



ISMIR
2017, SUZHOU, CHINA

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

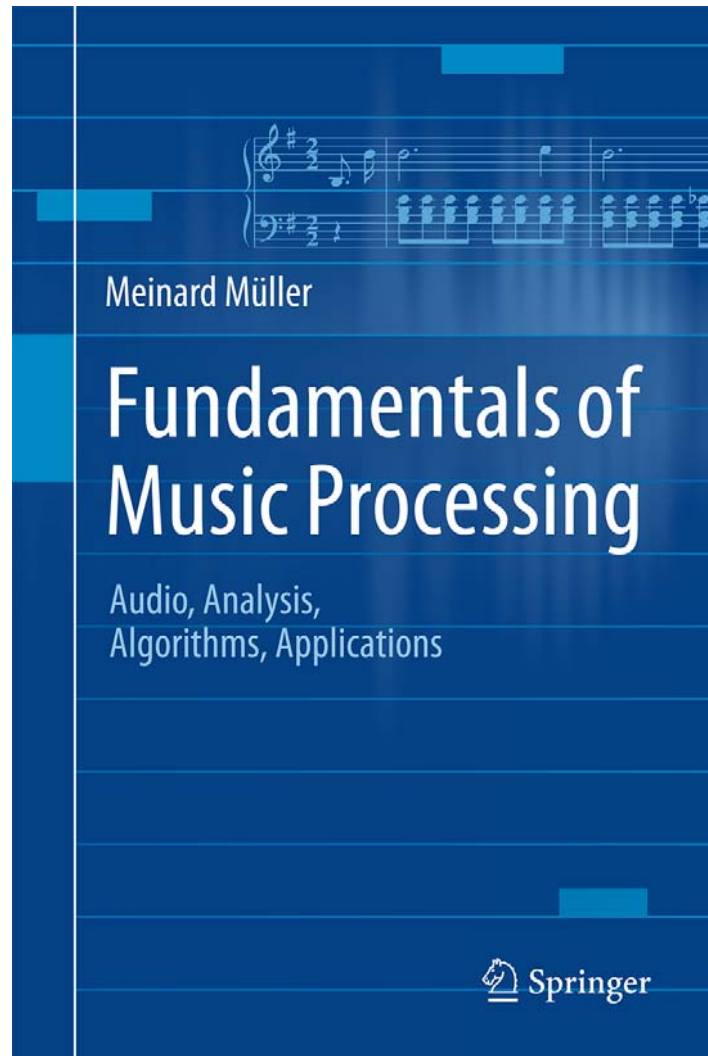
Tonal Analysis

Meinard Müller, Christof Weiß

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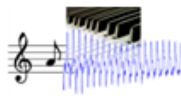

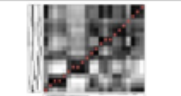
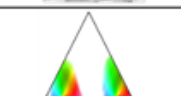

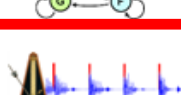


Book: Fundamentals of Music Processing



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

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Dissertation: Tonality-Based Style Analysis

Christof Weiß

*Computational Methods for Tonality-Based Style Analysis of
Classical Music Audio Recordings*

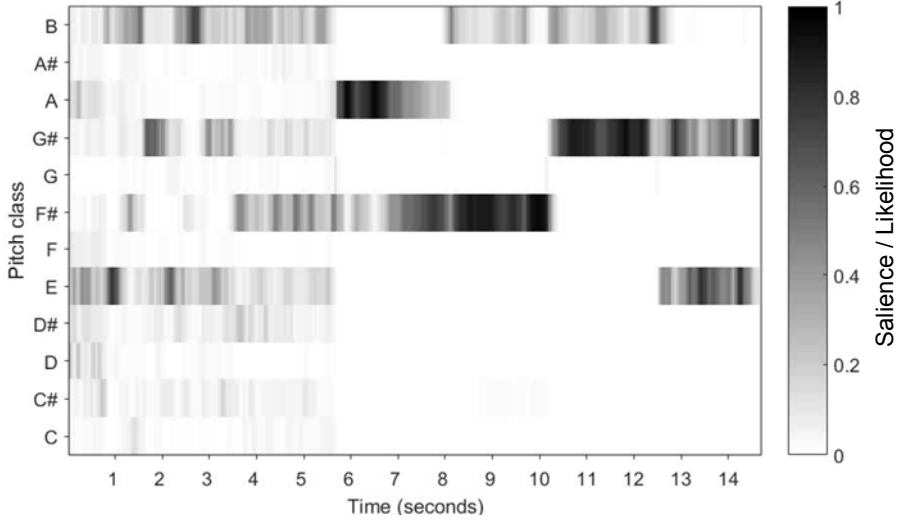
PhD thesis, Technical University of Ilmenau, 2017

Chapter 5: Analysis Methods for Key and Scale Structures

Chapter 6: Design of Tonal Features

Recall: Chroma Representations

Ouvertüre zu Fidelio Ludwig van Beethoven



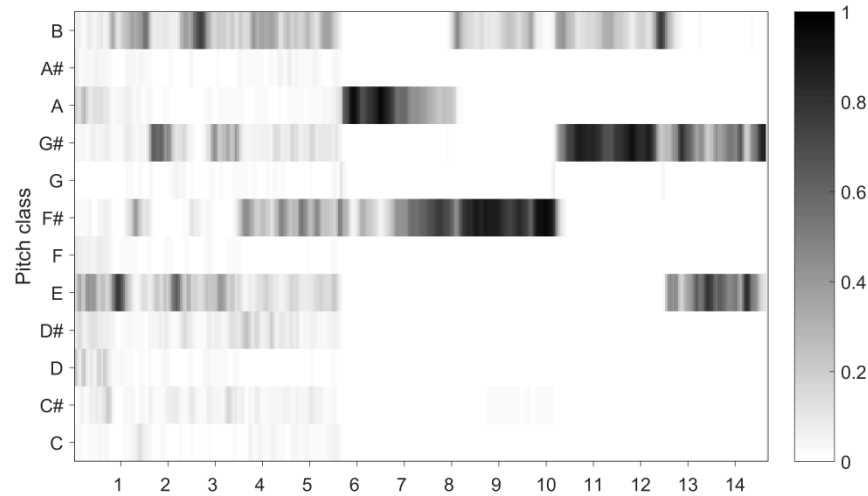
L. van Beethoven, *Fidelio*, Overture, Slovak Philharmonic

Recall: Chroma Representations

- Orchestra



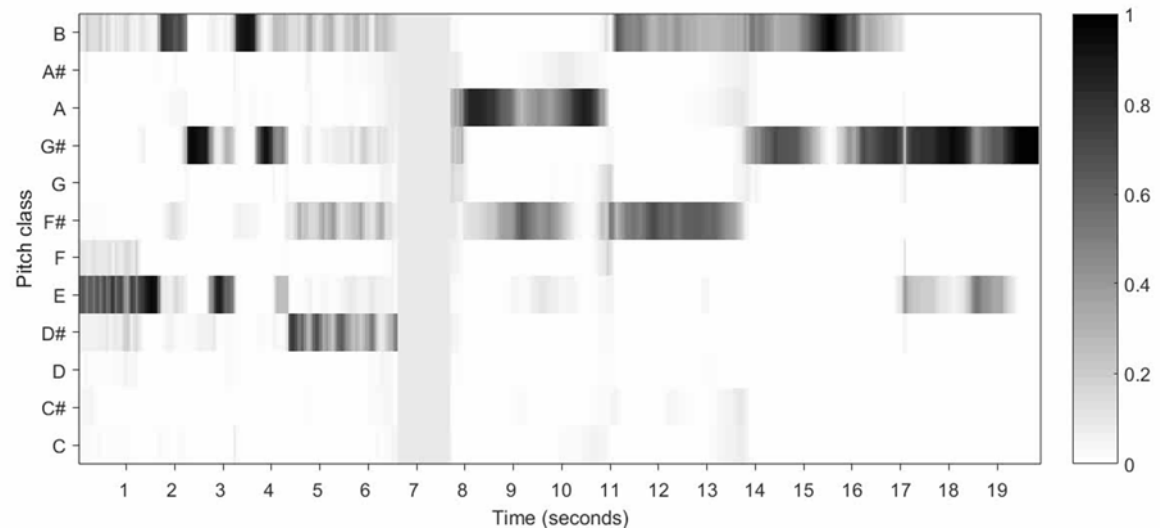
L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



- Piano



Fidelio, Overture,
arr. Alexander Zemlinsky
M. Namekawa, D.R. Davies,
piano four hands

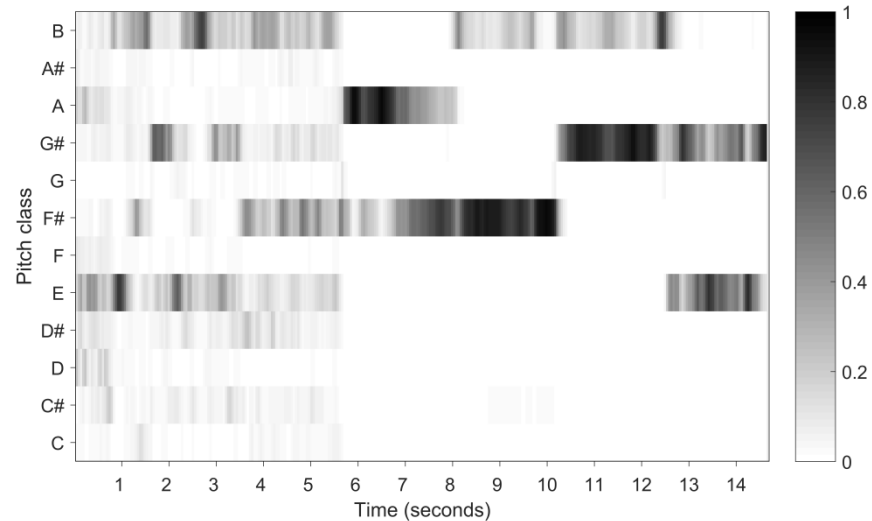


Recall: Chroma Representations

- Orchestra



L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



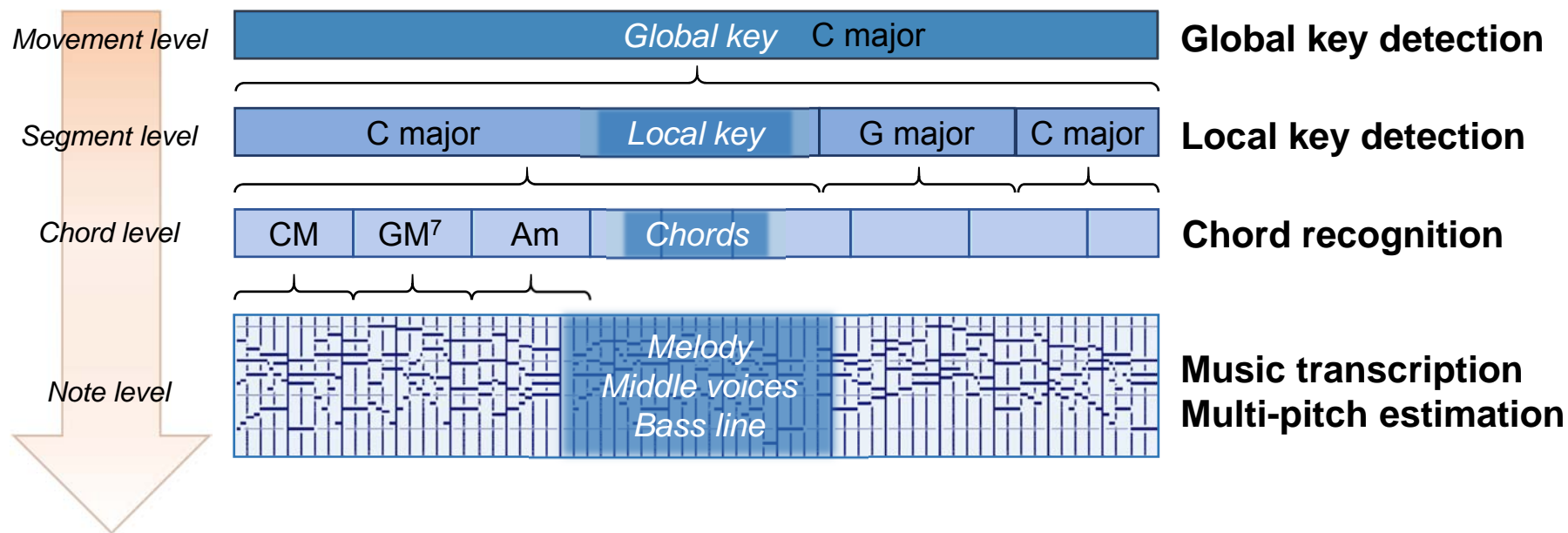
Gómez, *Tonal Description of Polyphonic Audio*, PhD thesis, UPF Barcelona 2006

Lee, *Automatic Chord Recognition from Audio Using Enhanced Pitch Class Profile*, ICMC 2006

