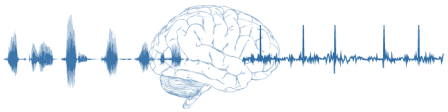

Primer on Auditory Processing

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601.467/667 Introduction to Human Language Technology

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Speech as waves

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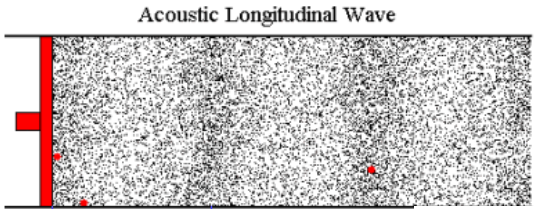
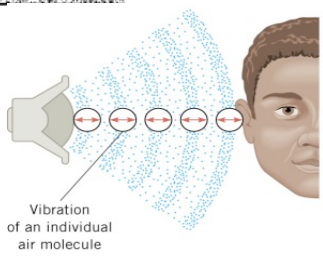
Sound is a wave

- Sound is a mechanical wave caused by a vibrating source
- The vibrating source that causes the matter around it to move



- No sound is produced in a vacuum
  - Matter (air, water, earth) must be present
- Individual air molecules do not move the wave. A given molecule vibrates forth about a fixed location.



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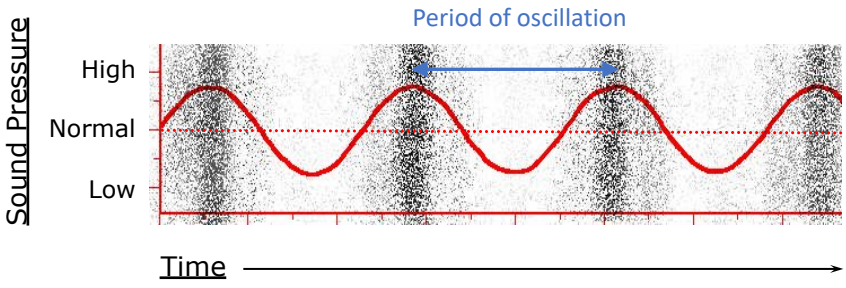
Sound waves



- Motion air particles do not travel, they oscillate around a point in space
- The rate of oscillation is called frequency (f)
  - ✓ denoted in cycles per second (cps) or hertz (Hz).

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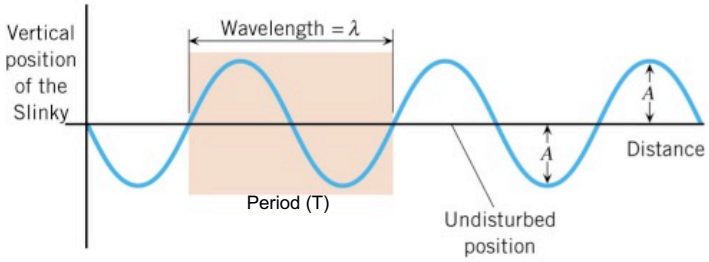
Physical Dimensions of Sound



Amplitude
- Height of a cycle

Frequency (F)
- Cycles per second

Wavelength (λ)
- Distance traveled by one cycle

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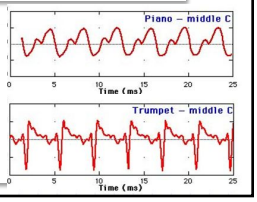
Perceptual dimensions of Sound

