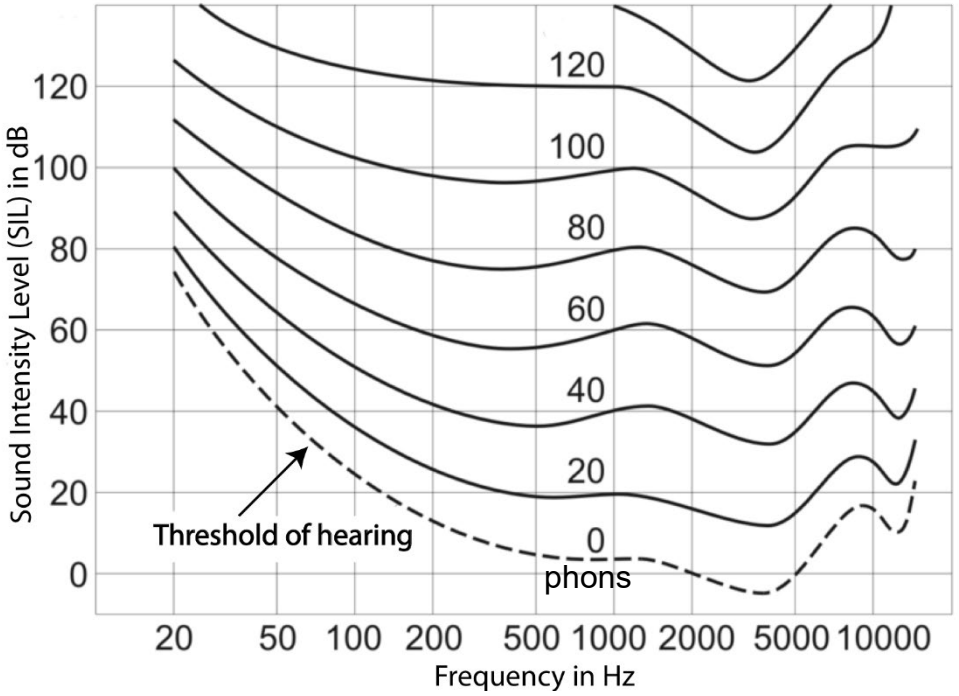
Physics 1240: Sound and Music

Today (7/17/19): Psychoacoustics: The Brain, Auditory Illusions, Dissonance

Next time: Music: Pythagoras, Intervals, Scales

Review

Pressure amplitude [N/m^2]
Intensity [W/m^2]
Sound Intensity Level [dB]
Loudness Level [phon]

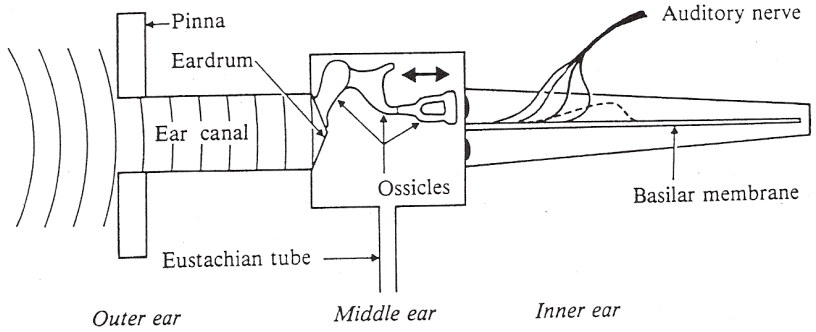


Outer ear: pinna, auditory canal

Middle ear: ear drum, ossicles: malleus, incus, stapes; Eustachian tube

Inner ear: cochlea, oval window, circular window, basilar membrane, hair cells, auditory nerve

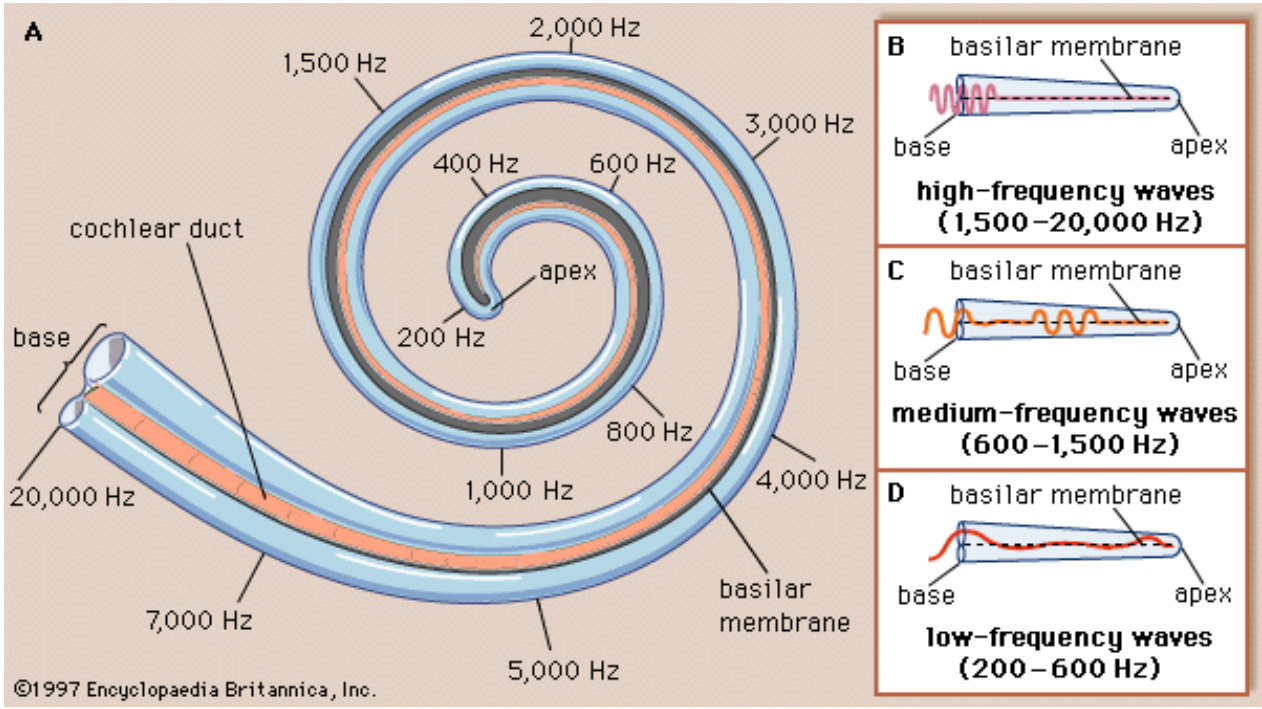
cochlea = “mechanical spectrum analyzer”



