Hearing in the Environment

- sound localization
- complex sounds
- auditory scene analysis
- continuity and restoration effects

Sound Localization

- How do you locate a sound?
  - two ears:
    - critical for determining auditory locations

Dimensions of auditory space

- Spatial dimensions are specified in terms of three planes, intersecting at the center of the head:
  - Horizontal plane
  - Frontal plane
  - Median plane

Binaural hearing

Source: B.C.J. Moore, An Introduction to the Psychology of Hearing
Dimensions of auditory space

- **Azimuth** (angle θ produced by projection onto the horizontal plane)
- **Elevation** (angle δ produced by projection onto the median plane)

  - 0° azimuth, 0° elevation: directly in front
  - 90° azimuth, 0° elevation: directly opposite the right ear
  - -90° azimuth, 0° elevation: directly opposite the left ear
  - 180° azimuth, 0° elevation: directly behind the head
  - 0° azimuth, 90° elevation: directly above the head
  - 0° azimuth, 270° elevation: directly below the head

Sound localization

![Sound localization graph]

*After Sekuler and Blake (1990, p. 344)*

**Sound Localization (cont’d)**

- interaural time difference (ITD):
  - difference in time between a sound arriving at one ear versus the other

**Different Inputs to the Two Ears**

- **Azimuth**:
  - locations on imaginary circle that extends around us, in a horizontal plane
  - ITD:
    - sound source location to produce
      - maximum ITD?
      - minimum possible ITD?
    - What happens at intermediate locations?
Interaural Time Differences (Part 1)

- Physiology of ITD
  - Medial superior olives (MSOs):
    - input converges from two ears
  - ITD detectors
    - form connections from inputs coming from two ears during first few months of life

Interaural Time Differences (Part 2)

- Interaural level difference (ILD):
  - difference in level (intensity) between a sound arriving at one ear versus the other
  - Sounds more intense at 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
Sound Localization (cont’d)

- Physiology of ILDs
  - lateral superior olives (LSOs):
    - location of neurons sensitive to ILD
      - excitatory connections from ipsilateral ear
      - inhibitory connections from contralateral ear

Interaural Intensity Differences

- limits of ITDs and ILDs for sound localization
  - cone of confusion:
    - differences in space where sounds produce the same time and level (intensity) differences (ITDs and ILDs)

- Wallach (1940) experiments
  - demonstrated this problem

Sound Localization (cont’d)

- pinnae
  - shape and form for localization of sound
  - head-related transfer function (HRTF):
    - pinnae, ear canal, head, and torso change intensity of sounds as
      - f(frequency) that arrive at each ear
      - f(locations in space)
        - azimuth and elevation

Cones of Confusion

- shape and form for localization of sound
- head-related transfer function (HRTF):
  - pinnae, ear canal, head, and torso change intensity of sounds as
    - f(frequency) that arrive at each ear
    - f(locations in space)
      - azimuth and elevation
Head-Related Transfer Functions (Part 2)

Distance of sound
- 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

Human Pinnae

Bat Pinnae

Sound Localization (cont’d)

Direct vs. Reverberant Energy

Binaural hearing- some terms
- **Monaural** – sound arrives at one ear only
- **Binaural** – sound arrives at both ears
  - **Diotic** – identical signal at the two ears
  - **Dichotic** – different signals at the two ears
Binaural hearing- some terms

- **Localization** – judgments of the direction of a sound source
- **Ranging** – judgments of the distance to a sound source
- **Lateralization** – when using headphones, the apparent location of a sound can appear to originate from an apparent location “within the head”

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### 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
      - temporal codes for frequency

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### Harmonic Sounds

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### Missing Fundamental (Part 1)

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### Missing Fundamental (Part 2)

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**Problem of the missing fundamental**

- Helmholz proposed that nonlinear interaction in the cochlea re-introduces the missing fundamental.
  (We now know this hypothesis was incorrect).
Complex Sounds (cont’d)

- Timbre:
  - Sound quality
    - same loudness and pitch
    - differences in harmonics
  - perception of timbre depends on context in which sound is heard
    - Experiment by Summerfield et al. (1984)
      - “timbre contrast” or “timbre aftereffect”

Complex Sounds (cont’d)

- 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)

Auditory Scene Analysis (cont’d)

- Strategies to segregate sound sources
  - spatial separation between sounds
  - separation on basis of
    - spectral qualities
    - 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 Scene Analysis

- What happens in natural situations?
  - acoustic environment has multiple sound sources

- How does auditory system sort out sources?
  - source segregation or auditory scene analysis
Bregman (1990)
Auditory Scene Analysis

- **Auditory scene analysis** (ASA) is the process by which the auditory system organizes complex mixtures of sound.
- ASA involves grouping processes, in which sound components that are likely to have come from the same environmental source are linked to form a single perceptual unit.

Cocktail Party Effect

- Colin Cherry (1953) coined the term **cocktail party effect** to describe the ability of listeners to attend to a single talker in a mixture of conversations and other background noises.

Cocktail Party Phenomenon

- Cherry’s experiments involved listening to two different messages presented to one or both ears, on the same pitch or on different pitches, spoken by two talkers of the same gender or differing in gender.

Cocktail Party Phenomenon

- Cherry concluded that listeners rely on several cues to follow a conversation in the presence of competing voices, including:
  - Spatial separation
  - Pitch differences
  - Gender differences

**Factors that affect cocktail party listening**

**Beneficial**
- ITDs
- ILDs
- Envelope fluctuations of interfering voices
- Spectral differences between the voices

**Detrimental**
- Reverberation
- Spatial overlap of voices
- Timbre similarity of target and interference
- Hearing loss