



Tutorial T3
A Basic Introduction to Audio-Related Music Information Retrieval

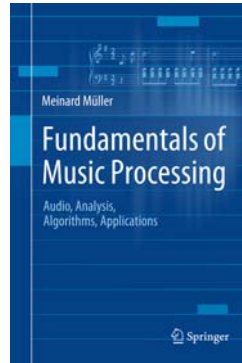
Tonal Analysis

Meinard Müller, Christof Weiß

International Audio Laboratories Erlangen
meinard.mueller@audiolabs-erlangen.de, christof.weiss@audiolabs-erlangen.de



Book: Fundamentals of Music Processing



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

Accompanying website:
www.music-processing.de

Book: Fundamentals of Music Processing

Chapter	Music Processing Scenario
1	Music Representations
2	Fourier Analysis of Signals
3	Music Synchronization
4	Music Structure Analysis
5	Chord Recognition
6	Tempo and Beat Tracking
7	Content-Based Audio Retrieval
8	Musically Informed Audio Decomposition

Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

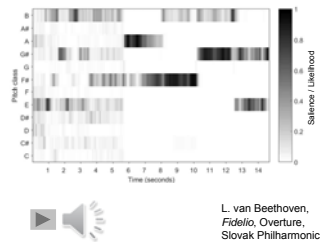
Accompanying website:
www.music-processing.de

Dissertation: Tonality-Based Style Analysis

Christof Weiß
Computational Methods for Tonality-Based Style Analysis of Classical Music Audio Recordings
PhD thesis, Technical University of Ilmenau, 2017

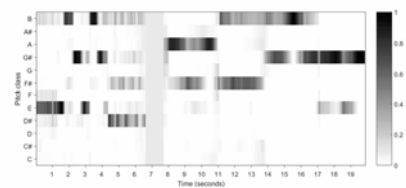
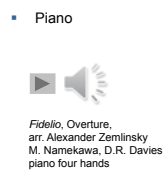
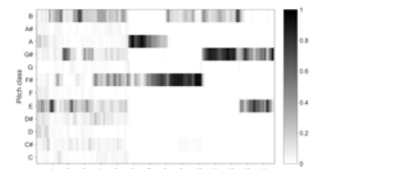
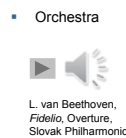
Chapter 5: Analysis Methods for Key and Scale Structures
Chapter 6: Design of Tonal Features

Recall: Chroma Representations



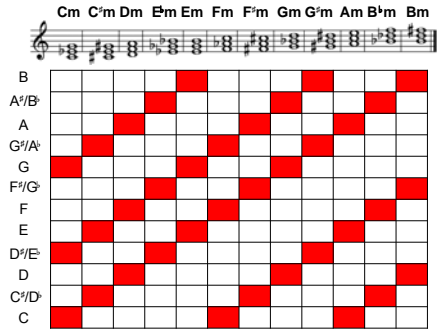
L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic

