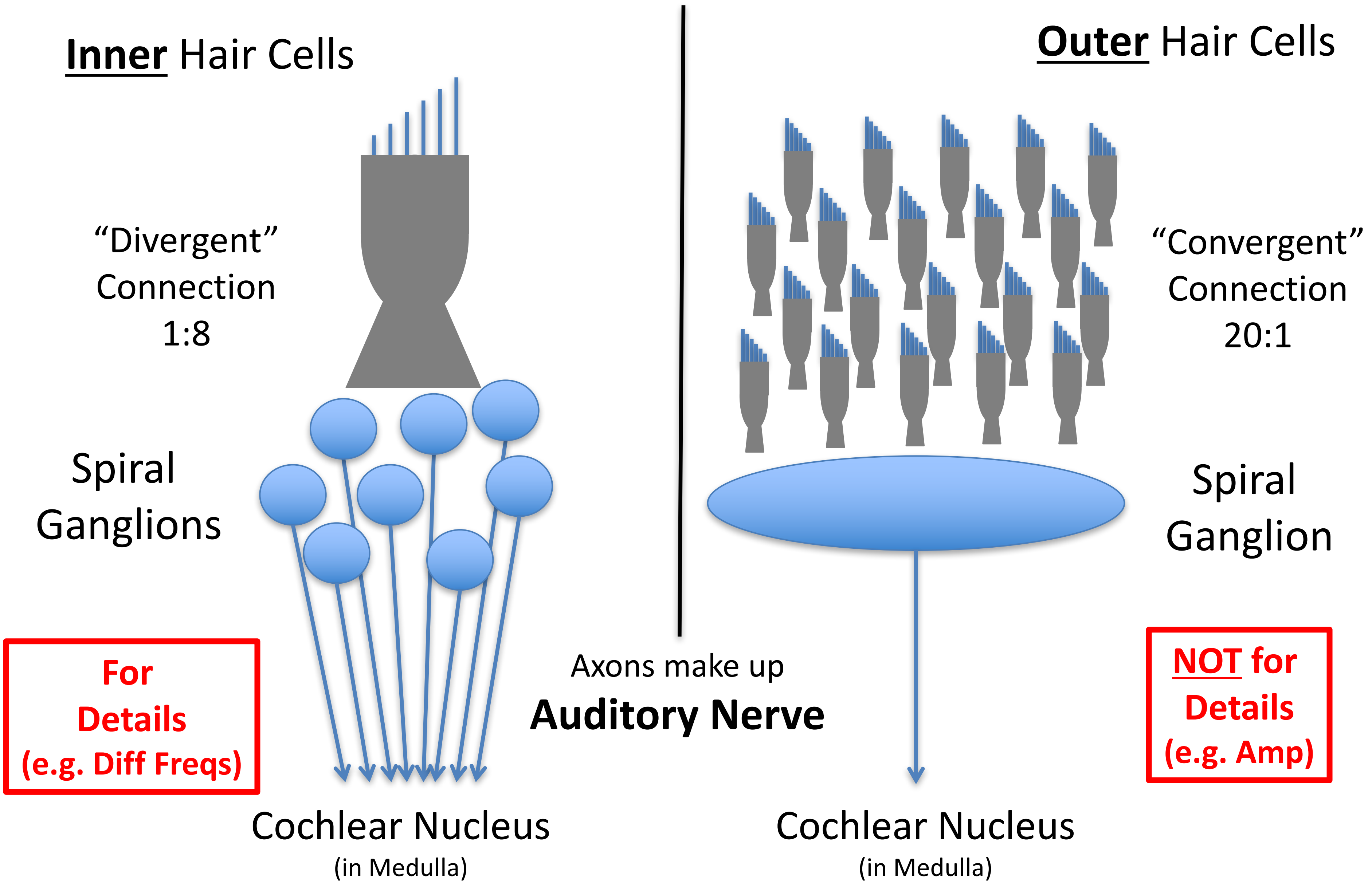
(Receptors)