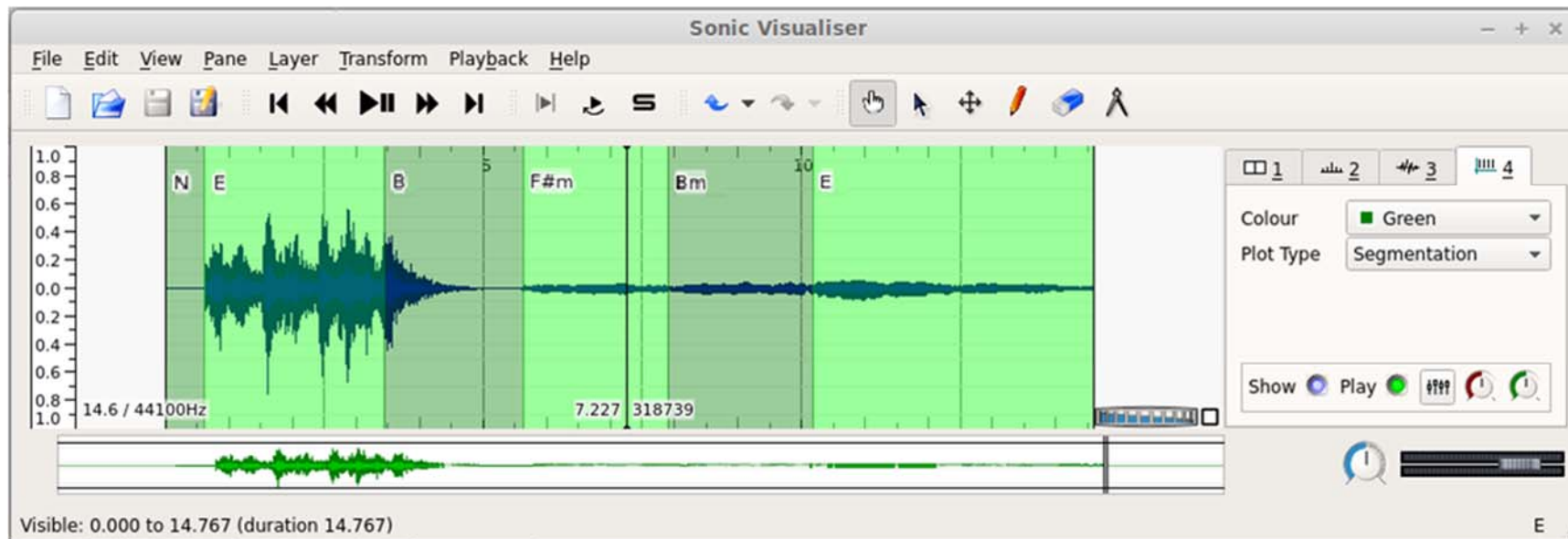
Müller / Ewert, *Towards Timbre-Invariant Audio Features for Harmony-Based Music*, IEEE TASLP 2010

Mauch / Dixon, *Approximate Note Transcription for the Improved Identification of Difficult Chords*, ISMIR 2010

Tonal Structures

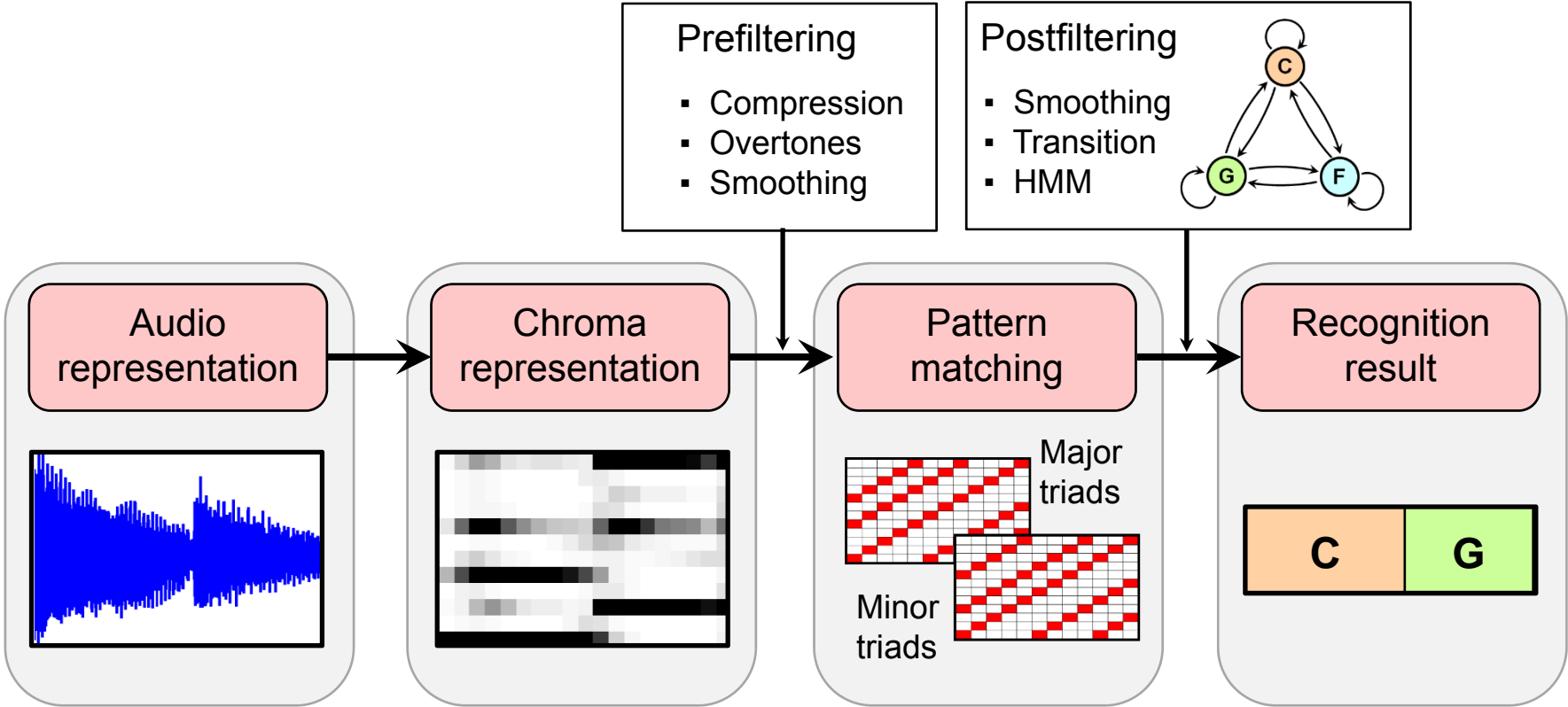


Chord Recognition



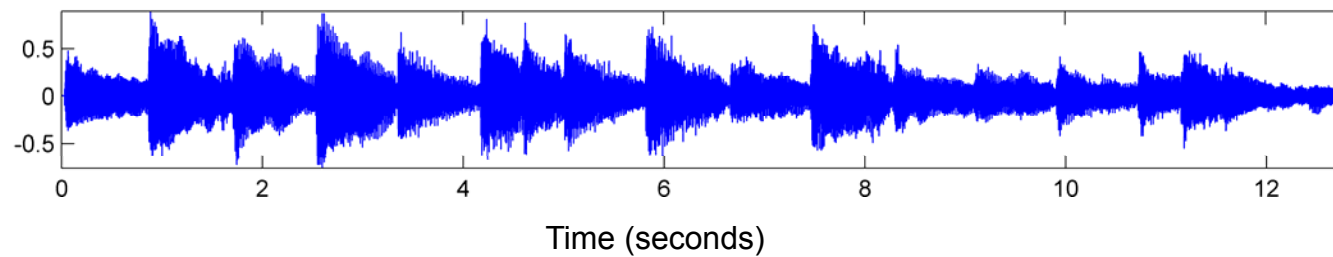
*CHORDINO Vamp Plugin with Sonic Visualizer
(Queen Mary University of London)*

Chord Recognition



Chord Recognition

- Scenario



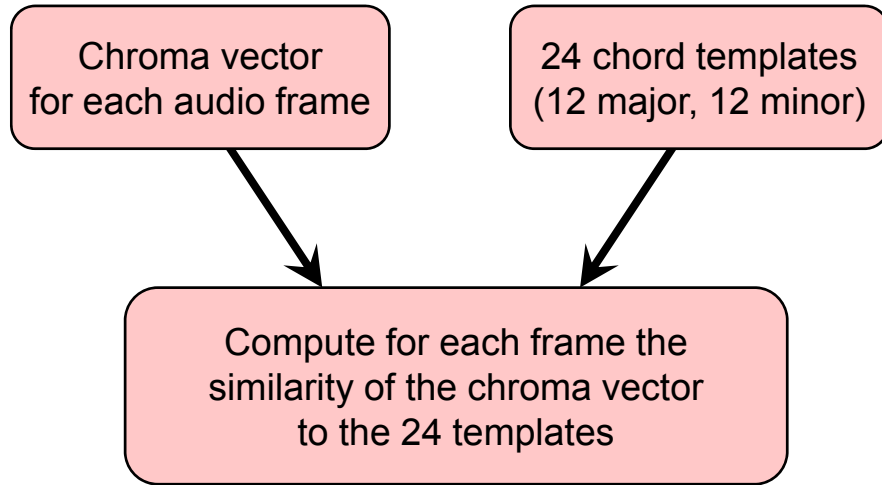
Chord Recognition: Basics

- Templates: **Minor Triads**

Cm C#m Dm Ebm Em Fm F#m Gm G#m Am Bbm Bm

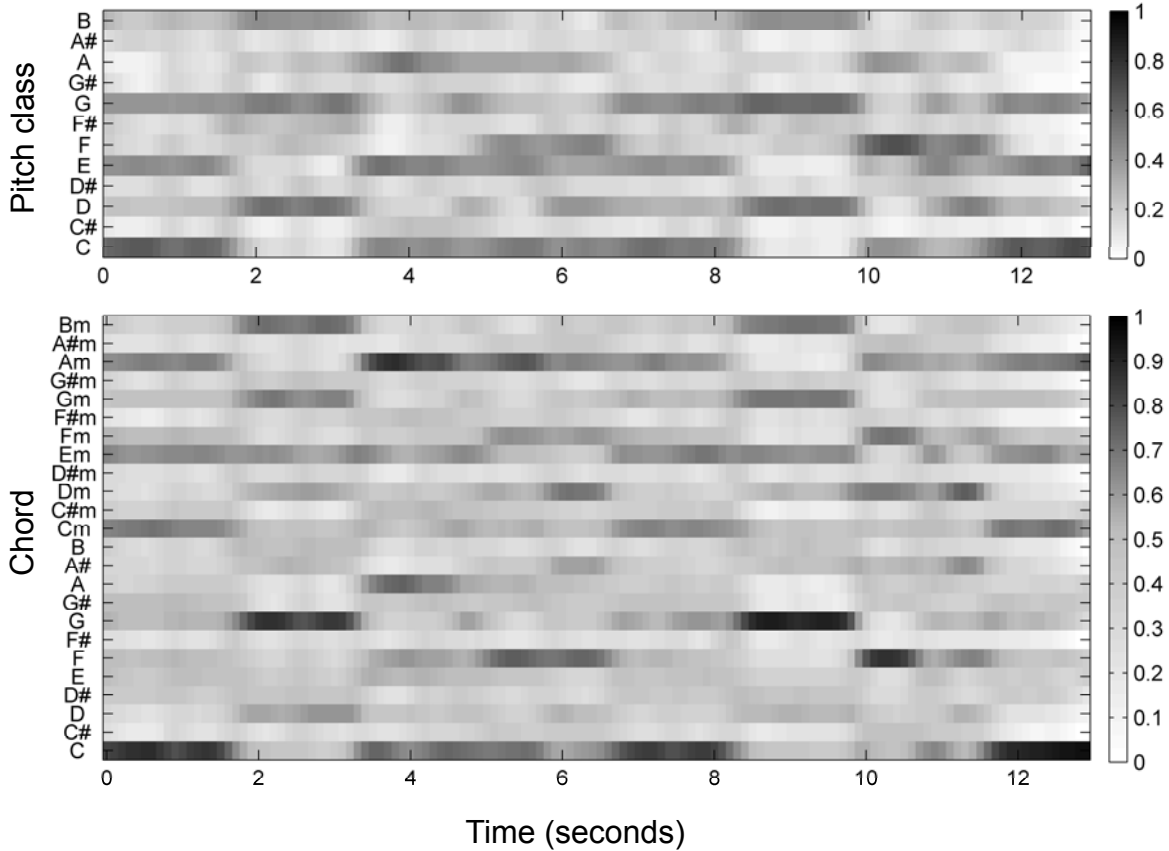
B												
A#/Bb												
A												
G#/Ab												
G												
F#/Gb												
F												
E												
D#/Eb												
D												
C#/Db												
C												

