Introduction to Audio Content Analysis

Module 7.5: Musical Key Recognition

alexander lerch

introduction
overview

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corresponding textbook section

Section 7.5

- **lecture content**
  - definition of musical key
  - pitch chroma feature
  - standard approach for key recognition

- **learning objectives**
  - explain the defining properties of a musical key
  - implement a simple pitch chroma feature extractor
  - describe and discuss a simple automatic key recognition system

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introduction

corresponding textbook section

Section 7.5

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key
tonic & mode

- **tonic**: first scale degree
  - most "important" pitch class
- **mode**: set of diatonic pitch relationships
  - Major: 2, 2, 1, 2, 2, 2, 1
  - Minor: 2, 1, 2, 2, 1, 2, 2

Major   (Aeolic) Minor

(Harmonic) Minor   Dorian

Phrygian   Lydian

Mixolydian   Lokrian

Chromatic   Wholetone

key
key & key signature 1/2

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- **key**:
  defined by *tonic* (root note) and *mode*
  - defines a set of pitch classes constructing both pitch and harmonic content

- **modulation** (local key changes):
  common in various styles, uncommon in others

- **key signature**:
  indicates current key with accidentals (score notation)

key
key & key signature 1/2

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key & key signature 1/2

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key
key & key signature 2/2

musical pitch
key: circle of fifths

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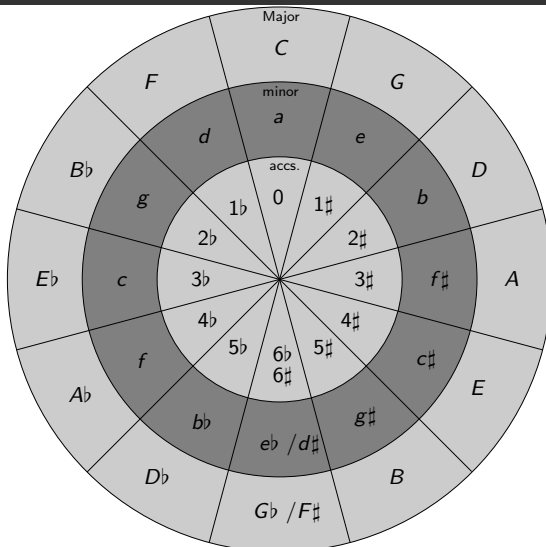
pitch chroma
introduction

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- pitch class distribution

- 12-dimensional vector

- **no** octave information
  - robust representation
  - no differentiation between unison and octave

matlab source: plotPitchChroma.m

pitch chroma
computation 1/2

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1 divide spectral representation into **semi-tone bands**

2 compute **mean per band**

$$\mu(j, n) = \frac{1}{k_{\mathrm{u}}(j) - k_{\mathrm{l}}(j) + 1} \sum_{k=k_{\mathrm{l}}(j)}^{k_{\mathrm{u}}(j)} |X(k, n)|$$

3 sum/mean every 12th band

$$\nu(j \% 12, n) = \sum_{o=o_l}^{o_u} \mu(j, n),$$

$$\nu(n) = [\nu(0, n), \nu(1, n), \nu(2, n), \ldots, \nu(10, n), \nu(11, n)]^{\mathrm{T}}$$

pitch chroma
computation 1/2

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1. divide spectral representation into **semi-tone bands**
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pitch chroma
computation 1/2

1. divide spectral representation into **semi-tone bands**
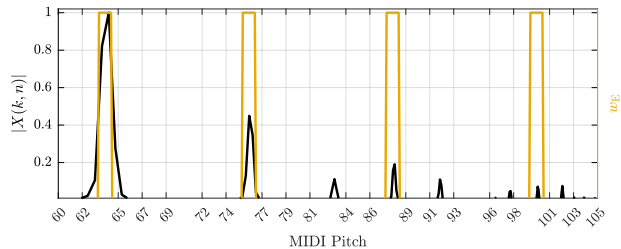2. compute **mean per band**

$$\mu(j, n) = \frac{1}{k_\mathrm{u}(j) - k_\mathrm{l}(j) + 1} \sum_{k=k_\mathrm{l}(j)}^{k_\mathrm{u}(j)} |X(k, n)|$$

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pitch chroma
computation 2/2

matlab source: plotPitchChromaGrouping.m

pitch chroma
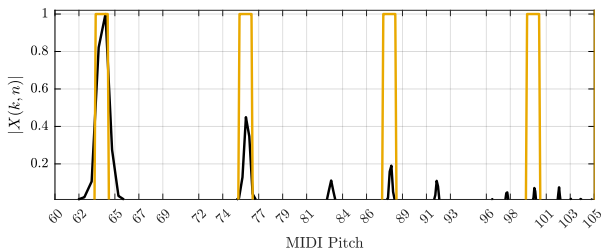computation: simple variants

