Topic 4

Pitch & Frequency

(Some slides are adapted from Zhiyao Duan’s course slides on Computer Audition and Its Applications in Music)
A musical interlude

• KOMBU – This solo by Kaigal-ool of Huun-Huur-Tu (accompanying himself on doshpuluur) demonstrates perfectly the characteristic sound of the Xorekteer voice

– An example of Tuvan throat-singing, or Khoomei
The Cochlea

- Each point on the Basilar membrane resonates to a particular frequency
- At the resonance point, the membrane moves
Anatomy of the Ear

- Temporal muscle
- Temporal bone
- Semicircular canals
- Malleus
- Incus
- Stapes
- Cochlea
- Vestibular nerve
- Cochlear nerve
- Trigeminal nerve
- Auditory nerve
- Medial auditory nerve
- Lateral auditory nerve
- Acoustic nerve
- Cochlear duct
- vestibular duct
- Basilar membrane
- Hair cells
- Ossicles
- External acoustic meatus (Ear canal)
- Tympanic membrane (Eardrum)
- Tympanic cavity
- Cartilage
- Eustachian tube

Outer Ear
- Scapha
- Helix
- Concha
- Auricular lobule (Earlobe)

Middle Ear
- Trigeminal fossa
- Antihelix

Inner Ear
- Vestibular nerve
- Cochlear nerve

Cross section of Cochlea

cross section of cochlea with labels:
- scala vestibuli
- scala media
- scala tympani
- Reissner's membrane
- stria vascularis
- organ of corti
- tectorial membrane
- inner hair cells
- cochlear nerve fibres
- tunnel
- tunnel fibres
- outer hair nerve cells
- basilar membrane

Thanks to Oarih Ropshkow
Frequency Sensitivity

• single nerve measurements
We decompose sounds into sines

Input: complex sound

Peripheral Auditory system

Cochlea, Auditory nerve

Output: sine waves

1100 Hz
660 Hz
220 Hz
A loud tone masks perception of tones at nearby frequencies.
Critical Band

- Critical band – the frequency range over which a pure tone interferes with perception of other pure tones
- Critical bands get wider as frequency increases
More Critical Bands
Coding frequency information (a simplified story)

• Frequencies under 5 kHz
  – Individual harmonics are resolved by the cochlea
  – Coded by *place* (which nerve bundles along the cochlea are firing)
  – Coded by *time* (nerves fire in synchrony to harmonics)

• Frequencies over 5 kHz
  – Individual harmonics can’t be resolved by the inner ear and the frequency is revealed by temporal modulations of the waveform amplitude (resulting in synched neuron activity)
Pitch (ANSI 1994 Definition)

• That attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high. Pitch depends mainly on the frequency content of the sound stimulus, but also depends on the sound pressure and waveform of the stimulus.
Pitch (Operational)

• A sound has a certain pitch if it can be reliably matched to a sine tone of a given frequency at 40 db SPL
Mel Scale

• A perceptual scale of pitches judged by listeners to be equal in distance from one another. The reference point between this scale and normal frequency measurement is defined by equating a 1000 Hz tone, 40 dB SPL, with a pitch of 1000 mels.
Mel Scale

Mel = 2595 \log_{10}(1 + \frac{f}{700})
Mel Scale

• Above about 500 Hz, larger and larger intervals are judged by listeners to produce equal pitch increments.

• The name mel comes from the word melody to indicate that the scale is based on pitch comparisons.

• proposed by Stevens, Volkman and Newman (Journal of the Acoustic Society of America 8(3), pp 185-190, 1937)
Ear Craziness

• Binaural Diplacusis
  – Left ear hears a different pitch from the right.
  – Can be up to 4% difference in perceived pitch

• Otoacoustic Emissions
  – Ears sometimes make noise.
  – Thought to be a by-product of the sound amplification system in the inner ear.
  – Caused by activity of the outer hair cells in the cochlea.
Harmonic Sound

• A complex sound with strong sinusoid components at integer multiples of a fundamental frequency. These components are called **harmonics** or **overtones** or **partials**

• Sine waves and harmonic sounds are the sounds that may give a perception of “pitch”
Continuity of Sounds

• Sine wave
• Strongly harmonic (Flute)
• Somewhat harmonic (Me)
• Not very harmonic (Vacuum cleaner)
• Absolutely not harmonic (White noise)
Classify Sounds by Harmonicity

- Sine wave
- Strongly harmonic

![Waveform of Sine Wave](image1.png)
![Magnitude Spectrum of Sine Wave](image2.png)

![Waveform of Oboe Sound](image3.png)
![Magnitude Spectrum of Oboe Sound](image4.png)

![Waveform of Clarinet Sound](image5.png)
![Magnitude Spectrum of Clarinet Sound](image6.png)
Classify Sounds by Harmonicity

- Somewhat harmonic (quasi-harmonic)
Classify Sounds by Harmonicity

- **Inharmonic**

<table>
<thead>
<tr>
<th>Sounds</th>
<th>Instrument family</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic</td>
<td>Woodwind, Brass, Arco string, Pluck string, Vocal</td>
<td>Piccolo, flute, oboe, clarinet, bassoon, saxophone, Trumpet, horn, euphonium, trombone, tuba, Violin, viola, cello, double bass, Piano, guitar, harp, celesta, Voiced phonemes</td>
</tr>
<tr>
<td>Quasi-harmonic</td>
<td>Pitched percussive</td>
<td>Timpani, marimba, vibraphone, xylophone</td>
</tr>
<tr>
<td>Inharmonic</td>
<td>Non-pitched percussive</td>
<td>Drums, cymbal, gong, tambourine</td>
</tr>
</tbody>
</table>
Frequency (often) equals pitch

• Complex tones
  – Strongest frequency?
  – Lowest frequency?
  – Something else?

• Let’s listen and explore…
Hypothesis

• Pitch is determined by the lowest strong frequency component in a complex tone.
The Missing Fundamental
Hypothesis

• Pitch is determined by the lowest strong frequency component in a complex tone.

• The case of the missing fundamental proves that ain’t always so.
Hypothesis

• Pitch is determined by the strongest frequency component in a harmonic tone.

• Tuvan throat singing seems to back this up.

• But what about that case of the missing fundamental?
Hypothesis – “It’s complicated”

• We hear which frequency components are loudest

• We decide if they all go together
  – Do they all start together?
  – Do they modulate together?

• We hear how they are spaced in frequency
  – Are they all spaced at intervals which are multiples of a common frequency?
  – Are their frequencies multiples of the same common frequency?

• We hear (or don’t hear) a pitch.
Shepard Tones


Shepard

Risset

EECS 352: Machine Perception of Music and Audio
Bryan Pardo 2008
Shepard tones

• Make a sound composed of sine waves spaced at octave intervals.
• Control their amplitudes by imposing a gaussian (or something like it) filter in the (log of the) frequency dimension
• Move all the sine waves up a musical $\frac{1}{2}$ step.
• Wrap around in frequency.