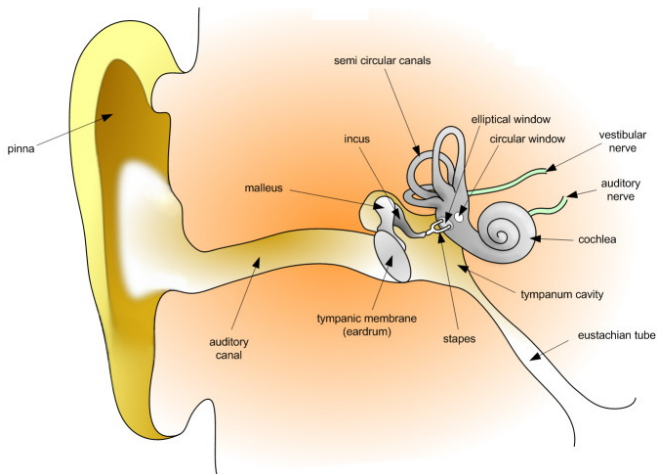


Creative Computing II

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Autumn 2009, Tuesdays, 10:00–15:00
Winter 2010, tbc

The Ear



The Ear

Outer Ear

Outer Ear:

- ▶ *pinna*: flap of skin;
 - ▶ assists in sound source location.
- ▶ *auditory canal*:
 - ▶ resonant cavity;
 - ▶ amplifies frequencies close to 4kHz.
- ▶ *tympanic membrane* (ear drum):
 - ▶ converts pressure differences to mechanical vibration.

The Ear

Middle Ear

Middle Ear:

- ▶ *ossicles* (small bones):
 - ▶ *malleus* (hammer);
 - ▶ *incus* (anvil);
 - ▶ *stapes* (stirrup);
 - ▶ transmit mechanical vibrations to inner ear;
 - ▶ amplification by lever principle.
- ▶ elliptical window
 - ▶ small membrane (compare with ear drum);
 - ▶ amplification by area.

The Ear

Inner Ear

Inner Ear or *Cochlea*:

- ▶ filled with *perilymph fluid*
 - ▶ incompressible;
 - ▶ moves in response to elliptical window;
 - ▶ (circular window moves to compensate).
- ▶ *scala media* (inner channel)
 - ▶ walls made from membranes (Reissner's membrane and basilar membrane)
 - ▶ walls displaced by fluid motion
- ▶ basilar membrane
 - ▶ tapered in thickness;
 - ▶ different regions respond best to different frequencies;
 - ▶ regions attached to hair cells;
 - ▶ hair cells attached to *auditory nerve*.

Sound Perception

Pitch

- ▶ Pressure waves (oscillating between overpressure and underpressure) impact on Tympanic Membrane
- ▶ Oscillations transmitted (and amplified) through hammer to stirrup
- ▶ Moves fluid in Cochlea, moving against receptor cells; those cells fire, sending signal to brain.
- ▶ Sensitive to oscillations between 20Hz and 20kHz.
- ▶ High frequency sensitivity decreases with age.
- ▶ Peak sensitivity: between 1kHz and 3kHz.

Sound Perception

Pitch in speech

Vowel formants:

Vowel	Main formant region/Hz
u	200–400
o	400–600
a	800–1200
e	400–600 & 2200–2600
i	200–400 & 3000–3500

Sibilants:

- ▶ sh: peak energy around 4000Hz, top at 8000Hz;
- ▶ s: peak energy around 8000Hz, top at 10000Hz.

Sound Perception

Pitch in singing

Singing:

- ▶ sustained pitch on the vowels;
- ▶ terminal consonants are delayed and short.

How can a singer be heard over an entire orchestra?

- ▶ amplification (cheating!);
- ▶ *singer's formant*;
- ▶ in *trained* voices, clear formant around 3kHz.
- ▶ (refer back to perceived loudness)

[demonstration]

Sound Perception

Pitch and harmony

Harmony:

- ▶ perceptual quality when pitched sounds (notes) occur simultaneously or in close temporal proximity;
- ▶ structural theory for describing same.

What is a consonant chord?

- ▶ chord: multiple tones;
- ▶ **fundamental frequencies** related by small integer ratio.

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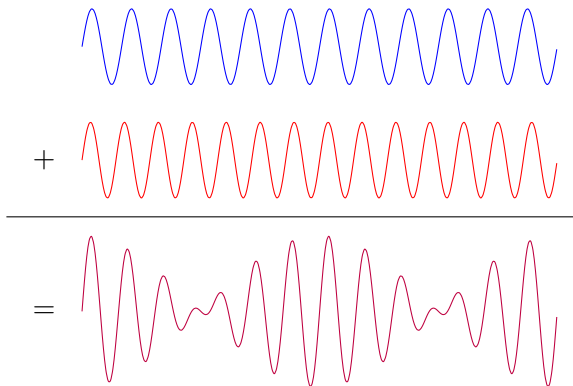
Why?

- ▶ no *beating*;
- ▶ no *dissonance*.

