Meisterklasse HfM Karlsruhe

Music Information Retrieval

Harmony Analysis

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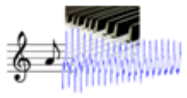
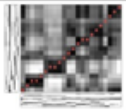
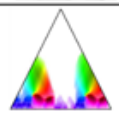
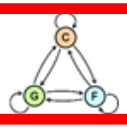
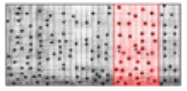
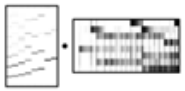
Book: Fundamentals of Music Processing

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 Represenations
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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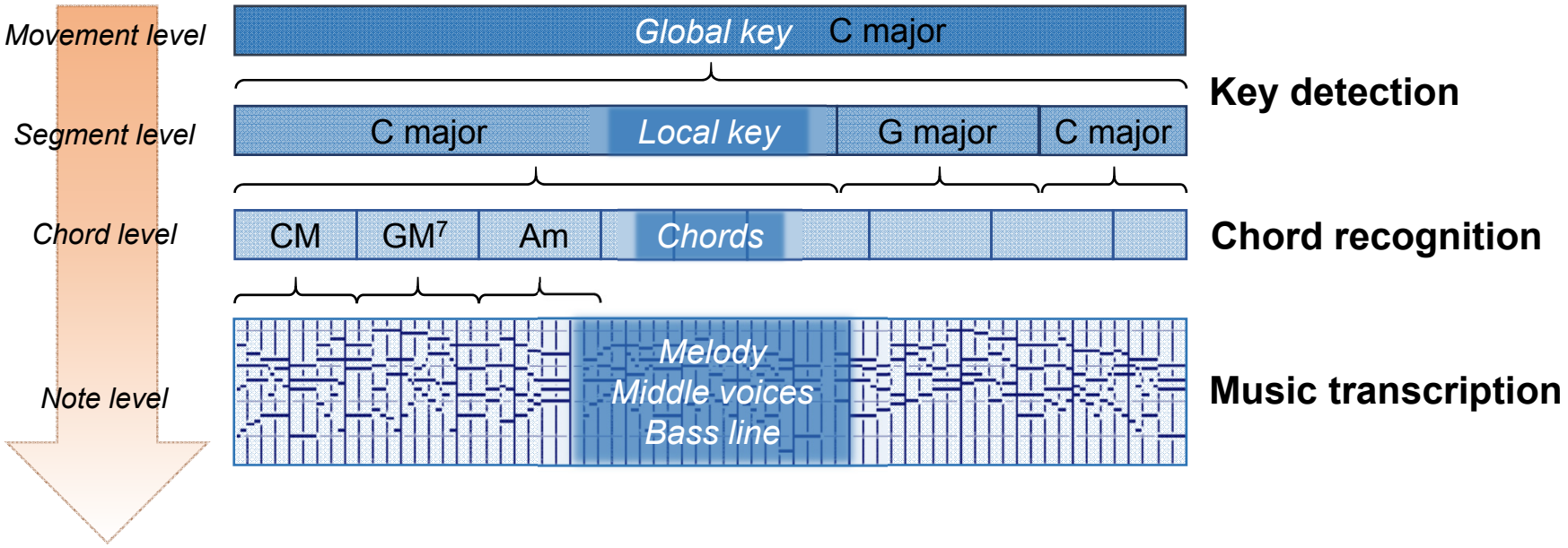
Dissertation: Tonality-Based Style Analysis

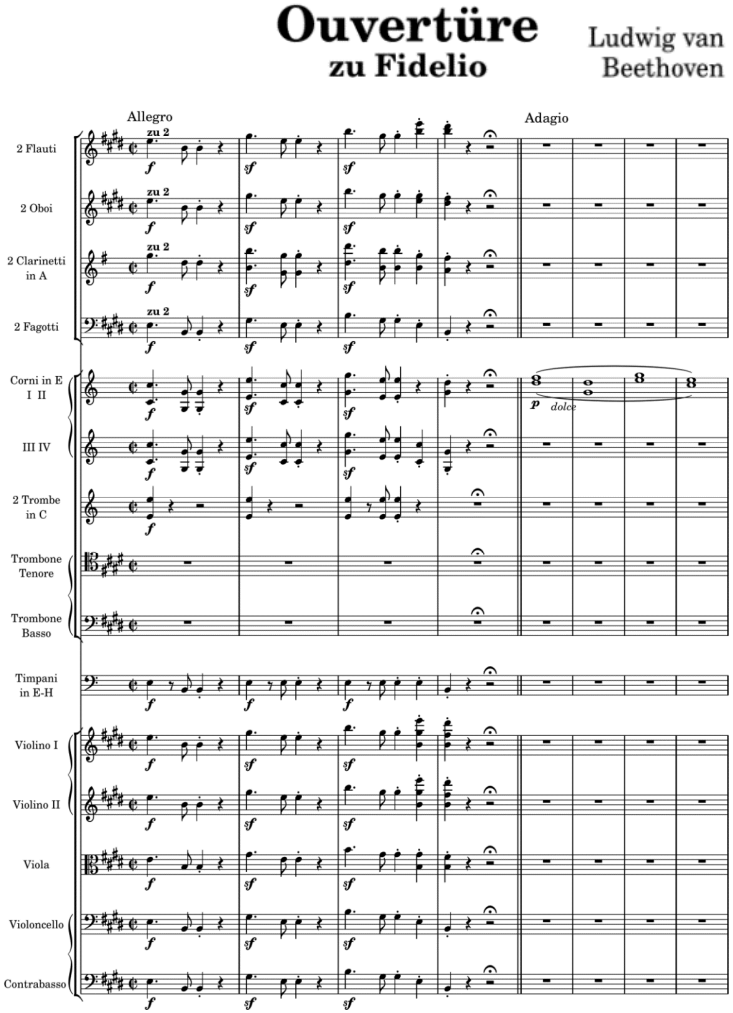
Christof Weiß
Computational Methods for Tonality-Based Style Analysis of Classical Music Audio Recordings
Dissertation, Technical University of Ilmenau 2017
to appear

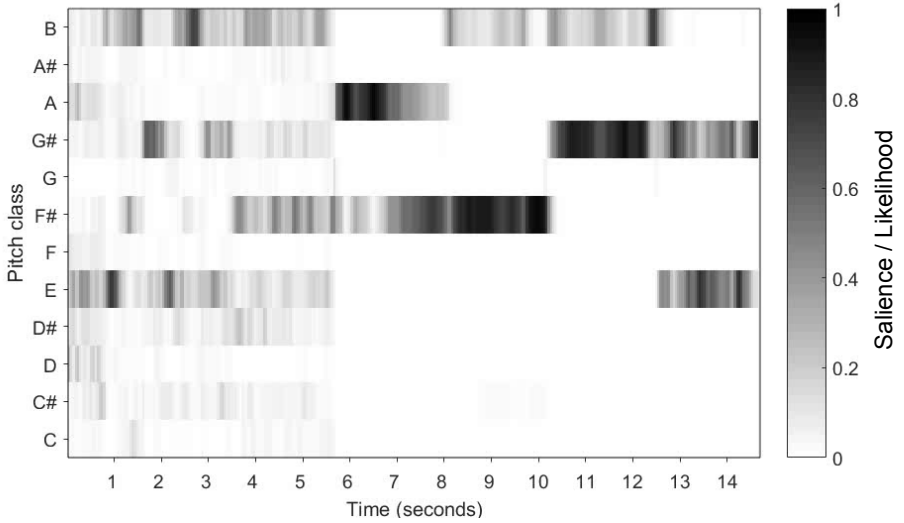
Chapter 5: Analysis Methods for Key and Scale Structures
Chapter 6: Design of Tonal Features

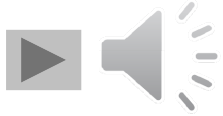
Tonal Structures



Recall: Chroma Representations





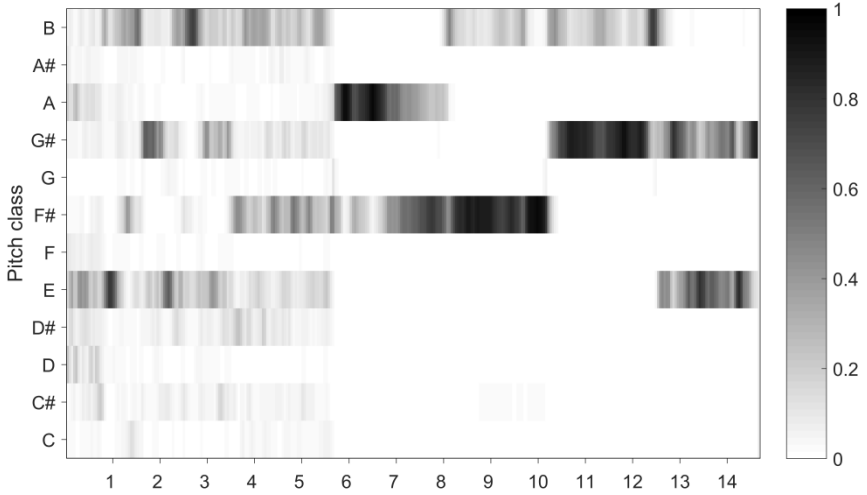


L. van Beethoven, *Fidelio*, Overture, Slovak Philharmonic

Recall: Chroma Representations

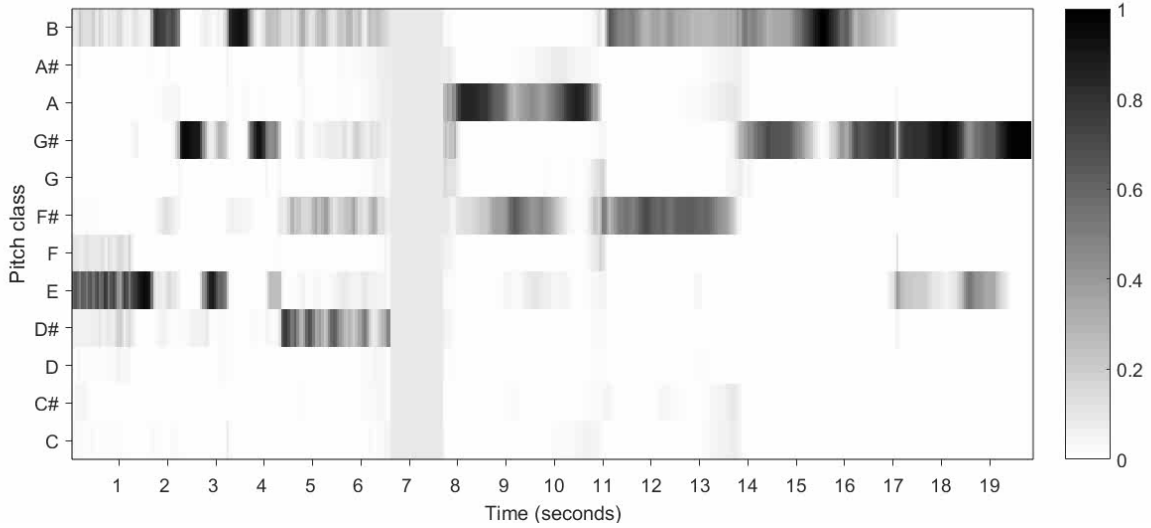
- Orchestra

L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



- Piano

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



Recall: Chroma Representations

- Orchestra

L. van Beethoven,
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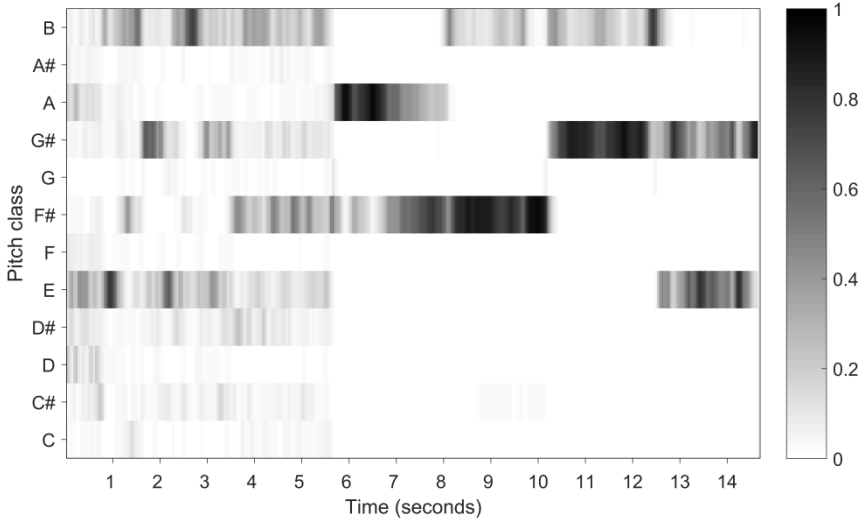
Slovak Philharmonic