Recall: Chroma Representations

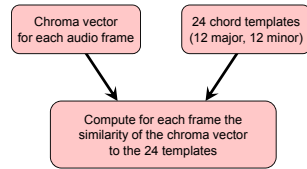


Chord Recognition: Basics

- Templates: **Minor Triads**

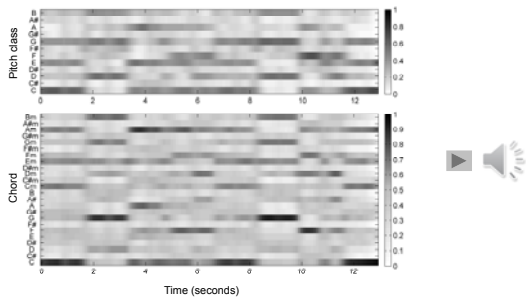


Chord Recognition: Template Matching

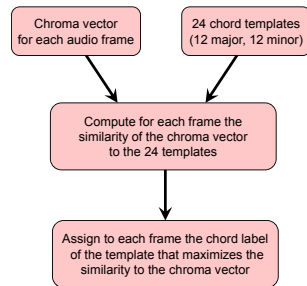


	C	C [♯]	D	...	Cm	C ^{♯m}	Dm	...
B	0	0	0	...	0	0	0	...
A [♯]	0	0	0	...	0	0	0	...
A	0	0	1	...	0	0	1	...
G [♯]	0	1	0	...	0	1	0	...
G	1	0	0	...	1	0	0	...
F [♯]	0	0	1	...	0	0	0	...
F	0	1	0	...	0	0	1	...
E	1	0	0	...	0	1	0	...
D [♯]	0	0	0	...	1	0	0	...
D	0	0	1	...	0	0	1	...
C [♯]	0	1	0	...	0	1	0	...
C	1	0	0	...	1	0	0	...

Chord Recognition: Template Matching

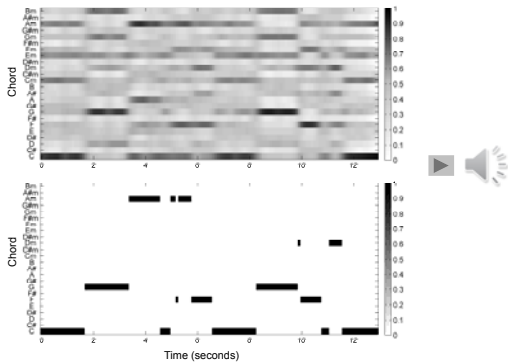


Chord Recognition: Label Assignment

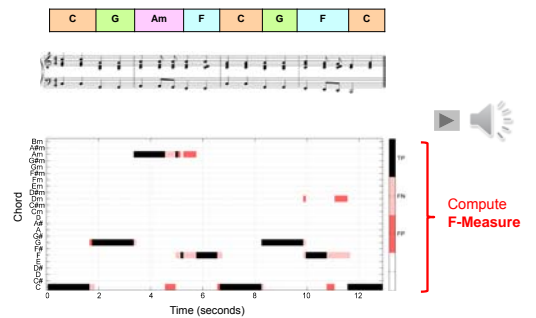


	C	C [♯]	D	...	Cm	C ^{♯m}	Dm	...
B	0	0	0	...	0	0	0	...
A [♯]	0	0	0	...	0	0	0	...
A	0	0	1	...	0	0	1	...
G [♯]	0	1	0	...	0	1	0	...
G	1	0	0	...	1	0	0	...
F [♯]	0	0	1	...	0	0	0	...
F	0	1	0	...	0	0	1	...
E	1	0	0	...	0	1	0	...
D [♯]	0	0	0	...	1	0	0	...
D	0	0	1	...	0	0	1	...
C [♯]	0	1	0	...	0	1	0	...
C	1	0	0	...	1	0	0	...

Chord Recognition: Label Assignment

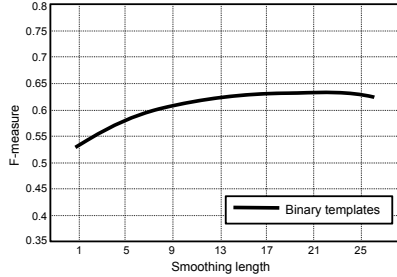


Chord Recognition: Evaluation



Chord Recognition: Evaluation

- Frame-wise approach: Too many / too rapid changes of output label
- Improvement strategies:
 - Pre-filtering: Average chroma features over several frames (**smoothing**)
 - Evaluation on all Beatles songs



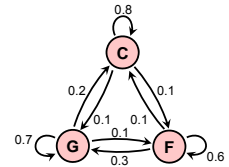
Chord Recognition: Markov Chains

- Probabilistic model for sequential data
- Markov property: Next state depends only on current state (no "memory")
- Consist of:

Set of states

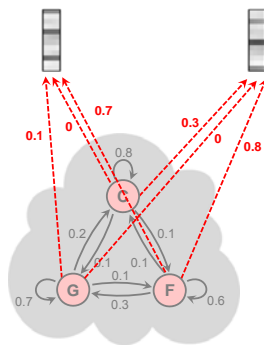
State transition probabilities

Initial state probabilities



Chord Recognition: Hidden Markov Models

- States as **hidden** variables
- Consist of:
 - Set of states (hidden)
 - State transition probabilities
 - Initial state probabilities
 - Observations (visible)
 - Emission probabilities
- Decoding: **Viterbi** algorithm (based on dynamic programming)

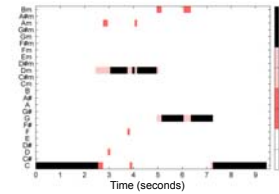


Chord Recognition: Evaluation

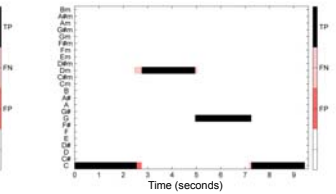
- Effect of HMM-based chord estimation and smoothing:



(a) Template Matching (frame-wise)

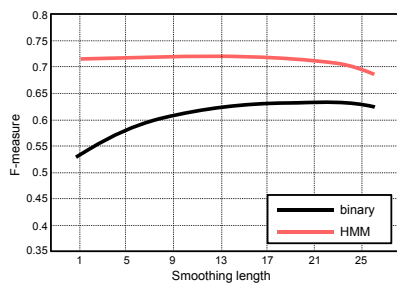


(b) HMM

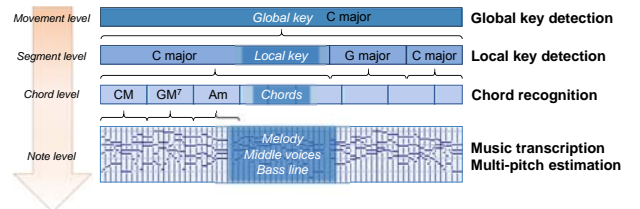


Chord Recognition: Evaluation

- Evaluation on all Beatles songs

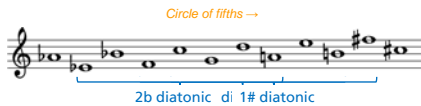


Tonal Structures



Local Key Detection

- Key as an important musical concept ("*Symphony in C major*")
- Modulations → Local approach
- Diatonic Scales
 - Simplification of keys (equivalent to *number of accidentals*)
 - Perfect-fifth relation

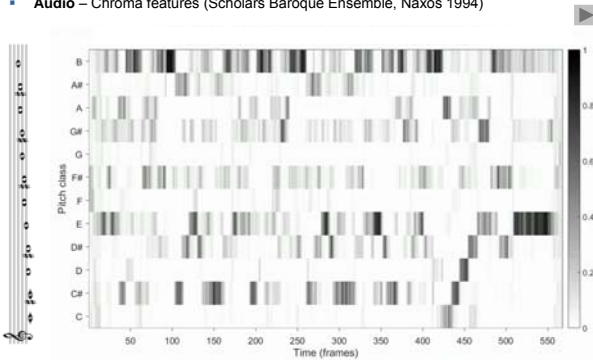


Local Key Detection

- Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
- **Score** – Piano reduction

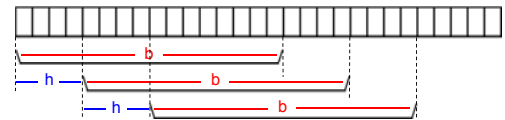
Local Key Detection: Chroma Features

- Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
- **Audio** – Chroma features (Scholars Baroque Ensemble, Naxos 1994)