Place theory

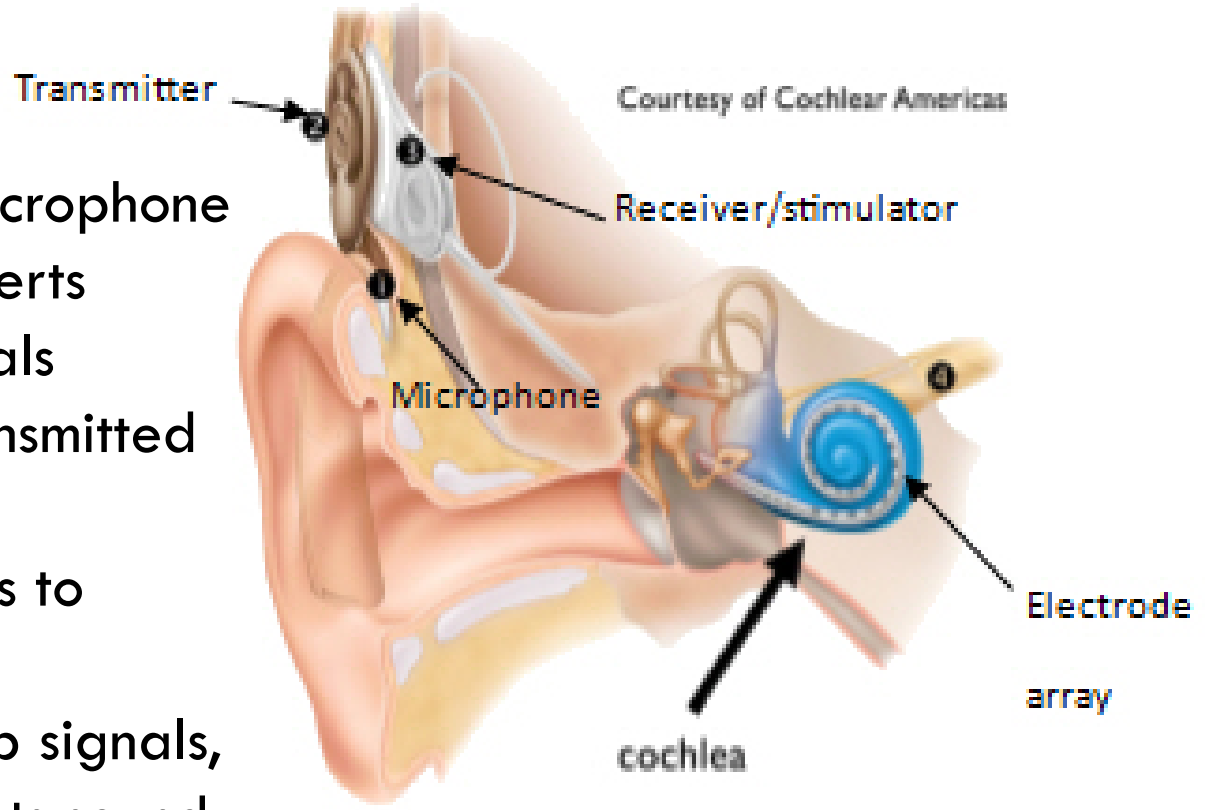
- Inner ear converts intensity information to frequency information (cochlea="mechanical spectrum analyzer")
- Different places on the basilar membrane pick up different frequencies