Physical Properties of Sound — **Perceptual Dimensions**

Amplitude/Intensity ⟷ Loudness

Frequency ⟷ Pitch

Complexity (frequency content & time) ⟷ Timbre



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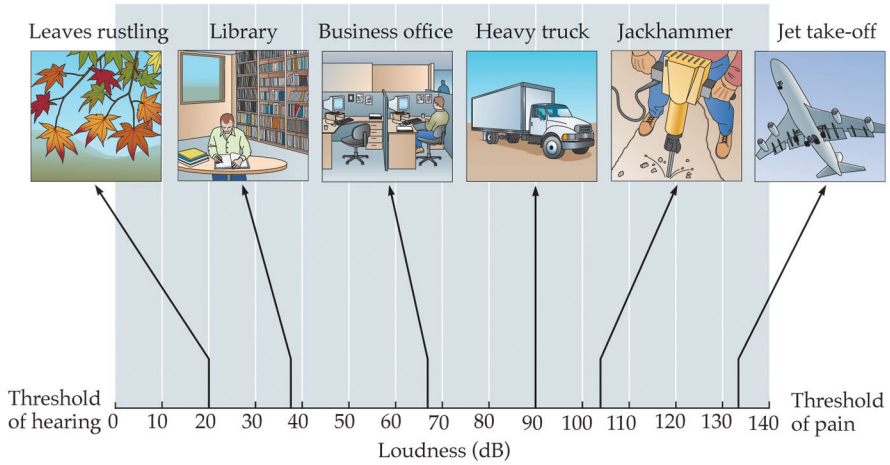
Sounds in the environment



Note: Listening to loud music will gradually damage your hearing!

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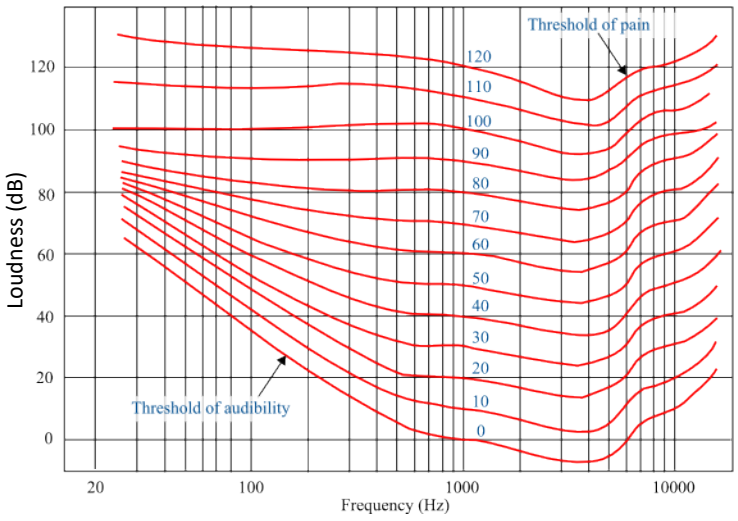
Equal Loudness Curves/Contours



Each contour represents equally-perceived tones

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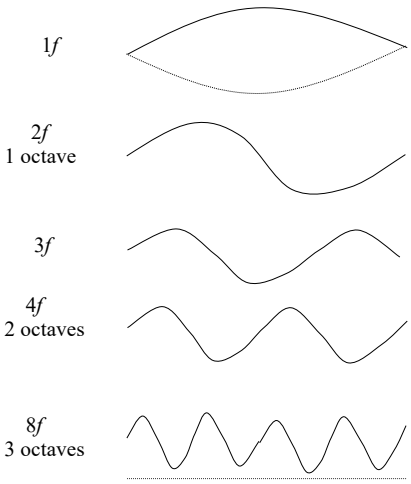
Pitch



- At first approximation, the pitch of a simple periodic signal is determined by its frequency.
- Most oscillators (guitar string, vocal chords) naturally oscillate at a fundamental frequency (F_0) as well as its integer multiples (called harmonics/partials/overtones).
- The pitch of a *complex* period signal is often determined by its *fundamental* frequency (F_0)

