Introduction to **Audio Content Analysis**

Module 7.1: Human Perception of Pitch

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introduction
overview

corresponding textbook section

section 7.1

- **lecture content**
  - pitch as perceptual phenomenon
  - non-linear relation of frequency and pitch
  - frequency content of a simple pitched sound
  - dimensions of pitch perception

- **learning objectives**
  - describe basic properties of models for pitch
  - explain the two dimensions of pitch perception

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tonal analysis
introduction

- **pitch & pitch-based properties** belong to the most important parameters describing music
  - melody
  - harmony
  - tonality
  - tuning & intonation

- **related ACA tasks**
  - fundamental frequency detection
  - key detection
  - chord detection
  - tuning frequency & temperament estimation

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pitch perception
pitch definition

definition (American Standards Association)

pitch is that attribute of auditory sensation in terms of which sounds may be ordered on a musical scale[1]

- temporal variations in pitch give rise to a sense of melody
- closely related to frequency, but **subjective**

$\Rightarrow$ assigning a pitch value to a sound means **specifying the frequency of a pure tone having the same subjective pitch** as the sound

[1] ASA, "Acoustical Terminology," American Standards Association (ASA), Standard, 1960.

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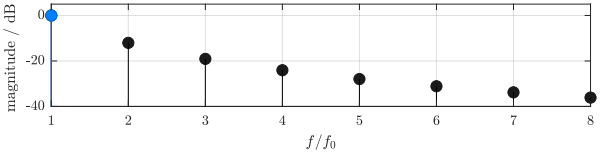
pitch perception
fundamental frequency



- *fundamental* frequency is relevant for pitch perception ($f_0, 2f_0, 3f_0, \ldots$)
- higher fundamental frequency $\Rightarrow$ higher pitch (mono-dimensional)

matlab source: plotHarmonics.m

pitch perception
missing fundamental

- basilar membrane location **does not explain** the pitch perception of complex tones

$\Rightarrow$ **virtual pitch**, **residue pitch**

- **example 1**: missing fundamental
  - $f_0 = 120\,\mathrm{Hz}$, 33 harmonics, with(out) bandpass 300-2400 Hz
- **example 2**: missing fundamental
  - speech $f_0 \approx 100\,\mathrm{Hz}$, with(out) bandpass 300-4000 Hz

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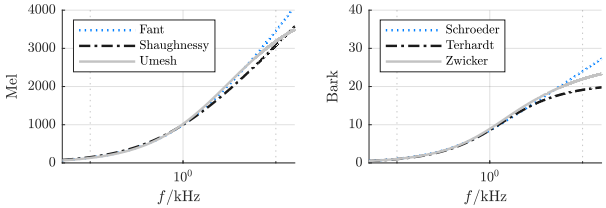
pitch perception
frequency & pitch



non-linear pitch frequency relation:

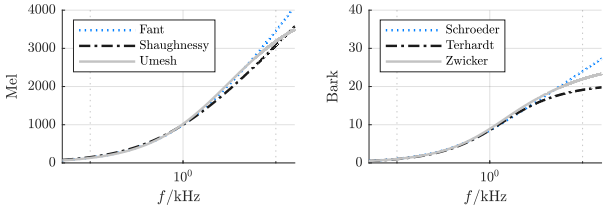
- perceptual pitch distance $\neq$ frequency distance

$\Rightarrow$ *models* for psycho-acoustic/physiological data

- *Mel* scale (equal pitch distance)
- *Bark* scale (critical band width)
- physiological frequency location (basilar membrane)

matlab source: plotMelBark.m

pitch perception
frequency & pitch



Fant: $\mathfrak{m}_{\mathrm{F}}(f) = 1000 \cdot \log_2\left(1 + \frac{f}{1000\,\mathrm{Hz}}\right)$

O'Shaughnessy: $\mathfrak{m}_{\mathrm{S}}(f) = 2595 \cdot \log_{10}\left(1 + \frac{f}{700\,\mathrm{Hz}}\right)$

$\mathfrak{m}_{\mathrm{S}}(f) = 1127 \cdot \log\left(1 + \frac{f}{700\,\mathrm{Hz}}\right)$

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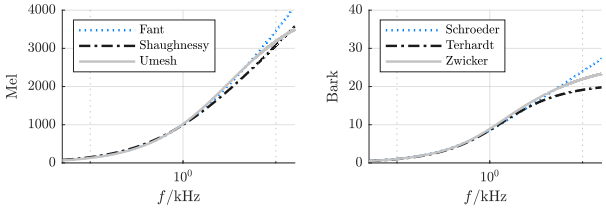

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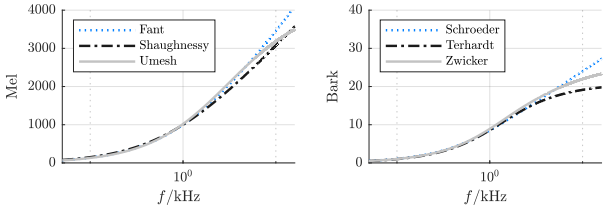

Schröder: $$\mathfrak{z}_{\mathrm{S}}(f) = 7 \cdot \operatorname{arcsinh}\left(\frac{f}{650\,\mathrm{Hz}}\right)$$

Terhardt: $$\mathfrak{z}_{\mathrm{T}}(f) = 13.3 \cdot \arctan\left(0.75 \cdot \frac{f}{1000\,\mathrm{Hz}}\right)$$

Zwicker: $$\mathfrak{z}_{Z}(f) = 13 \cdot \operatorname{atan}\left(0.76 \cdot \frac{f}{1000\,\mathrm{Hz}}\right) + 3.5 \cdot \operatorname{atan}\left(\frac{f}{7500\,\mathrm{Hz}}\right)$$

matlab source: plotMelBark.m

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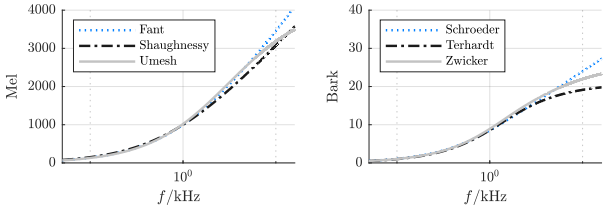

ERB: $\mathfrak{e}(f) = 9.26 \log\left(1 + \frac{f}{228.7}\right)$

Cochlear Map: $\mathfrak{x}(f) = \frac{1}{2.1} \log_{10}\left(\frac{f}{165.4} + 1\right)$

matlab source: plotMelBark.m

pitch perception
pitch dimensions

2 dimensions of musical pitch

- **tone height**: monotonic relationship to frequency (increasing frequency $\Rightarrow$ increasing pitch)
- **tone chroma**: two tones separated by octave sound similar (same *pitch class*)

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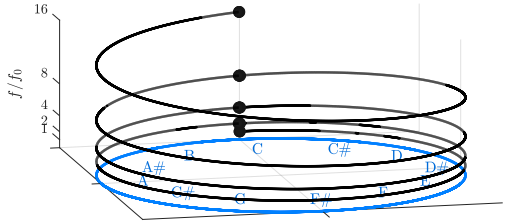

matlab source: plotPitchHelix.m

summary
lecture content

- **pitch**
  - **subjective** phenomenon
  - **non-linear** monotonic relationship to frequency (tone height increases with fundamental frequency)
  - pitch grouping based on powers of two: tone **chroma perception**