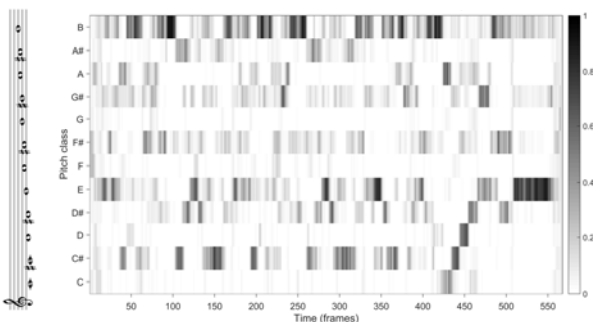
Local Key Detection: Chroma Smoothing

- Average pitch classes over a certain time
- **Chroma smoothing**
- Parameters: blocksize **b** and hopsize **h**



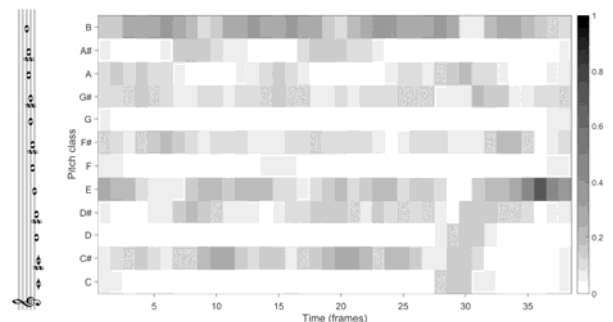
Local Key Detection: Chroma Smoothing

- Choral (Bach)



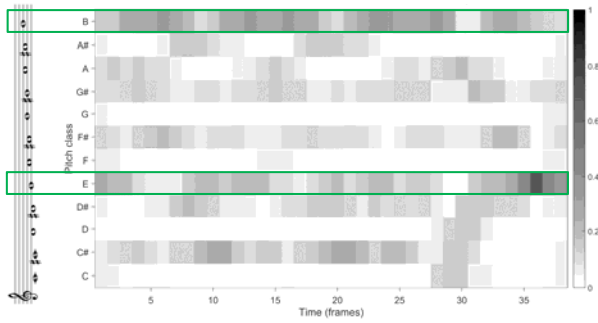
Local Key Detection: Chroma Smoothing

- Choral (Bach) — smoothed with **b** = 42 seconds and **h** = 15 seconds



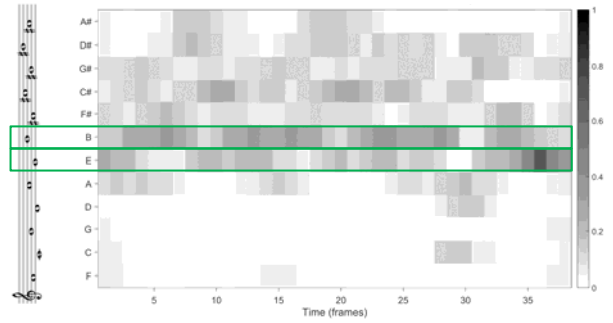
Local Key Detection: Diatonic Scales

- Choral (Bach) — Re-ordering to **perfect fifth** series



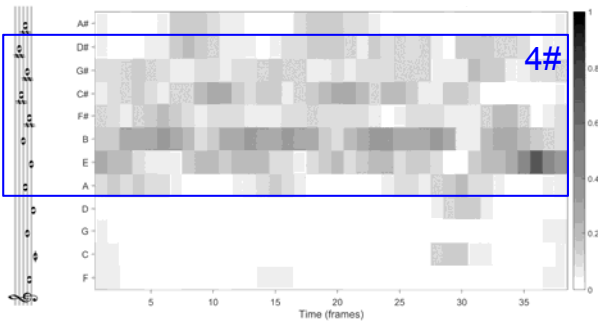
Local Key Detection: Diatonic Scales

- Choral (Bach) — Re-ordering to **perfect fifth** series



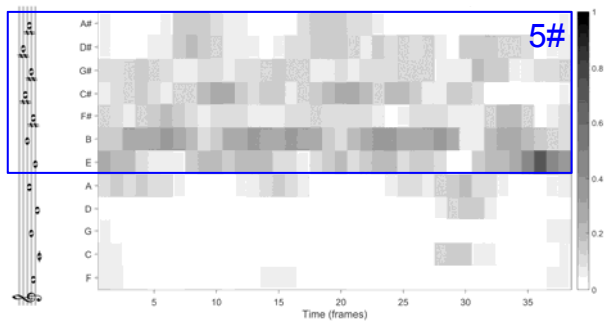
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation (**7 fifth-related pitch classes**)