in Cochlea

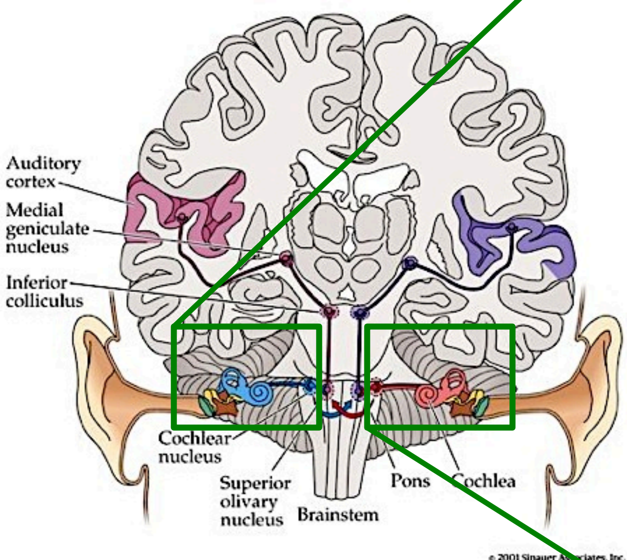
Hair Cells – Auditory Receptors

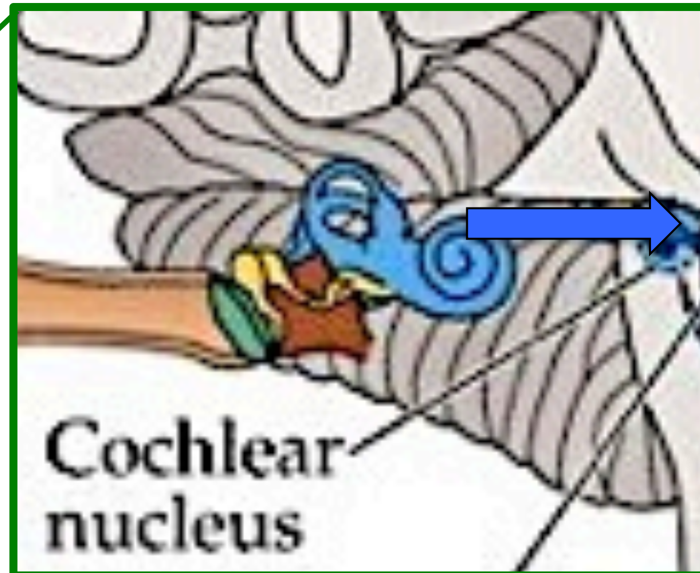


Hair Cells – Auditory Receptors

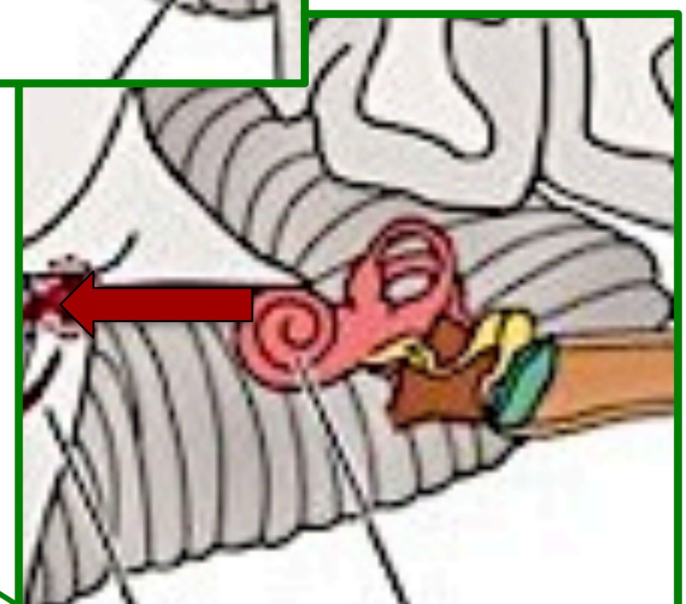


Auditory Pathways





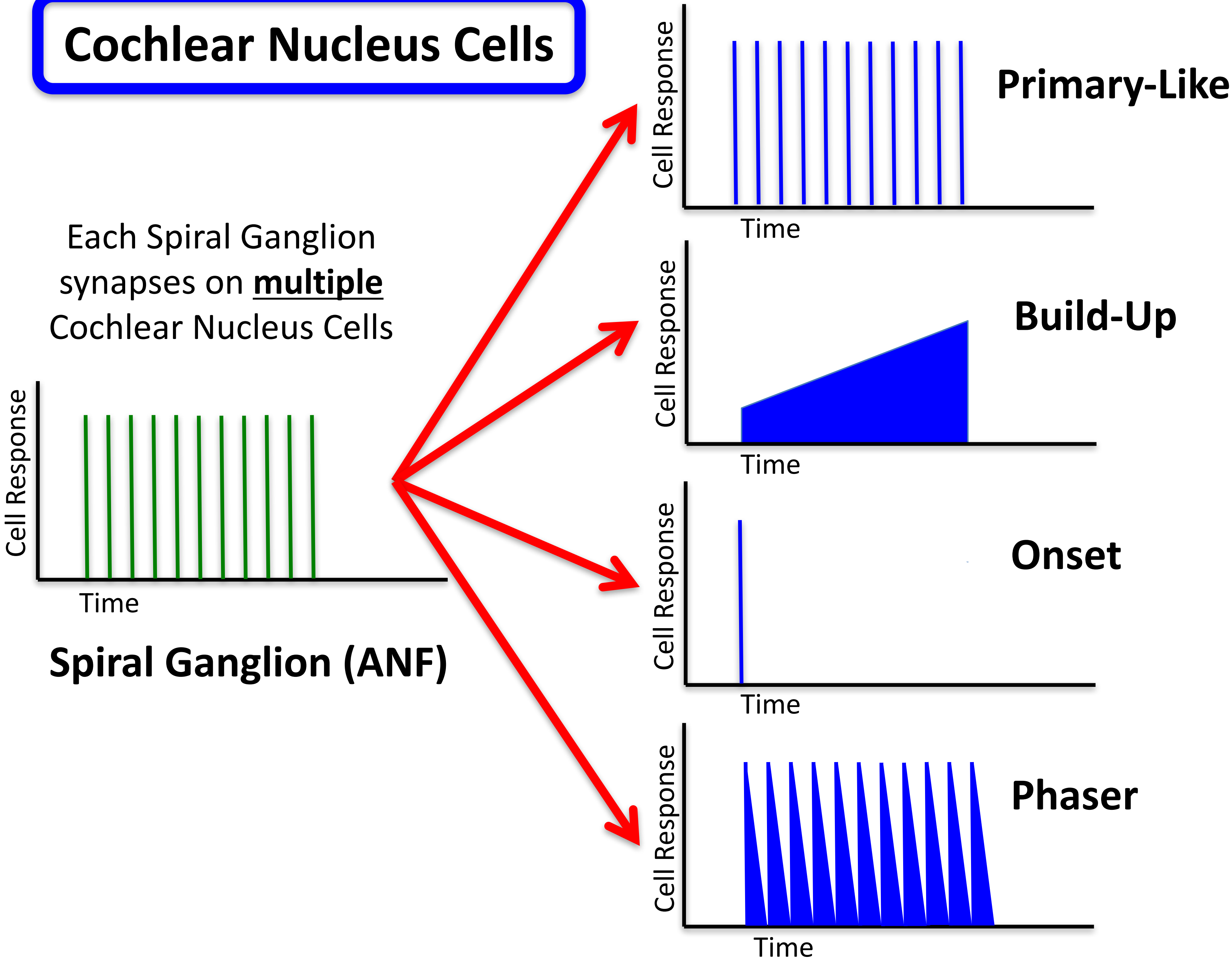
Auditory Nerve
to
Cochlear Nucleus
in
Medulla



