Announcements:

1. Exam 3: next Tuesday!
   - review session Monday
   - request made for 6:30-8pm, Meliora 203
2. Journal due date change
   - in class 11/15 (Thursday after the exam)
   - feel free to use images
   - turn in a hard copy
   - this deadline is strict
   - do not summarize class material
3. No class Tuesday before Thanksgiving

Sometimes they behave so strangely.

https://www.youtube.com/watch?v=BVsF0m7O9kY
https://www.youtube.com/watch?v=0MgTD9bc3o

How to break a glass with sound

http://www.youtube.com/watch?v=9KuwJXMQUdc&feature=related

Hearing outline

• How ear/hearing works?
  – Outer & Middle ear
  – Cochlea
  – Cochlear implants
  – Auditory cortex

• Localization of sounds
  – Interaural intensity difference
  – Interaural time difference
  – Vertical localization
  – Complex sound localization problems

http://www.tutis.ca/Senses/L9Auditory/L9AuditoryCanvas.html

How ear works

1) Sound passes down the air filled outer ear canal striking the ear drum.
2) The vibration is conveyed to across the air-filled middle ear by bones called ossicles.
3) Finally, vibrations reach the fluid filled inner ear where, inside a coiled shaped cochlea, neurons are activated.

First step: vibration of the ear drum

What is sound?

A loud sound is produced when the speaker generates a large vibration. The large vibration produces large waves of compressed air. Soft sounds are produced by a small vibration and a small wave.

Demo: #3
First step: vibration of the ear drum

What is sound?

A high frequency (high pitch) sound is produced when the speaker vibrates rapidly. This produces a closely spaced series of air pressure waves. Low frequency sounds are produced when the speaker vibrates slowly. The normal range of frequencies audible to humans is 20 to 20,000 Hz (the number of waves per second). We are most sensitive to frequencies between 2000 to 4000 Hz, the frequency range of the spoken words.

Demo: #3

Second step: impedance matching & sound gating

The function of the middle ear

The ossicles transmit vibrations from the large ear drum to a smaller drum called the oval window. (The picture shows a simplified cochlea that is "unrolled")

Demo: #167-70

Second step: impedance matching & sound gating

Why such a complicated chain of transmission?

The middle ear has two functions:

1. Impedance matching.

The ear drum picks up weak vibrations over a large area. The ossicles then act like a lever system, concentrating these movements to more forceful vibrations over the smaller area of the oval window. These more forceful vibrations are able to displace the oval window against the cochlear fluid.

Demo: #167-70

How ear works

frequency analysis  impedance matching & sound gating  sound pickup & amplification

Second step: impedance matching & sound gating

Why such a complicated chain of transmission?

2. Gating.

Muscles in the middle ear are able to reduce the transmission efficiency of the ossicles in order to protect the inner ear from loud noises.

These muscles contract:

a) before you speak (a pre-programmed response) or
b) after a sustained loud noise such as a rock concert (a reflexive response).

Demo: #167-70
How ear works

Frequency analysis

Impedance matching & sound gating

sound pickup & amplification

How are sounds analyzed?

A synthetic sound composed of many frequencies

Cochlea: Nature’s simple but elegant “frequency analyzer”

Frequency Analysis of Sounds

Structural properties: Wider at apex, stiffness decreases from base to apex

Cochlea: round and oval windows

There is a second window the round window. What is its function?
The idea is to displace the basilar membrane. But this membrane is surrounded by fluid which cannot be compressed. This problem is solved by the round window.

When the oval window is pressed in, some portion of the pliable basilar membrane also bulges. This in turn produces a bulge in the round window into the middle ear.

Thus pressure waves are transmitted across the basilar membrane to the round window, which acts as a pressure release outlet. Without it, the oval window could not move.

Demo: #171

Frequency Analysis of Sounds

‘tonotopic’ mapping

Oval window

Low Hz

Middle frequency sound

High frequency sound

White noise (all frequencies)

Same as above, but with low freq. filtered out

Frequency Analysis of Sounds

‘tonotopic’ mapping

Describe the traveling wave theory.

A traveling wave sweeps down the basilar membrane starting near the round window and ending at the opposite end.

Notice that as it sweeps down the basilar membrane, the wave becomes larger and then smaller.

Demo #174-8
Frequency Analysis of Sounds
‘tonotopic’ mapping

How is the frequency of a sound coded?

The basilar membrane is narrow and stiff (like a piano high string) near the oval window.

wides and floppy (like a low string) at the other end.

Because of this each portion of the basilar membrane vibrates maximally for a particular frequency of sound.

High frequency sounds maximally displace the hair cells near the oval window.

Low frequency sounds maximally displaced hair at the other end.

Demo #174-8

Analysis of Sounds
Loudness encoding

How is loudness coded?

Loud sounds produce a larger amplitude vibration of the basilar membrane than soft sounds.

The large vibration produces more activation of the hair cells.

Thus loudness is encoded by the frequency of AP's in a particular afferent fiber.

Demo #174-8

Complex, natural sounds

fingernails on chalkboard

pot lid falling on the floor

Demo #174-8

Frequency Analysis of Sounds
Complex natural sounds

Frogs saying “Bud-weis-er”

“Bud” part, all freq.

“Bud” part, only low freq.

“Bud” part, only high freq.

Demo #174-8

Analysis of Sounds
Natural sounds

Most every day sounds are complex because they contain multiple frequencies of different amplitudes.

This is what makes one sound of one musical instrument different from that of another.

The hair cells decompose this sound into its different frequencies, as does a synthesizer.

Each hair cell encodes the loudness of a particular frequency.

Demo #174-8

Frequency Analysis of Sounds
Loudness encoding

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Demo #174-8

Complex, natural sounds

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Demo #174-8
Detection of basilar membrane vibrations
Inner and outer hair cells

How ear works - summary

Hair cells summary

Neural coding of intensity and frequency

• Response Properties of Auditory Neurons
  − Characteristic frequency: Frequency at which neuron is most responsive - from cochlea to cortex
  − Binaural neurons are present in the superior olive

Neural coding of intensity and frequency

• Encoding Information About Sound Intensity
  − Firing rates of neurons
  − Number of active neurons

• Encoding Information About Sound Frequency
  − Tonotopic maps

Cochlear implant
Cochlear implants: How good they are?

- 1 channel
- 2 channels
- 3 channels
- 4 channels
- 6 channels
- 8 channels
- 24 channels

song with 4 channels, then 8, 16, and 32 channels. Ends with the original song.

Auditory cortex: tonotopic layout

Frequency sweep

Hearing outline:

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  - Auditory cortex

- Localization of sounds
  - Interaural intensity difference
  - Interaural time difference
  - Vertical localization
  - Complex sound localization problems

Auditory localization: The problem

- Allows us to pinpoint a sound of interest
- Locate the position of another person
- Locate direction and distance of a moving sound source
- Allows us to quickly locate & attend to a speaker, esp. in multi-talker situations

Auditory localization: The solutions

1. Interaural Intensity Difference, best for high frequency sounds
2. Interaural Time Difference, best for low frequency sounds
3. "Coloring" of the sound by your pinnas, best for vertical localization

ALL IN CLASS DEMOS CAN BE SEEN HERE:
http://www.tutis.ca/Senses/L9Auditory/L9AuditoryCanvas.html
Auditory localization: Interaural Intensity Difference

- Due to head shadow effects
- Head and pinna defraction attenuates sound at far ear, while boosting the sound at near ear.

About 20 dB at 10,000 Hz, almost 0 at 200 Hz.

Demo #185