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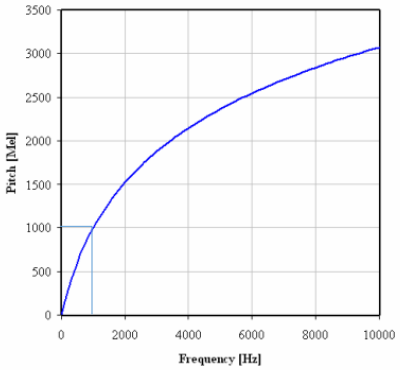
a Pitch scale

- Perceptual scale of pitch: mel scale
  - *How far in frequency do we have to be in order to feel a tone as doubled in pitch?*



➡ It's a relative scale, based on pitch comparisons

$$m = 2595 \log_{10}\left(1 + \frac{f}{700}\right)$$

✓ Mel-scaling is used in signal processing to build filters that approximate human pitch perception (MFCC)

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Masking

- Hearing phenomenon
  - When the perception of one sound is affected by presence of *another* sound
  - one sound being *masked* by another
- Term masking is used to describe effects of noise and interference in sound perception
- We experience masking everyday

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Masking

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How do we perceive sounds?

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The auditory system

- Two major components in the auditory system
  - The peripheral auditory organs (the ear)
    - Converts sounds pressure into mechanical vibration patterns, which then are transformed into neural firings
  - The auditory nervous system (the brain)
    - Extracts perceptual information in various stages

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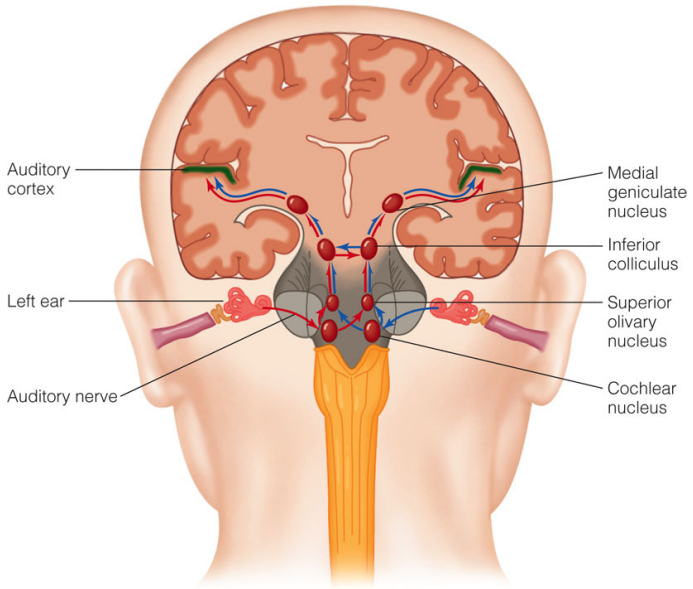
Auditory Pathway



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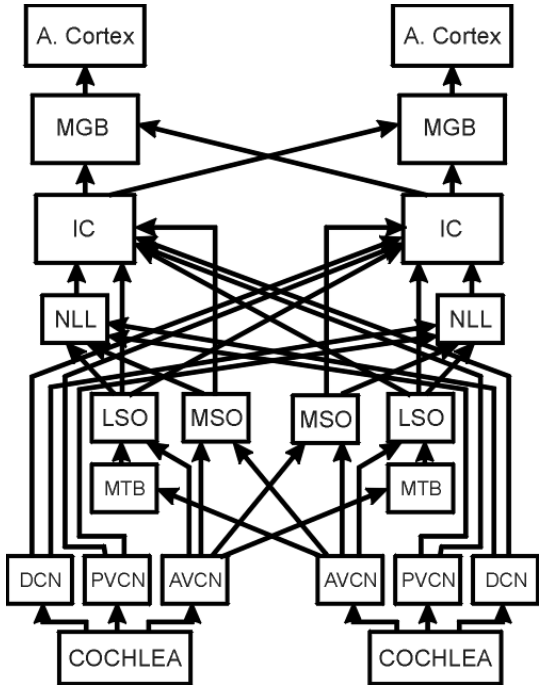