*The closer to the base, the higher the resonant frequency



Cochlear Implants

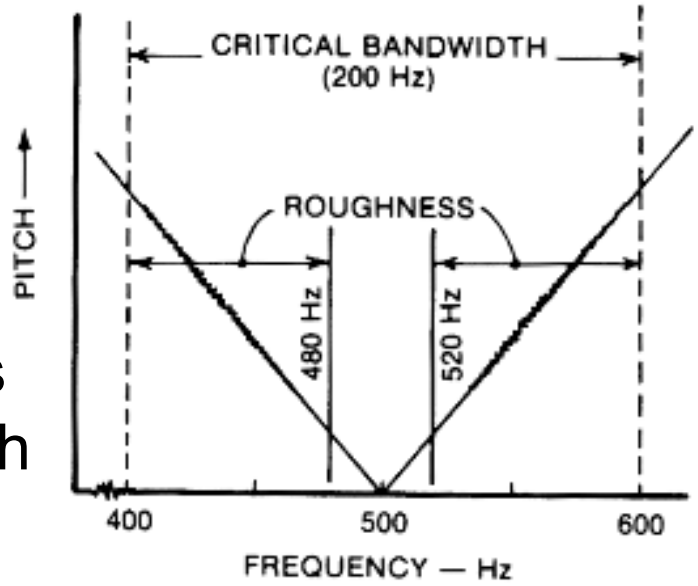
1. Sound picked up by microphone
2. Speech processor converts sound to encoded signals
3. Signals sent to coil, transmitted across skin to receiver
4. Stimulator sends signals to electrodes in cochlea
5. Auditory nerve picks up signals, sends to brain, interprets sound



Placement of electrodes is determined by the critical bands (one electrode per critical band)

Critical Bands

Two pure tones played together

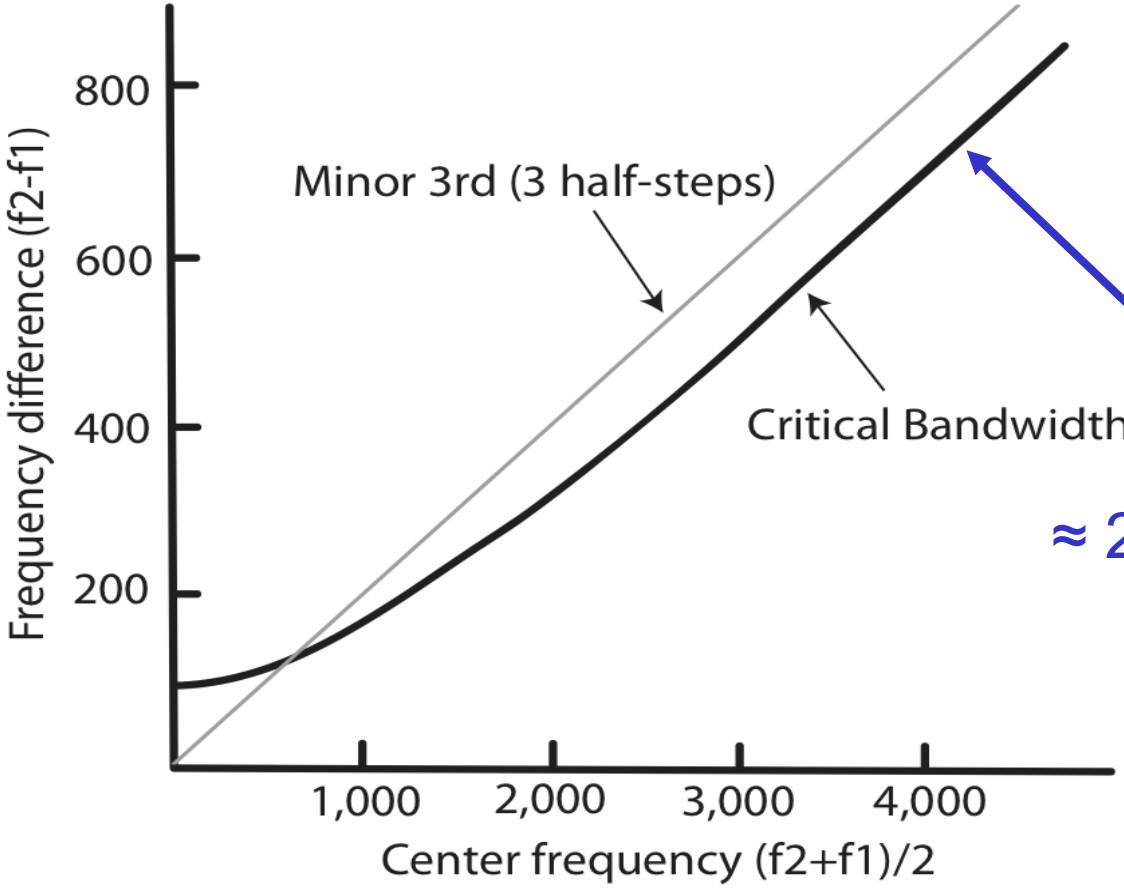


Critical band: region of frequencies inside of which you can't distinguish two tones

- Below 500 Hz critical bandwidth is about 100 Hz (±50 Hz)
- Above 500 Hz critical bandwidth is about 20% of the center frequency (±10%)

Each of the cochlea's 24 critical bands is about 1.2 mm on the basilar membrane and has about 1300 hair cells

Critical Bands



≈ 20% center frequency

Clicker Question 7.1

Two pure tones of the same loudness level are played together. In Case 1, they have frequencies of 100 Hz and 500 Hz, and in Case 2, the frequencies are 100 Hz and 110 Hz. In which case is the combined sound louder?