Monaural
i.e. each Auditory Nerve
connects only to
IPSI-lateral side

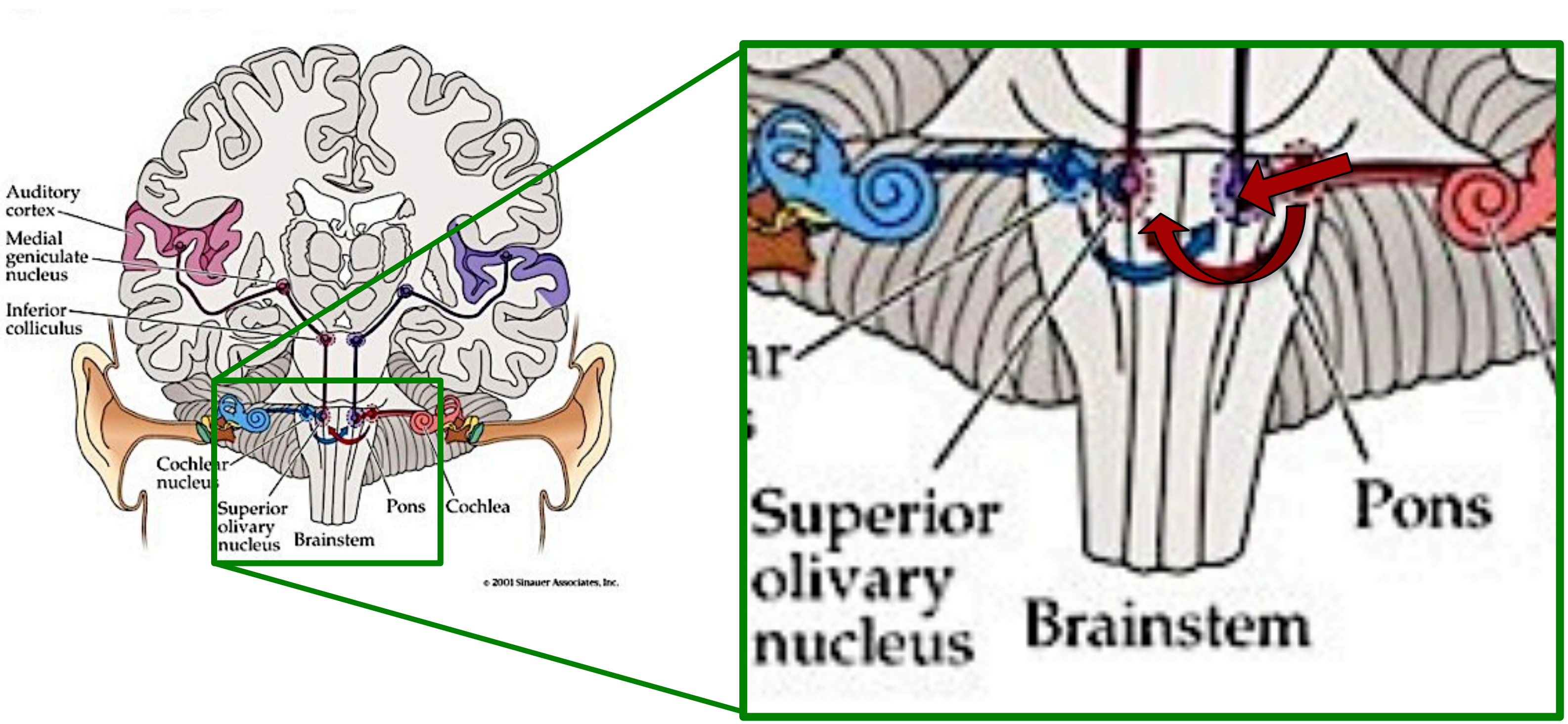
Cochlear Nucleus Cells

Each Spiral Ganglion synapses on **multiple** Cochlear Nucleus Cells



Auditory Pathways

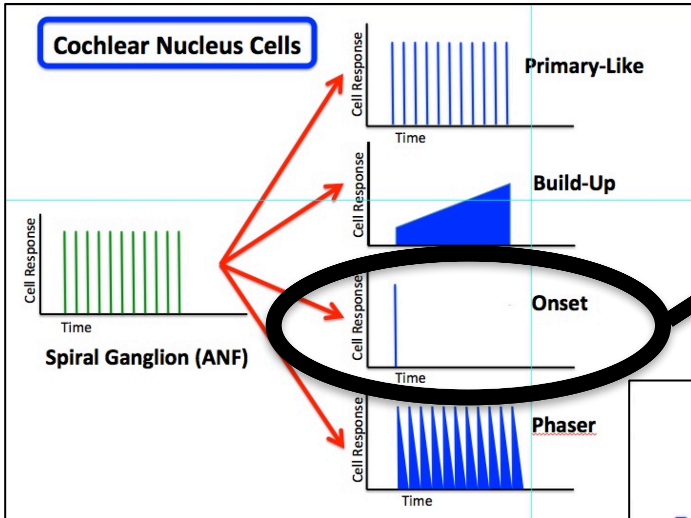
Fibers from Cochlear Nucleus
go to IPSI-lateral and CONTRA-lateral
Superior Olives in Cerebellum



Combining info from both ears
allows for localization.