Chord Recognition: Template Matching

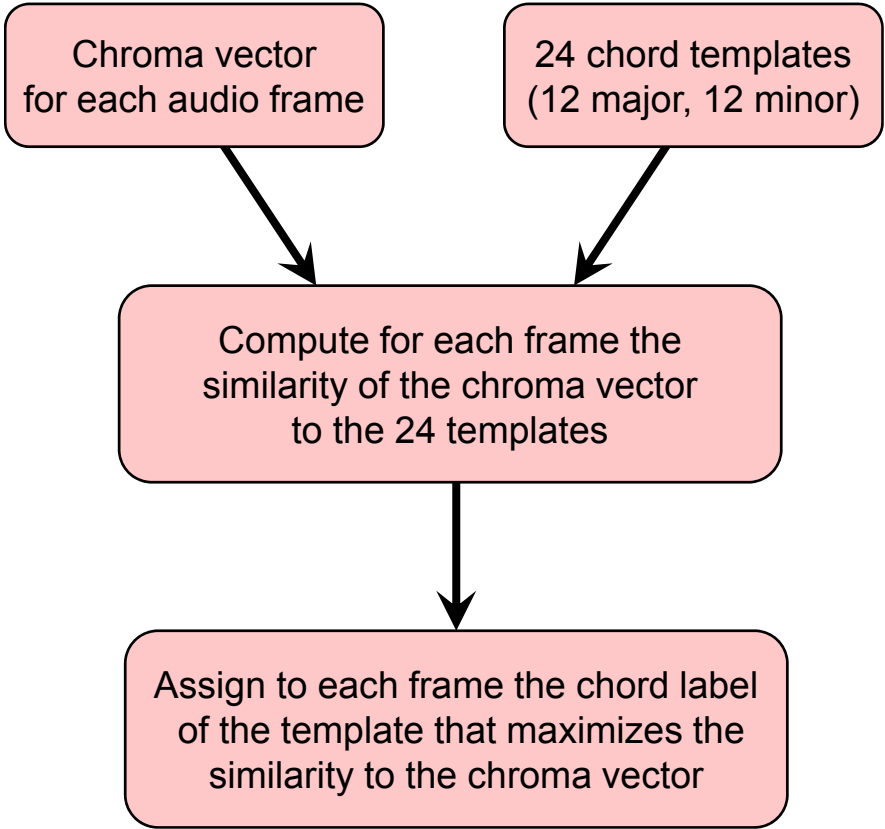


	C	C [#]	D	...	C ^m	C ^{#m}	D ^m	...
B	0	0	0	...	0	0	0	...
A [#]	0	0	0	...	0	0	0	...
A	0	0	1	...	0	0	1	...
G [#]	0	1	0	...	0	1	0	...
G	1	0	0	...	1	0	0	...
F [#]	0	0	1	...	0	0	0	...
F	0	1	0	...	0	0	1	...
E	1	0	0	...	0	1	0	...
D [#]	0	0	0	...	1	0	0	...
D	0	0	1	...	0	0	1	...
C [#]	0	1	0	...	0	1	0	...
C	1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

Chord Recognition: Template Matching

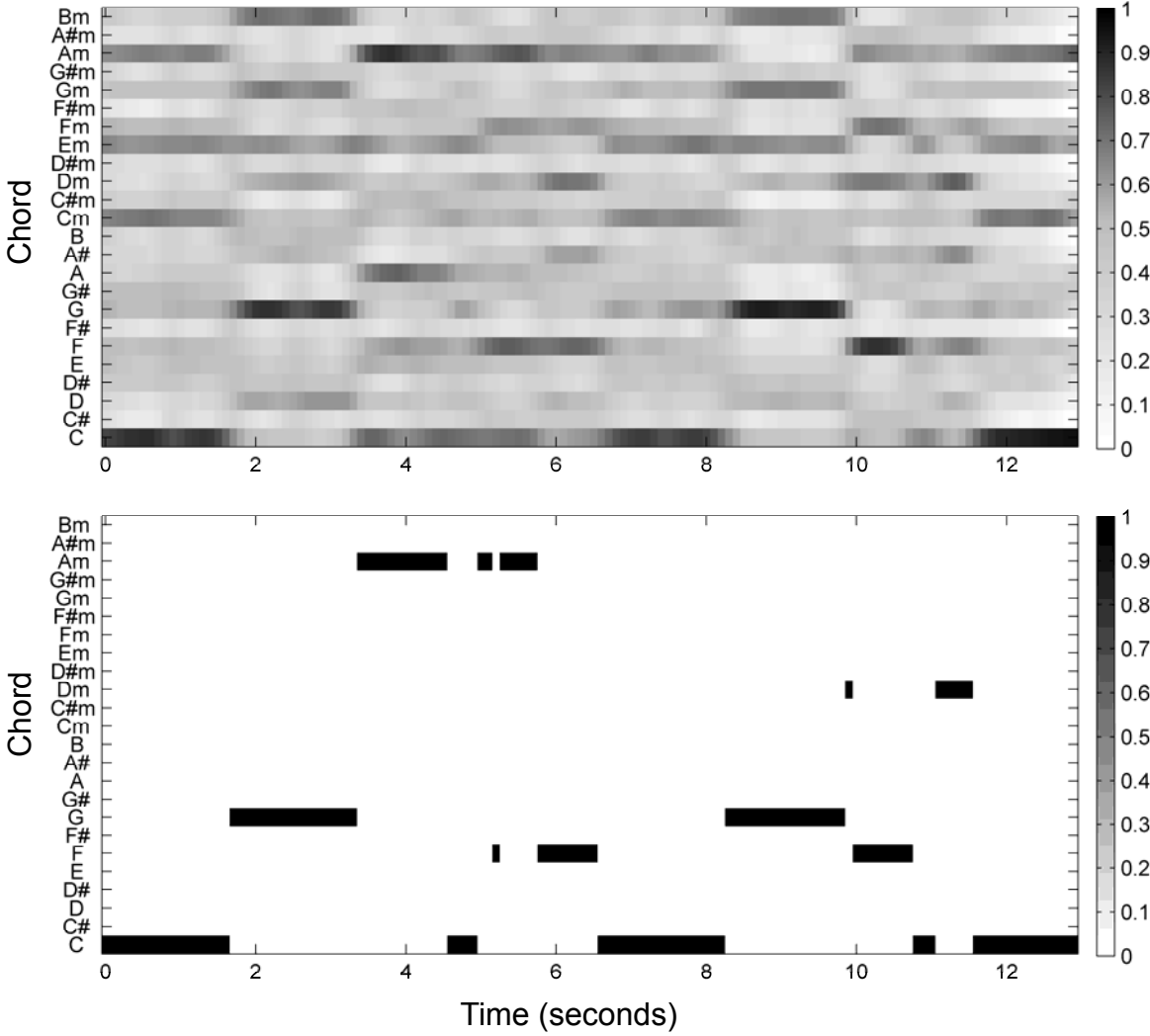


Chord Recognition: Label Assignment

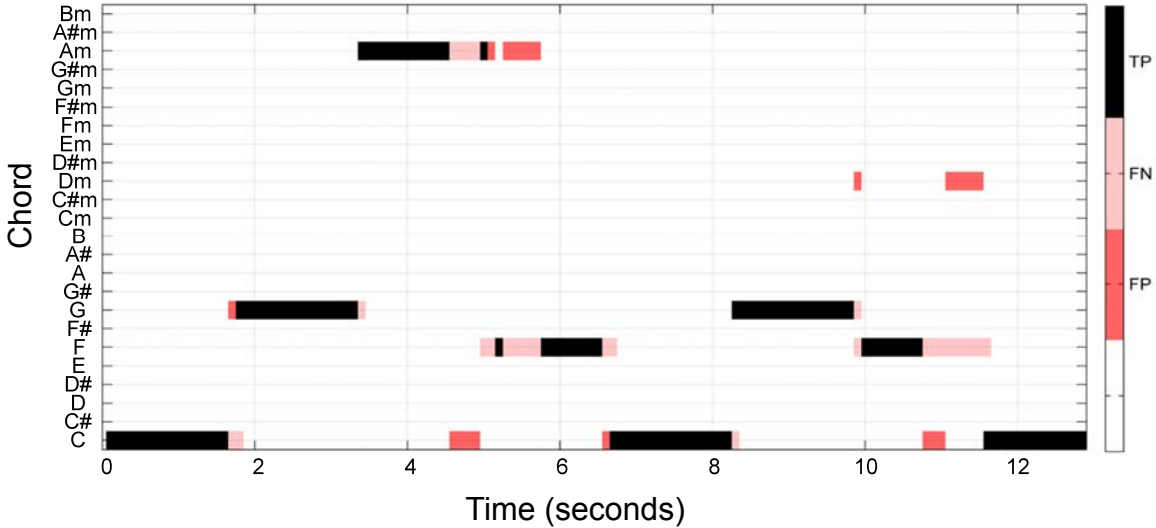


	C	C [#]	D	...	C ^m	C ^{#m}	D ^m	...
B	0	0	0	...	0	0	0	...
A [#]	0	0	0	...	0	0	0	...
A	0	0	1	...	0	0	1	...
G [#]	0	1	0	...	0	1	0	...
G	1	0	0	...	1	0	0	...
F [#]	0	0	1	...	0	0	0	...
F	0	1	0	...	0	0	1	...
E	1	0	0	...	0	1	0	...
D [#]	0	0	0	...	1	0	0	...
D	0	0	1	...	0	0	1	...
C [#]	0	1	0	...	0	1	0	...
C	1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