A) Case 1
B) Case 2
C) Same in both cases

Clicker Question 7.1

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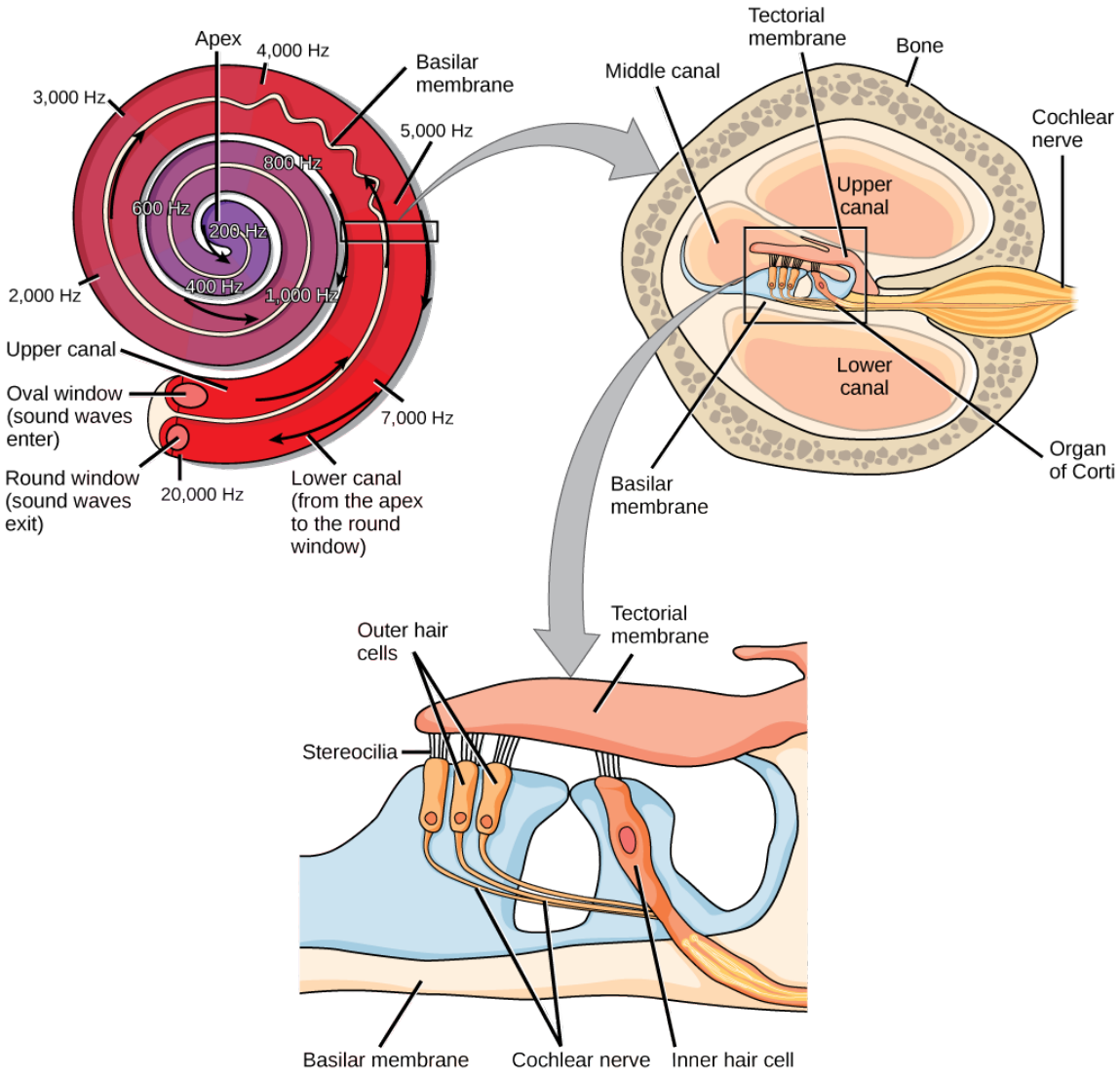
Just-Noticeable Difference

What about detecting changes in loudness?

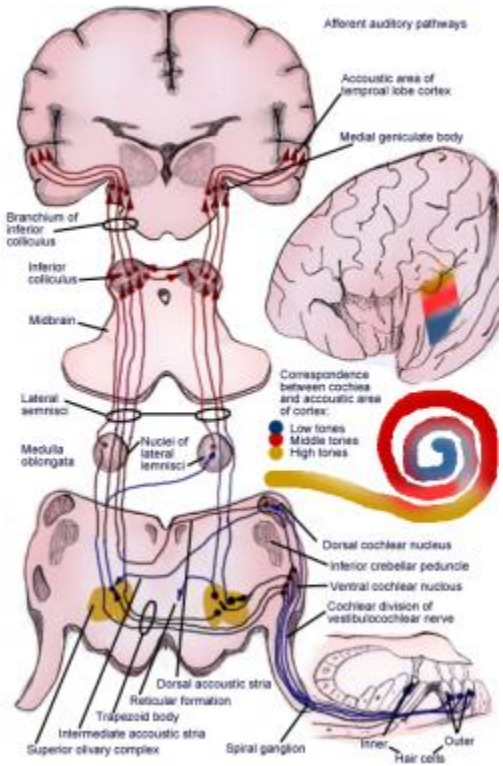
- Just-Noticeable Difference (JND): smallest change in the loudness level that the human ear can detect

