How do you locate a sound?

- Cricket example.
- Similar dilemma to determining how far an object is.
- Two ears: Critical for determining auditory locations.
Interaural time difference (ITD): The difference in time between a sound arriving at one ear versus the other.

Different Inputs to the Two Ears
Azimuth: Used to describe locations on imaginary circle that extends around us, in a horizontal plane

- Can analyze ITD: Where would a sound source need to be located to produce maximum possible ITD?
- What location would lead to minimum possible ITD?
- What would happen at intermediate locations?

**Interaural Time Differences (Part 1)**

![Graph showing interaural time differences](image)

**Interaural Time Differences (Part 2)**

![Diagram showing ITD values](image)
Physiology of ITD
- Medial superior olives (MSOs): First place where input converges from two ears.
- ITD detectors form connections from inputs coming from two ears during first few months of life.

Interaural level difference (ILD): The difference in level (intensity) between a sound arriving at one ear versus the other.
Sound Localization

Sounds are more intense at the ear closer to sound source.

- ILD is largest at 90 degrees and –90 degrees, nonexistent for 0 degrees and 180 degrees.
- ILD generally correlates with angle of sound source, but correlation is not quite as great as it is with ITDs.

Physiology of ILDs

- Lateral superior olives (LSOs): Neurons that are sensitive to intensity differences between two ears.
- Excitatory connections to LSO come from ipsilateral ear.
- Inhibitory connections to LSO come from contralateral ear.
Potential problem with using ITDs and ILDs for sound localization.

- Cone of confusion: Regions of positions in space where all sounds produce the same time and level (intensity) differences (ITDs and ILDs).
- Experiments by Wallach (1940) demonstrated this problem.

Shape and form of pinnae helps determine localization of sound.

- Head-related transfer function: Describes how pinnae, ear canal, head, and torso change intensity of sounds with different frequencies that arrive at each ear from different locations in space (azimuth and elevation).
How do listeners know how far a sound is?

- Simplest cue: Relative intensity of sound
- Inverse-square law: As distance from a source increases, intensity decreases faster such that decrease in intensity is distance squared
- Spectral composition of sounds: Higher frequencies decrease in energy more than lower frequencies as sound waves travel from source to one ear
- Relative amounts of direct vs. reverberant energy

Direct vs. Reverberant Energy

Complex Sounds

Harmonics
- Lowest frequency of harmonic spectrum: Fundamental frequency
- Auditory system is acutely sensitive to natural relationships between harmonics
- What happens when first harmonic is missing?
- Missing-fundamental effect
Timbre: Psychological sensation by which a listener can judge that two sounds that have the same loudness and pitch are dissimilar; conveyed by harmonics and other high frequencies

- Perception of timbre depends on context in which sound is heard.
- Experiment by Summerfield et al. (1984).
- "Timbre contrast" or "timbre aftereffect".

Attack and decay of sound.

- Attack: Part of a sound during which amplitude increases (onset).
- Decay: Part of a sound during which amplitude decreases (offset).
Sound Onsets (Attacks)

1. Violin (pluck)
2. Violin (bow)

1. Speech ('tes')
2. Speech ('too')

Auditory Scene Analysis

What happens in natural situations?
- Acoustic environment can be a busy place
- Multiple sound sources.
- How does auditory system sort out these sources?
- Source segregation, or auditory scene analysis.

A number of strategies to segregate sound sources.
- Spatial separation between sounds.
- Separation on basis of sounds' spectral or temporal qualities.
- Auditory stream segregation: Perceptual organization of a complex acoustic signal into separate auditory events for which each stream is heard as a separate event.
Auditory Stream Segregation

Grouping by timbre
- Tones that have increasing and decreasing frequencies, or tones that deviate from rising/falling pattern “pop out” of sequence.

“Pop Out” (Part 1)
Auditory Scene Analysis

Grouping by onset
- Harmonics of speech sound or music.
- Grouping different harmonics into a single complex tone.
- Rasch (1987) showed that it is much easier to distinguish two notes from one another when onset of one precedes onset of other by very short time.
- Gestalt law of common fate.

Continuity and Restoration Effects

How do we know that listeners really hear a sound as continuous?
- Principle of good continuation: In spite of interruptions, one can still “hear” sound.
- Experiments that use signal detection task (e.g., Kluender and Jenison) suggest that at some point restored missing sounds are encoded in brain as if they were actually present!
Restoration of complex sound, (e.g., music, speech).

- “Higher-order” sources of information, not just auditory information.