Chord Recognition: Label Assignment



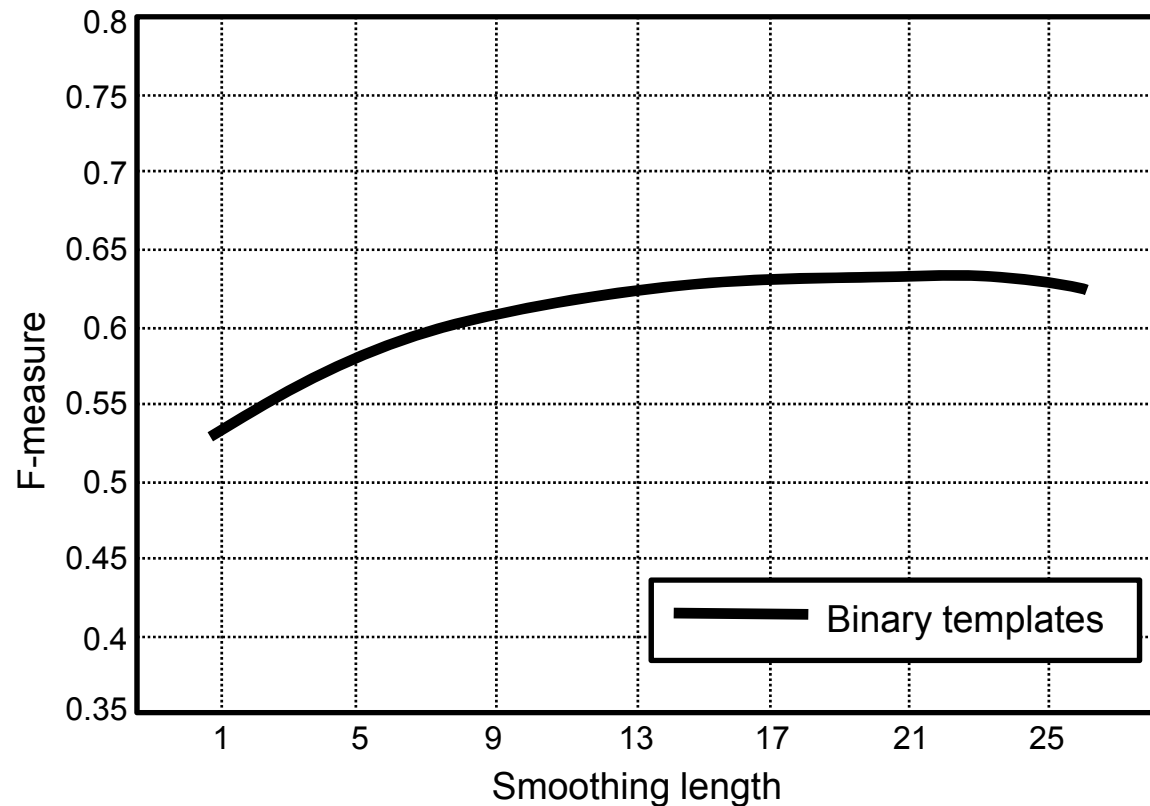
Chord Recognition: Evaluation



Compute F-Measure

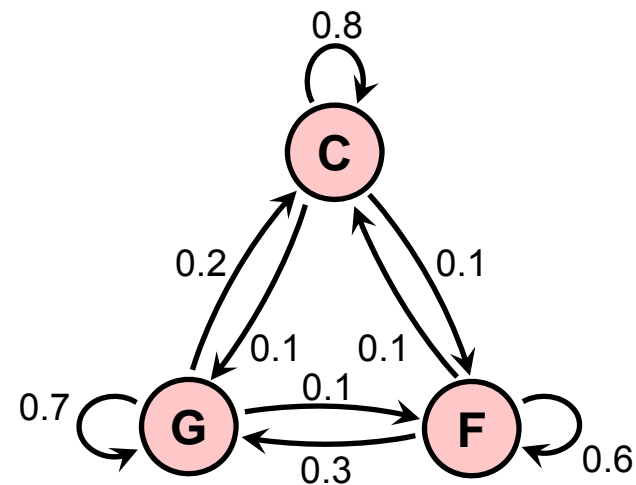
Chord Recognition: Evaluation

- 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



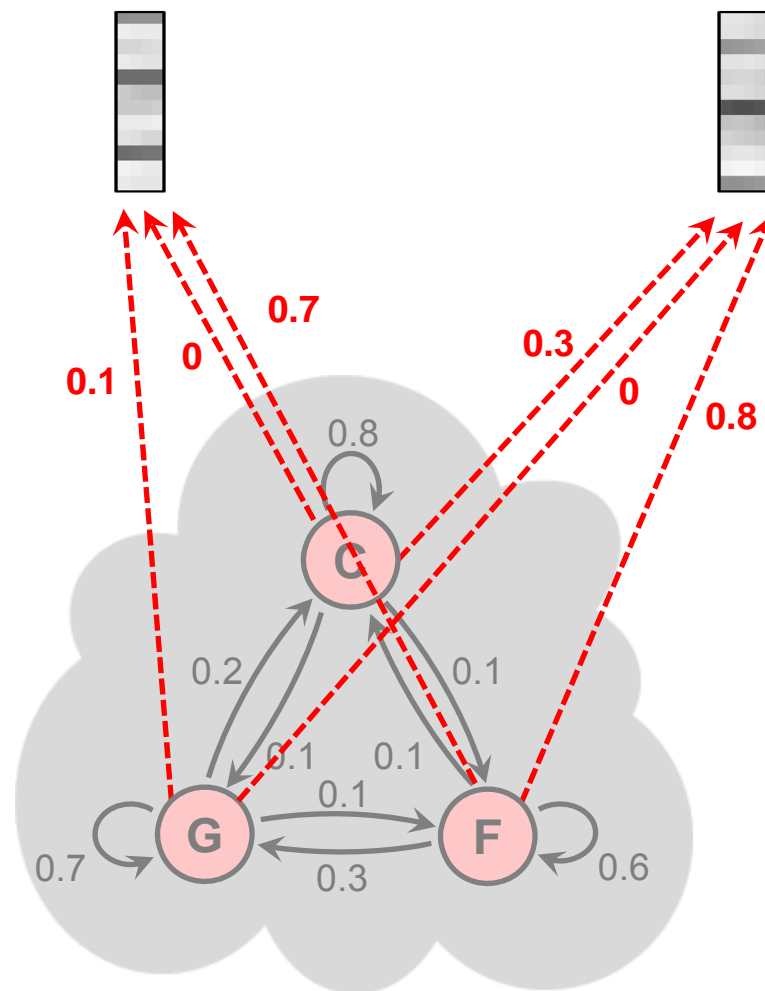
Chord Recognition: Markov Chains

- 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*



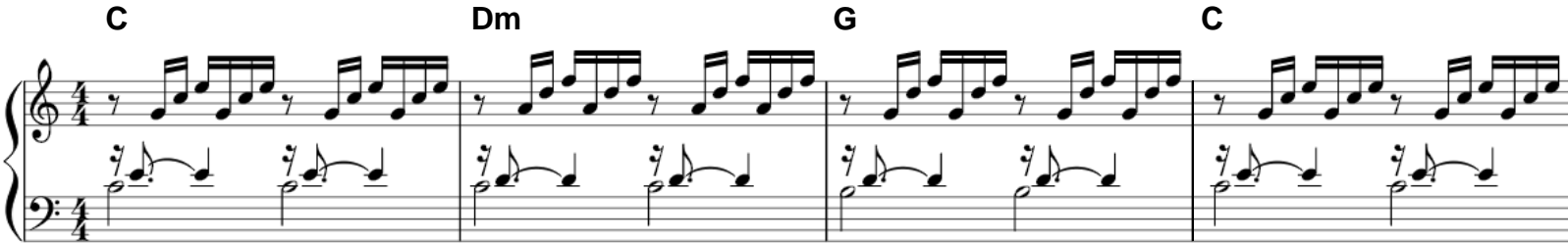
Chord Recognition: Hidden Markov Models

- 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)

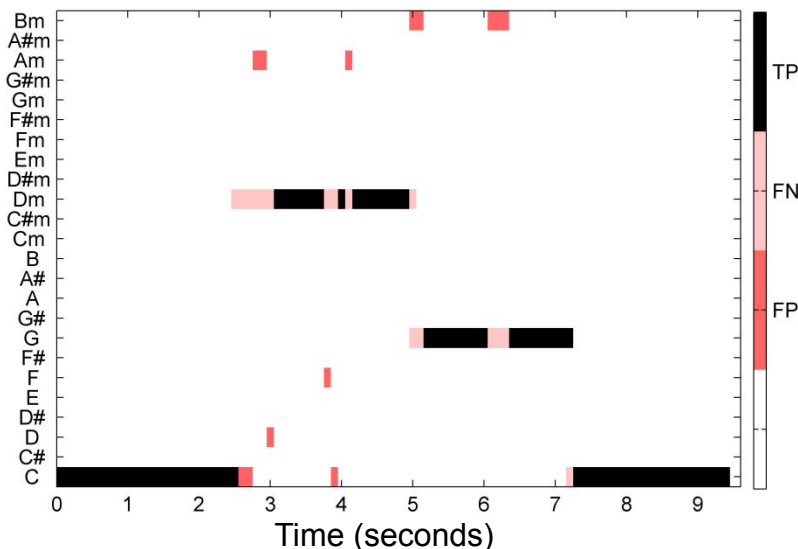


Chord Recognition: Evaluation

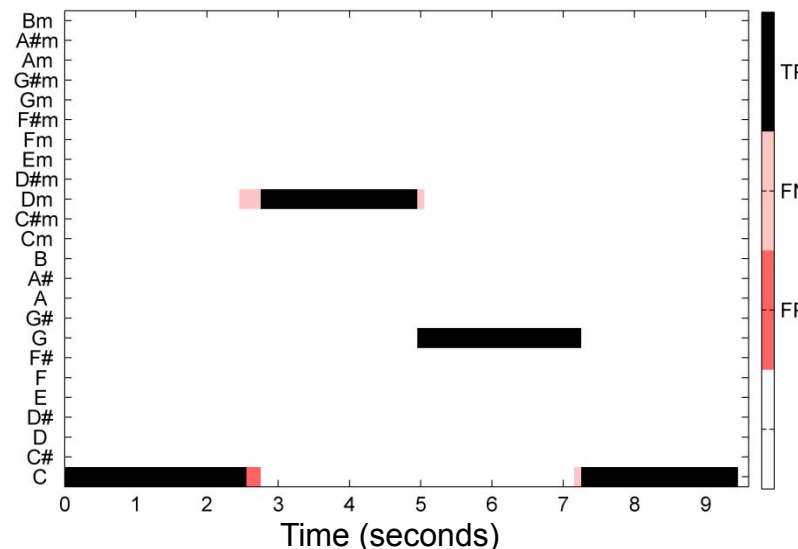
- Effect of HMM-based chord estimation and smoothing:



(a) Template Matching (frame-wise)