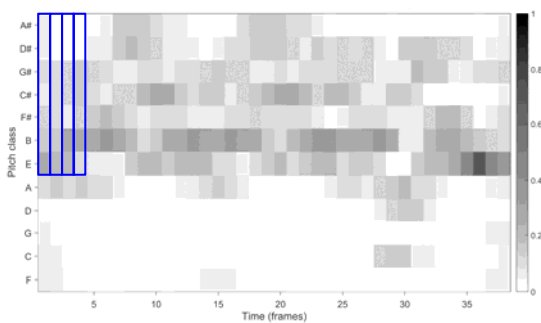
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation (**7 fifth-related pitch classes**)



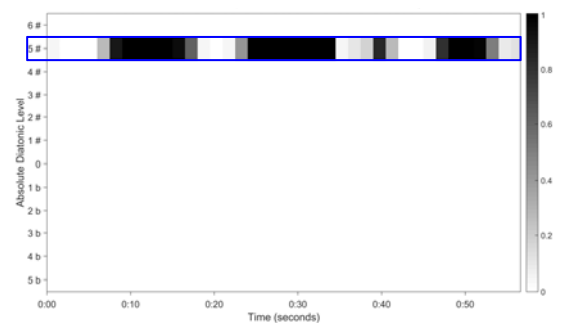
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation: **Multiply chroma values**



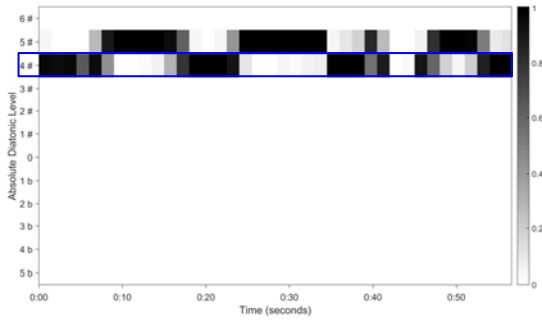
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation: **Multiply chroma values**



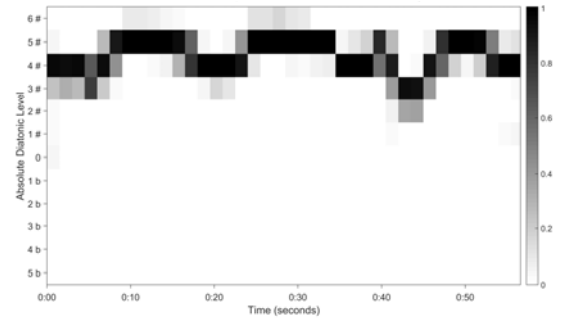
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation



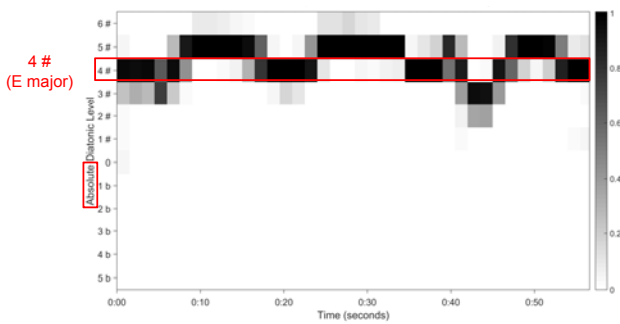
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation



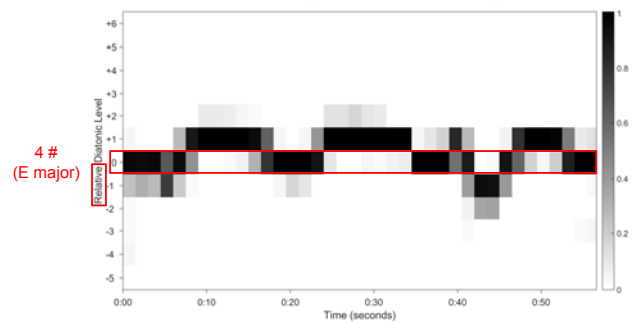
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation: Shift to global key



Local Key Detection: Diatonic Scales

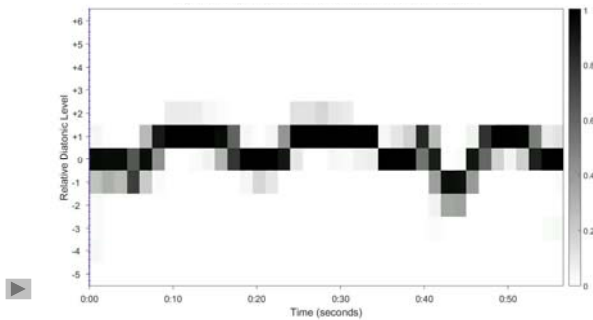
- Choral (Bach) — Diatonic Scale Estimation: Shift to global key



Local Key Detection: Diatonic Scales

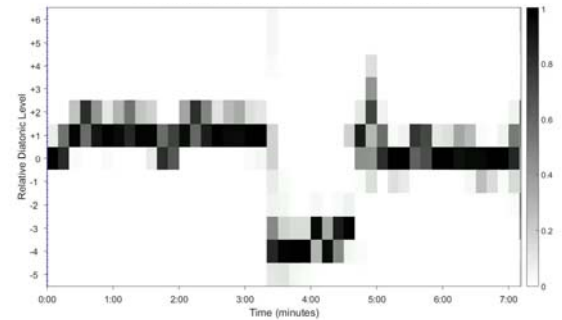
- Choral (Bach) — level 0 \triangleq 4#

Weiss / Habryka, *Chroma-Based Scale Matching for Audio Tonality Analysis*, CIM 2014



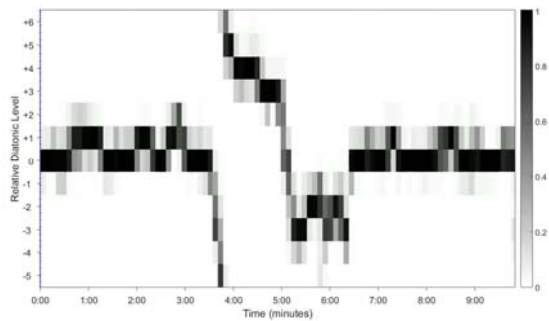
Local Key Detection: Examples

- L. v. Beethoven – Sonata No. 10 op. 14 Nr. 2, 1. Allegro — level 0 \triangleq 1# (Barenboim, EMI 1998)



Local Key Detection: Examples

- R. Wagner, *Die Meistersinger von Nürnberg*, Vorspiel — level 0 \triangleq no accidentals
(Polish National Radio Symphony Orchestra, J. Wildner, Naxos 1993)



Further Information

- Chord recognition overview and evaluation
[Cho/Bello, IEEE TASLP 2014]
- Chord recognition with Deep Learning
[Sigita/Boulanger-Lewandowski/Dixon, ISMIR 2015]
[Korzeniowski/Widmer, ISMIR 2016]
[McFee/Bello, ISMIR 2017] → Oral Session 6
- Harmony analysis for musicology
[Sears et al., ISMIR 2017] → Poster Session 1
[Zalkow/Weiß/Müller, ISMIR 2017] → Poster Session 3
[Bigo et al., ISMIR 2017] → Poster Session 3
- CHORDINO, Vamp plugin for Sonic Visualizer
[Mauch/Dixon, ISMIR 2010]
www.isophonics.org/npls-chroma