The Auditory System
The function of the auditory system is to perceive sounds (i.e., to localize and to identify sounds in space). Physical dimensions of sound relate to perceptual dimensions.
Natural sounds are complex patterns of vibrations.

Fourier analysis breaks a natural sound down into its component sine waves.

There is a complex relationship between sound components and perception.
The Ear

Sound propagation:
- wave enters auditory canal
- strikes the eardrum (or tympanic membrane)
- ossicles (hammer, anvil and stirrup) vibrate
- oval window vibrates
- fluid in cochlea set in motion
- vibrations of fluid dissipated at round window
The cochlea is divided into three chambers (scala) by Reissner’s membrane and the basilar membrane. The auditory receptor organ, the organ of Corti, sits on the basilar membrane in the middle scala.
Motion of the Basilar Membrane
Organ of Corti

There are two types of hair cells in the Organ of Corti:
• inner hair cells, ~3,500
• outer hair cells, ~14,000

All hair cells have stereocilia on their upper surfaces which are in or near the tectorial membrane.

Up-down motion of basilar membrane converted to side-to-side motion of stereocilia.
Transduction of Sound-Induced Motion

Mechanotransduction: conversion of mechanical stimulus to an electrical or chemical signal

Outer hair cells change length and augment basilar membrane motion

Inner hair cells release transmitter onto axons of the auditory nerve
Like the cochlea, most structures of the auditory system are arrayed according to frequency (i.e., in a tonotopic manner).
From Ear to Primary Auditory Cortex

The axons of each auditory nerve synapse in the cochlear nuclei on the same side (ipsilateral)

From there, projections lead to the superior olives on both sides of the brain stem (binaural)

Cochlear nuclei and superior olives $\rightarrow$ inferior colliculi $\rightarrow$ ipsilateral medial geniculate nuclei of the thalamus $\rightarrow$ ipsilateral primary auditory cortex
The auditory cortex is located in the temporal lobe.

The auditory cortex includes:
- a core (primary; A1) and
- up to 10 belt (secondary) regions

Each area appears to be organized on the basis of frequency (tonotopic).
Auditory Scene Analysis

Fan

Speech

Printer

![Diagram of auditory scene analysis]

![Waveform and spectrum analysis]

Frequency (kHz)

dB
Left-Right Sound Localization Cues

Sounds located off the midline reach the two ears at different times and different intensities

**Interaural time difference**

**Interaural level difference**

From Feddersen et al. 1959
Subcortical Processing of Localization Cues

![Diagram of subcortical processing of localization cues](image)

**Key Terms:**
- \( t_{\text{ipsi}} \) for ipsilateral side
- \( t_{\text{contra}} \) for contralateral side
- \( L_{\text{ipsi}} \) for ipsilateral input
- \( L_{\text{contra}} \) for contralateral input

**Diagram Details:**
- Ipsilateral side vs. Contralateral side
- Excitatory vs. Inhibitory pathways
- MSO (Medial Superior Olive)
- Auditory nerve
- Other brain regions and pathways not labeled

**Legend:**
- Black line: excitatory
- Red line: inhibitory
One small area just anterior to the primary auditory cortex has neurons that respond to pitch rather than frequency (sensitive to missing fundamental)
Auditory signals are conducted to two areas of association cortex:

- Posterior parietal cortex
- Prefrontal cortex

Posterior vs Anterior:

- “where” vs “what”
- in register with visual pathways
Auditory-Visual Interactions

There is evidence for interactions between the auditory and visual systems.

For example, some posterior parietal neurons have both auditory and visual receptive fields.

Vision can affect the way sounds are perceived, the McGurk Effect.

https://www.youtube.com/watch?v=G-lN8vWm3m0
Lesions of auditory cortex
• unilateral: disrupts ability to localize sounds in contralateral hemifield
• bilateral: localization and pitch discrimination

Deafness:
• conductive: damage to ossicles; and
• nerve: damage to cochlea