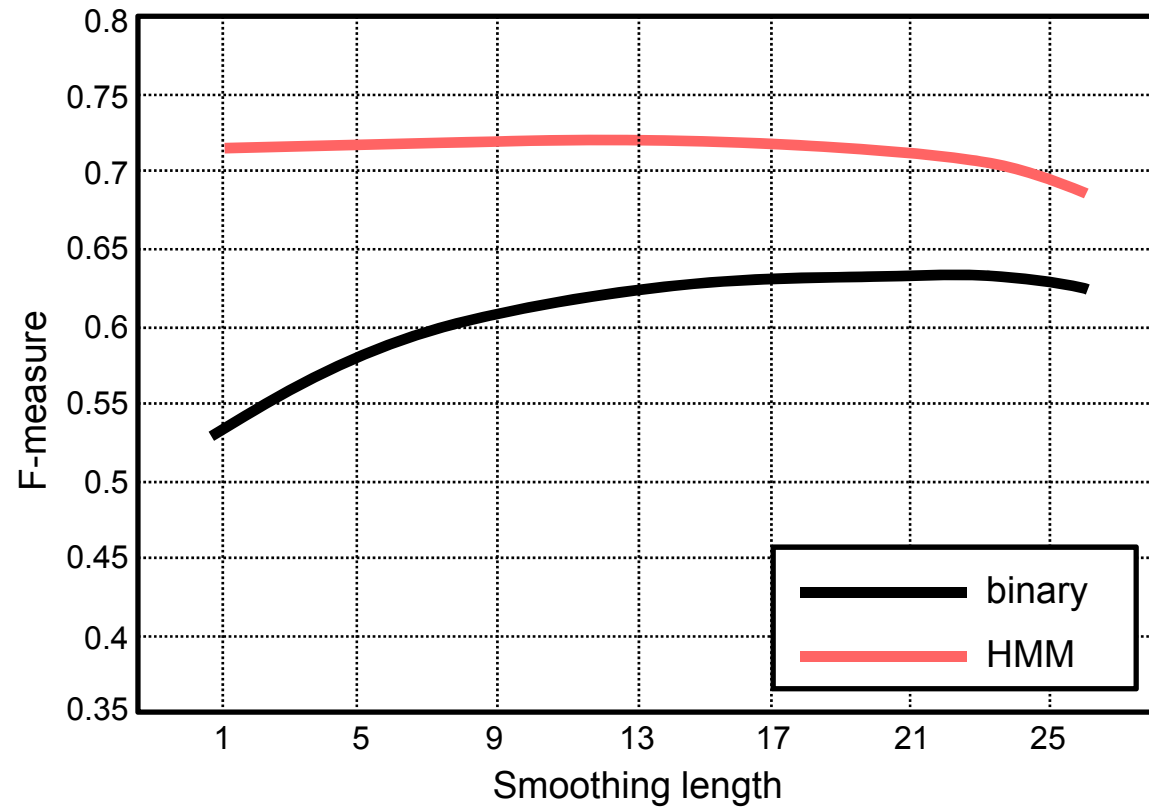


(b) HMM

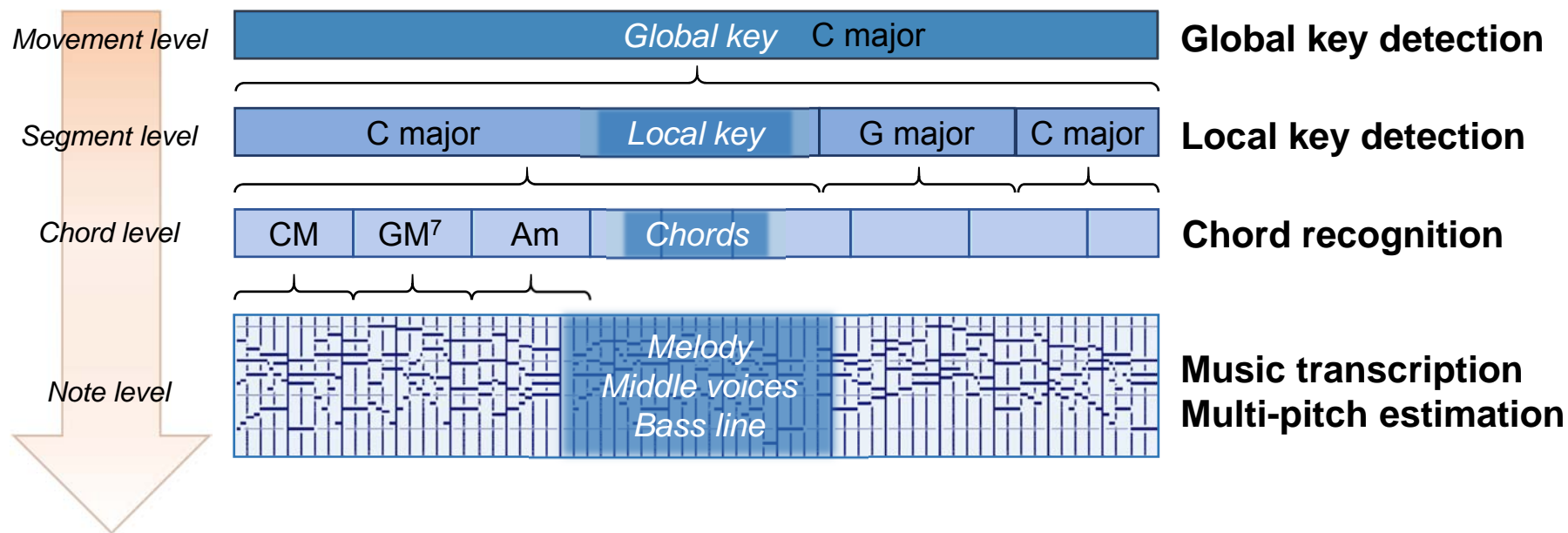


Chord Recognition: Evaluation

- Evaluation on all Beatles songs

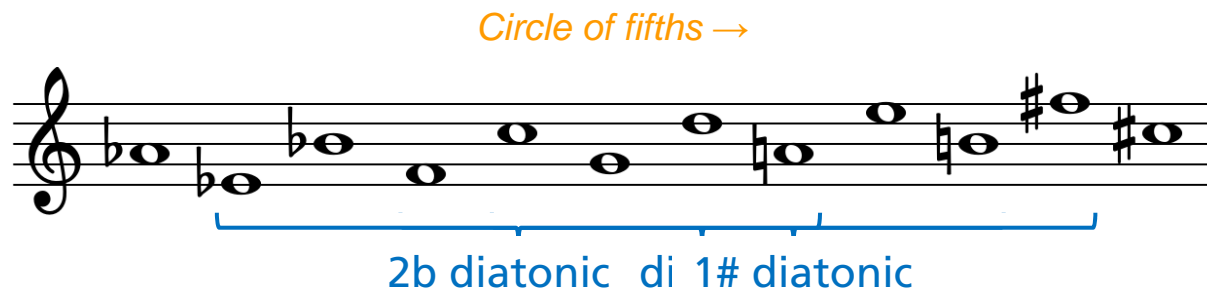


Tonal Structures



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

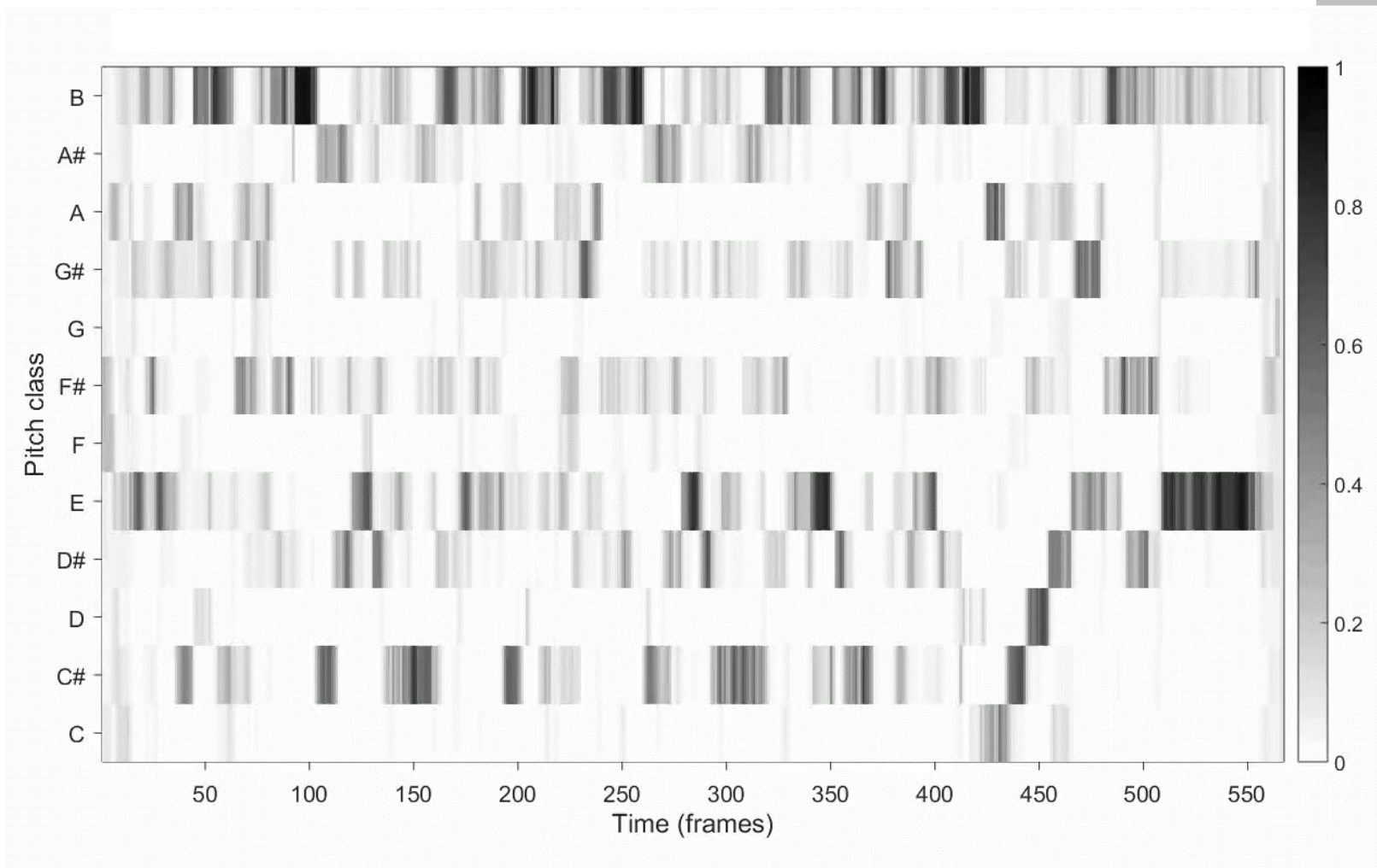
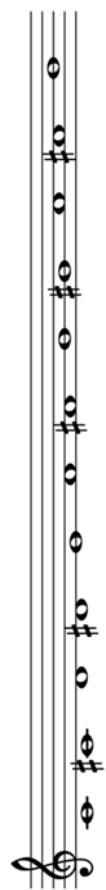
- Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
- **Score** – Piano reduction

Durch dein Ge-fäng-nis, Got-tes Sohn, muß uns die Frei-heit kom-men;
Dein Ker-ker ist der Gna-den-thron, die Frei-statt al-ler From-men;

9
Denn gingst du nicht die Knecht-schaft ein, müßt uns-re Knecht-schaft e-wig sein.

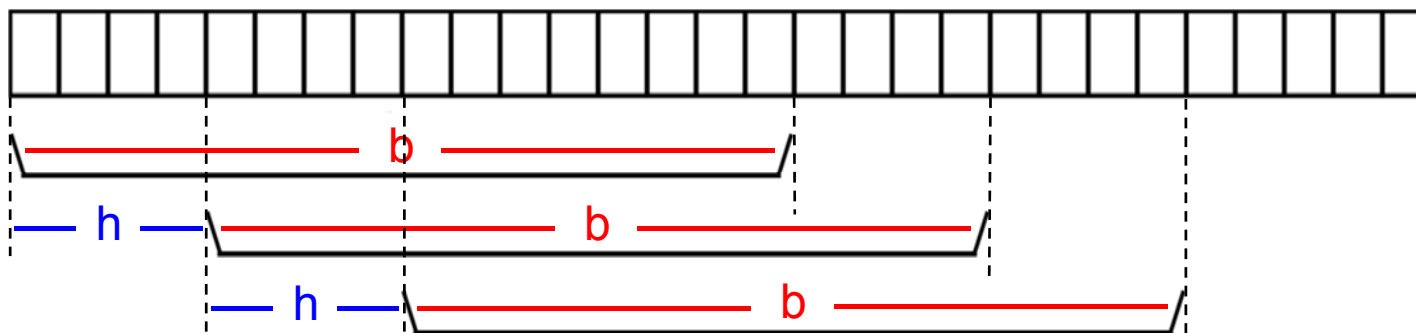
Local Key Detection: Chroma Features

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



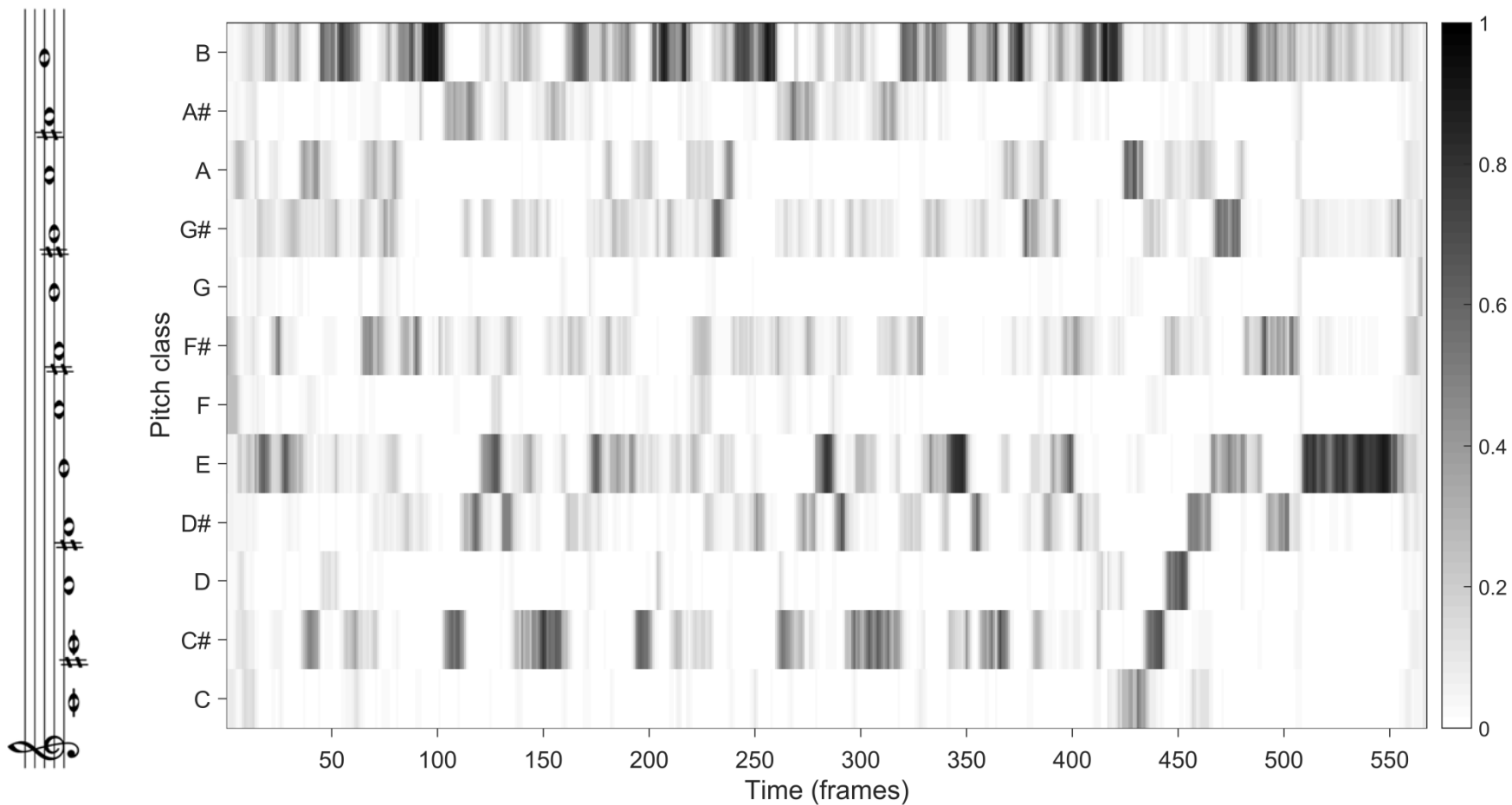
Local Key Detection: Chroma Smoothing

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



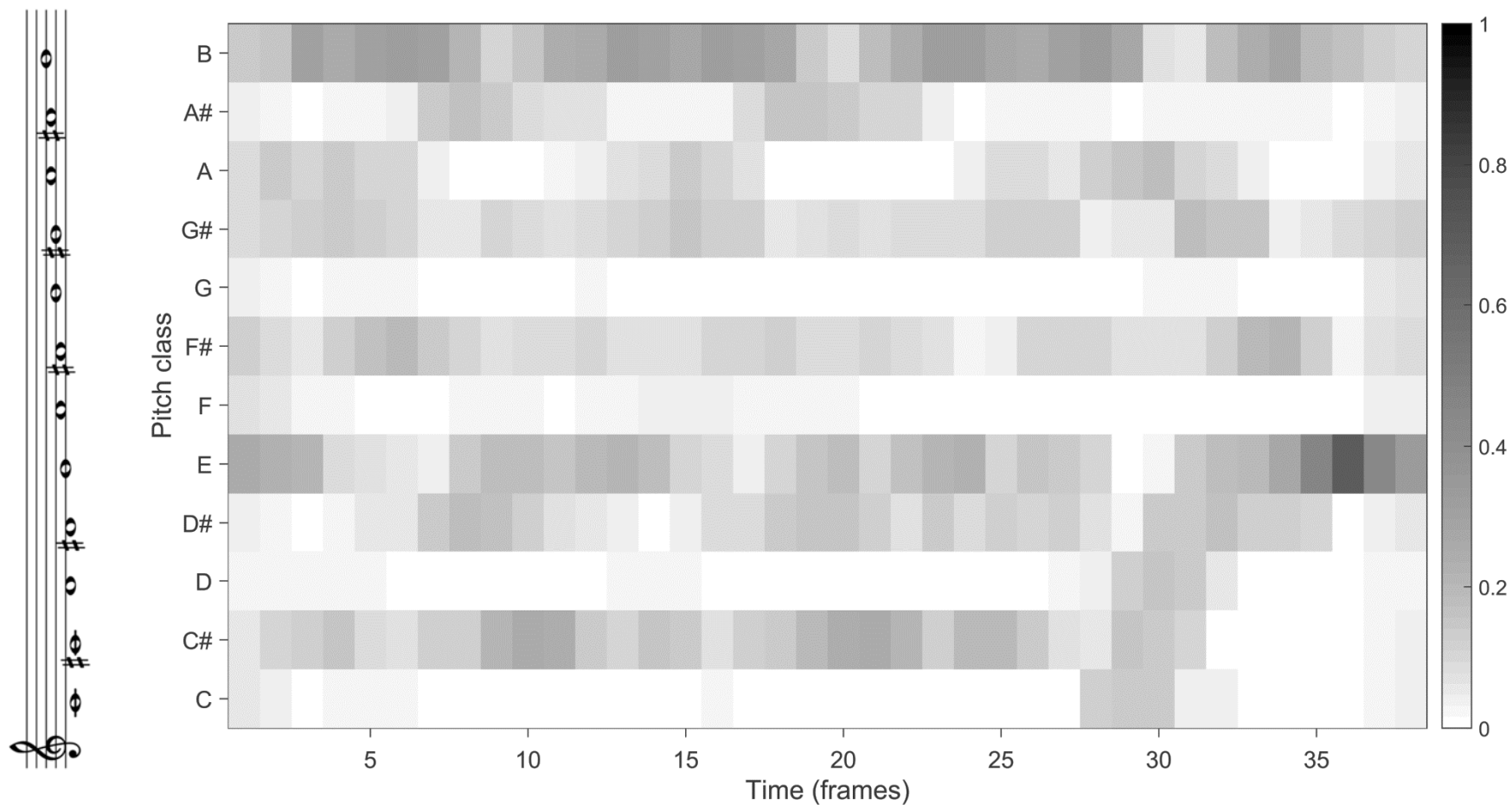
Local Key Detection: Chroma Smoothing

- Choral (Bach)