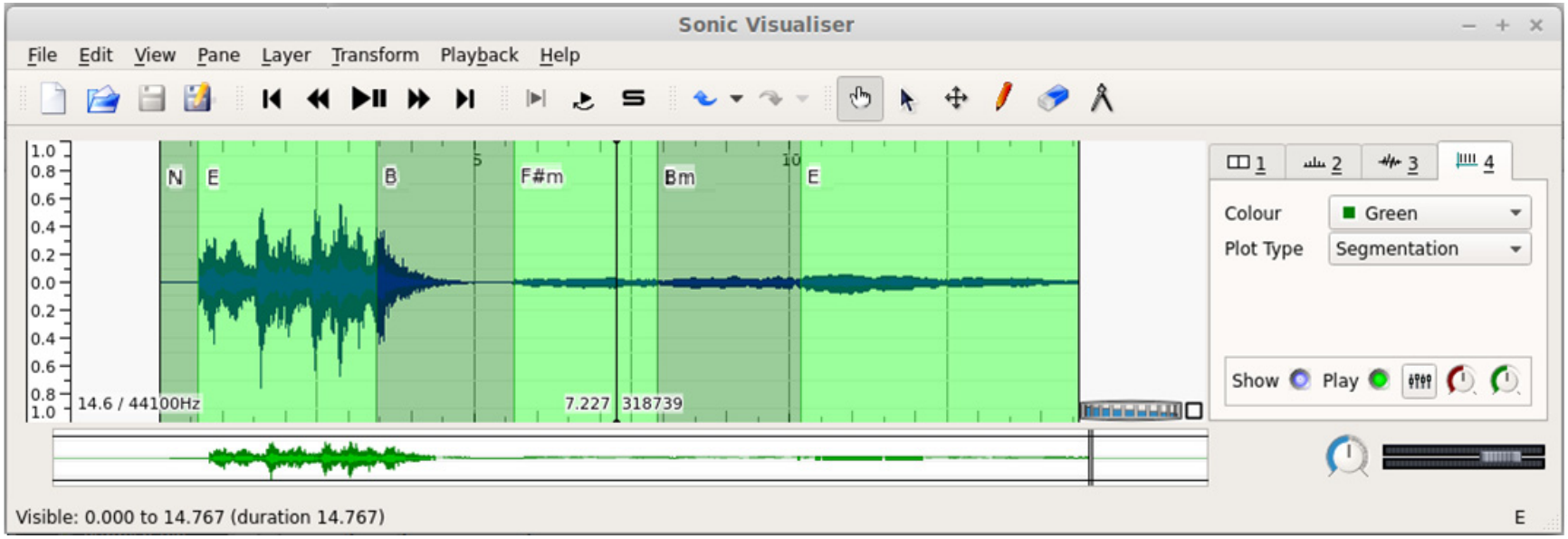
Gómez, *Tonal Description of Polyphonic Audio*, PhD thesis, Barcelona 2006

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

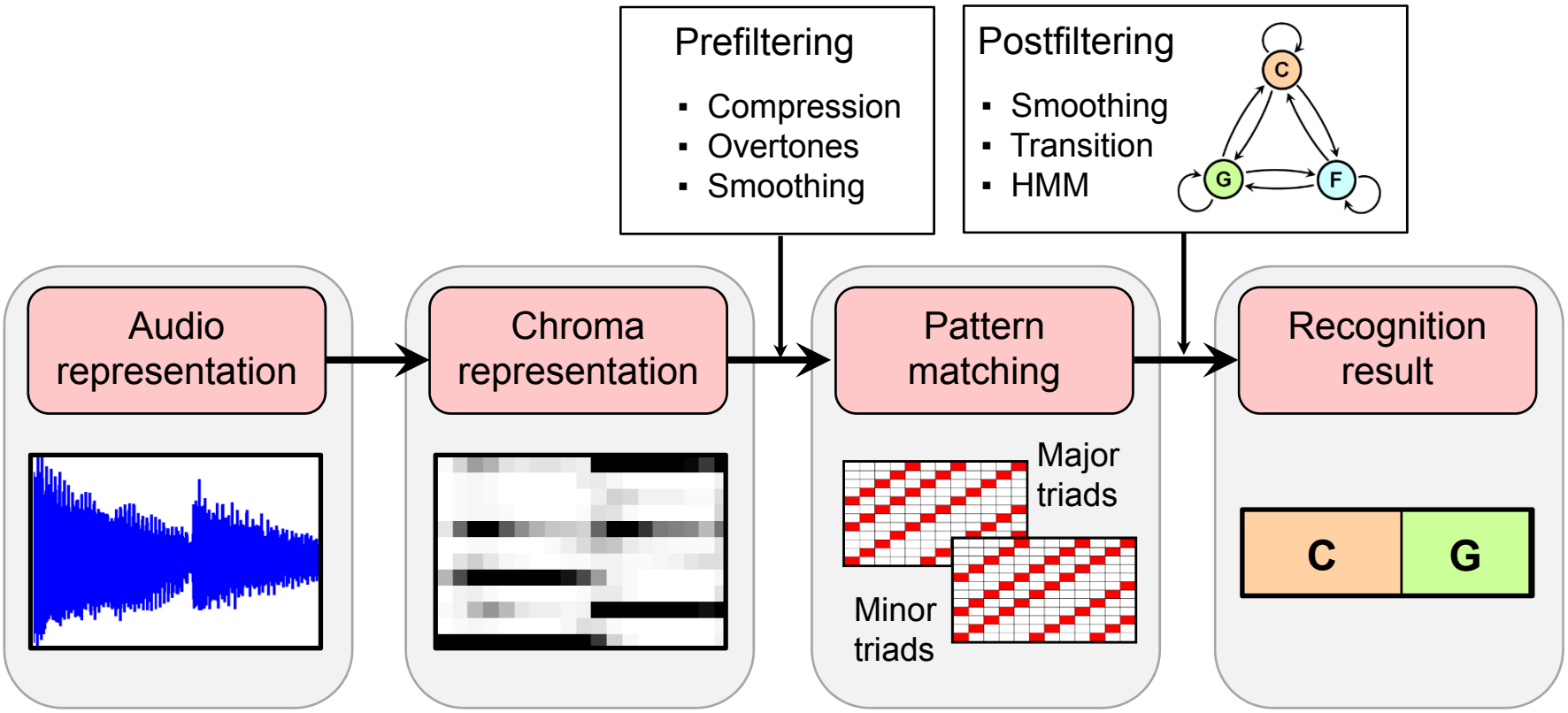
Tonal Structures: Chords

- Chord recognition
  - Typically: Feature extraction, pattern matching, filtering (HMM)
  - „Out-of-the-box“ solutions

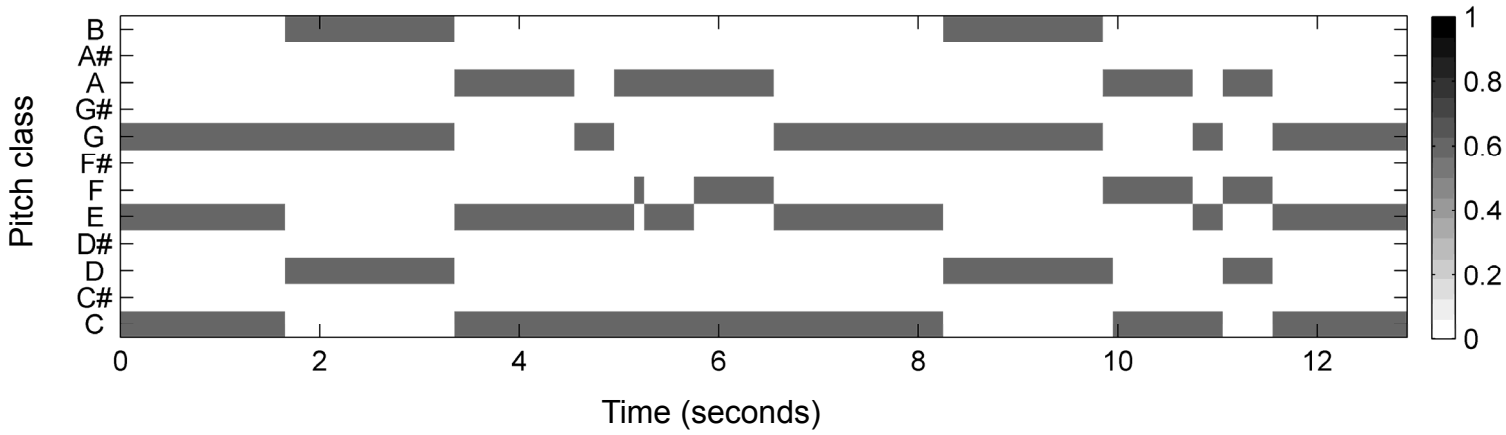


Sonic Visualizer, Chordino Vamp Plugin (Queen Mary University of London)