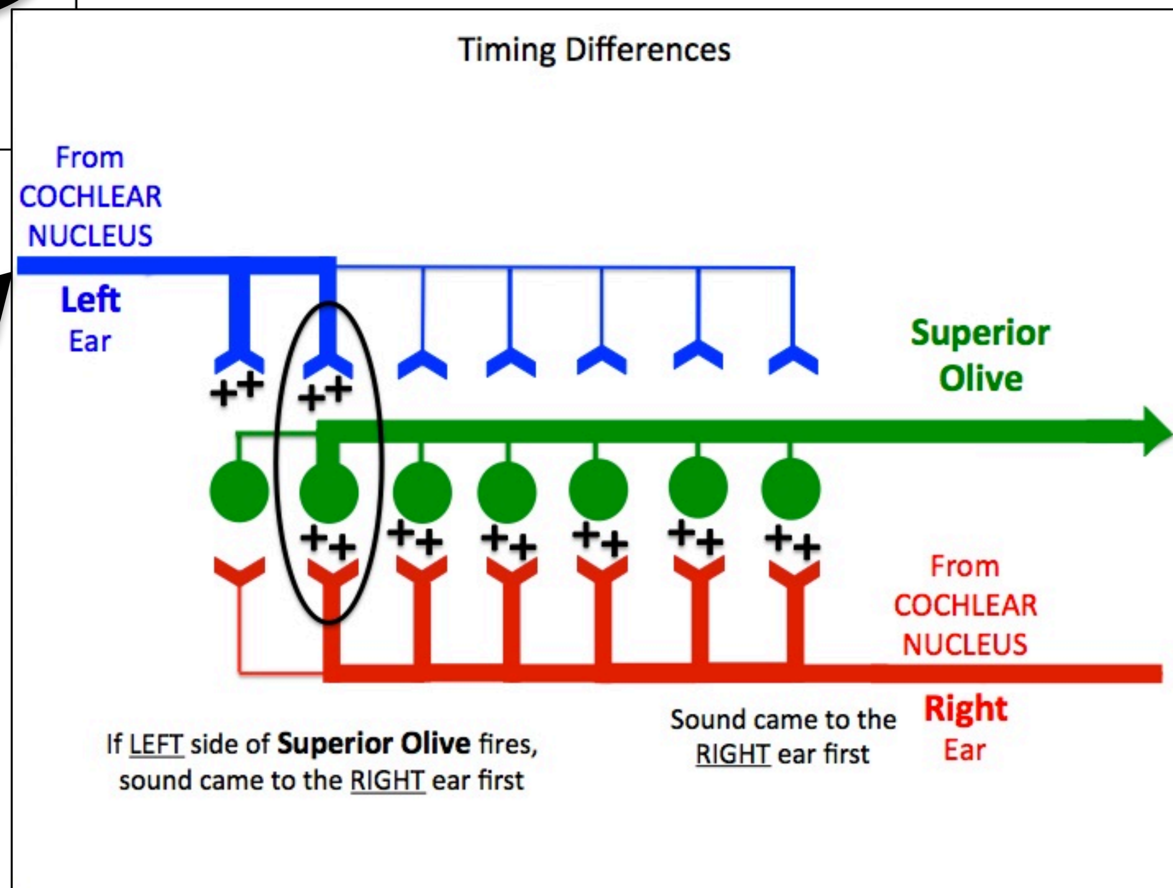
Thus, these, and
all subsequent connections,
are **Binaural**

Auditory Pathways

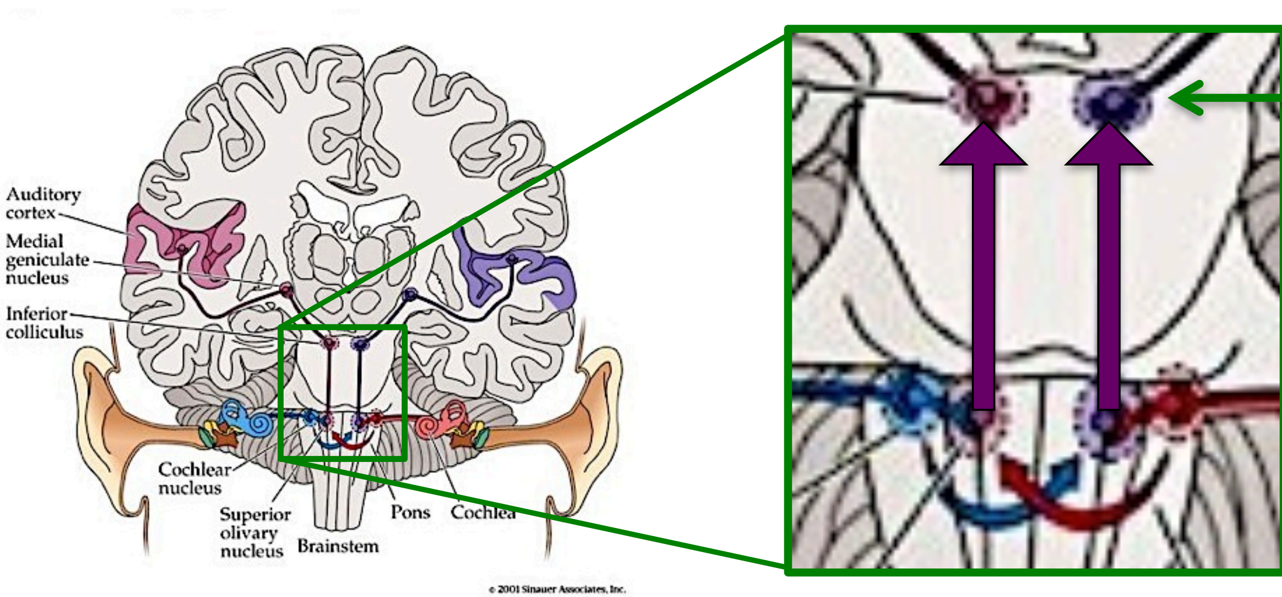


Onset signal from
Cochlear Nucleus . . .

. . . is input to
Superior Olive
localization circuit



Auditory Pathways



From
Superior Olives,
connect to
Inferior Colliculi
in Midbrain

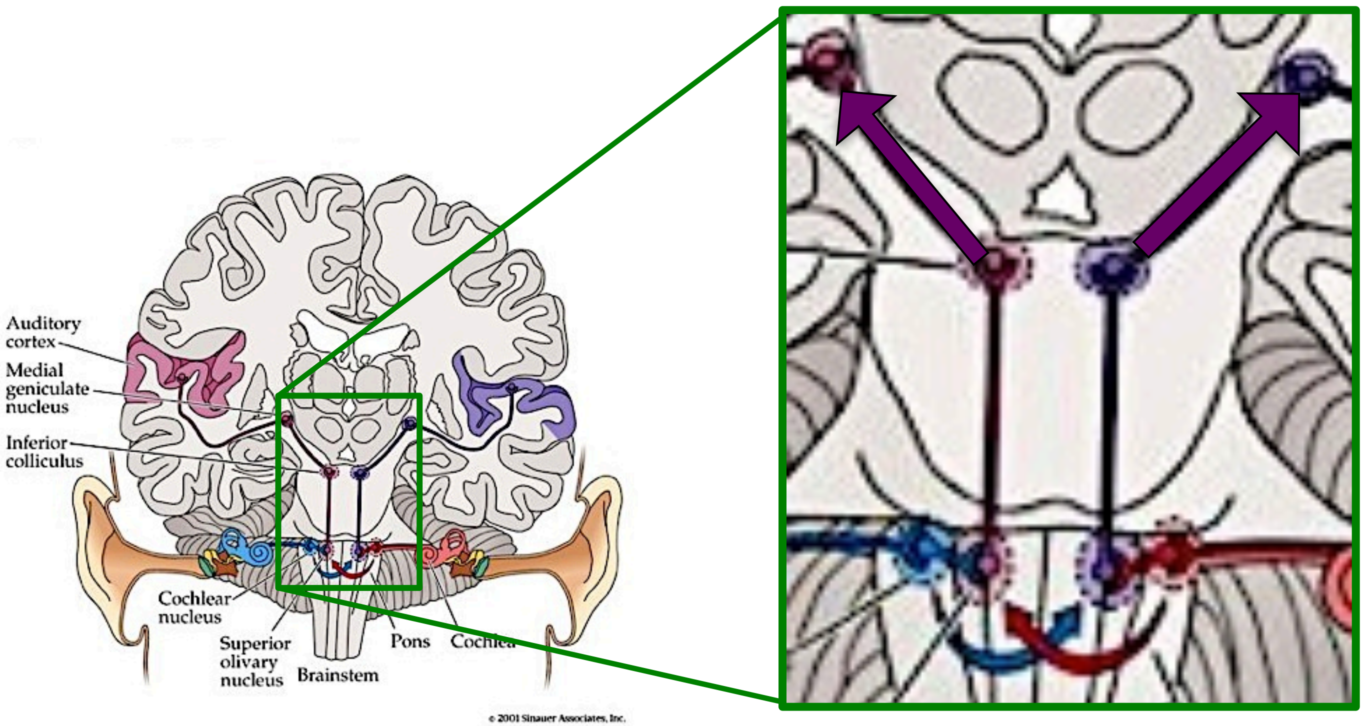
These communicate w/Superior Colliculi
(visual motion maps)
and Tegmentum, to direct eyes
to source of sound

