Lecture 11
Space perception

Overview

- Horizontal localization: cues from time, level and spectral interaural differences
- Vertical localization: role of pinna
- Perception of distance in free space and in rooms

Localization is the ability to perceive the direction and the distance to the sound source

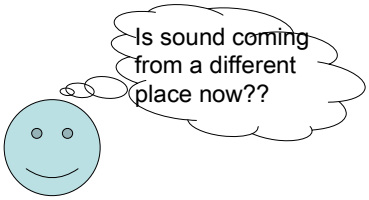
Why is it important?

- Allows us to locate the position of the source of interest, especially in a complex environment
- Makes it possible to locate the position and estimate the speed of the moving source

Two aspects of localization

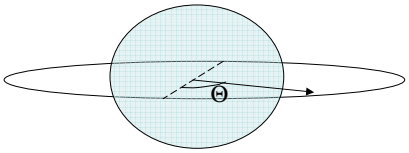
- Correlation between actual and perceived position of the source

- Detection of small shifts in source position

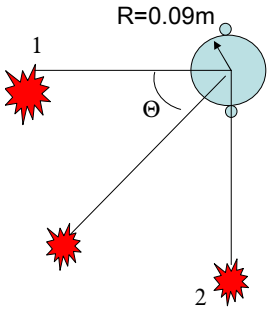


Main cues to horizontal localization

- Interaural time difference – ITD: sound needs less time to reach the ear nearest to the source. Relates to interaural phase difference (IPD)
- Interaural level difference – ILD: head and pinna diffraction effects
- Interaural spectral differences: important for complex sounds



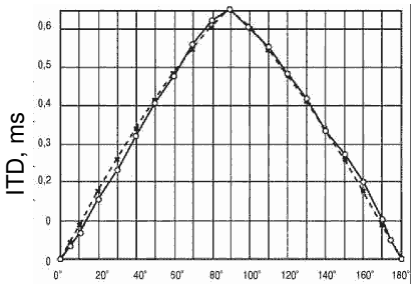
Interaural time difference - ITD



Θ=0 – source straight ahead (1)
Θ=π/2 - source directly opposite one ear (2)

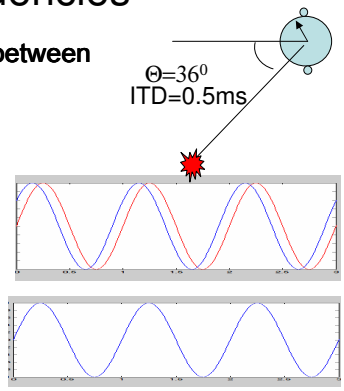
$$ITD = \frac{R}{c}(\Theta + \sin(\Theta))$$

$\max(ITD) \approx 0.69ms$ when Θ=π/2



Ambiguity of information from ITD at high frequencies

ITD is equivalent to the phase difference between sounds reaching different ears



Frequency, Hz	Period ms	ITD/period
200	5	1/10
4000	0.25	2/1

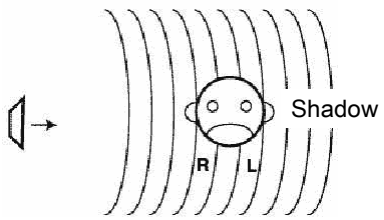
Impossible to "measure" phase difference

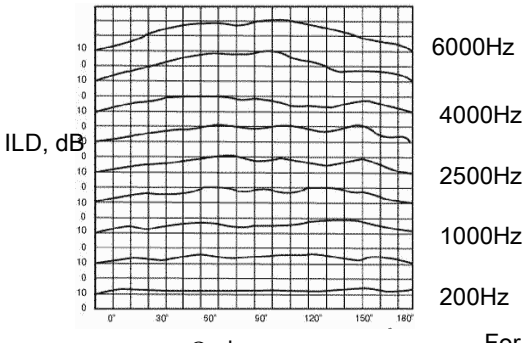
Information from time delay becomes ambiguous for frequencies higher than approximately 700Hz

Interaural level difference - ILD

Diffraction effects come into play when wavelength exceeds size of the head:

$$f > \frac{c}{2R} \approx 2000Hz$$

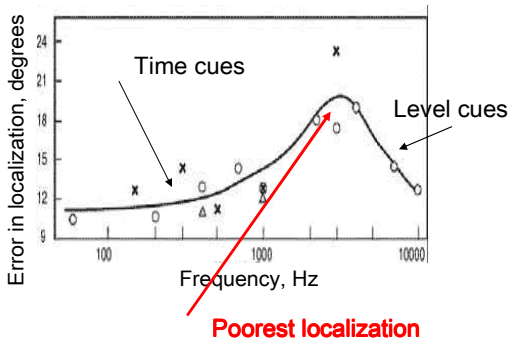




For high frequencies ILD can be 20dB

Duplex theory of horizontal localization

- Low frequencies – time and phase difference information (ITD and IPD)
- Higher frequencies – level difference information (ILD)



Interaural spectral differences

- Improves localization of complex sounds
- Interaural spectral changes occur due to diffraction effects – less high frequency components on the shadow side
- Spectral filtration by the pinnae also contributes to the effect

•Good horizontal localization is only possible with a pair of ears

•Hearing loss in one ear severely disrupts horizontal localization ability

•Low frequency hearing loss decreases the horizontal localization ability

Angle discrimination – 3º

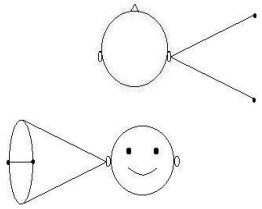
Minimum error in absolute value of angle – 12º

The role of head movements

Error in horizontal localization increases when source positioned almost opposite one of the ears (up to 20º) :

1. too small relative changes in ITD and ILD due to change in source position

2. multiple locations can produce the same ITD and ILD (**cone of confusion**)



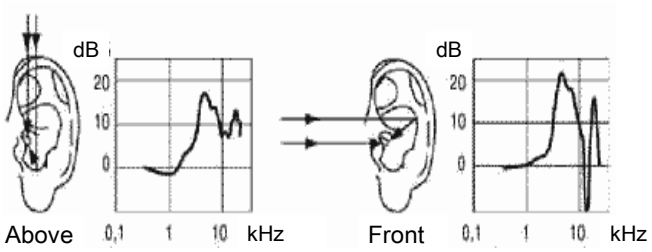
Head movements change position of the **cone of confusion** and eventually cancel its influence
Cues are found in variance of ITDs and ILDs as listener moves head

Vertical localization - perception of source elevation

•Less precise than horizontal localization

•Pinna cues – most effective in 5 -16kHz range

•Reflections from head and shoulders – works in 2-3kHz range



HRTFs (head related transfer functions) at different source locations

- Vertical localization is possible with just one ear
- Better localization for complex sounds
- Most affected by high frequency hearing loss

Angle discrimination – 10-15^{o}

Localization in reverberant environment

- ITD cue suffers from reverberations and reflections as it depends on coherence between signals in the two ears

- ILD can be affected by standing wave in the room, but generally suffers less. Listeners mostly use the highest frequency information that can be heard for localization

- The precedence effect – listeners make localization judgements based on the earliest arriving waves in the onset of a sound (direct waves)

Perception of distance

- **Free space and anechoic environment:**

Importance of familiarity with the source

Loudness cues – decrease of loudness with distance due to spherical spreading, works for distances >3m

Spectrum cues – absorption in air depend on distance and stronger for higher frequencies, works for distances >15m

- **Environment with echoes:**

Better distance estimation

Comparison of sound and its echoes

Error – 15-30% and higher

Further reading

- BCJ Moore Chapter 7