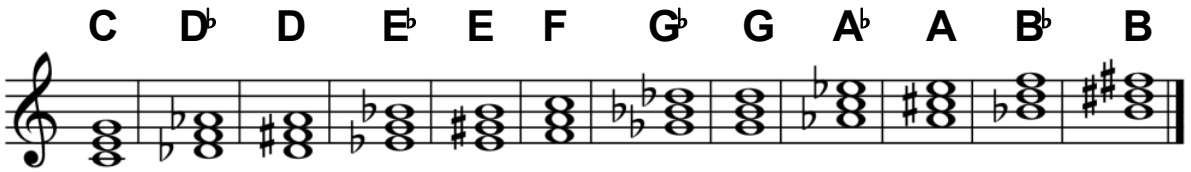
Tonal Structures: Chords

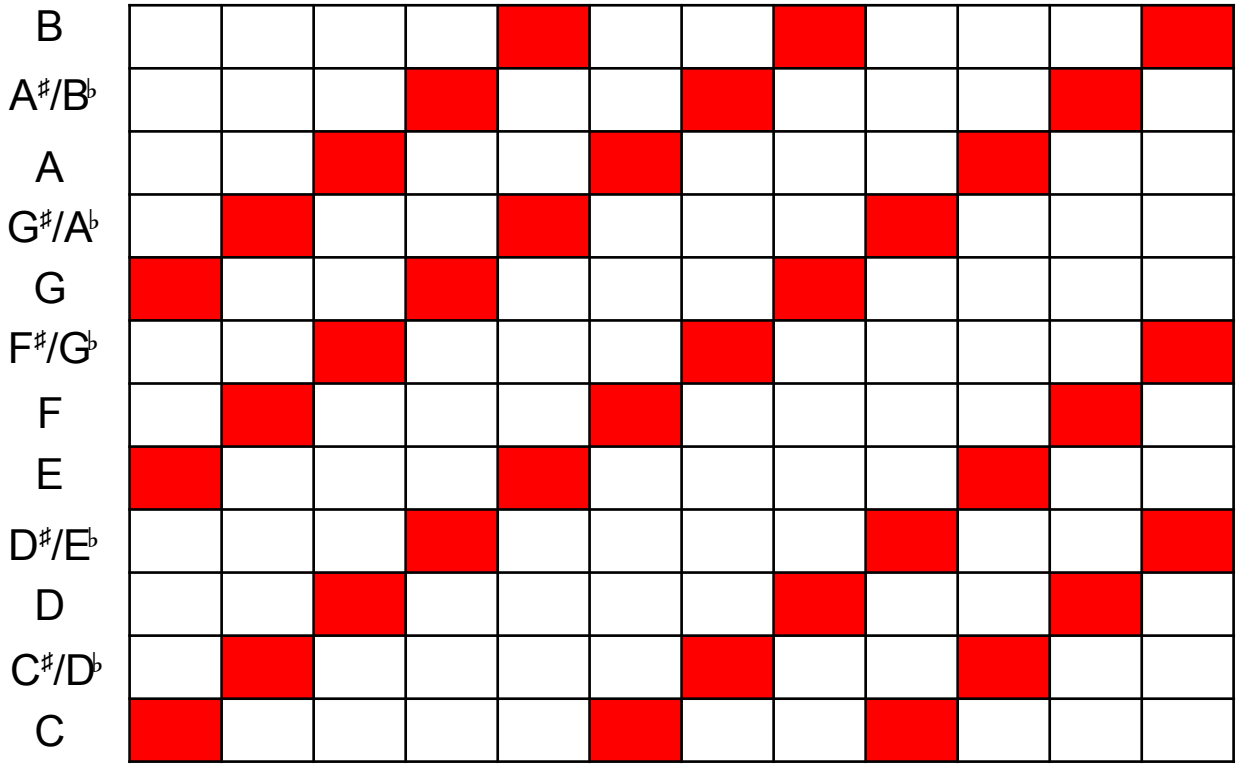


Tonal Structures: Chords



Chord Recognition: Basics





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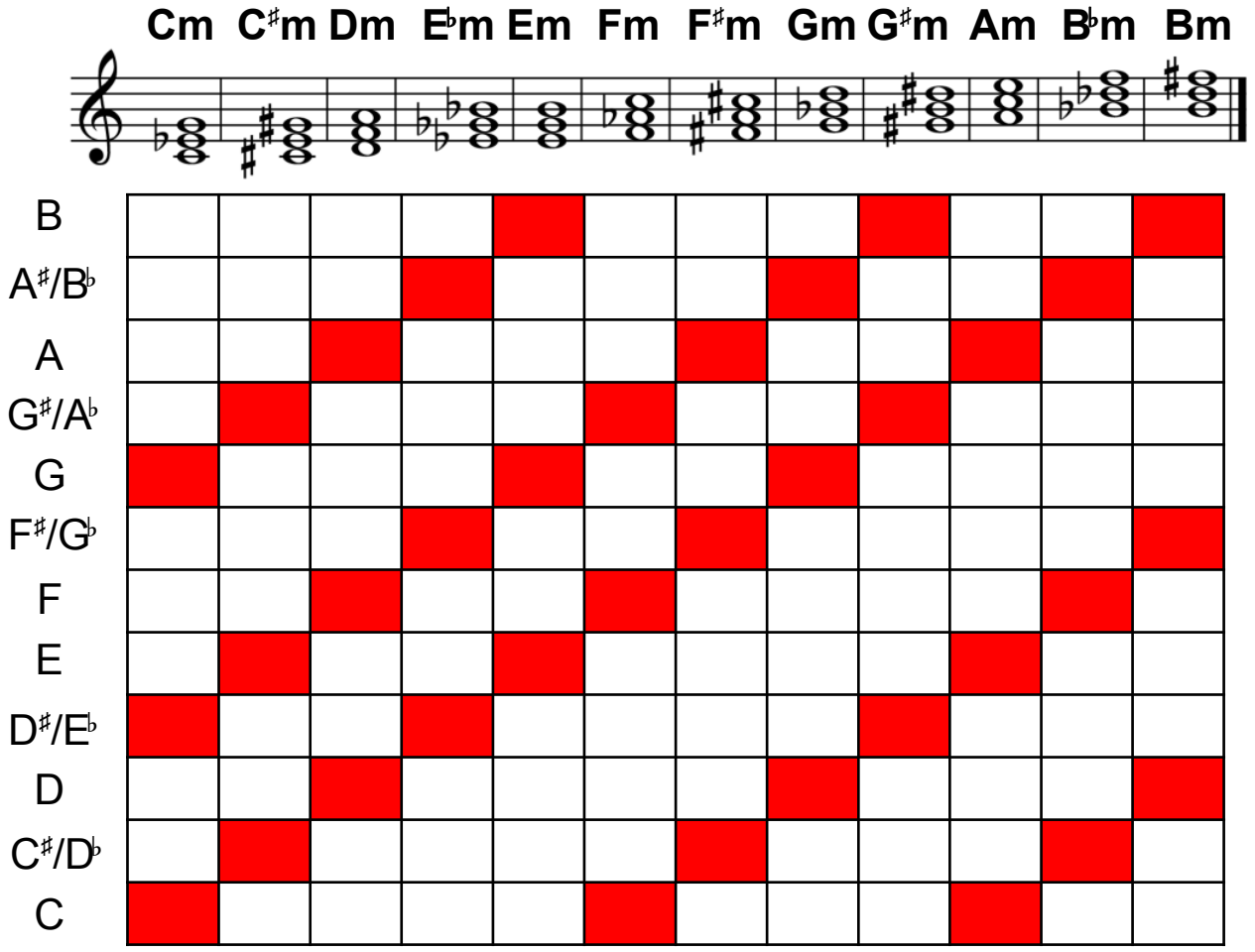
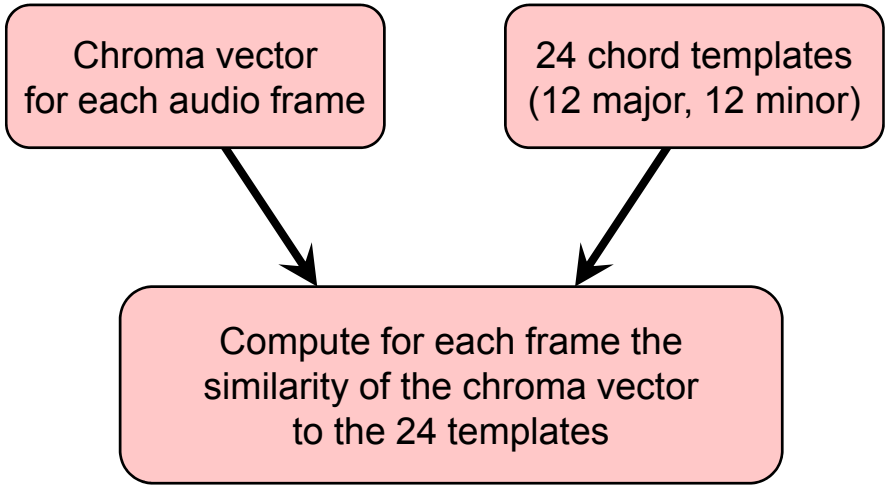
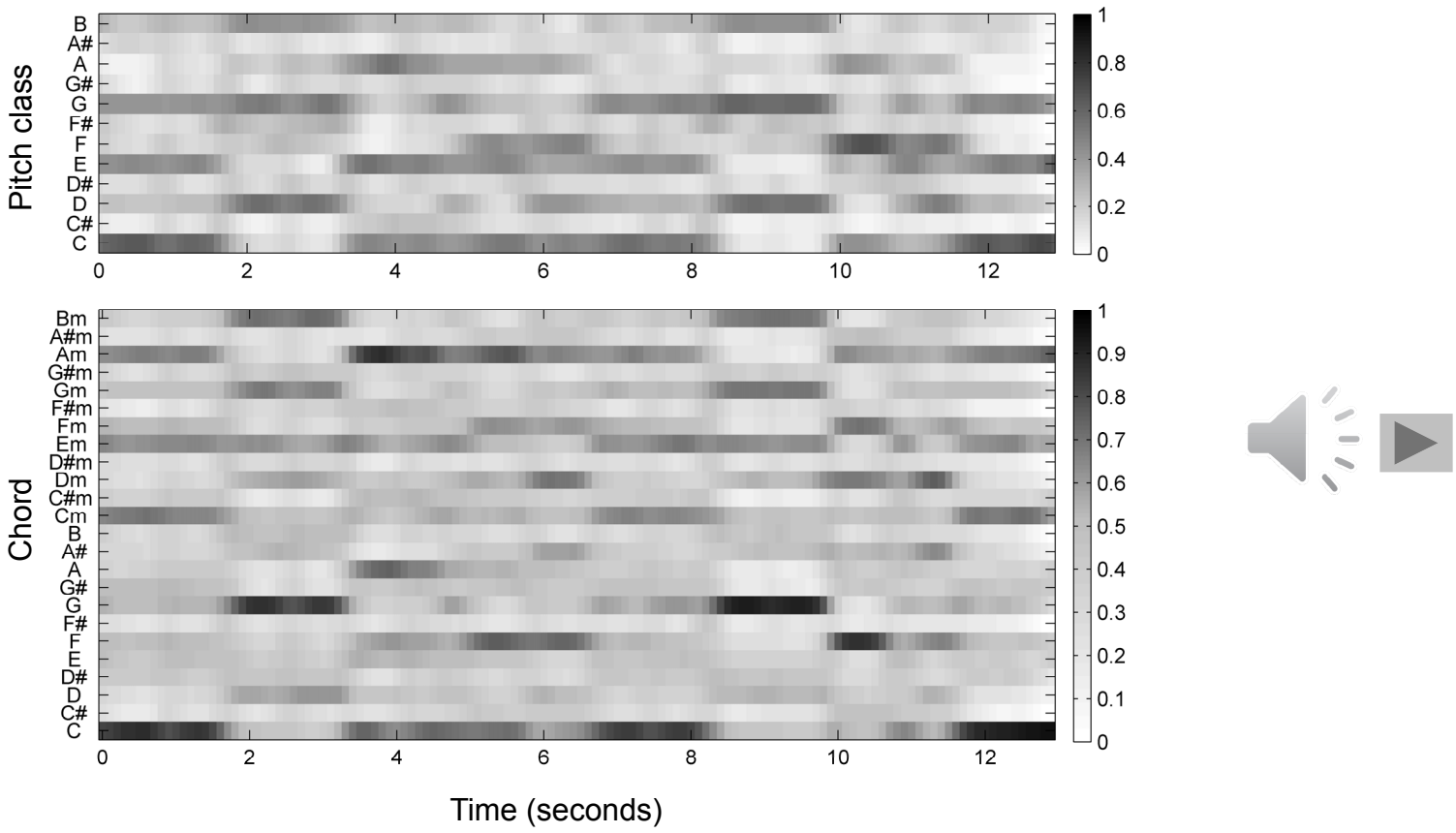