- About 1 dB

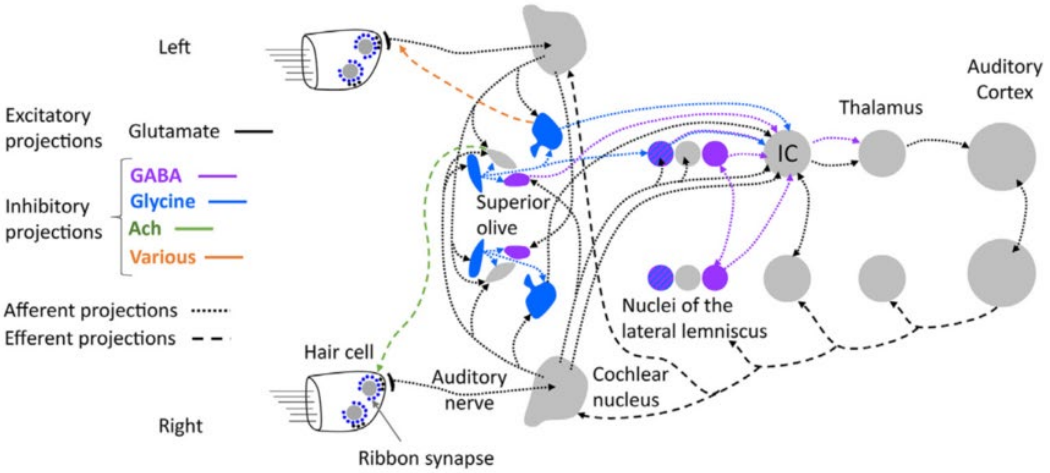
Inner Ear to Brain



…the brain is complicated!



A

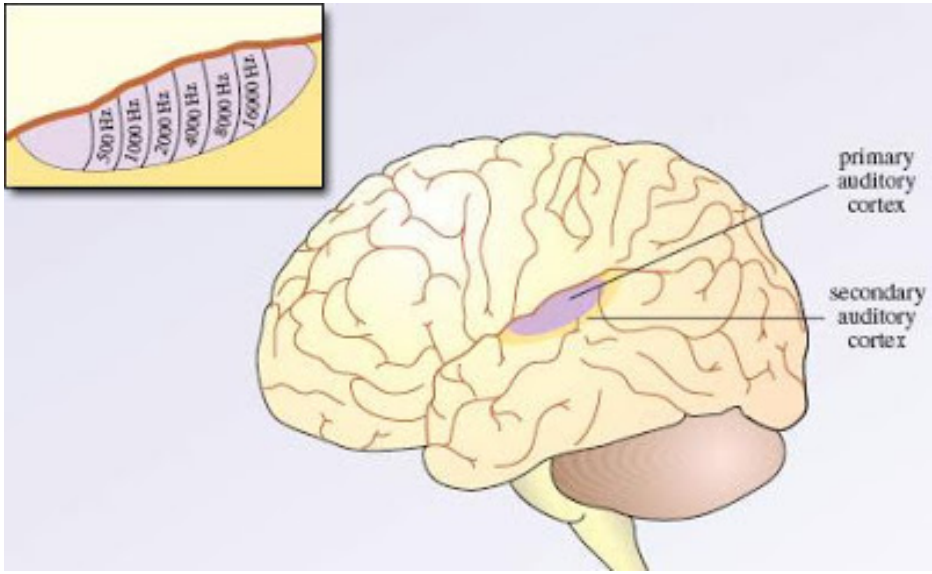


B

Auditory Cortex

- Located in the temporal lobe
- Reaction time: auditory vs visual
- Tonotopic mapping:

Neurons associated with different frequencies are arranged spatially in the brain



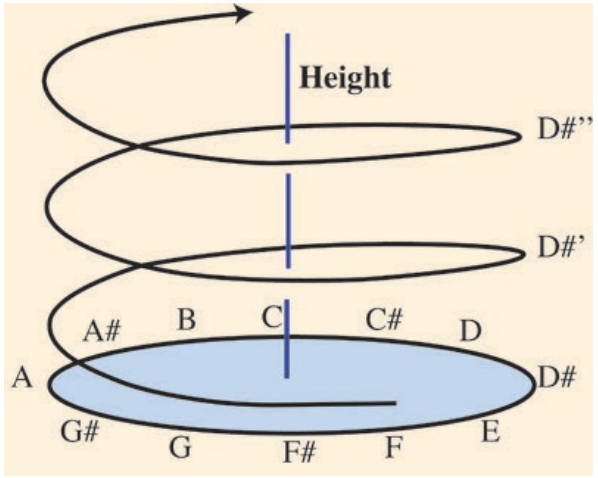
- Stacked by factors of 2 in frequency

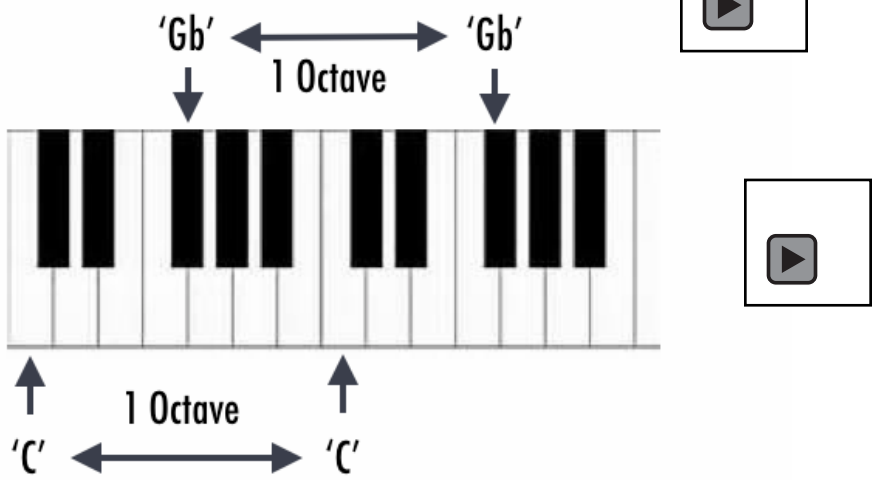
Octave Equivalence (Pitch Circularity)