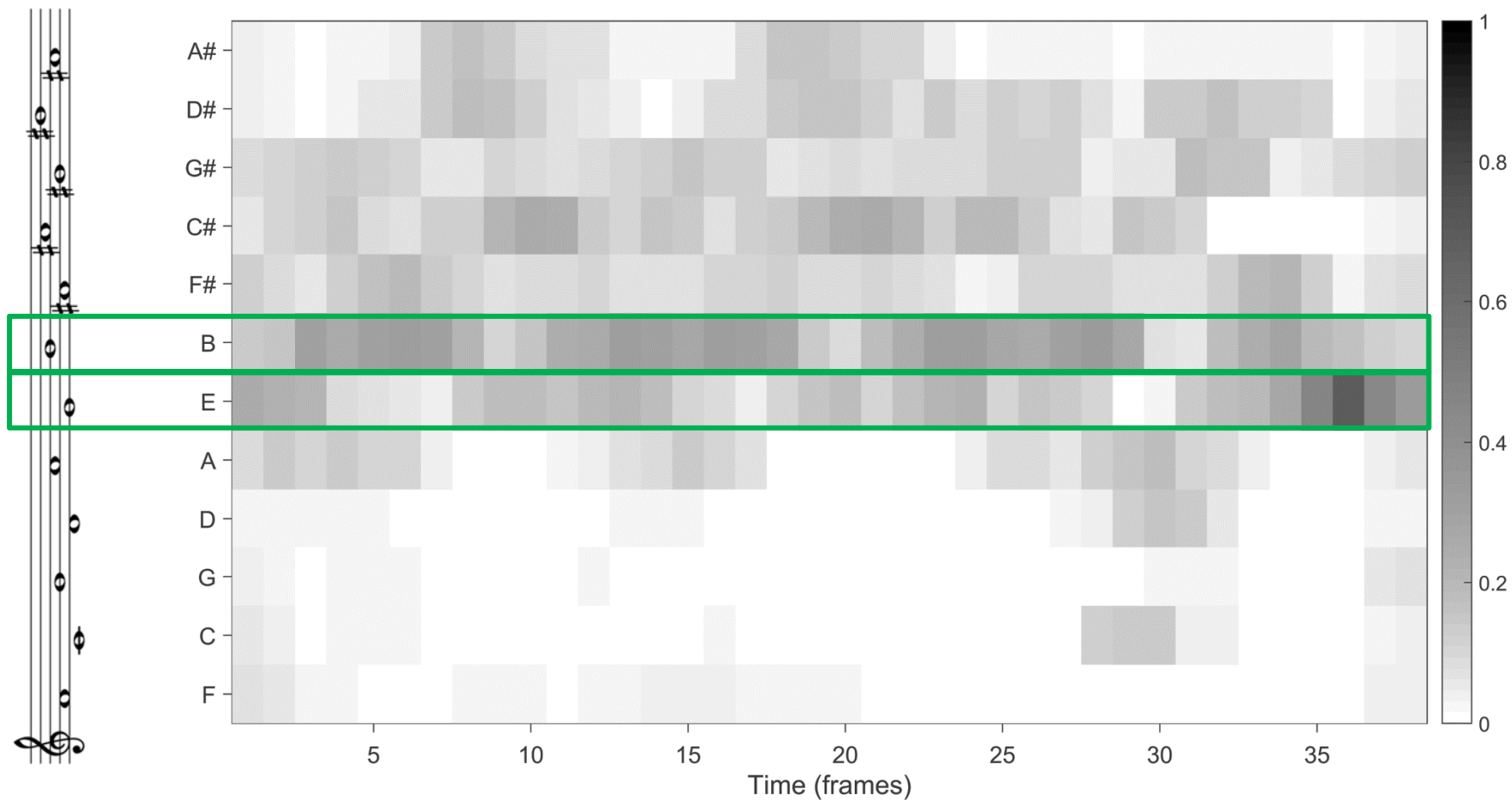
Local Key Detection: Chroma Smoothing

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



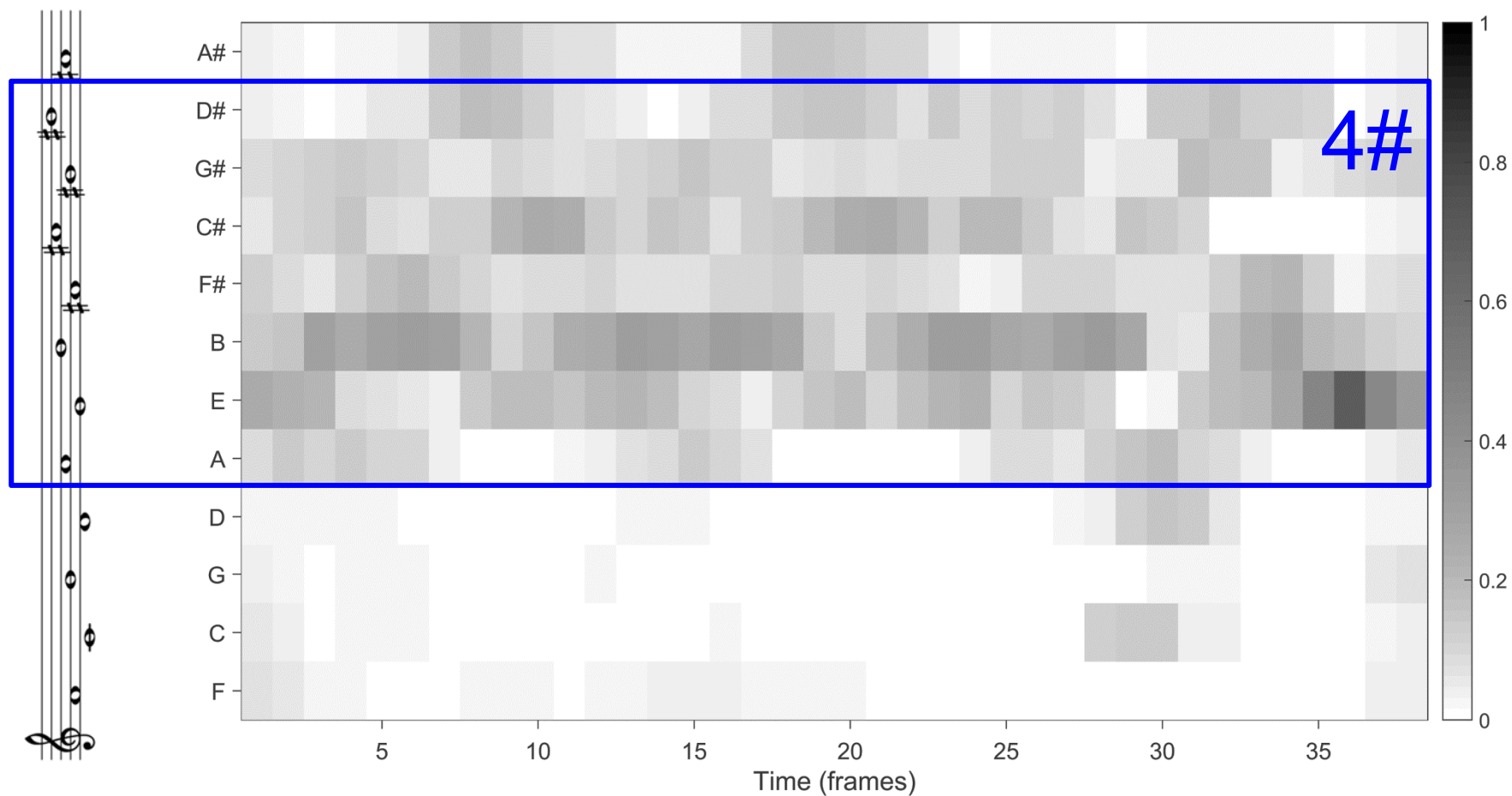
Local Key Detection: Diatonic Scales

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



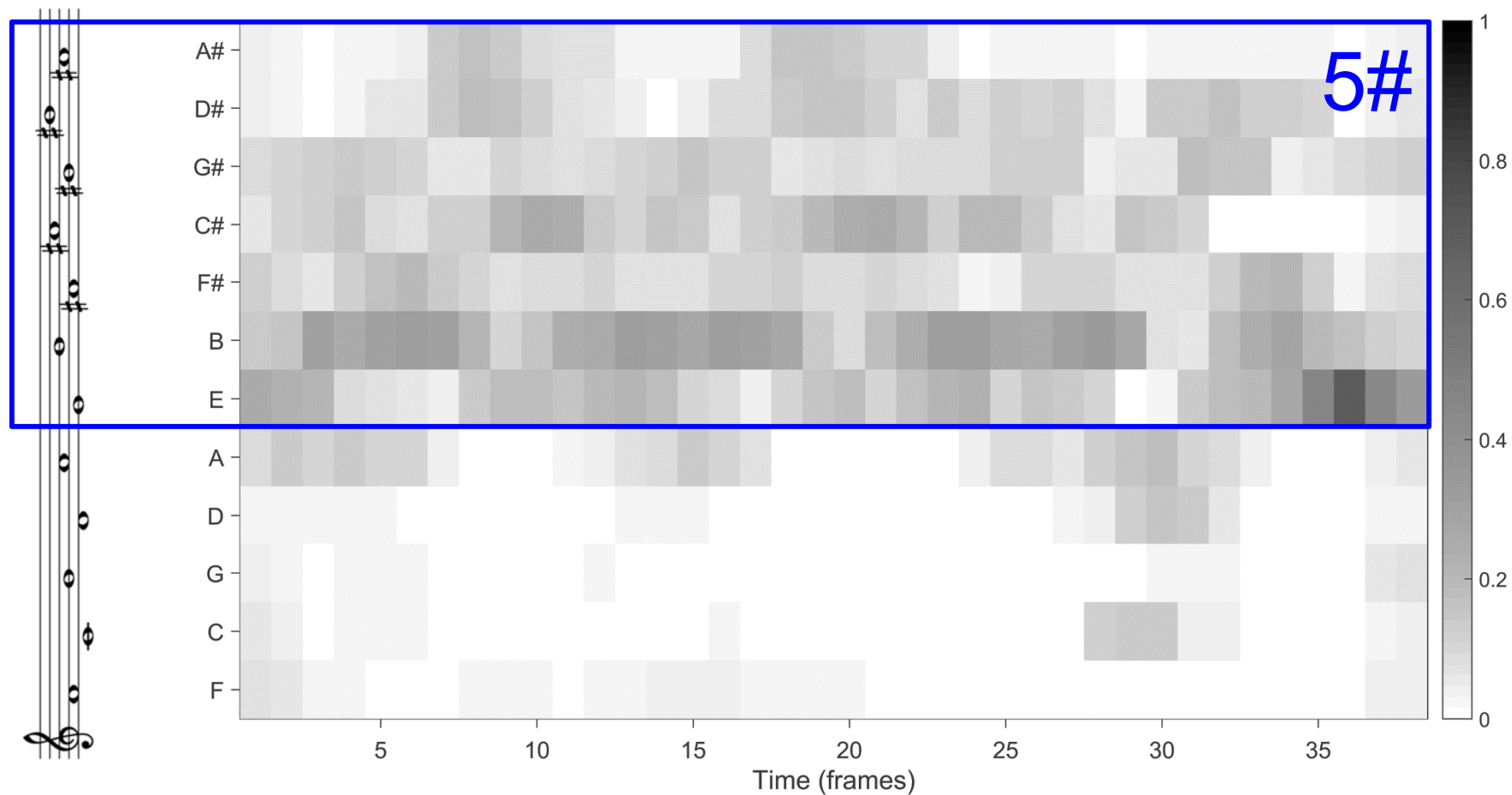
Local Key Detection: Diatonic Scales

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



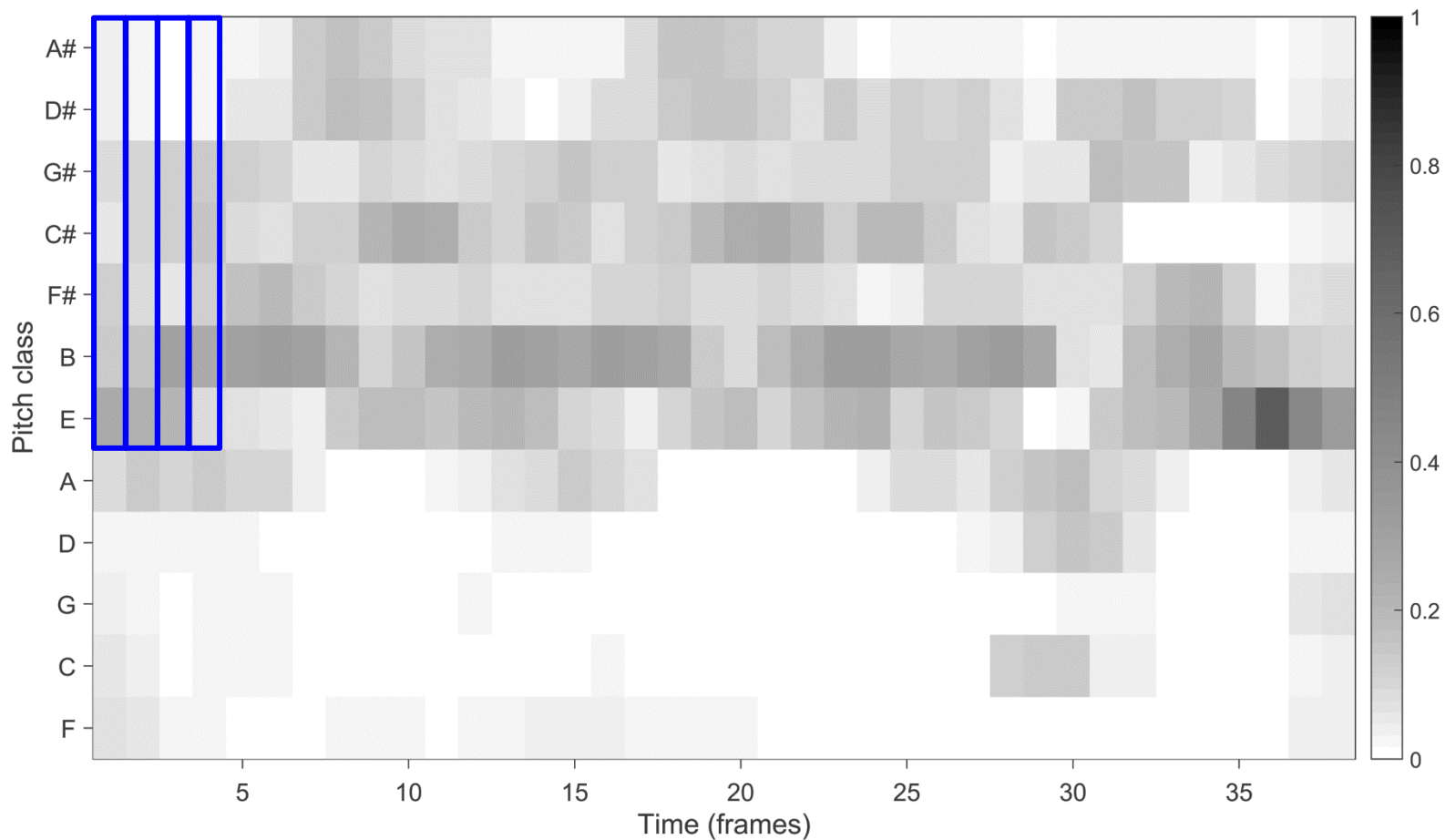