Chord Recognition: Template Matching

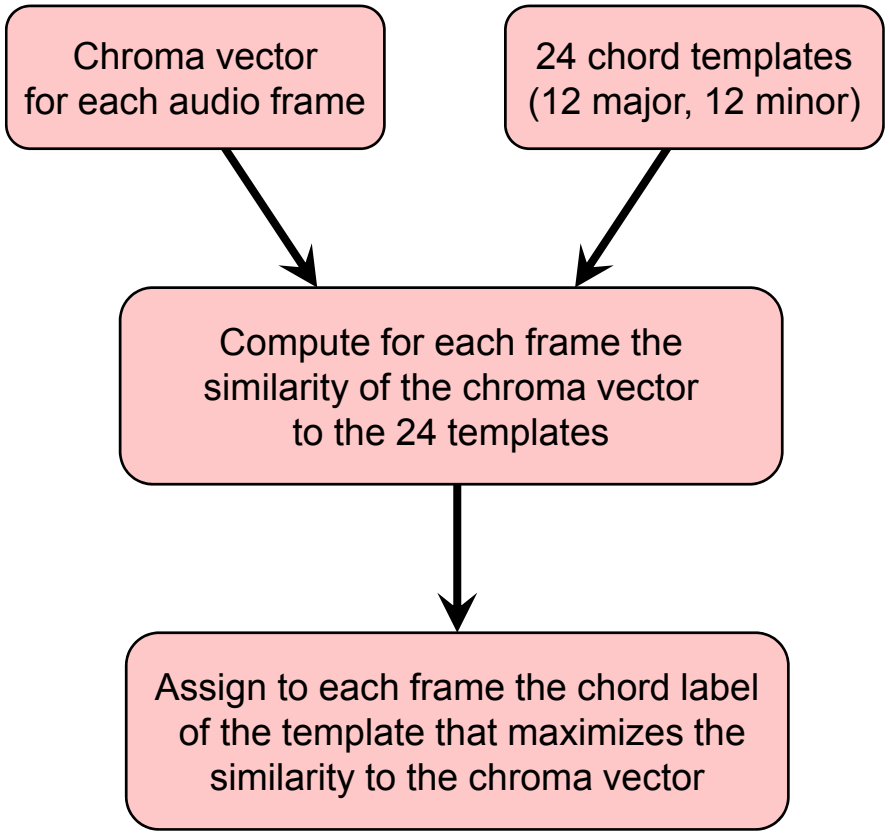


	C	C♯	D	…	Cm	C♯m	Dm	…
B	0	0	0	…	0	0	0	…
A♯	0	0	0	…	0	0	0	…
A	0	0	1	…	0	0	1	…
G♯	0	1	0	…	0	1	0	…
G	1	0	0	…	1	0	0	…
F♯	0	0	1	…	0	0	0	…
F	0	1	0	…	0	0	1	…
E	1	0	0	…	0	1	0	…
D♯	0	0	0	…	1	0	0	…
D	0	0	1	…	0	0	1	…
C♯	0	1	0	…	0	1	0	…
C	1	0	0	…	1	0	0	…

Chord Recognition: Template Matching

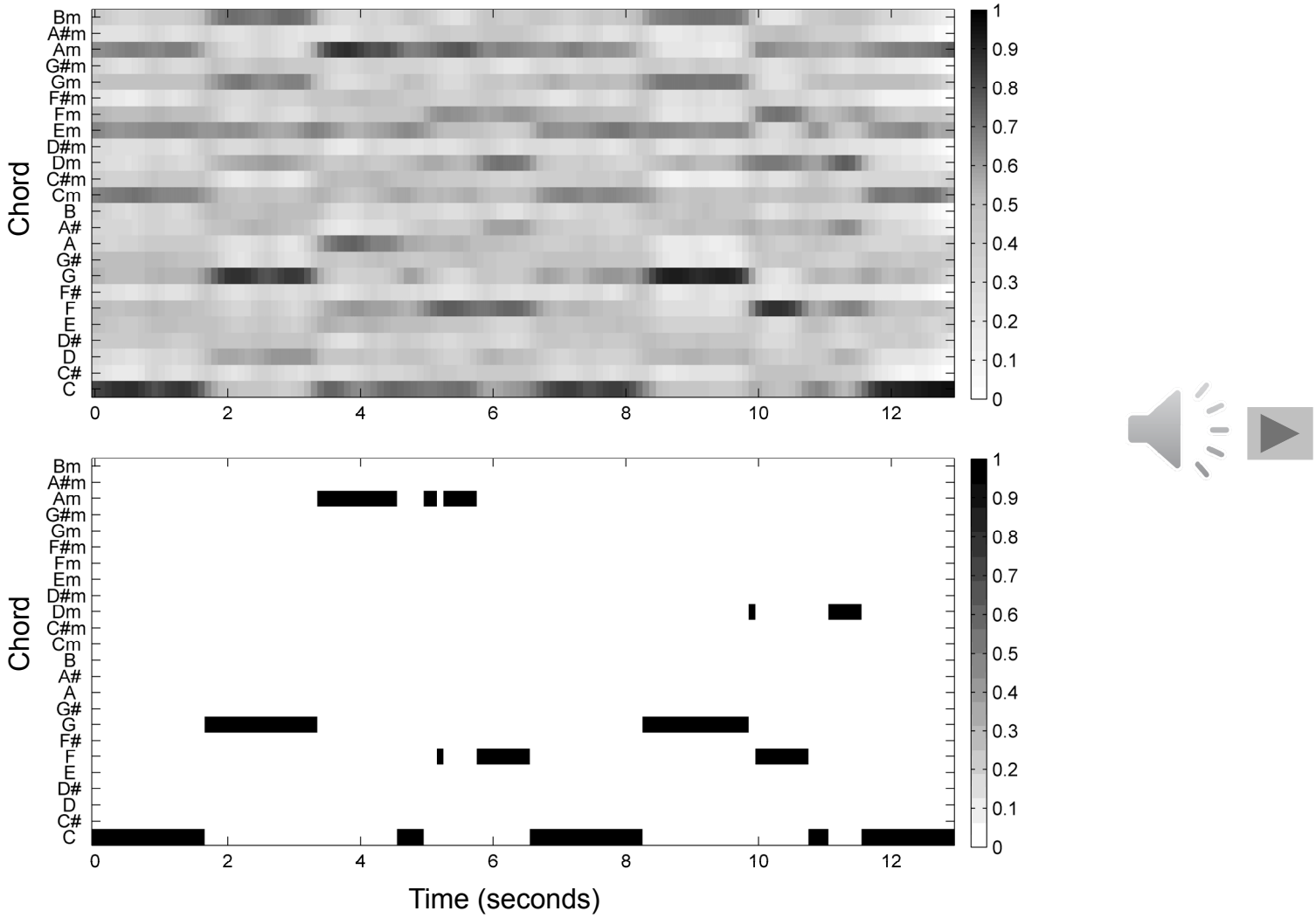


Chord Recognition: Label Assignment

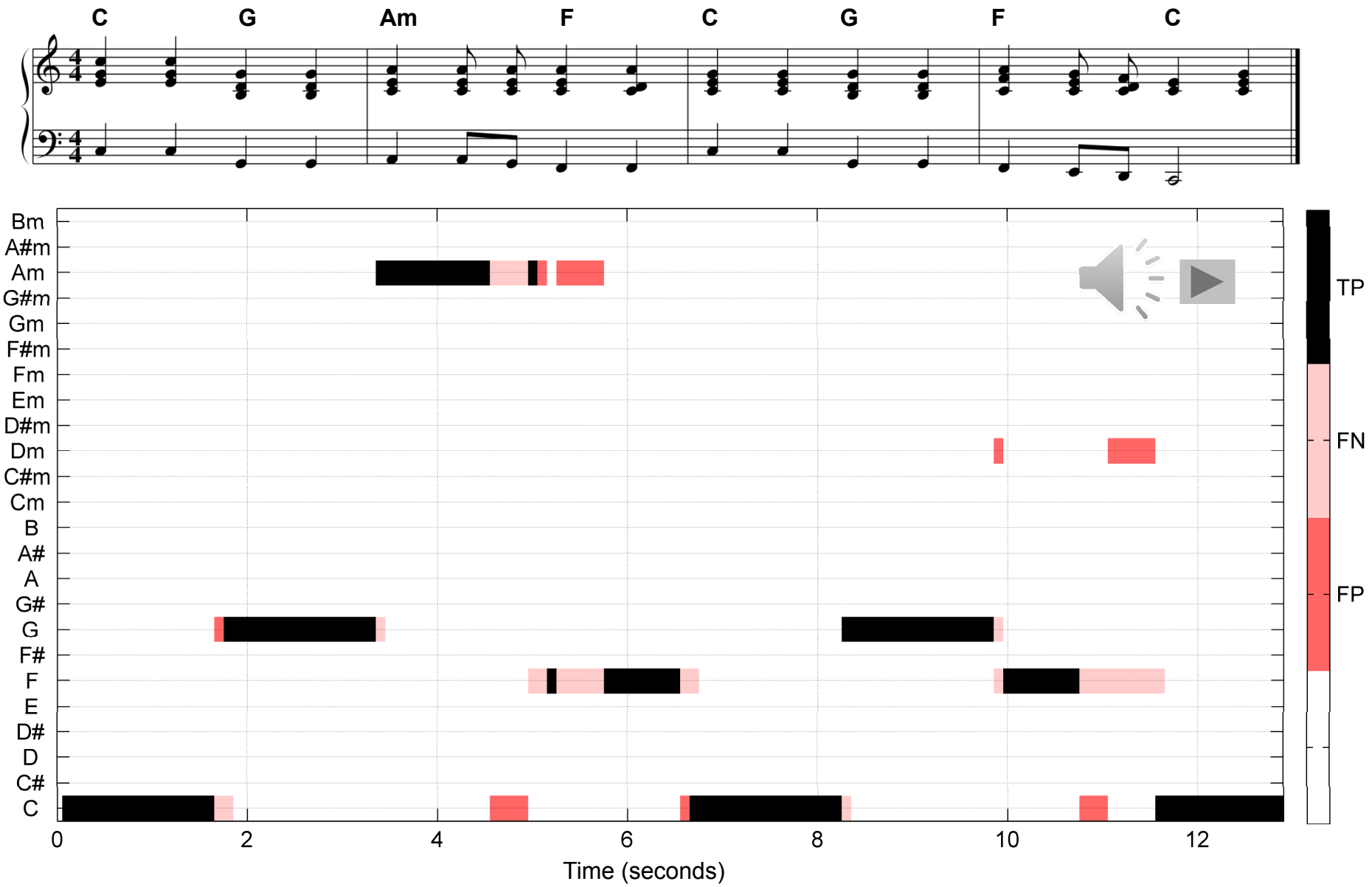


	C	**C♯**	**D**	**…**	**Cm**	**C♯m**	**Dm**	**…**
B	0	0	0	…	0	0	0	…
A♯	0	0	0	…	0	0	0	…
A	0	0	1	…	0	0	1	…
G♯	0	1	0	…	0	1	0	…
G	1	0	0	…	1	0	0	…
F♯	0	0	1	…	0	0	0	…
F	0	1	0	…	0	0	1	…
E	1	0	0	…	0	1	0	…
D♯	0	0	0	…	1	0	0	…
D	0	0	1	…	0	0	1	…
C♯	0	1	0	…	0	1	0	…
C	1	0	0	…	1	0	0	…