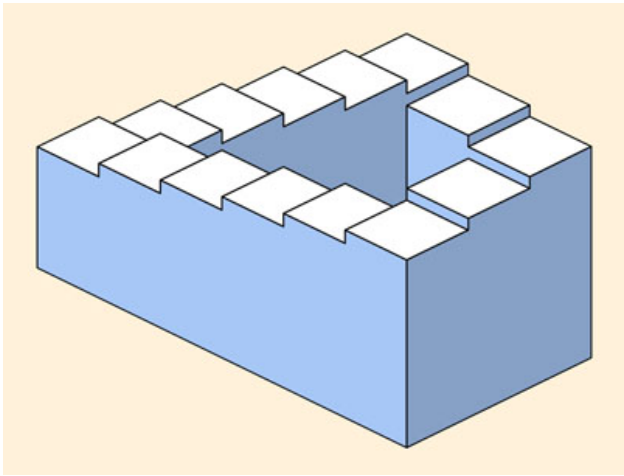
- Frequency ratio of 2:1 corresponds to an octave
- Harmonic series:

$$f,\ 2f,\ 3f,\ 4f,\ 5f,\ 6f,\ 7f,\ 8f,\ \ldots$$

- Shepard tones

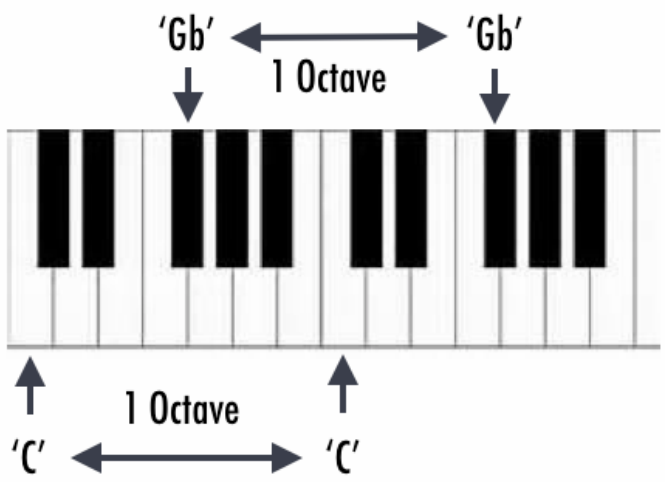






Octave Equivalence (Pitch Circularity)

- Top-down processing
  - Mysterious melody:
  - Unscrambled:



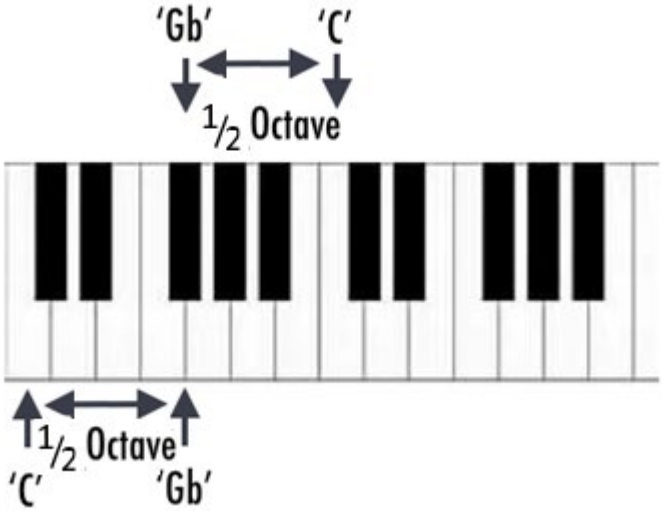
Talking piano

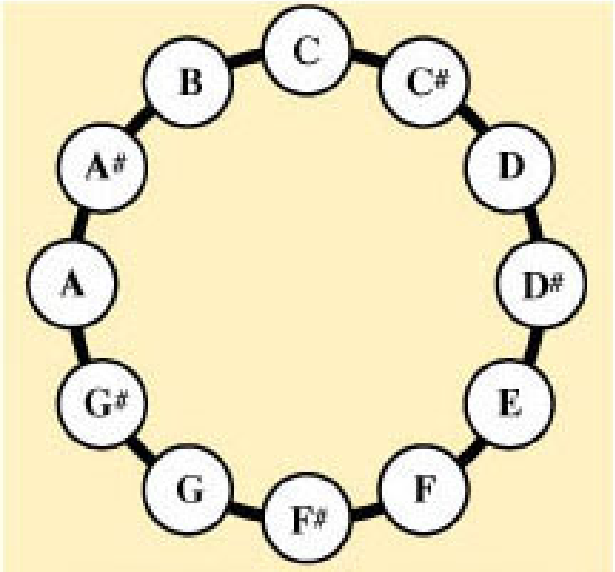
https://www.youtube.com/watch?v=muCPjK4nGY4

https://www.youtube.com/watch?v=-6e2c0v4sBM

What about half an octave?