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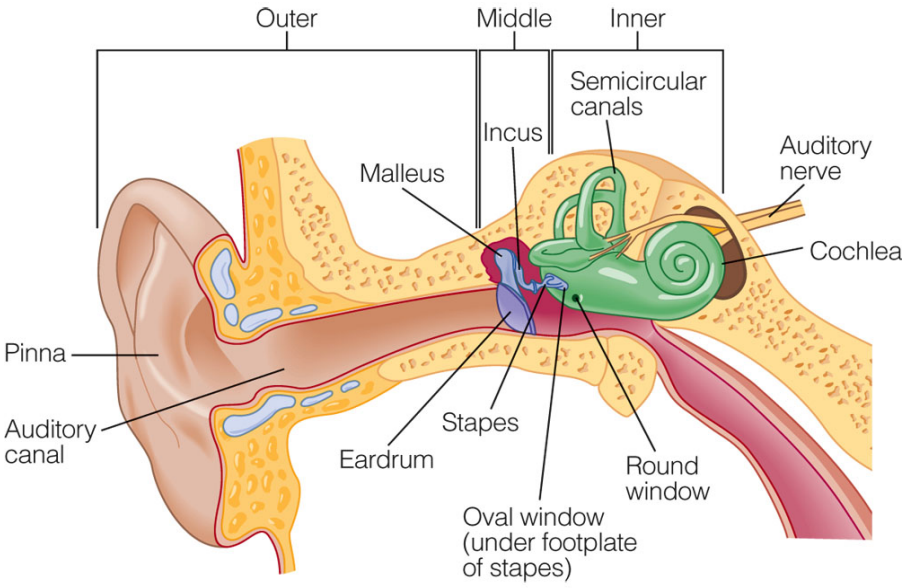

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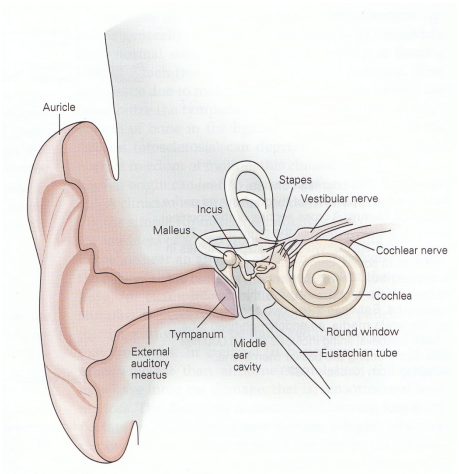
The ear

- The ear is the organ of hearing
- It changes sound pressure waves from the outside world into a signal of nerve impulses sent to the brain.
- It consists of 3 components:
  - Outer ear
  - Middle ear
  - Inner ear



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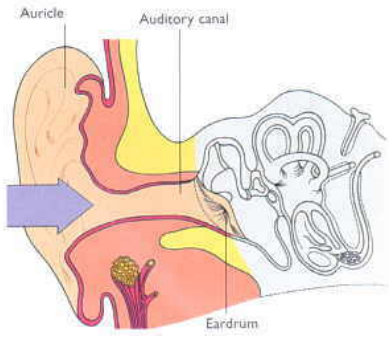
Organ of hearing
outer ear

- The external ear plays the role of an acoustic antenna,
- It diffracts and focuses sound waves (pinna), while the ear canal acts as a resonator => amplifies sounds in 2-5 kHz range
- The end of the canal has an eardrum which vibrates with sound