Auditory Pathways

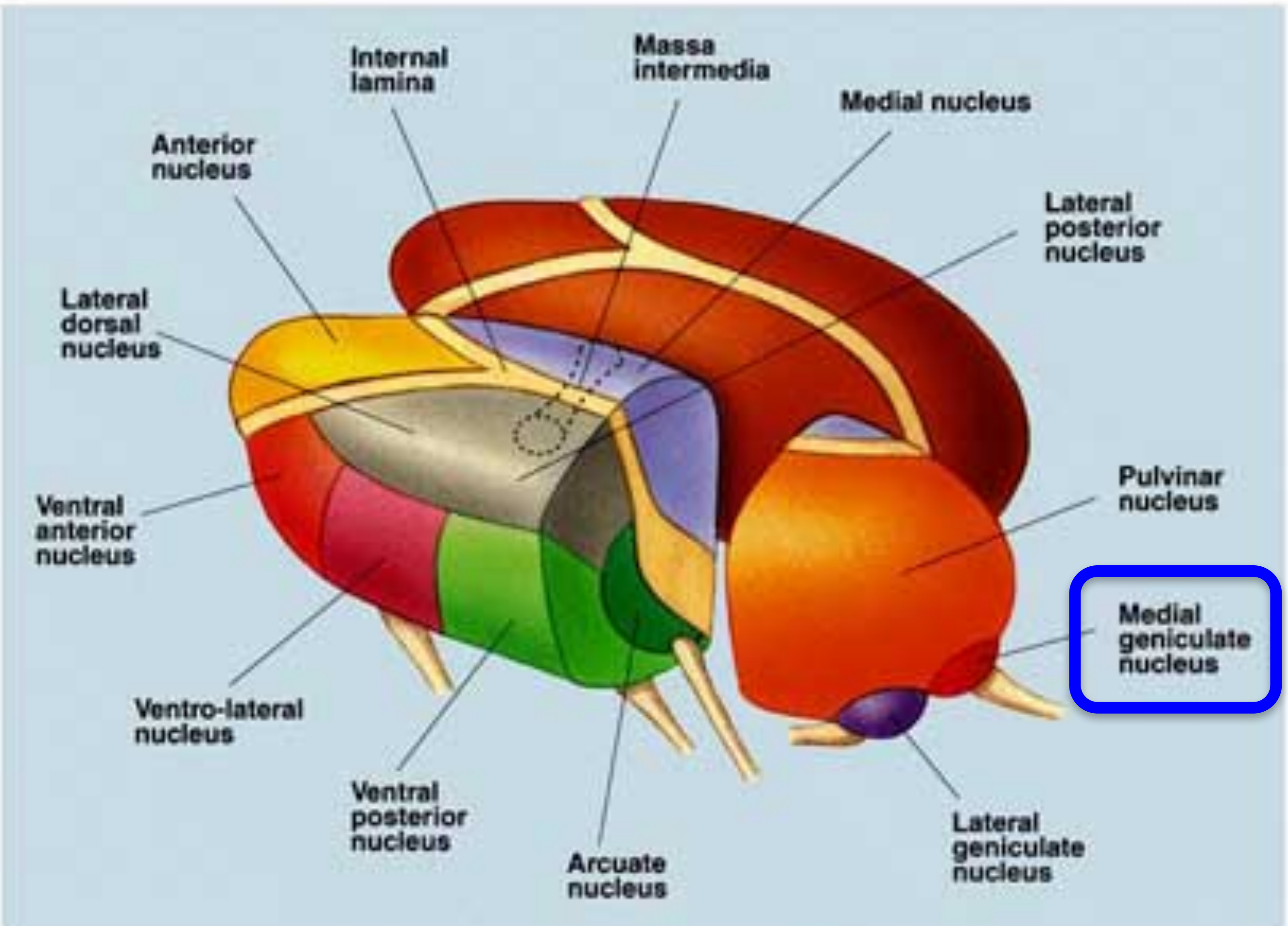
From Inferior Colliculi to

Medial Geniculate Nucleus (MGN)