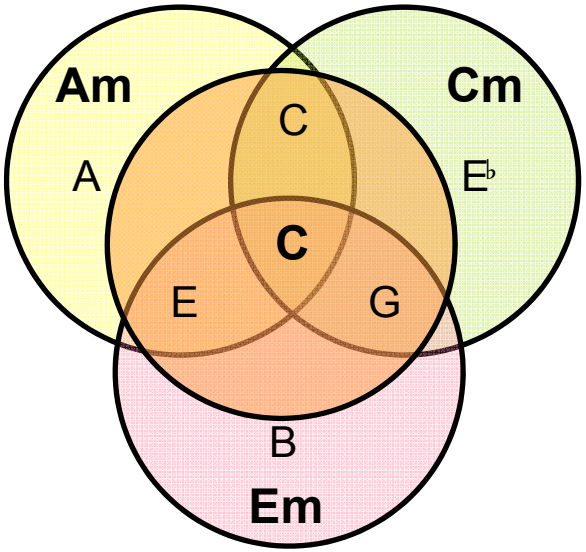
Chord Recognition: Label Assignment

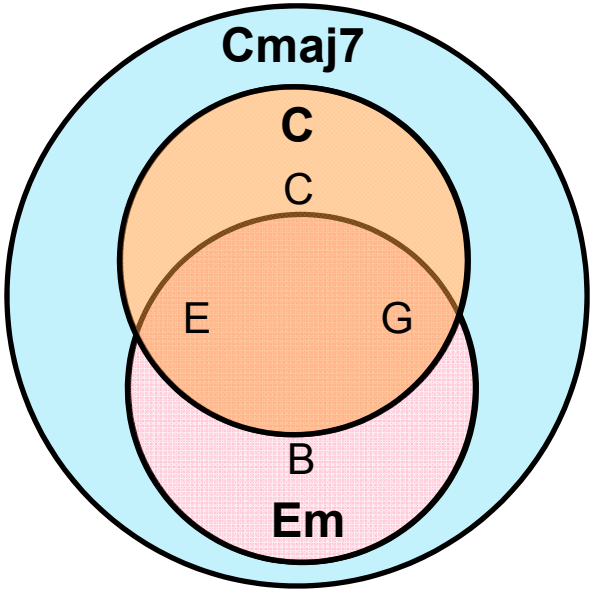


Chord Recognition: Evaluation



Chord Recognition: Challenges





Tonal Structures: Chords

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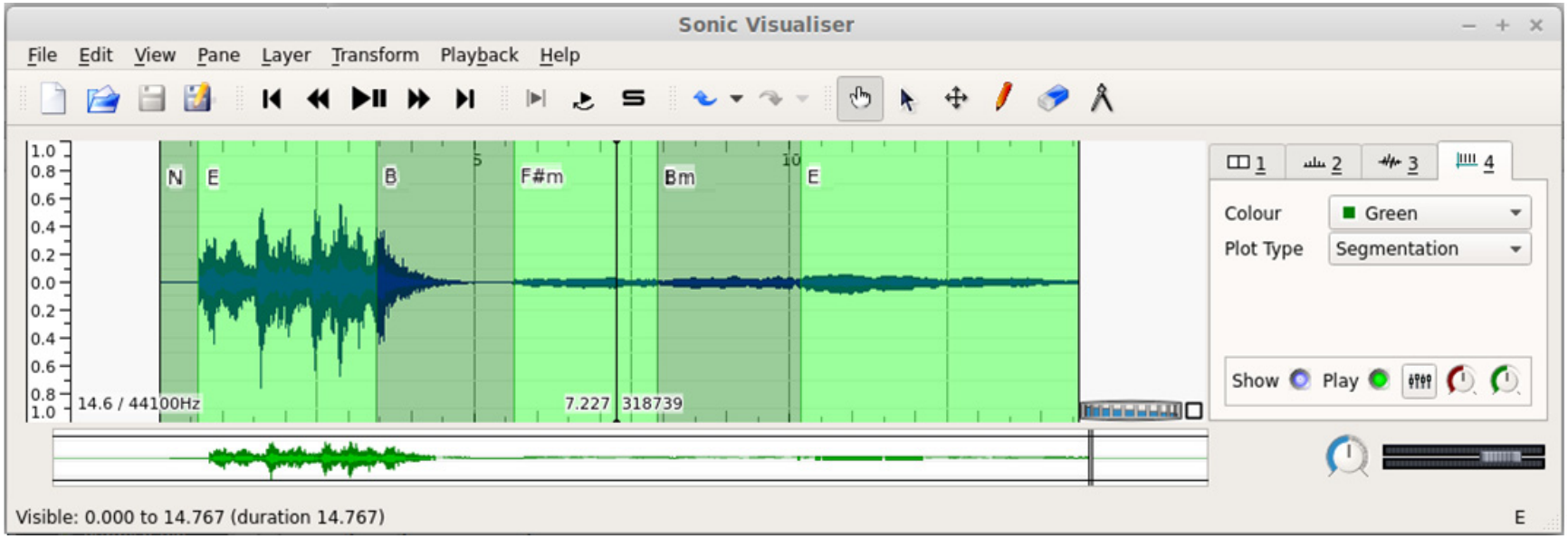
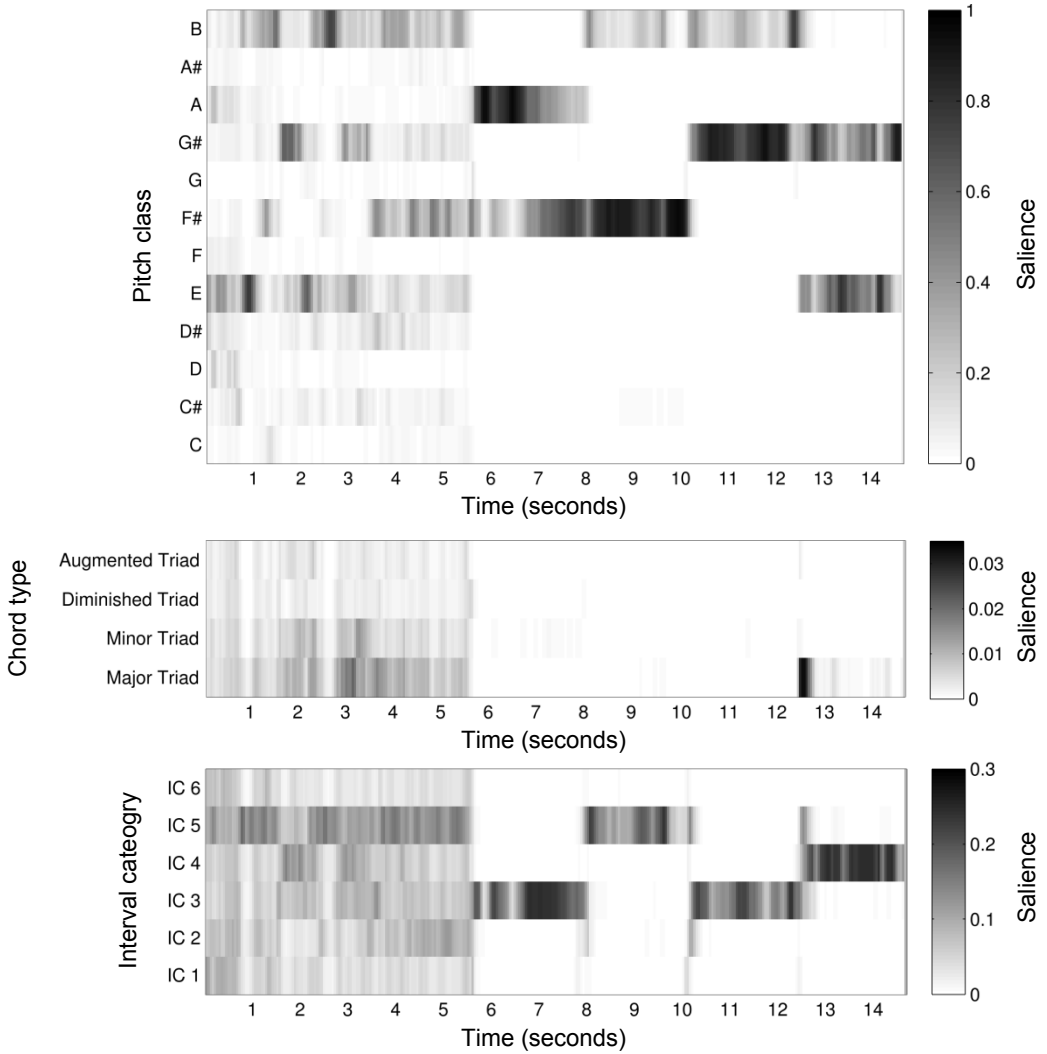
  - „Out-of-the-box“ solutions



Sonic Visualizer, Chordino Vamp Plugin (Queen Mary University of London)

Tonal Structures: Chord & Interval Categories

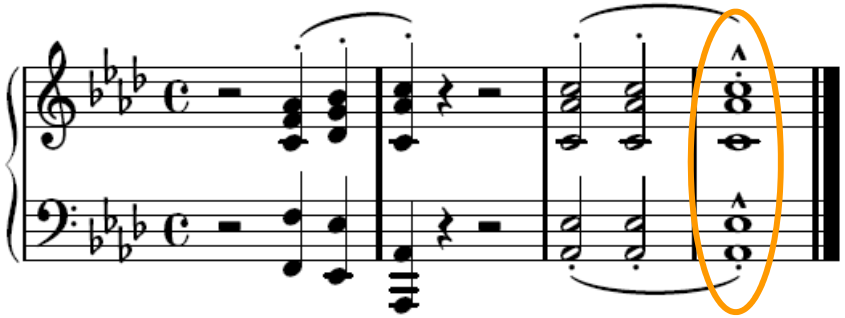
- Chromagram
- Chord type
- Interval categories



Tonal Structures: Final Chord

- Global key detection – typical approach:
  - Full piece chroma statistics
  - Template matching

- Idea: Use particular role of **final chord**



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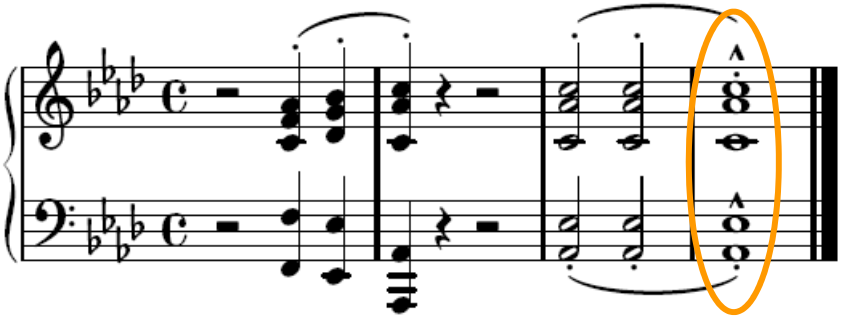