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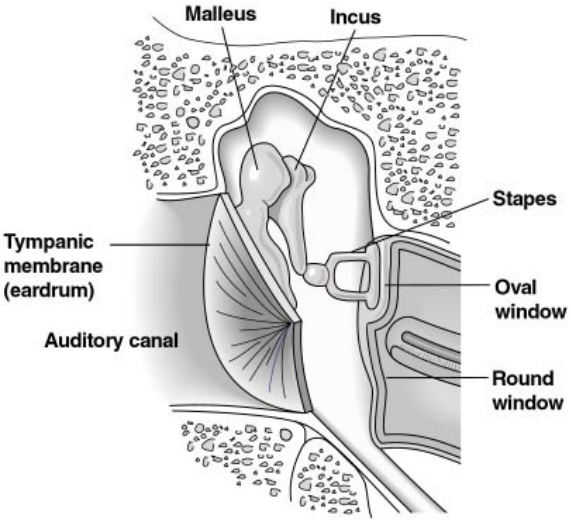
Organ of hearing
middle ear

- Eardrum (or tympanic membrane) vibrations cause mechanical motion of the small bones of the middle ear (malleus, incus & stapes) [3 smallest bones in the human body]
- The middle ear acts as an impedance adapter to adjust energy difference between air environment and fluid environment



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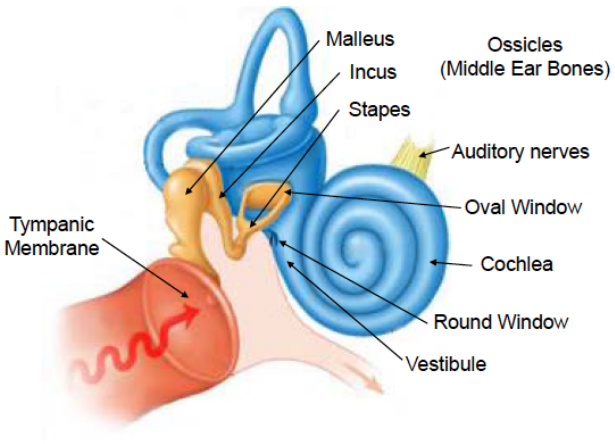
Organ of hearing inner ear

- Cochlea translates physical vibrations into electrical signals for the brain to process
- Cochlea acts a frequency analyzer of sound signals



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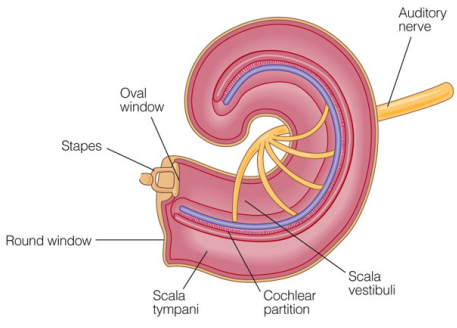
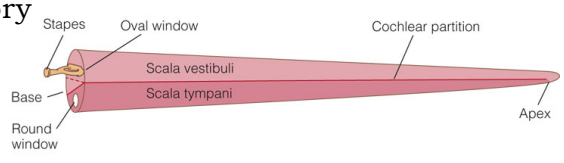
The Cochlea

- The cochlea is the inner ear organ that converts sound waves into neural signals.
- The neural signals are passed to the brain via the auditory nerve.





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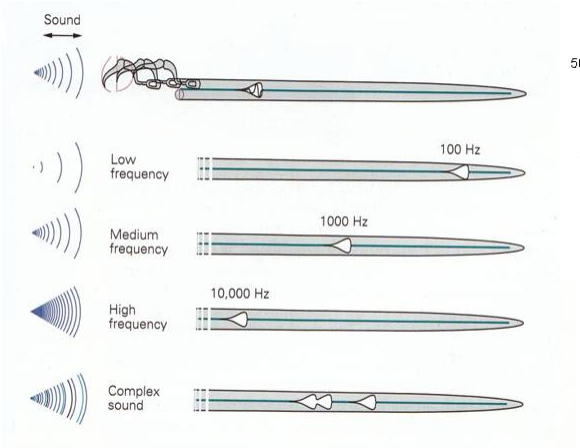
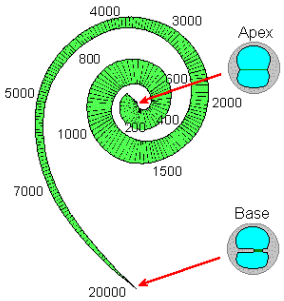
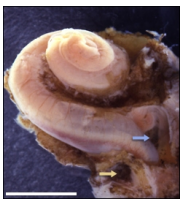
Cochlea as frequency analyzer