of Thalamus



► Nuclei of the Thalamus



MGN

Medial Geniculate Nucleus

MNEMONICS: Nuclei of the **Thalamus**

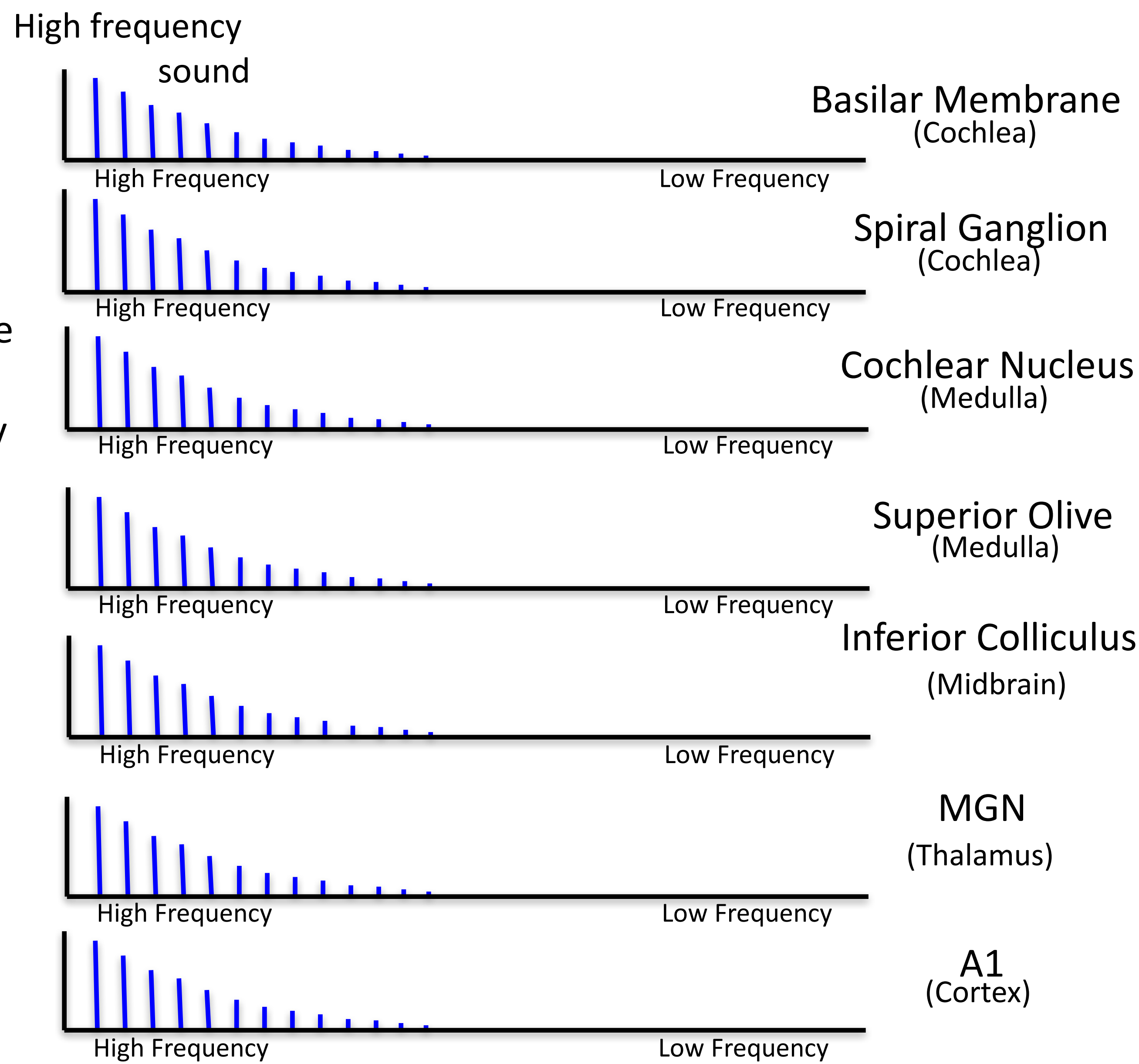
- **L**GN (Lateral Geniculate Nucleus)
- **M**GN (Medial Geniculate Nucleus)
- **VP**N (Ventral Posterior Nucleus)
- **DM**N (Dorsal Medial Nucleus)
- **VL**N (Ventro Lateral Nucleus)
- **MD**N (Medial Dorsal Nucleus)

- **L** is for Light (Visual)
- **M** is for Music (Auditory)
- **VP** is for Very Personal (Touch)
- **DM** is for Dog Muzzle (Smell)
- **VL** is for Victory Lap (Motor)
- **MD** is for Memory Doctor (Memory)

Others?!

Topological Maps in Auditory System

Distribution of activity across the Basilar Membrane (“Place-coded” frequency) is preserved up the pathway



