



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 scale¹

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

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

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

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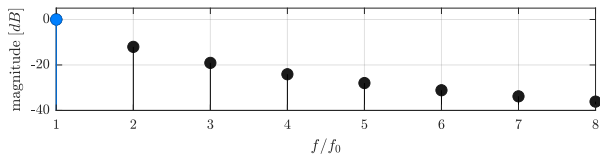
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pitch perception

fundamental frequency



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

pitch perception

missing fundamental

PITCH PITCH

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

⇒ virtual pitch, residue pitch

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

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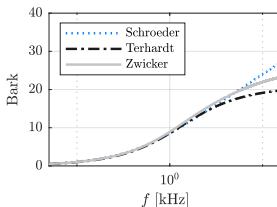
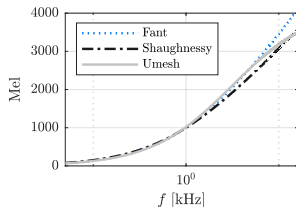
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pitch perception

frequency & pitch

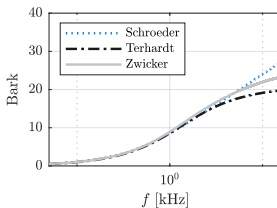
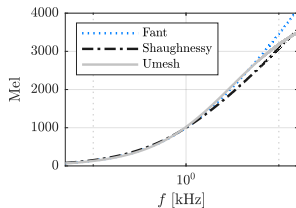


non-linear pitch frequency relation:

- 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)

pitch perception

frequency & pitch



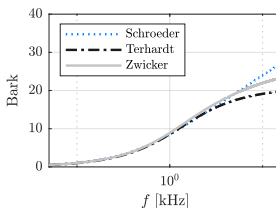
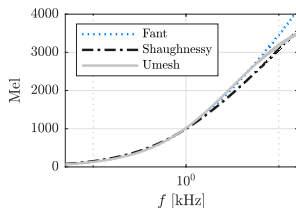
Fant: $m_F(f) = 1000 \cdot \log_2 \left(1 + \frac{f}{1000 \text{ Hz}} \right)$

O'Shaughnessy: $m_S(f) = 2595 \cdot \log_{10} \left(1 + \frac{f}{700 \text{ Hz}} \right)$

$$m_S(f) = 1127 \cdot \log \left(1 + \frac{f}{700 \text{ Hz}} \right)$$

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frequency & pitch



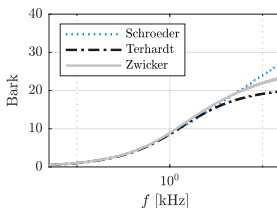
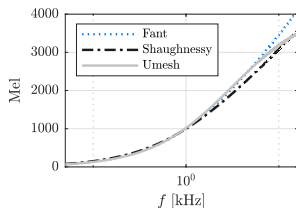
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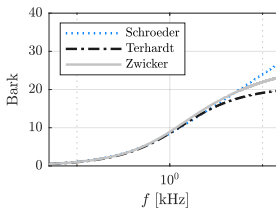
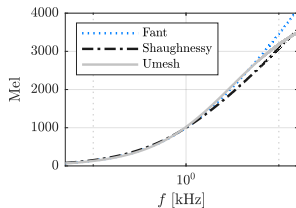
Schröder:
$$\mathfrak{z}_S(f) = 7 \cdot \operatorname{arcsinh} \left(\frac{f}{650 \text{ Hz}} \right)$$

Terhardt:
$$\mathfrak{z}_T(f) = 13.3 \cdot \arctan \left(0.75 \cdot \frac{f}{1000 \text{ Hz}} \right)$$

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

pitch perception

frequency & pitch



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

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

pitch perception

pitch dimensions

2 dimensions of musical pitch

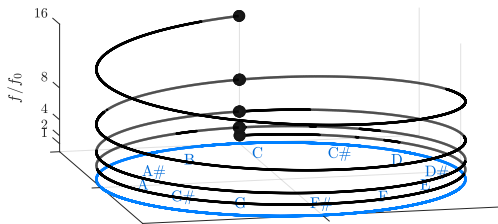
- **tone height**: monotonic relationship to frequency (increasing frequency \Rightarrow increasing pitch)
- **tone chroma**: two tones separated by octave sound similar (same *pitch class*)

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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**