Local Key Detection: Diatonic Scales

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



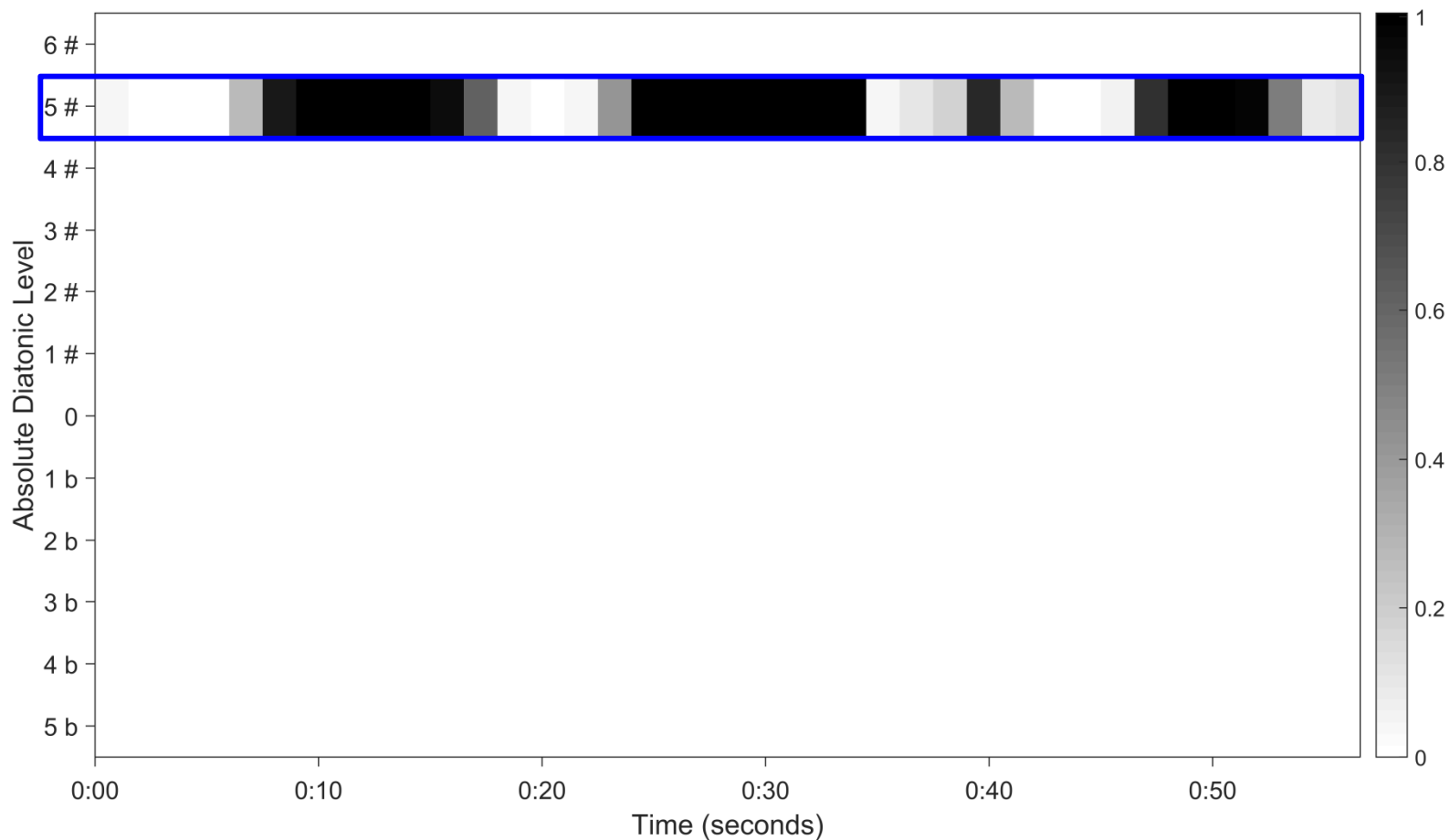
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation: [Multiply chroma values](#)



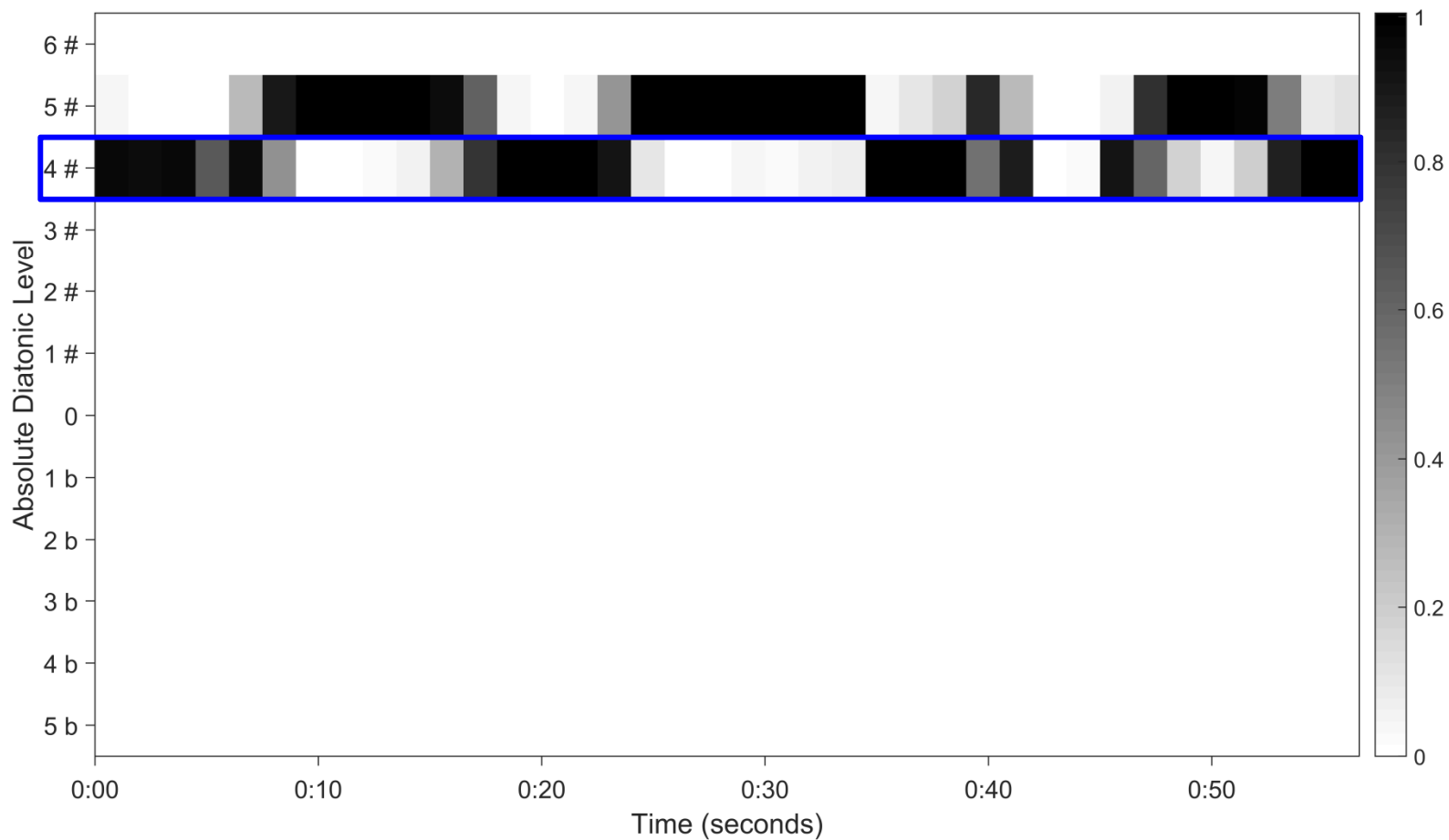
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation: [Multiply chroma values](#)



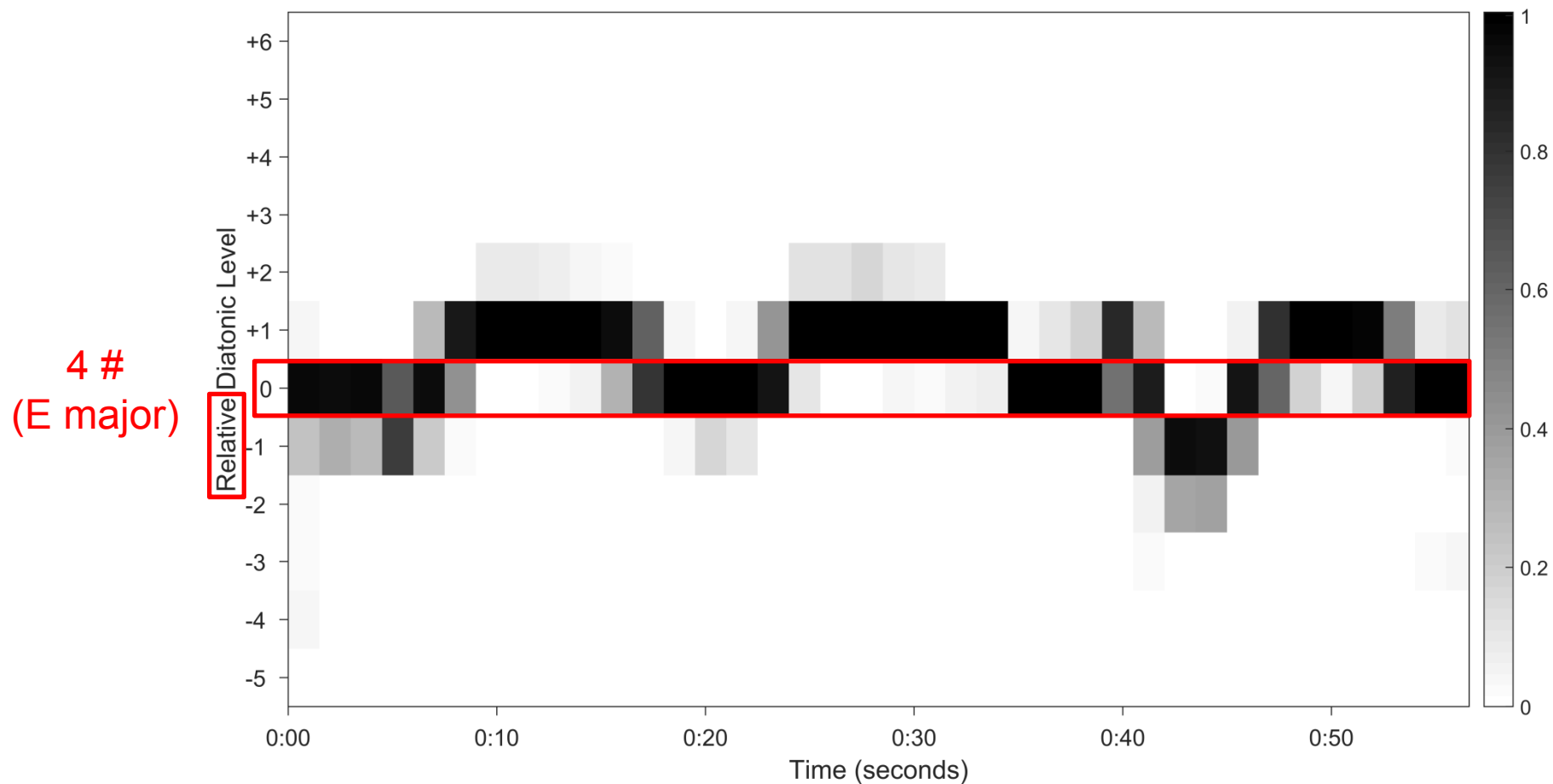
Local Key Detection: Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation



