Gustav Mahler
(1860 – 1911)

Symphony #1 in D
Last Movement
Structure of The Ear

- Outer Ear
- Middle Ear
- Inner Ear
Hildegard von Bingen
(1098-1179)

Music from
Symphonia Harmonia Caelestium Revelationum
Discrimination Between Sounds

Just Noticeable Difference

or

JND
2AFC Testing

- 100% correct ⇒ Certainty
- 50% Correct ⇒ Guess
- Cutoff is defined for 75%
JND for Frequency
Physical Characteristics

- Intensity = $I$ (W/m$^2$)
- Sound Intensity Level = SIL (dB)
Psychological Characteristic

Loudness
Psychological Characteristic

For two sounds, A and B, if $\frac{I_A}{I_B} = 2$, what do we hear?
For two sounds, A and B, if $\frac{\text{SIL}_A}{\text{SIL}_B} = 2$, what do we hear?
The phon is the unit of Loudness Level (LL).
The LL (in phons) of a sound is defined to be numerically equal to the SIL (in dB) of a 1000 Hz tone that sounds equally loud to the listener.
Physical Characteristics

Frequency
Psychological Characteristic

Pitch
Pitch and Frequency

If note A *sounds* twice as high in pitch as note B, it is found that the frequency of A is twice that of B.
Pitch and Frequency

- Natural unit of pitch is the Octave.
- Simple relationship between pitch and frequency.
Pitch and Frequency

Demo with keyboard.
The loudness of a sound depends on the frequency of the sound.
1. Play 1000 Hz at SIL=40 dB.
2. Play 100 Hz. Ask listener to adjust for the same loudness.
3. Repeat for many frequencies.
<table>
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<th>f(Hz)</th>
<th>SIL (dB)</th>
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<th>SIL (dB)</th>
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<td>1500</td>
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<td>15000</td>
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Equal Loudness Contour

Fletcher-Munson Curve

SIL (dB) vs. Frequency (Hz)

40 Phons
Loudness changes with Frequency

Auditory Demo CD
Tracks 17 and 18
Resonance

Hearing is most sensitive in the range 2,500 – 5,000 Hz. Why?

Ear canal is a tube closed at one end

\[ \lambda = 4L = 4(2.5 \text{ cm}) = 10 \text{ cm} \]

\[ f = \frac{v}{\lambda} = \frac{344 \text{ m/s}}{0.1 \text{ m}} = 3,440 \text{ Hz!} \]
Repeat for all SIL’s