- **STFT**:
  - *weighted* mean of bins (window function)
  - *tonalness preprocessing* (local maxima etc)
- sum of **filterbank** output energies
- **CQT**:
  - sum of bins/peaks
- beat-synchronous chroma

matlab source: plotPitchChromaGrouping.m

pitch chroma
computation: simple variants

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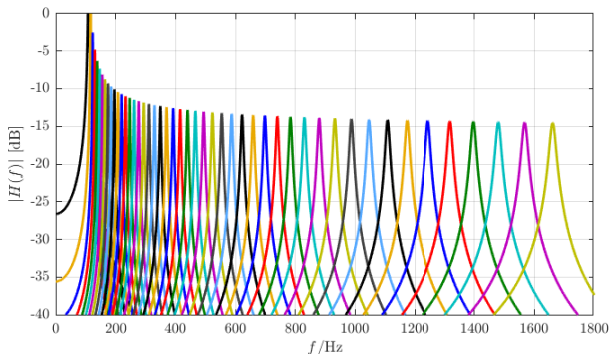Tech **Technology**
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matlab source: plotResonanceFilterBank.m

pitch chroma
computation: simple variants

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pitch chroma
computation: simple variants

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pitch chroma
normalization

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- pitch chroma as *distribution*:
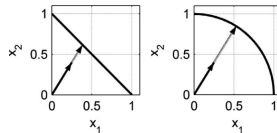
$$\sum_{k=0}^{11} \nu(k, n) = 1$$

- pitch chroma as *vector*:

$$\sqrt{\sum_{k=0}^{11} \nu(k, n)^2} = 1$$

- other options:
  - e.g., short-term energy normalization (CENS)

pitch chroma
normalization

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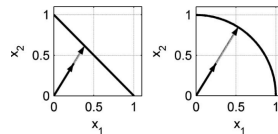- pitch chroma as *distribution*:

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pitch chroma
normalization

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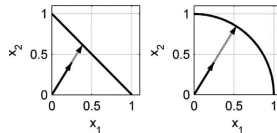College of Design

■ pitch chroma as *distribution*:

$$\sum_{k=0}^{11} \nu(k, n) = 1$$

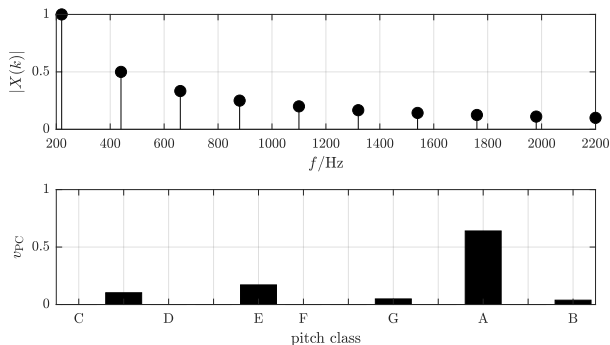■ pitch chroma as *vector*:

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pitch chroma
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key detection
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pitch chroma
problem 1: amplitude distortion
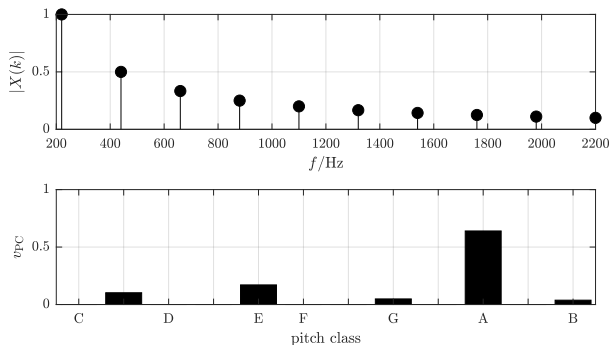
- every pitch contains not only fundamental but higher harmonics
⇒   ⇒ de-emphasize higher frequencies
     ⇒ build amplitude model
     ⇒ use multi-pitch detection system

matlab source: plotPitchChromaLeakage.m

pitch chroma
problem 1: amplitude distortion

- every pitch contains not only fundamental but higher harmonics
- $\Rightarrow$ de-emphasize higher frequencies
- $\Rightarrow$ build amplitude model
- $\Rightarrow$ use multi-pitch detection system

matlab source: plotPitchChromaLeakage.m

pitch chroma
problem 2: frequency distortion

- higher harmonics are not "in-tune"