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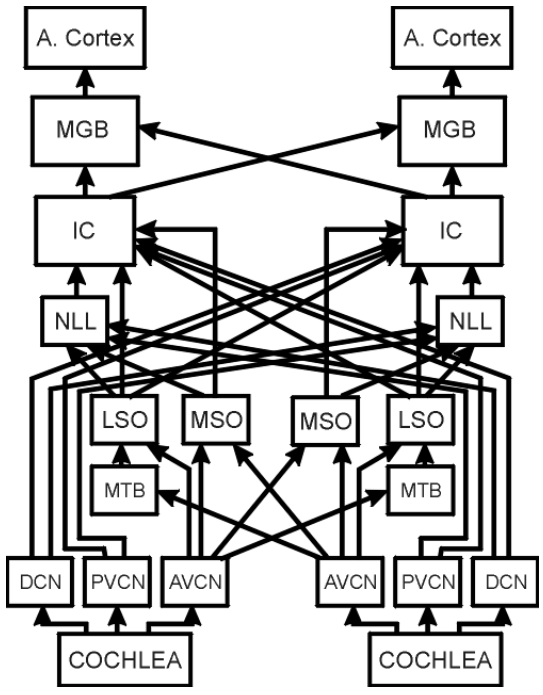

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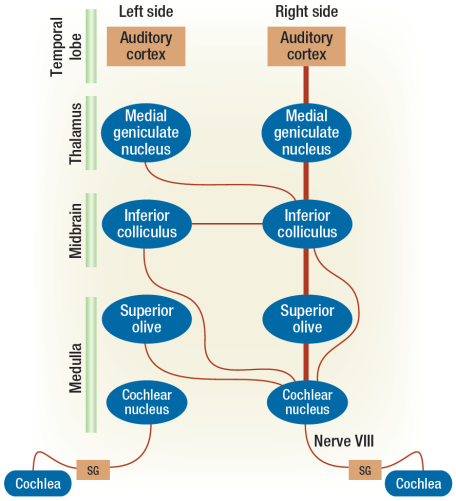
Ascending pathway



- Very complex. Just some major pathways shown.
- Extensive binaural interactions
- General principle:
  - ✓ Increasing complexity of responses (like vision, touch)

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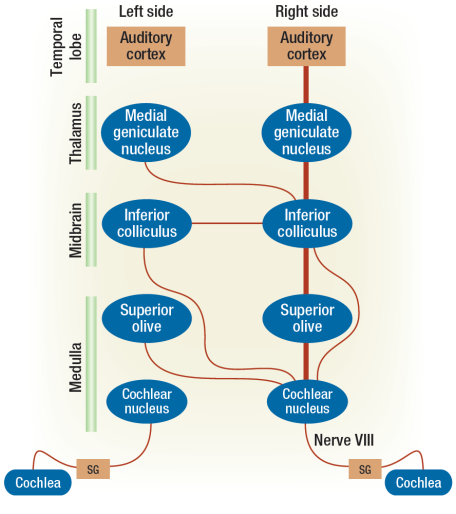
Ascending pathway



FUNCTION

Identify and process complex sounds

Principle relay to cortex

Form full spatial map

Locate sound sources in space

Start sound feature processing

Sound sensor / periphery

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Tonotopy

- Tonotopic map:
  - topographic organization (spatial arrangement) of where sound is processed
  - Derived from Greek tono/topos = place of tones
- Most nuclei along auditory pathway from cochlea to A1 are tonotopically organized (inherit *cochleotopy* from periphery)