- Half an octave ("tritone"): frequency ratio of $\sqrt{2}:1$
- Tritone paradox:





Brain filling in gaps

Missing fundamental: the brain can "hear" a tone that isn't actually there if the rest of its harmonic series is

(this is purely due to hearing perception)

Example

Suppose you heard the combination of pure tones at 200, 300, 400 Hz.

You would perceive a pitch with a fundamental at 100 Hz

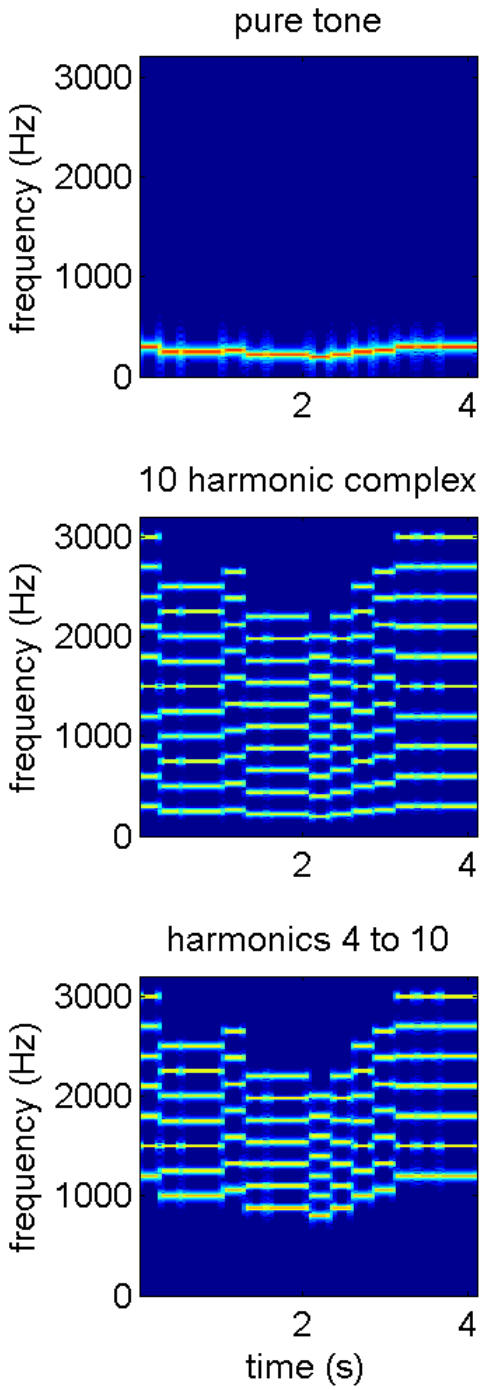
http://szhorvat.net/pelican/combination-tones.html

Brain filling in gaps

Missing fundamental

- Melody played with pure tone:
- Melody played with 1st-10th harmonics:
- Melody played with 4th-10th harmonics:

Applications: telephones transmit frequencies of >300 Hz, but male voices are around 150 Hz; timpani, violins, piano's low notes



Brain filling in gaps

Missing fundamental

- Harmonic series: $f,\ 2f,\ 3f,\ 4f,\ 5f,\ \ldots$

- Strategies:
  - Determine the greatest common factor (always works)
  - Try subtracting two nearby harmonics (may get you the answer quickly, but **must** check answer

BA

Clicker Question 7.2

A sound is made up of pure tones at the following frequencies: 400, 500, 600 Hz. What is the frequency of the perceived pitch?

A) 300 Hz
B) 200 Hz
C) 100 Hz
D) 50 Hz
E) None of the above

BA

Clicker Question 7.2

A sound is made up of pure tones at the following frequencies: 400, 500, 600 Hz. What is the frequency of the perceived pitch?

A) 300 Hz
B) 200 Hz
C) 100 Hz
D) 50 Hz
E) None of the above

BA

Clicker Question 7.3

A sound is made up of pure tones at the following frequencies: 450, 750, 900 Hz. What is the frequency of the perceived pitch?