Harmonic	$|\Delta C(f, f_T)|$
$f = f_0$	0
$f = 2 \cdot f_0$	0
$f = 3 \cdot f_0$	1.955
$f = 4 \cdot f_0$	0
$f = 5 \cdot f_0$	13.6863
$f = 6 \cdot f_0$	1.955
$f = 7 \cdot f_0$	31.1741
$\mu_{|\Delta C|}$	6.9672

key detection
introduction

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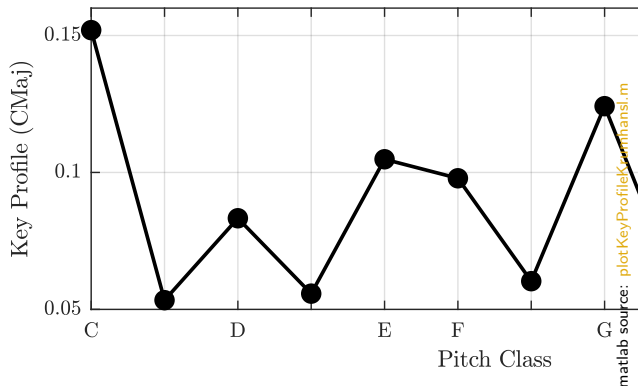Tech | Technology
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assumption:

- *pitch class distribution* is prototypical for key
    - tonic/root note is tonal center
    - tonal and harmonic relations define importance and occurrence of individual pitch classes
    - different root notes result in simple shift of distribution
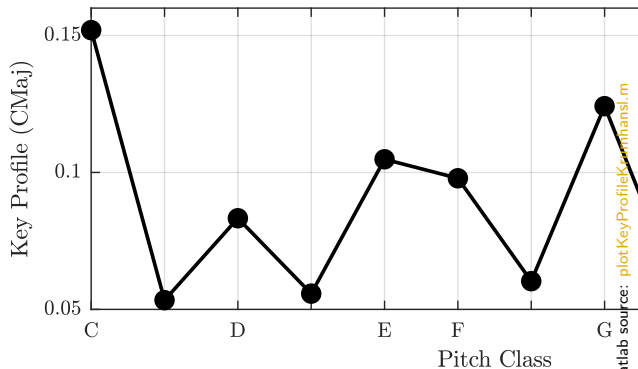
key detection
processing steps of simple key detection

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1. **define reference distribution for specific keys**

2. extract average pitch chroma from audio

3. compute distance between template and extracted chroma

matlab source: plotKeyProfileKrumhansl.m

key detection
processing steps of simple key detection

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matlab source: plotKeyProfileKrumhansl.m

key detection
processing steps of simple key detection

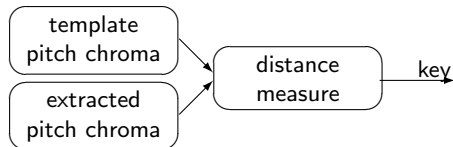Georgia | Center for Music
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1. define reference distribution for specific keys
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key detection
key template distance animation

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matlab source: matlab/animateKeyDetection.m

key detection
key templates

- *Orthogonal* ν_{o}: root note is most salient component, other components negligible
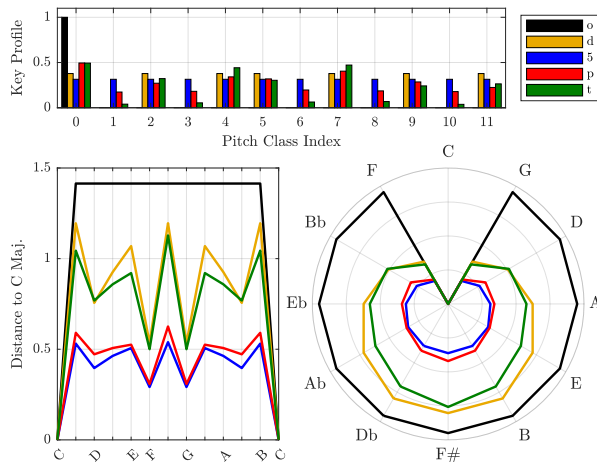 - same distance to all keys
  - no major/minor distinction

- *Diatonic* ν_{d}: all key-inherent pitches weighted equally
  - linear increasing key dist

