Lecture 11 (Feb 12\textsuperscript{th}):

Lecture Outline

1) Sound (and its similarities to light and vision)

2) The Ear

3) The Basilar Membrane as a Frequency Analyzer

4) Auditory Space Perception
AUDITION / HEARING

What is Sound?

Physical vibration of an object that produces local changes in air pressure (force/area), in the form of changes in the concentration of air molecules.

Sound is a mechanical phenomenon.
(Light is an electromagnetic phenomenon)
Both light and sound are composed of **wavelengths** (\(\lambda\))

(Spectral) LIGHT: \(\lambda\) (nm/cycle, i.e., distance of one cycle)  
(e.g., 580 nm, “yellow”)

(Pure Tone) SOUND: \(\text{“frequency”} = \#\lambda/\text{sec}\) (i.e., \#cycles/sec, or Hz)  
(e.g., 100 Hz)

Humans hear 20 - 20,000Hz  
Dogs?  Rats?

Note: Although light is usually described in the space domain, it is sometimes described in the time domain (i.e., frequency), which requires knowing the speed of light…. 

http://www.freemosquitoringtones.org/
SOUND "frequency" (cycles/sec, or Hz)  
(e.g., 100 Hz)

TWO TYPES OF SOUNDS (similar to color vision):  

(1) Pure tone: *single* frequency  (e.g., 5000 Hz)  
    (e.g., tuning forks)

(2) Complex tone: many frequencies (e.g., speech)

Most sounds in the world are (2), not (1)
The Ear

(1) Outer Ear:
- gathering of sound and
  funneling to the eardrum

(2) Middle Ear:
- Ossicles: act as mechanical transformers,
  transmit pressure signal from one membrane (ear drum) to another (oval window)

(3) Inner Ear:
- Oval Window:
- Contains auditory neurons
- Cochlea:
- Contains vestibular neurons
- Semicircular canals:
  Contains vestibular neurons

Diagram:
- Pinna
- External auditory canal
- Hammer
- Anvil
- Stirrup
- Lymppanic membrane (ear drum)
Middle and Inner Ear

What the Middle Ear has to overcome
Auditory Nerve Cells: (project via the 8th Cranial nerve to the “Cochlear Nucleus” in brainstem)

Tectorial membrane

Hair cells

Basilar membrane
Chain of events in EAR (it’s all mechanical, baby):

1) Changes in air pressure (vibrations) enter the outer ear ->
2) Vibrations on the tympanic membrane ->
3) Vibrations of the ossicles (middle ear) ->
4) Vibrations on the oval window ->
5) Vibrations in the INNER EAR
   a) Vibrations in fluid of scala media, basilar membrane and tectorial membrane ->
   b) Movements of cilia on hair cells ->
   c) Depolarization of hair cells ->
6) Hair cells provide input to auditory nerve Cells, which project (with AP) to the “Cochlear Nucleus” in Brainstem

https://www.youtube.com/watch?v=PeTriGTENoc
The Basilar Membrane as a “Frequency Encoder”

Frequency vs. Place Theory

**Frequency Theory:** the basilar membrane vibrates in synchrony with the sound entering the ear, which ultimately leads to producing action potentials -- *in auditory nerve cells* -- at the same frequency (e.g., 50 Hz sound -> 50 APs/sec).

**Limitations:** max APs/sec = 1000 Hz

**Place Theory:** each part of the basilar membrane is sensitive to a different range of sound frequencies (“tonotopic map”)

**Basic Answer:**

< 1000 Hz: frequency theory, > 5000 Hz: place theory

Between these frequencies, use some combination
Auditory Space Perception

azimuth (horizontal)
elevation (vertical)

Different from VISION:
- localization abilities
  .... but in the dark?
What Cues do Humans Use for *Elevation*?

**Monaural Cues from the Pinna!** (differential frequency filtering)

And, we’re pretty bad at it……

but it helps to move your head (I’ll show you)!

Hey, why does your voice sound funny when you hear it on tape?
What Cues do Humans Use for Azimuth?

**Binaural Cues** (i.e., comparison between the two ears)

1) **Interaural Time Differences (ITD)**
   A sound from the “Left” arrives at the Left Ear earlier than the Right Ear

2) **Interaural Intensity Differences (IID)**
   A sound from the “Left” has to go through the head to reach the Right Ear, and is attenuated in intensity in Right Ear as compared to Left Ear.
   
   “sound shadow”

Which system, Vision or Audition, encodes **space** earlier/later in processing?