



# 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<sup>1</sup>

- 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

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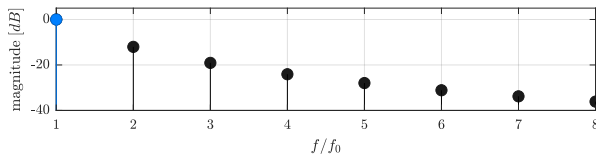
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# pitch perception

## 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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# pitch perception

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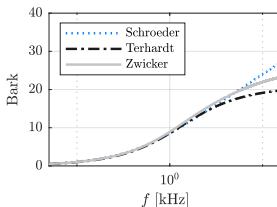
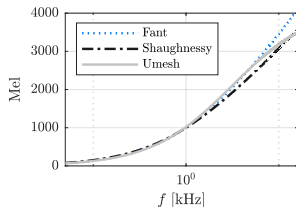
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# pitch perception

## frequency & pitch

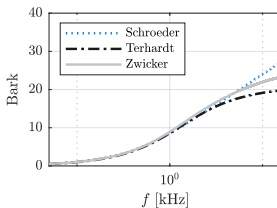
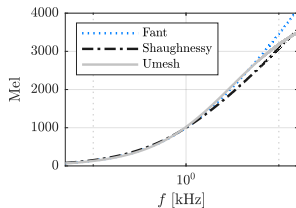


### non-linear pitch frequency relation:

- 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



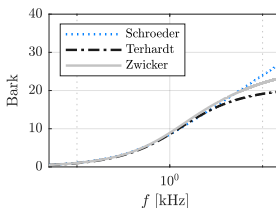
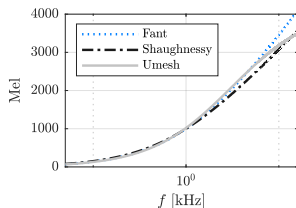
**Fant:**  $m_F(f) = 1000 \cdot \log_2 \left( 1 + \frac{f}{1000 \text{ Hz}} \right)$

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

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

# pitch perception

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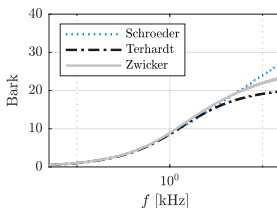
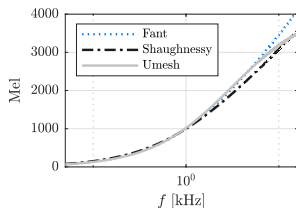
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## frequency & pitch



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

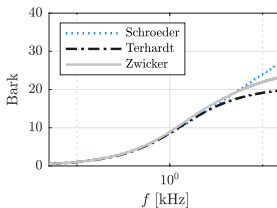
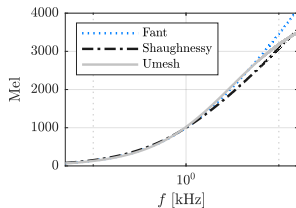
**Terhardt:** 
$$\mathfrak{z}_T(f) = 13.3 \cdot \arctan \left( 0.75 \cdot \frac{f}{1000 \text{ Hz}} \right)$$

**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



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

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

# pitch perception

## pitch dimensions

## 2 dimensions of musical pitch

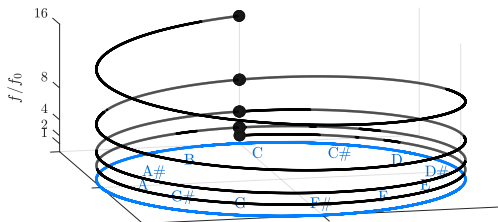
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- **tone chroma**: two tones separated by octave sound similar (same *pitch class*)

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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**