- *Probe tone Ratings* ν_{p}: derived from perceptual tonal similarity

- *Extracted Key Profiles* ν_{t}: derived from real-world data

matlab source: plotKeyProfiles.m

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key detection
key templates

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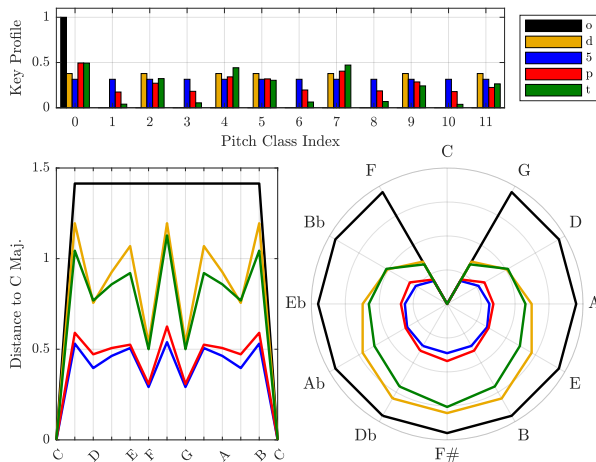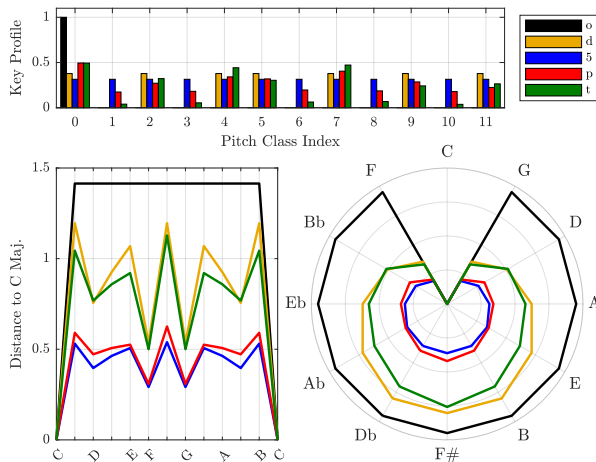- *Probe tone Ratings* ν_{p}: derived from perceptual tonal similarity
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matlab source: plotKeyProfiles.m

overview
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key
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pitch chroma
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key detection
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key detection
key templates

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key detection
key templates

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overview
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pitch chroma
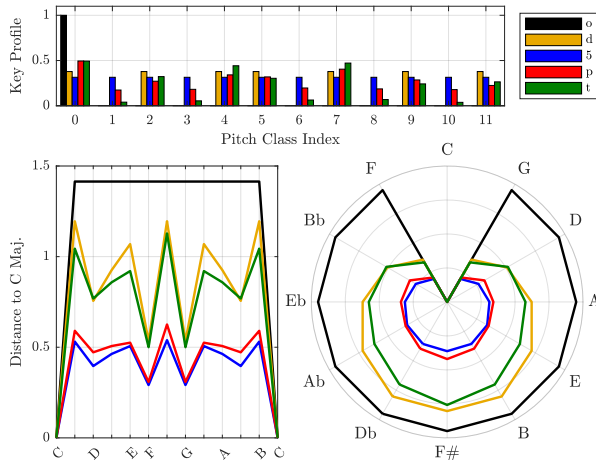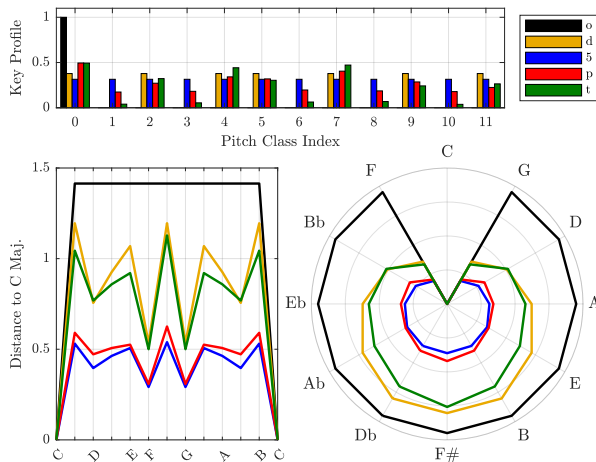○○○○○○○

key detection
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key detection

variants

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- **tonalness weight**:
  estimate the tonality/noisiness and weight instantaneous pitch chroma

- **multiple estimations**:
  split piece into regions and estimate key through majority

- **real-time key detection**:
  estimate in sliding window

key detection
variants

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key detection
variants

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key detection
results & typical errors

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- typical errors: related keys
  - Dominant
  - Subdominant
  - Relative
  - Major/Minor
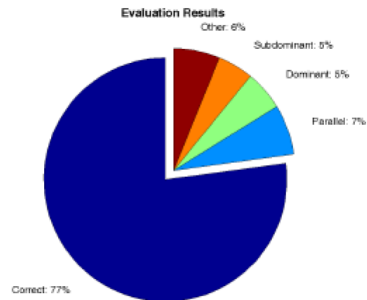
graph from[1]

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[1]**lerch˙ansatz˙2004**.

summary
lecture content

- **musical key**
  - set of pitch classes constructing pitched content
  - defined by *tonic* (important center) and *mode* (scale)

- **pitch chroma**
  - reduced 12-dimensional octave-independent pitch representation
  - relatively robust against timbre variation

- **automatic key recognition**
  - standard approach is template-based
  - extracted average pitch chroma is compared with predefined template
  - inverse distance measure indicates key likelihoods