A) 100 Hz
B) 150 Hz
C) 300 Hz
D) 350 Hz
E) None of the above

BA

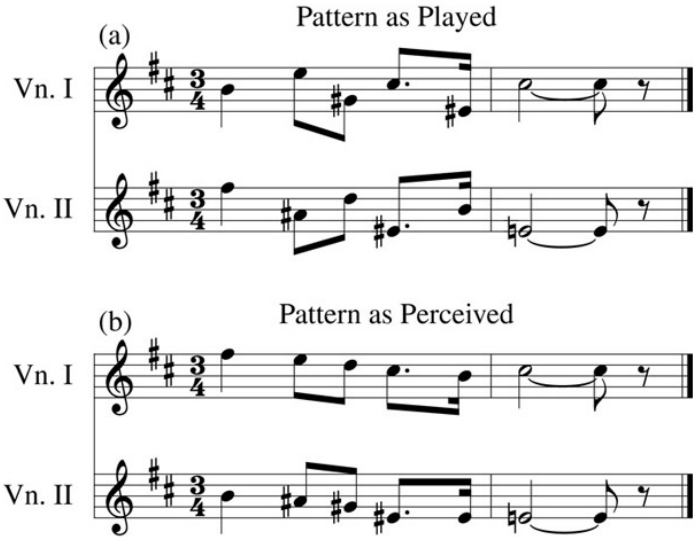
Clicker Question 7.3

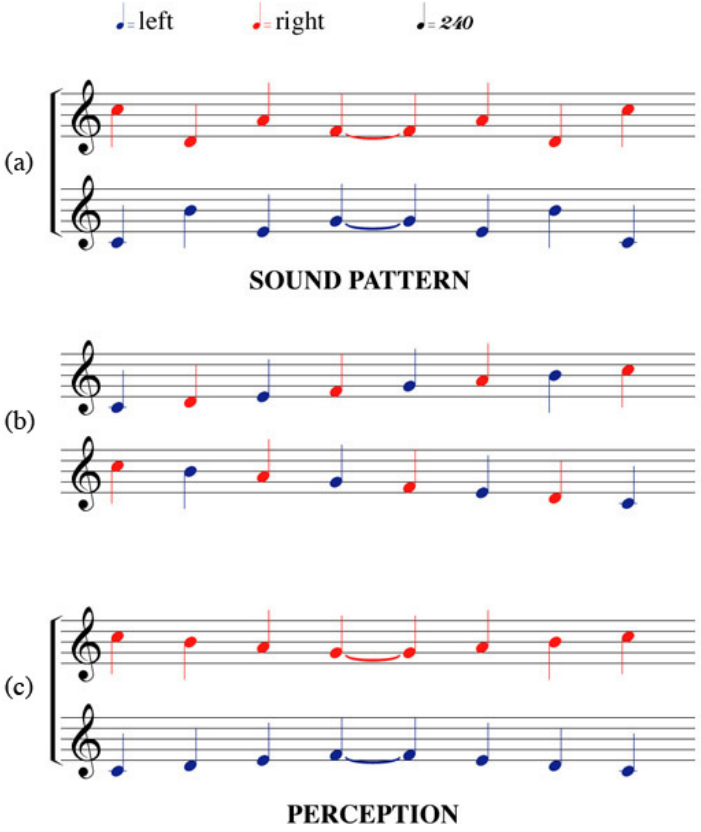
A sound is made up of pure tones at the following frequencies: 450, 750, 900 Hz. What is the frequency of the perceived pitch?

A) 100 Hz
B) 150 Hz
C) 300 Hz
D) 350 Hz
E) None of the above

Localizing sound

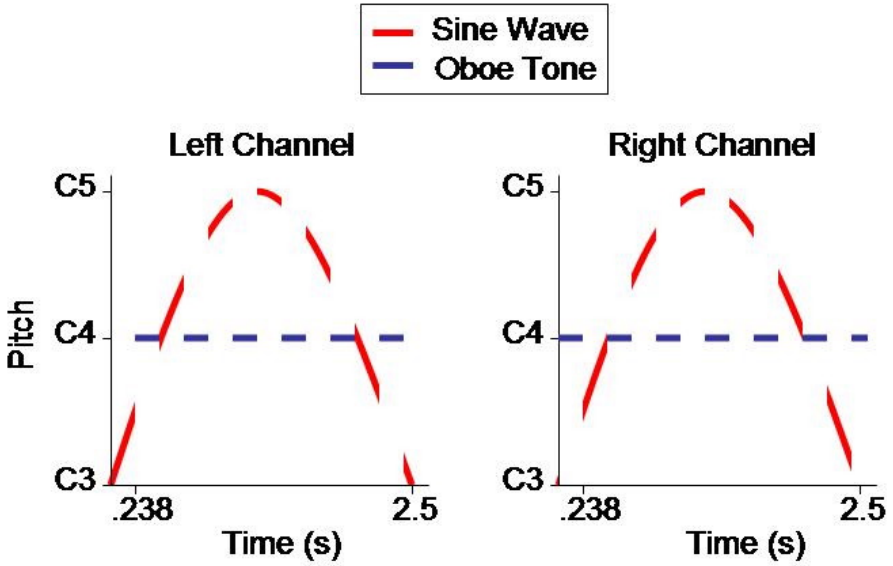
- If the brain detects a delay in the signal received from the two ears, the sound must have come from one side
- Deutsch's Scale Illusion
- Tchaikovsky's *Pathétique* Symphony No. 6, 4th movement





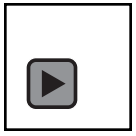
Localizing sound

- Deutsch's Glissando Illusion

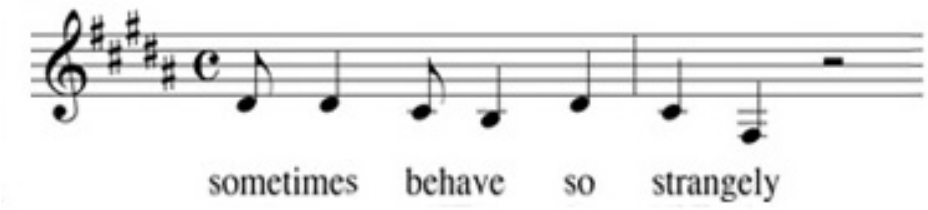


Speech Illusions

- Phantom words



- Speech-to-Song illusion



Consonance and Dissonance

- Consonance: when notes “sound good” together (sweet, pleasant, acceptable)
- Dissonance: when notes “sound bad” together (harsh, unpleasant, unacceptable)
  - Cause? When 2 tones are within the same critical band; when upper harmonics interfere (beats)