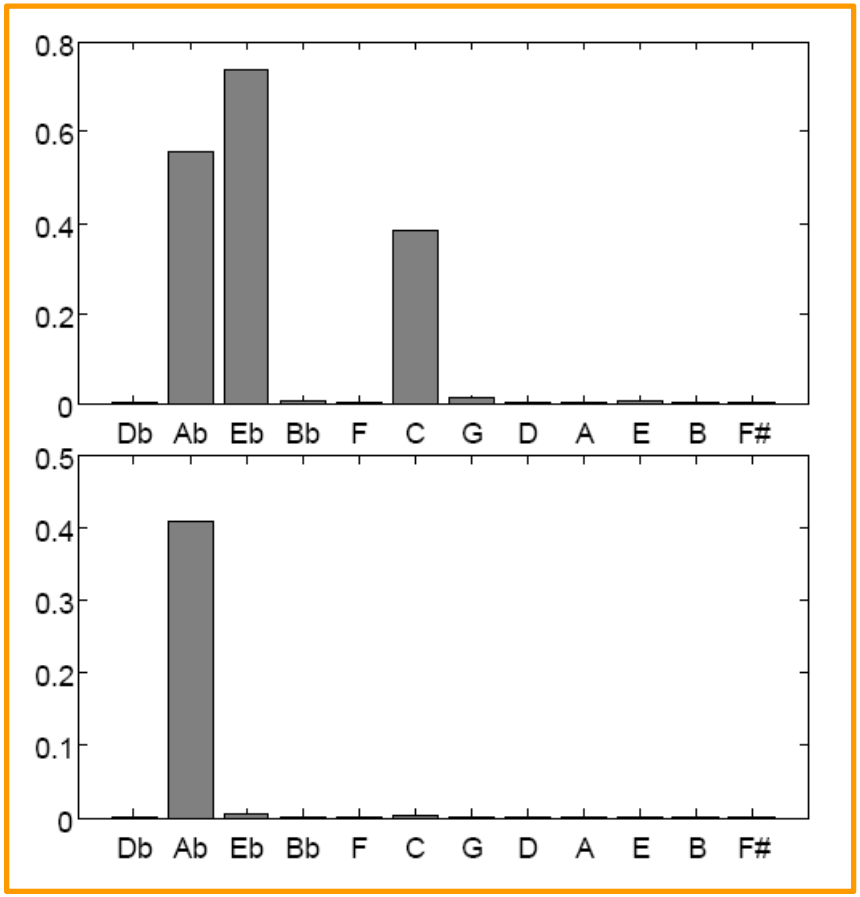

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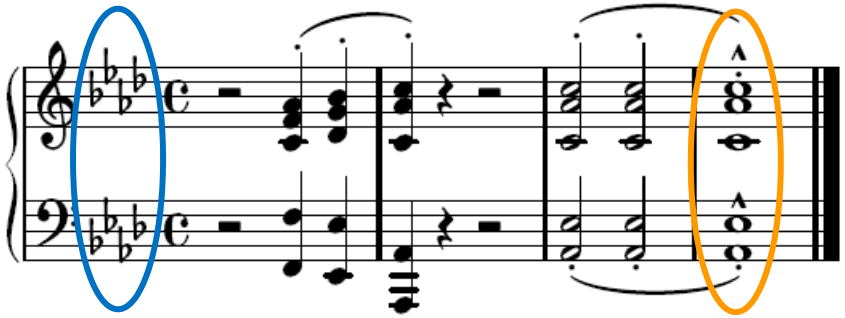


- Full piece chroma statistics → **Diatonic scale**

Weiss, *Global Key Extraction Based on the Final Chord*, SMC 2013
Weiss / Schaab, *On the Impact of Key Detection Performance*, ISMIR 2015

Tonal Structures: Final Chord

- State-of-the-art
  - Learning of pitch class profiles
  - Weighting of beginning and ending sections (15 seconds)

  Van de Par et al., *Musical Key Extraction from Audio Using Profile Training*, ISMIR 2006

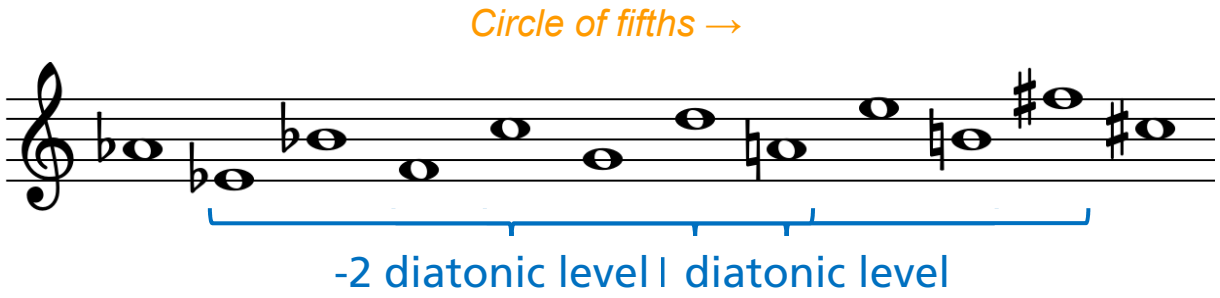
- Evaluation with *optimized parameters*
  - Dataset: symphonies, piano, chamber music, *478 pieces*
  - Final chord (own): **94 %**
  - Profile learning (*Van de Par*): **92 %**

- Evaluation on *unseen data*
  - Dataset: orchestra, piano, *1200 pieces*
  - Final chord (own): **85 %**
  - Profile learning (*Van de Par*): **87 %**