In the Auditory system, such Topological maps are called **"Tonotopic Maps"**

Auditory Pathways

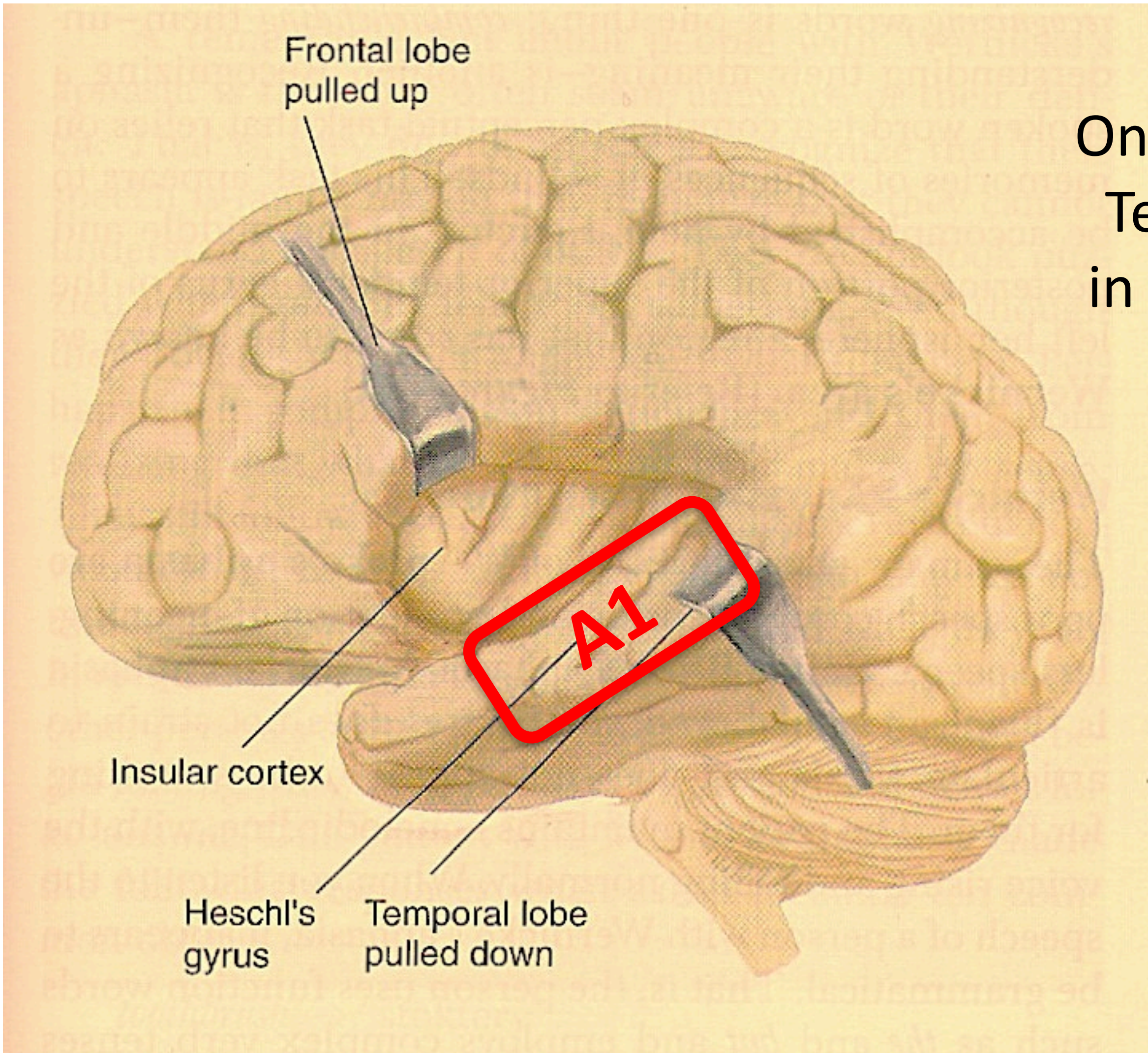
Auditory Cortex

From MGN to

A1 (Primary Projection Area)