Local Key Detection: Diatonic Scales

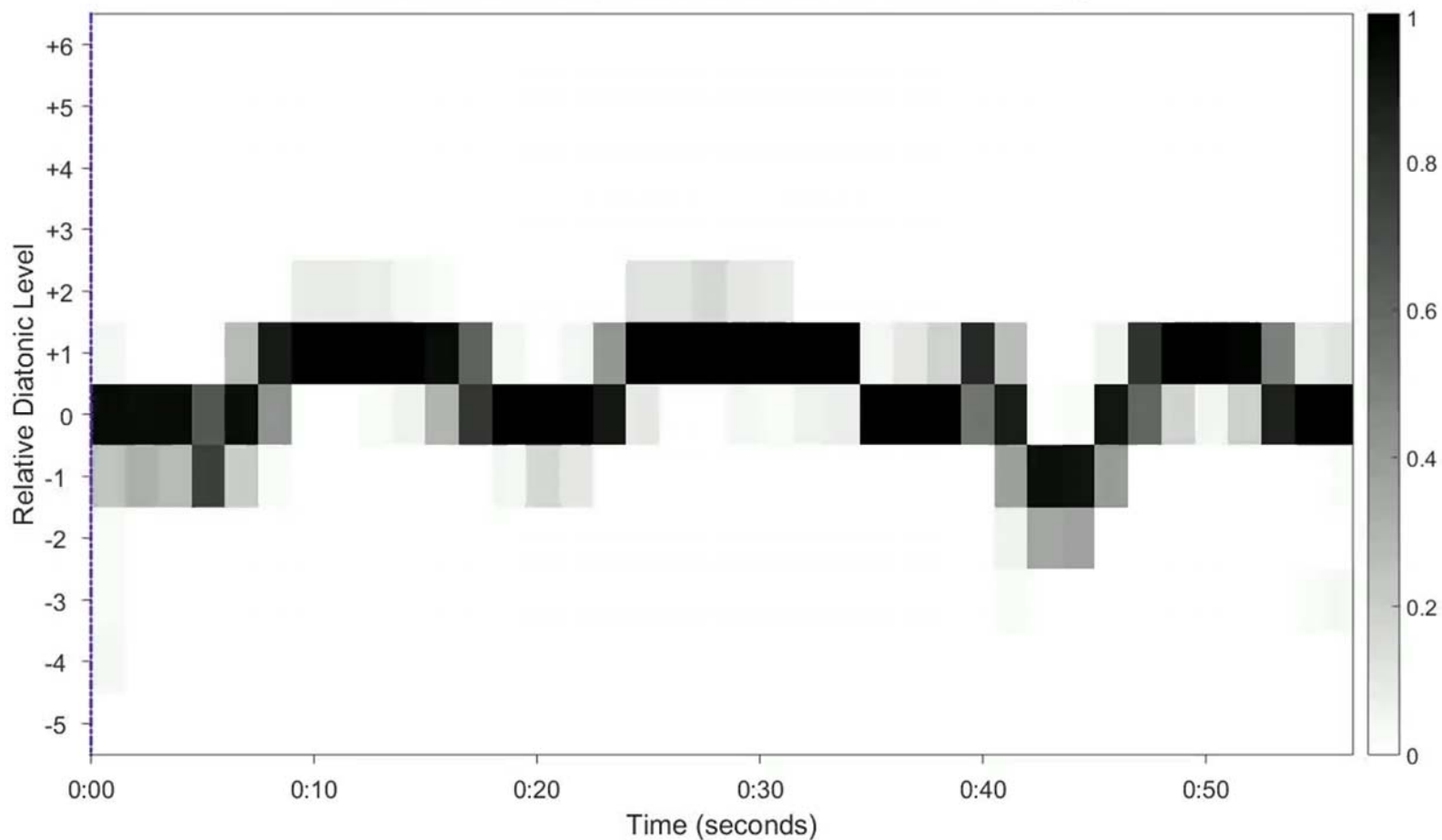
- Choral (Bach) — Diatonic Scale Estimation: **Shift to global key**



Local Key Detection: Diatonic Scales

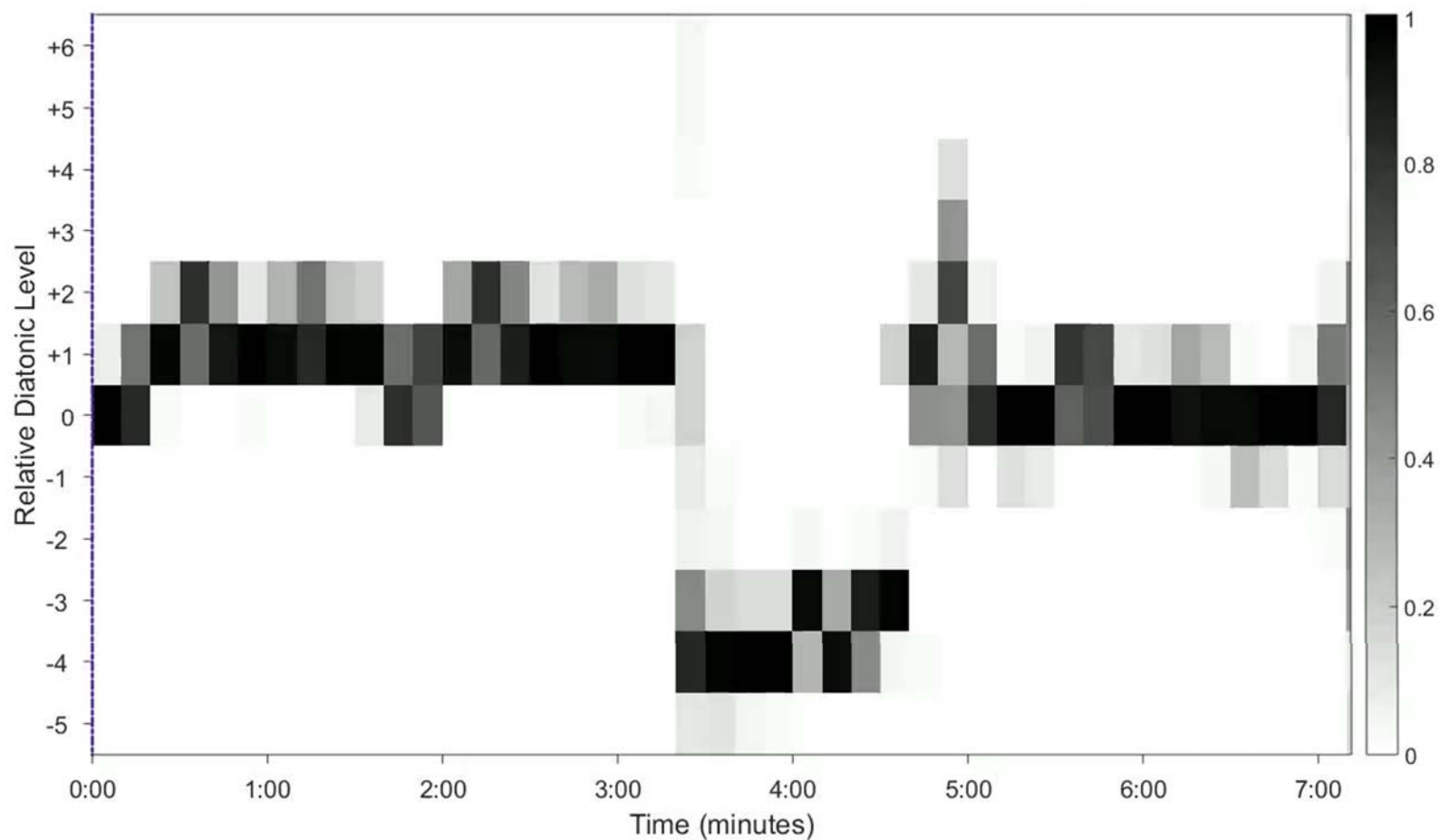
- Choral (Bach) — level 0 \triangleq 4#

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



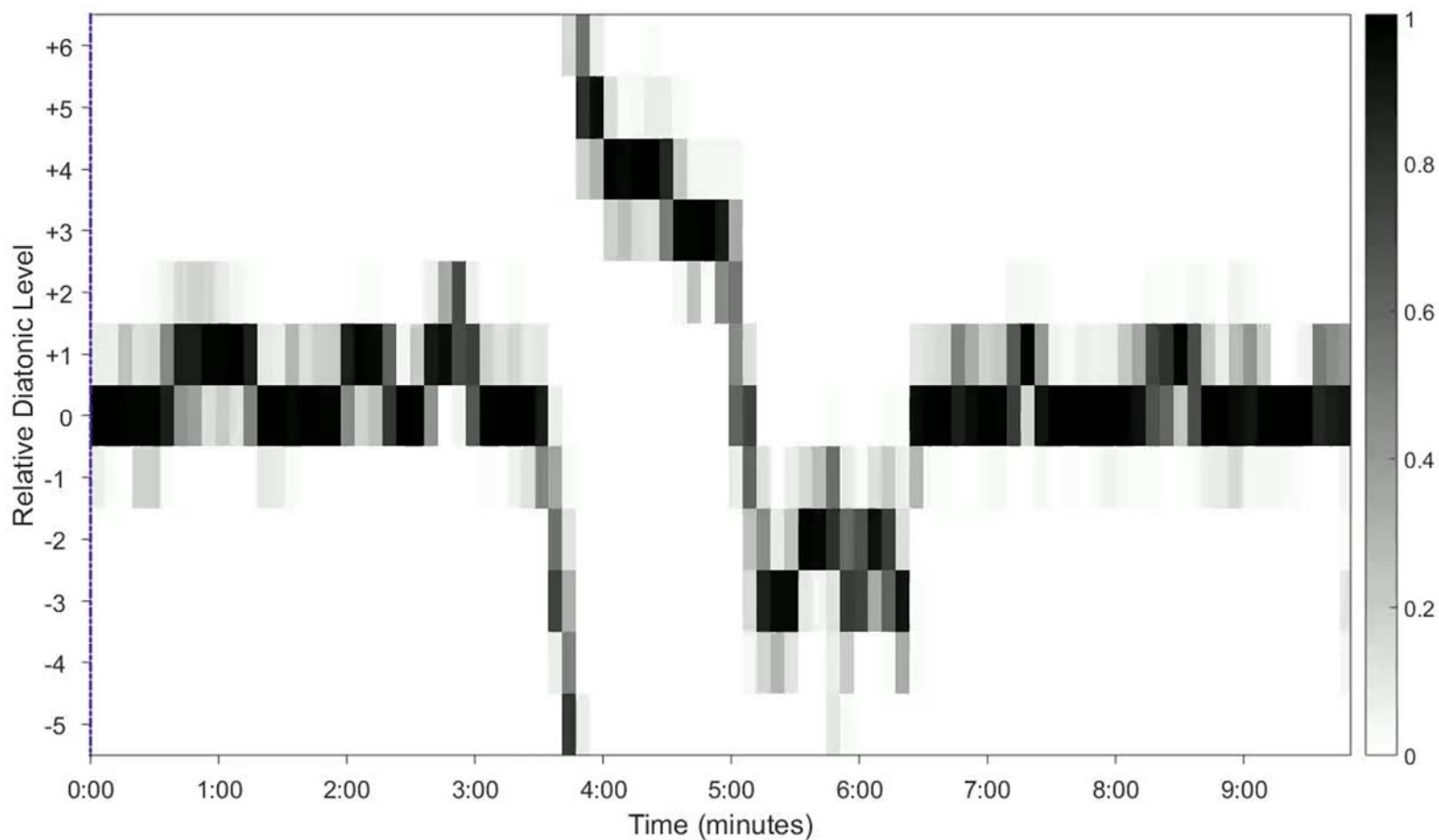
Local Key Detection: Examples

- 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
[Sigtia/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