Tonal Structures: Local Diatonic Scales

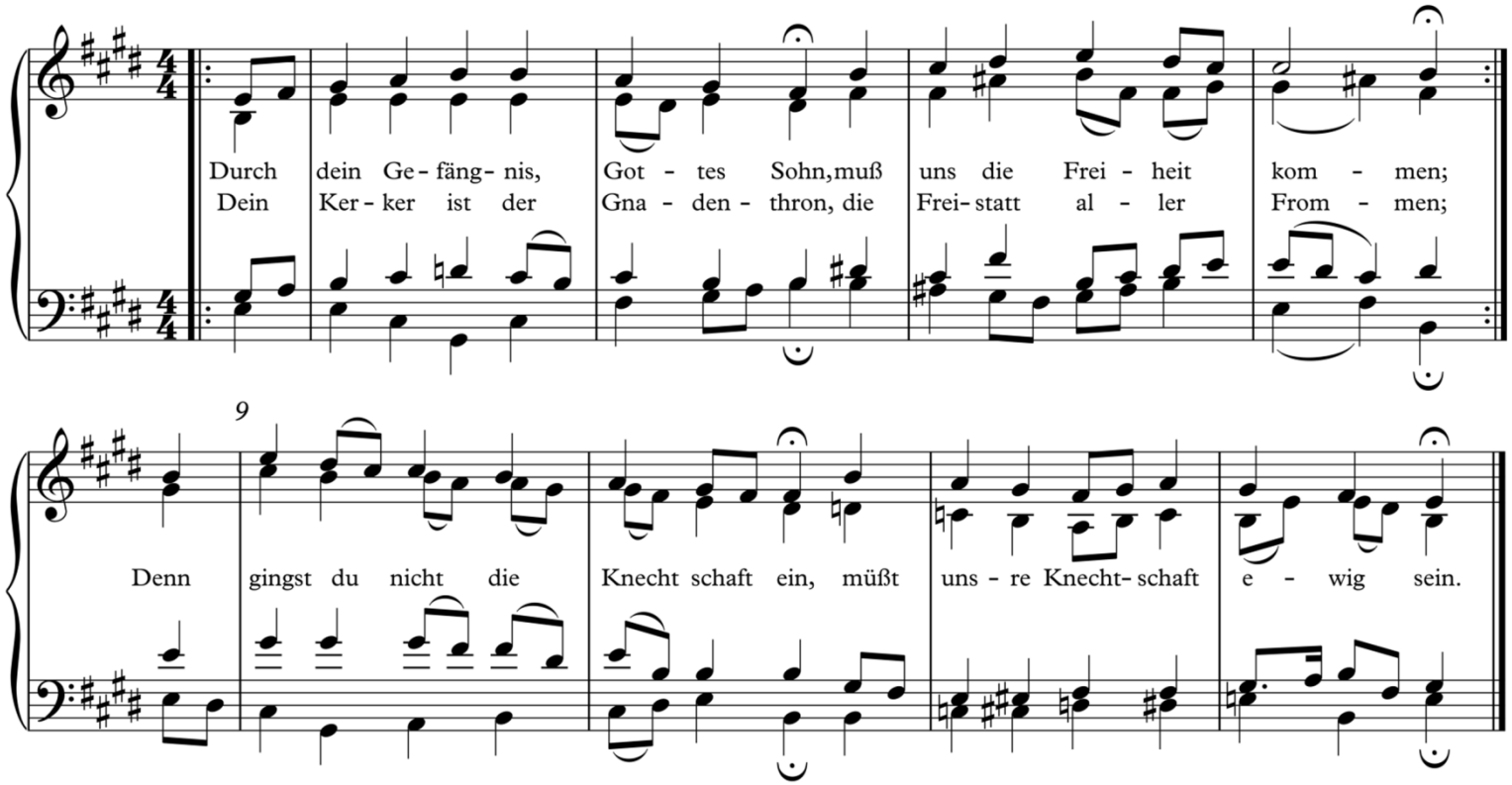
- Modulations → Local approach

- Diatonic Scales
  - Simplification of keys
  - Perfect-fifth relation



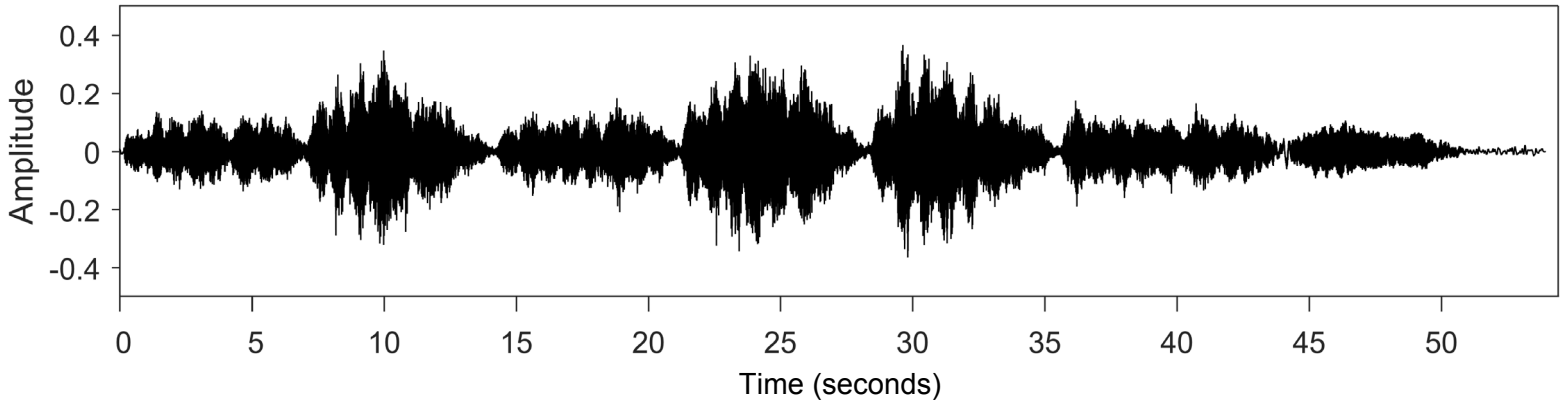
Tonal Structures: Local Diatonic Scales

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



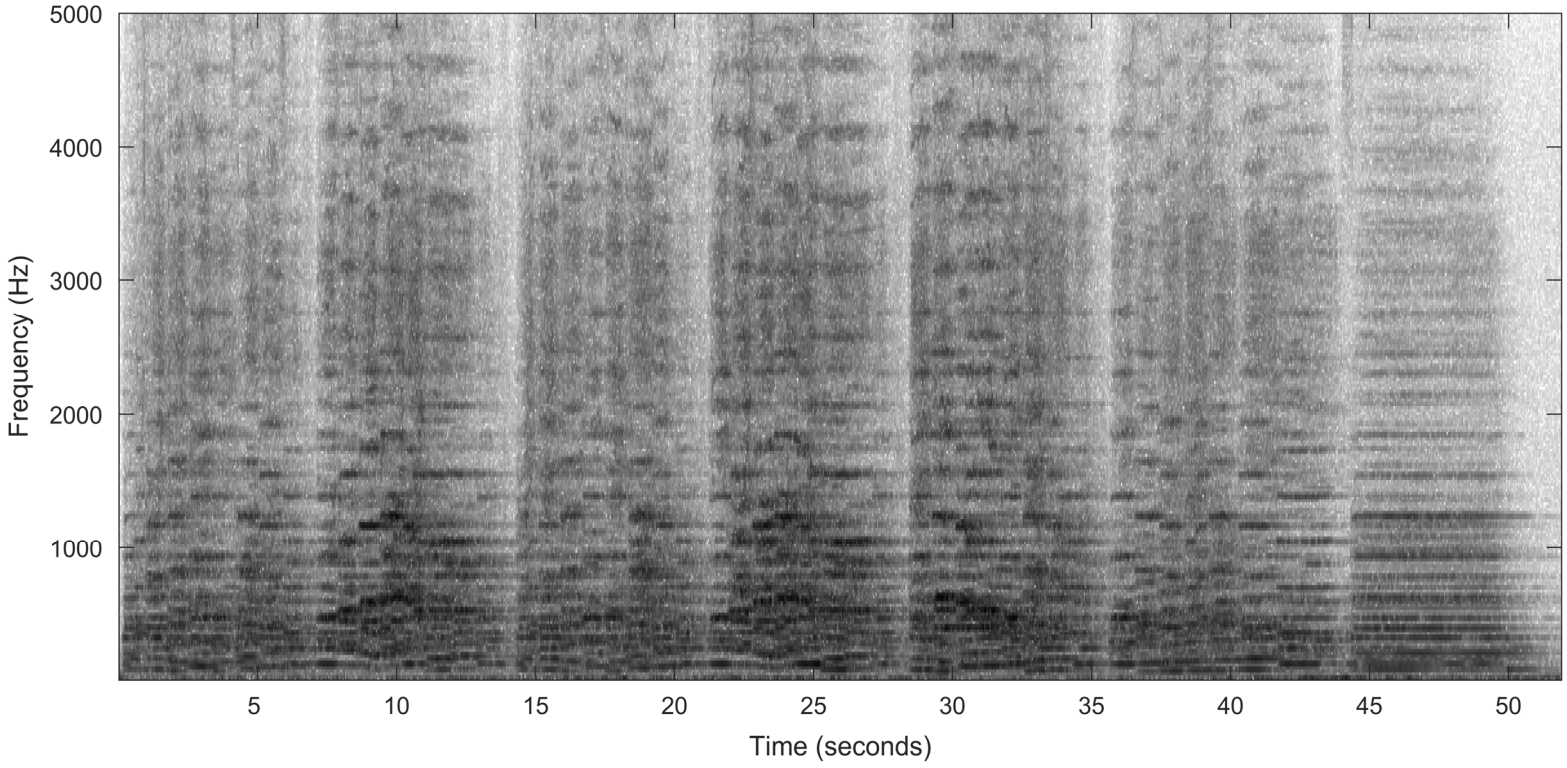
Tonal Structures: Local Diatonic Scales

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



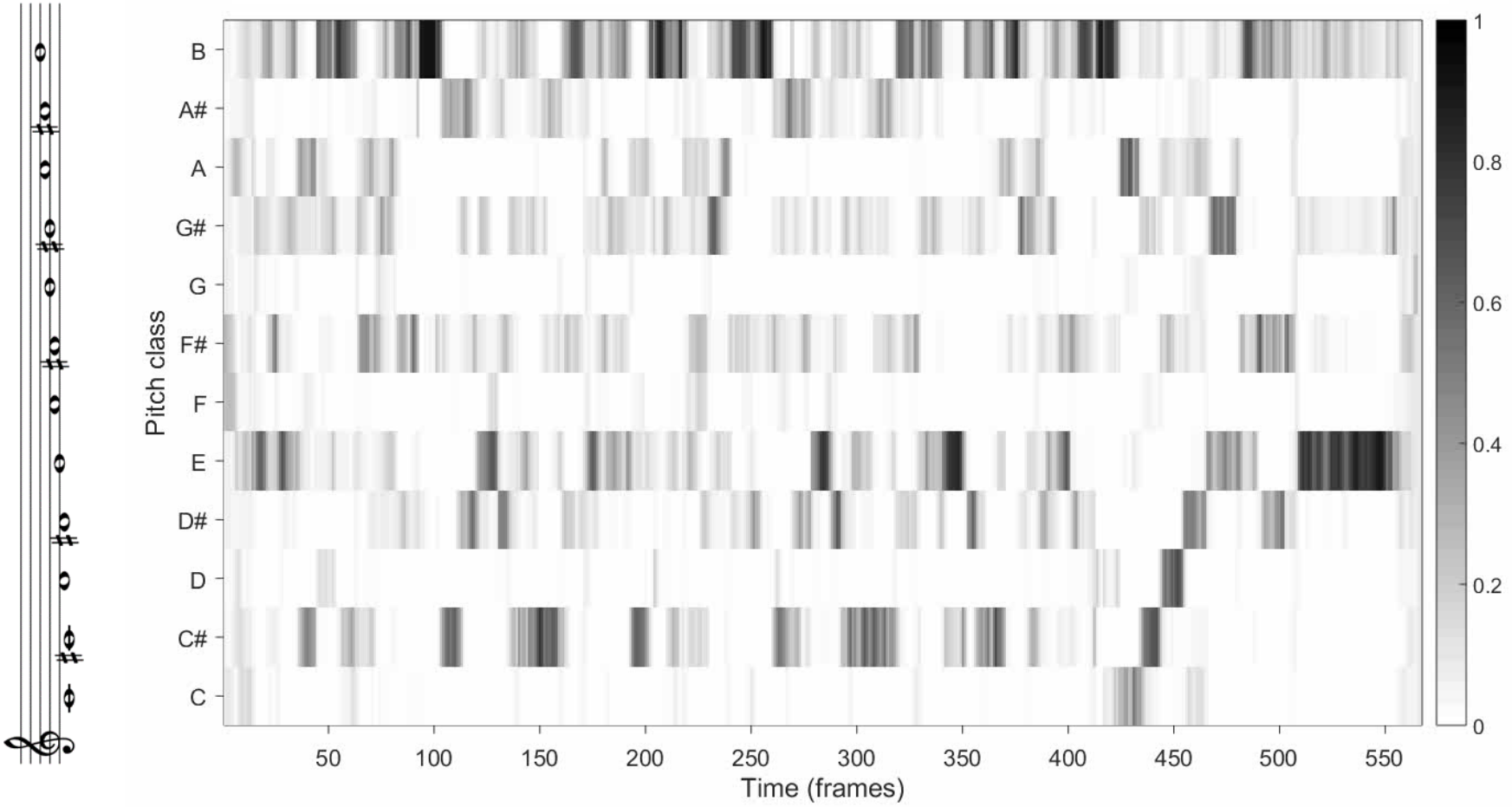
Tonal Structures: Local Diatonic Scales

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



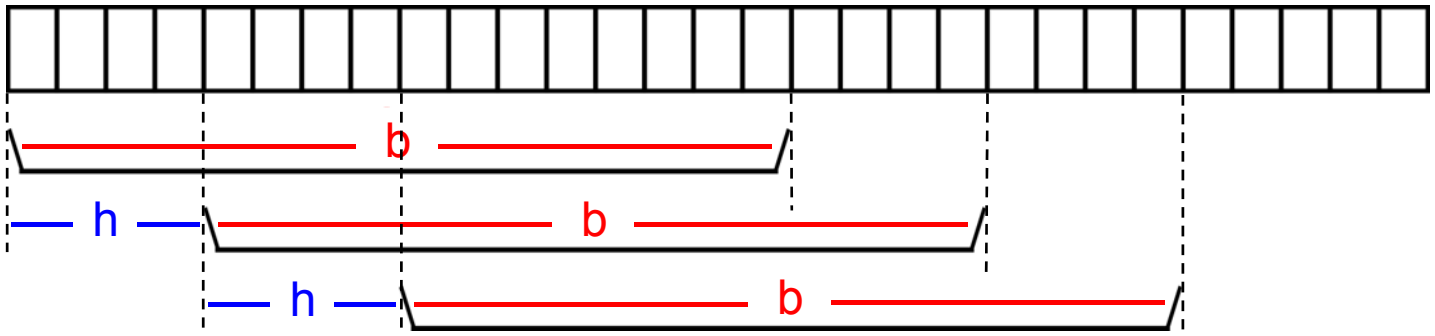