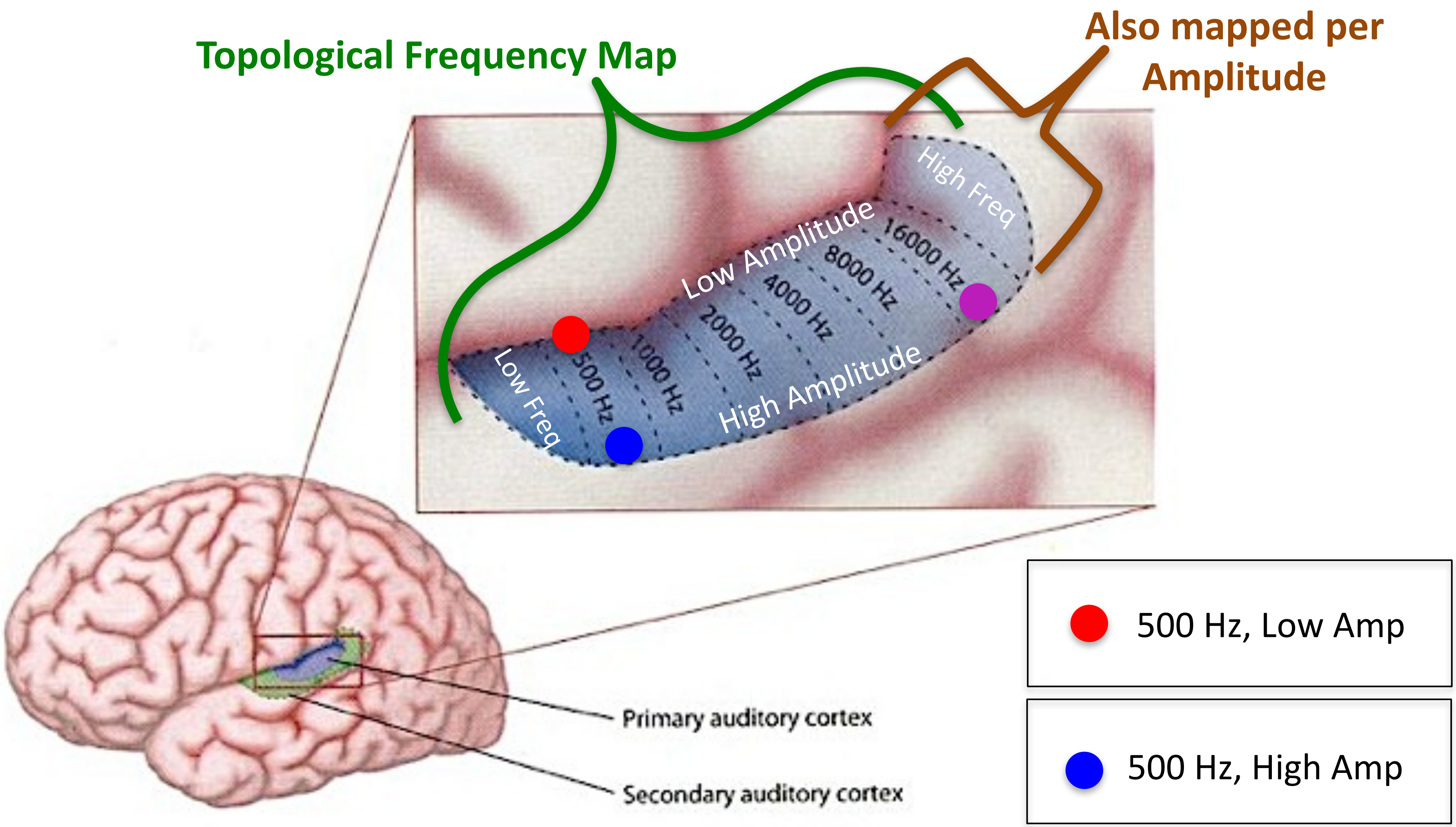
in Medial Temporal Cortex

Primary Projection Area for Audition



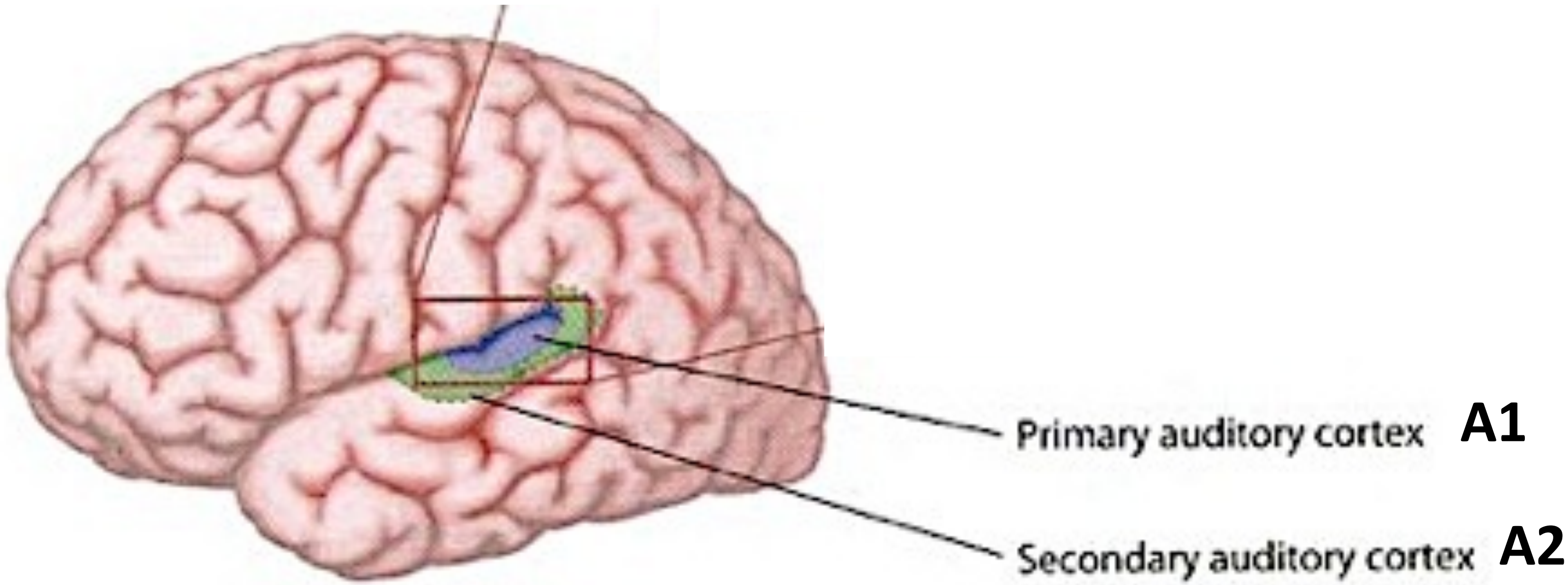
On Medial face of Temporal Lobe, in Lateral Fissure

A1 – Primary Projection Area for Audition in Cortex



All cells in each column
(through 6 layers, below each dot)
have same preferred stimulus

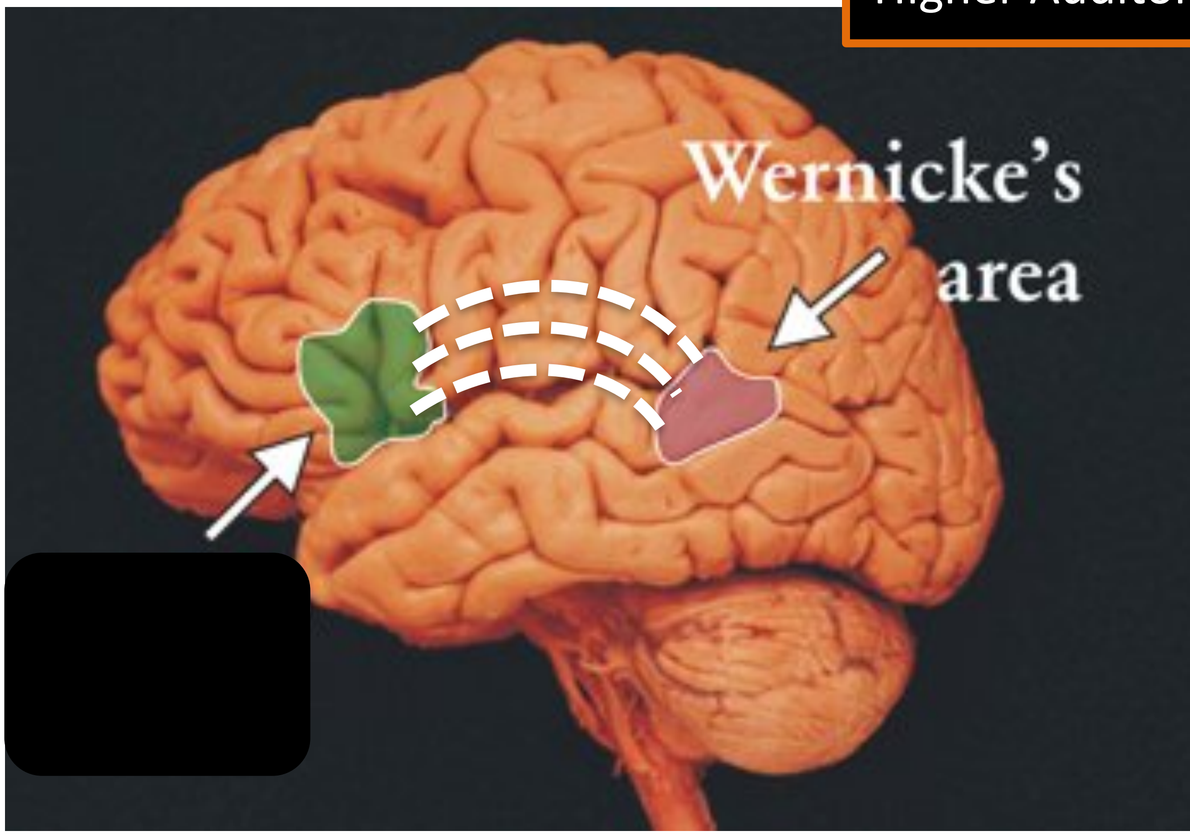
A2 – Secondary Auditory Cortex



A1 – Responds best to single frequency

A2 – Responds best to changing frequency

Wernicke's Area



Wernicke's Area – Specialized for comprehending SPEECH

Interacts with Broca's Area in Prefrontal Cortex, for speech Production