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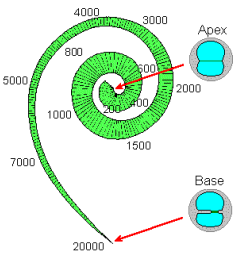
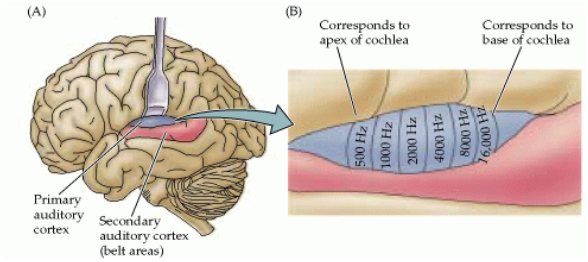
Auditory tonotopy

- Adjacent cells in A1 form a frequency-map, similar to the one observed in the cochlea.



Cochlea



A1

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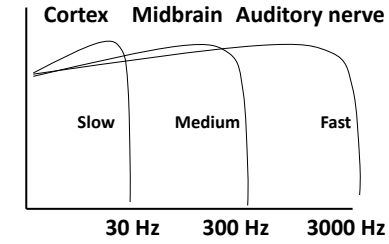
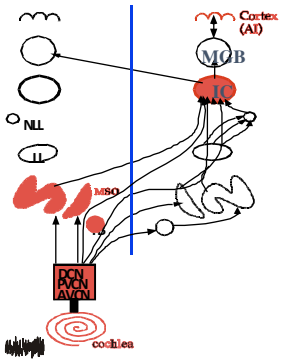
Encoding speech modulation beyond the cochlea





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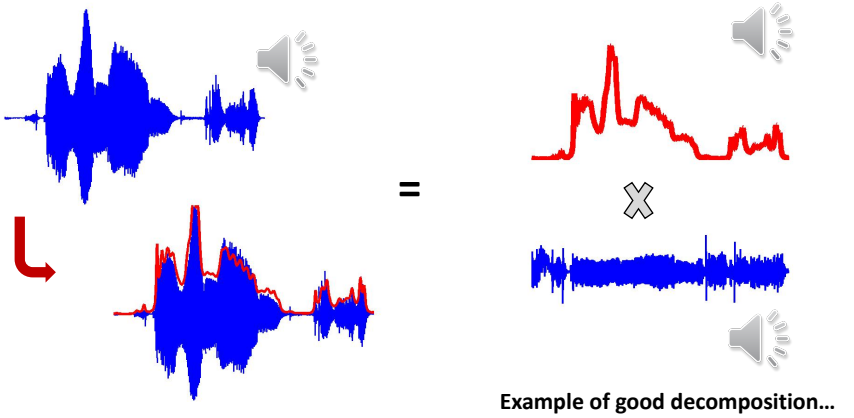
Speech carries information at multiple levels

- Any speech signal can be separated into two signals.



Example of good decomposition…
A non-trivial task

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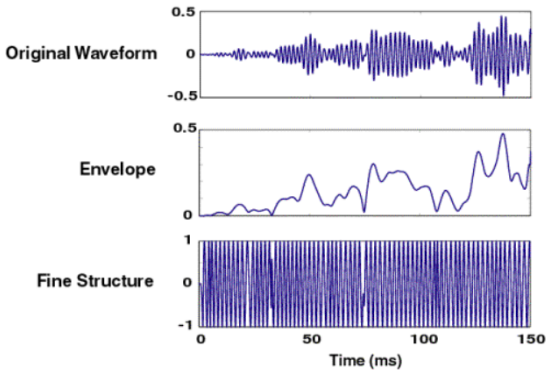
Speech carries information at multiple levels

- Any speech signal can be separated into two signals.
  - The envelope is the amplitude of the sound
  - The fine structure is the detailed waveform, without its envelope



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