Sound Perception

Pitch and harmony

Beating:



$$\sin(A) + \sin(B) = 2 \sin \left[\frac{A+B}{2} \right] \cos \left[\frac{A-B}{2} \right]$$

Sound Perception

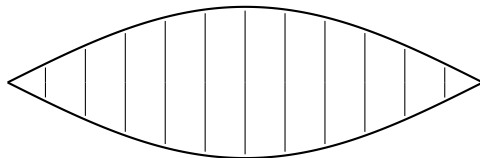
Pitch and harmony

One-dimensional instruments:

- ▶ stringed instruments (violin, viola, 'cello; guitar, piano) [string]
- ▶ wind instruments (flute, oboe, clarinet, bassoon) [cavity]
- ▶ brass instruments (trumpet, trombone, tuba) [tubing]
- ▶ tuned percussion (xylophone, glockenspiel) [bars]

Vibrate at

- ▶ *fundamental* frequency;
- ▶ **harmonics**: integer multiples of the fundamental.



Sound Perception

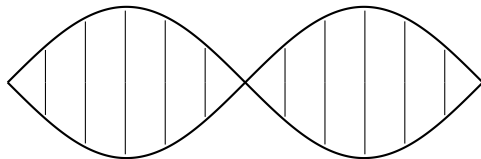
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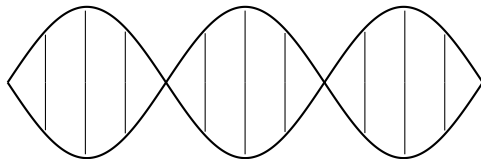
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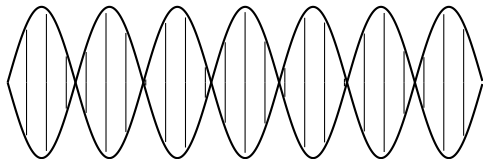
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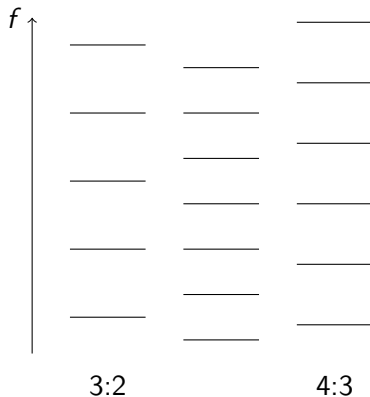


Sound Perception

Pitch and harmony

Dissonance:

- ▶ beating between *harmonics*:



critical bandwidth increases with frequency.

Sound Perception

Pitch and harmony

Western music: 12 equal-sized divisions to the octave.

- ▶ NB: not Universal.

Each note has a frequency a factor of $\sqrt[12]{2}$ above the previous one.

- ▶ Note names: C, C \sharp , D, E \flat , E, F, F \sharp , G, G \sharp , A, B \flat , B.
- ▶ Beware: labels different in different countries.
- ▶ Interval between notes: 'semitone'

Conventionally: A above 'middle C' is 440Hz

- ▶ Perfect fifth: should be $\frac{3}{2}$ above the root;
- ▶ $2^{\frac{7}{12}} = 1.4983\dots$
- ▶ close, but...

Sound Perception

Pitch and harmony

'Perfect pitch': like colour vision?

Different kinds:

- ▶ sing a named note without reference;
 - ▶ can be achieved by trained singers with muscle memory.
- ▶ name a heard note without reference.
 - ▶ difference in cognition;
 - ▶ not a different sensation;
 - ▶ correlation with
 - ▶ tonal languages?
 - ▶ musical exposure below age 4?
 - ▶ autism?

Sound Perception

Pitch and Melody

Melody:

- ▶ sequence of pitched events (notes) unfolding in musical time;

Perceived through large numbers of musical events:

- ▶ proximity (movement by small musical intervals);
- ▶ continuity (few breaks in a melody);
- ▶ common fate (repetition, with small alterations);

What makes a good melody?

Sound Perception

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What makes a good melody?

- ▶ if only I knew...

Sound Perception

Rhythm

Tempo:

- ▶ natural 'pulse' speed of music;
- ▶ often ambiguous (double / half speed).

Sound Perception

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Two experiments:

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Sound Perception

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Sound Perception

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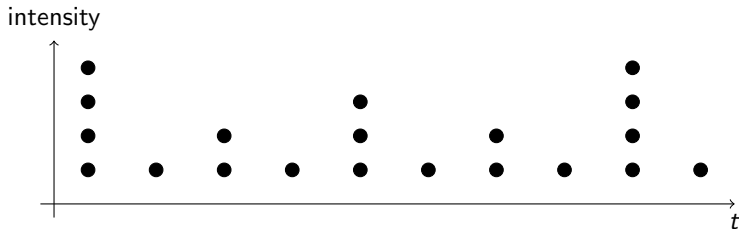
Preferred tempo: 0.2s – 0.8s

Sound Perception

Rhythm

Metrical Structure:

- ▶ hierarchy of temporal groups:
 - ▶ beats;
 - ▶ bars;
 - ▶ four-bar patterns;
 - ▶ larger groups (12-bar blues, 16-bar 'question'/'response').



Sound Perception

Rhythm

Rhythm:

- ▶ choice of which elements in the hierarchy to emphasize;
- ▶ which to elide;

What makes a good rhythm?

Sound Perception

Rhythm

Rhythm:

- ▶ choice of which elements in the hierarchy to emphasize;
- ▶ which to elide;

What makes a good rhythm?

- ▶ if only I knew...