Tonal Structures: Local Diatonic Scales

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



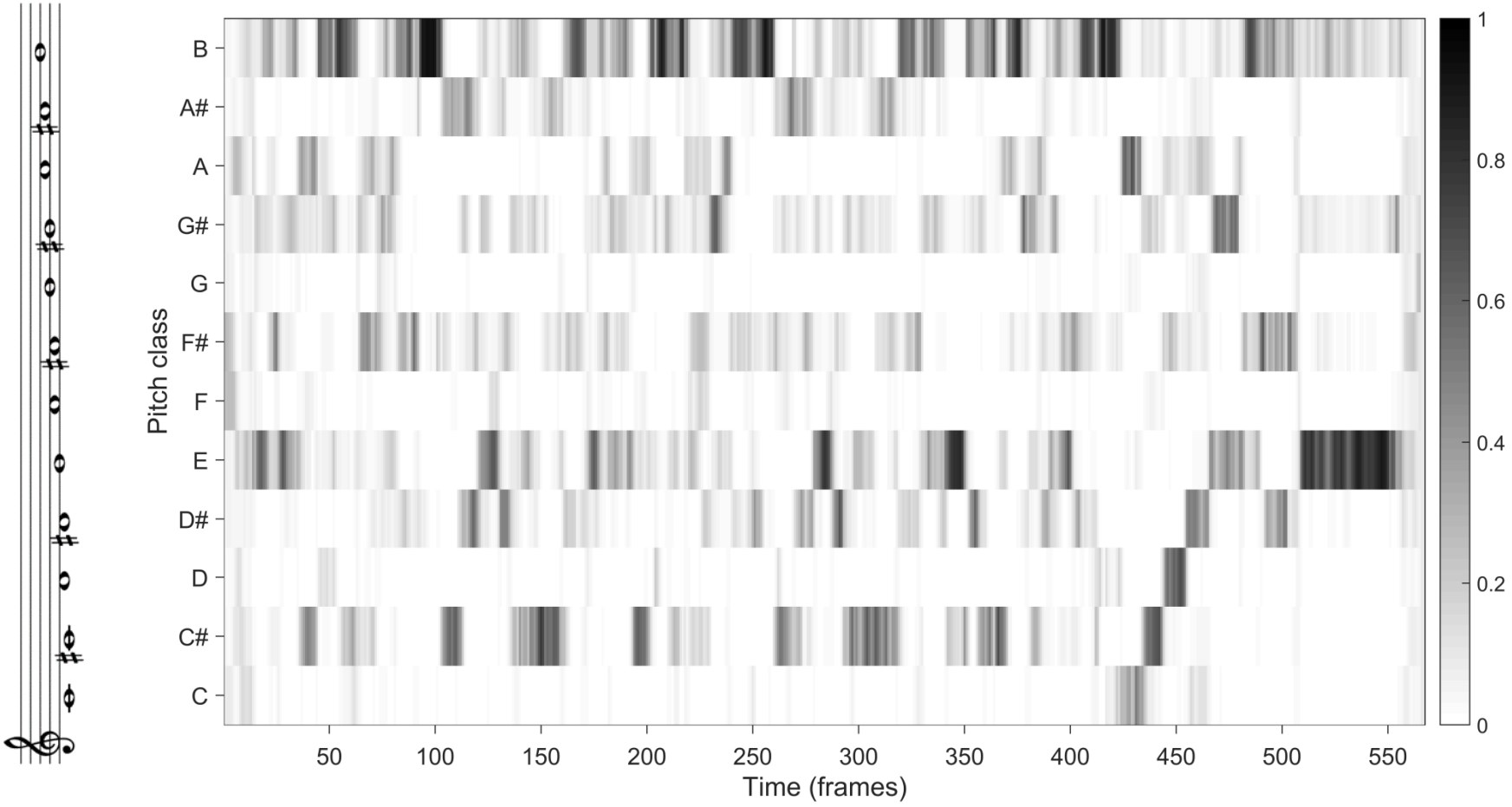
Tonal Structures: Local Diatonic Scales

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



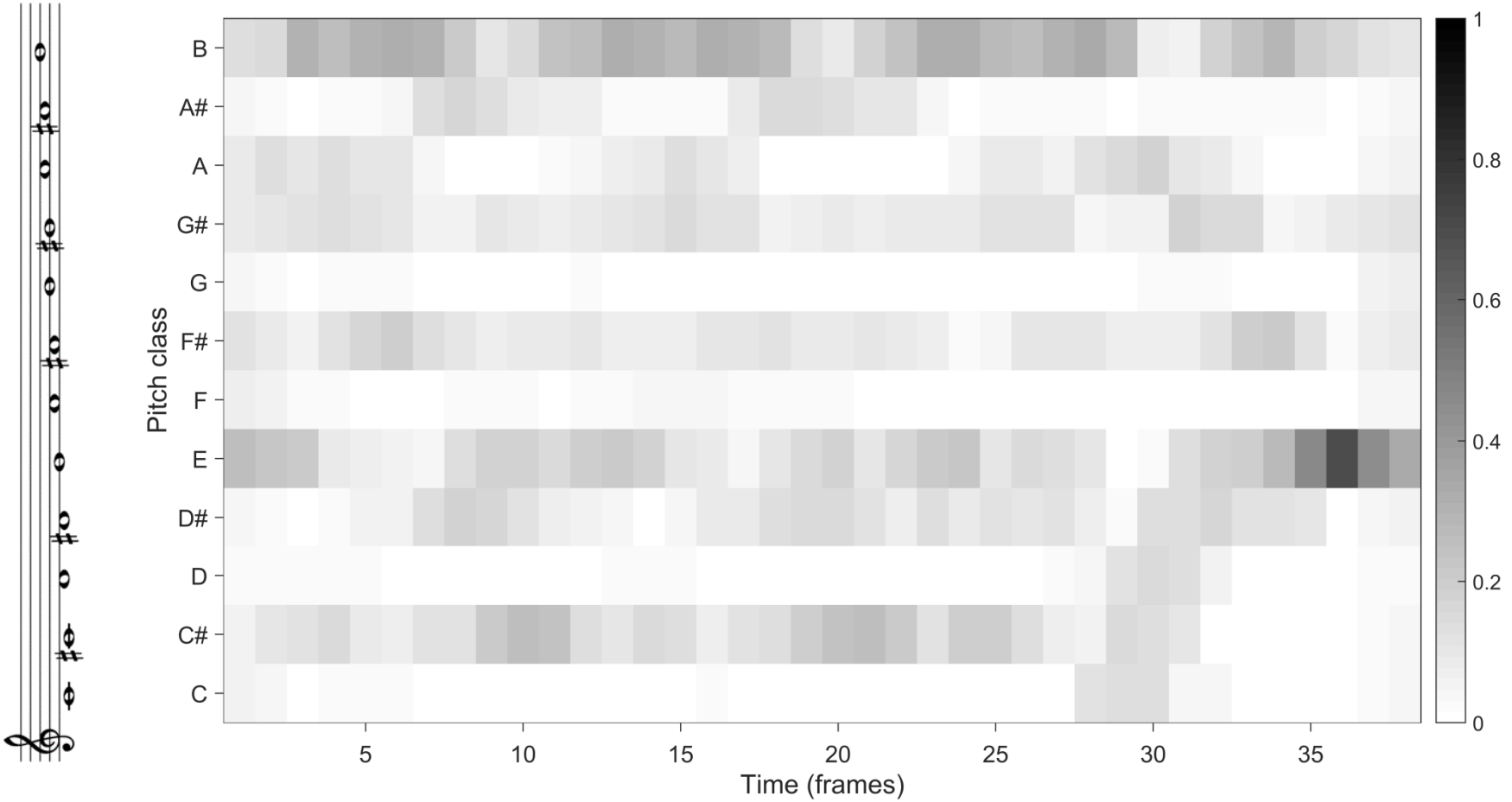
Tonal Structures: Local Diatonic Scales

- Choral (Bach)



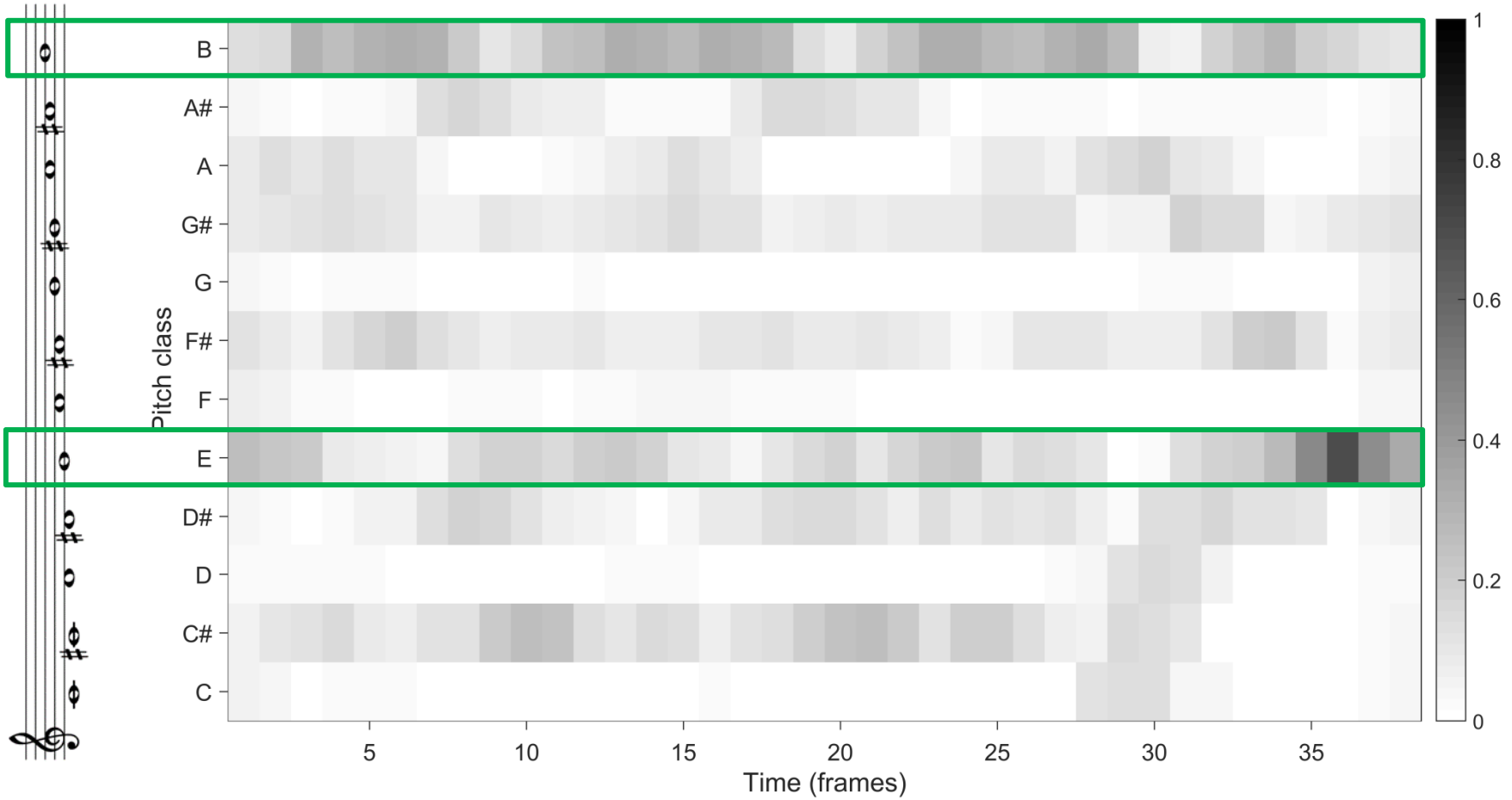
Tonal Structures: Local Diatonic Scales

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



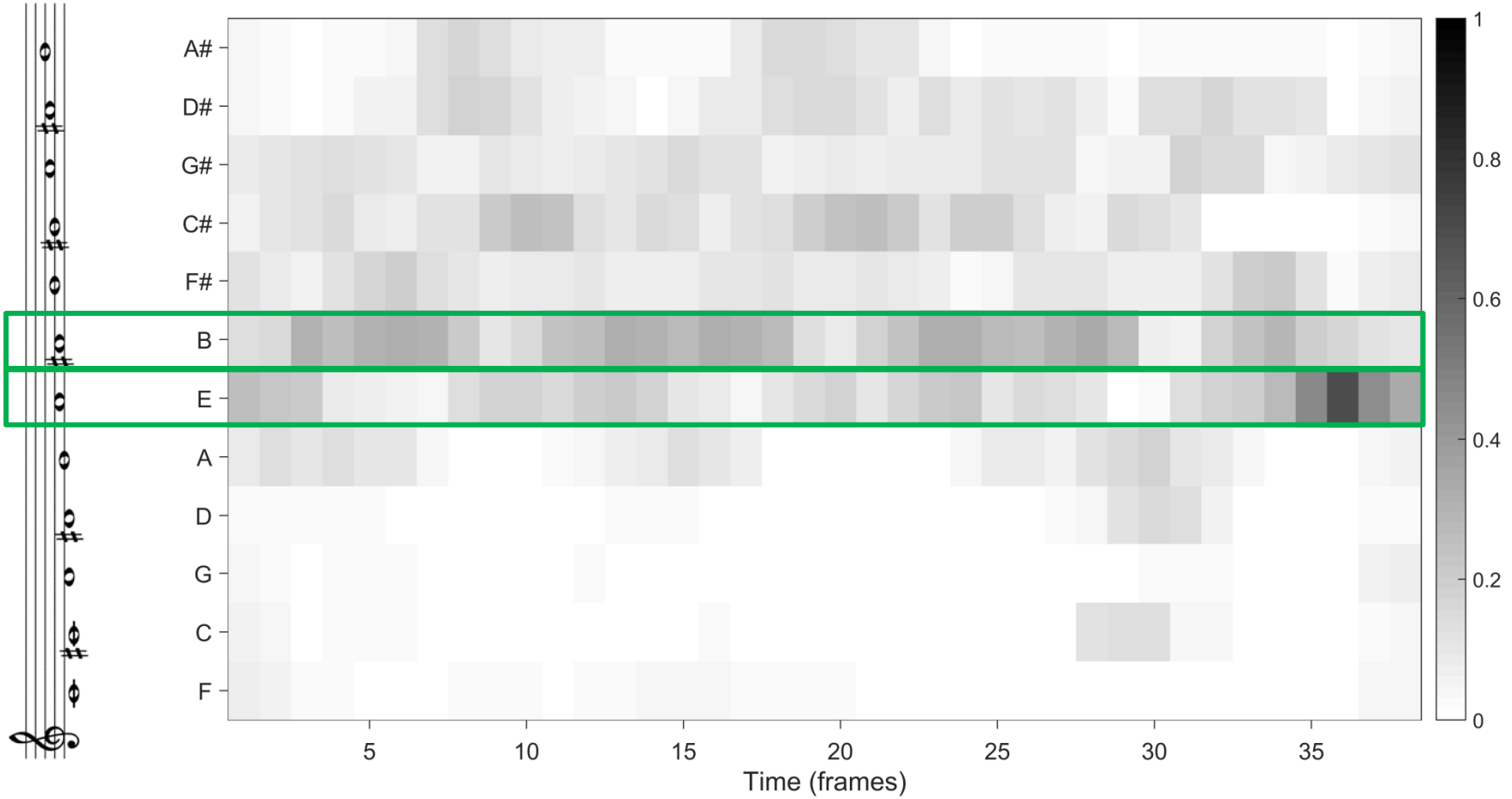
Tonal Structures: Local Diatonic Scales

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



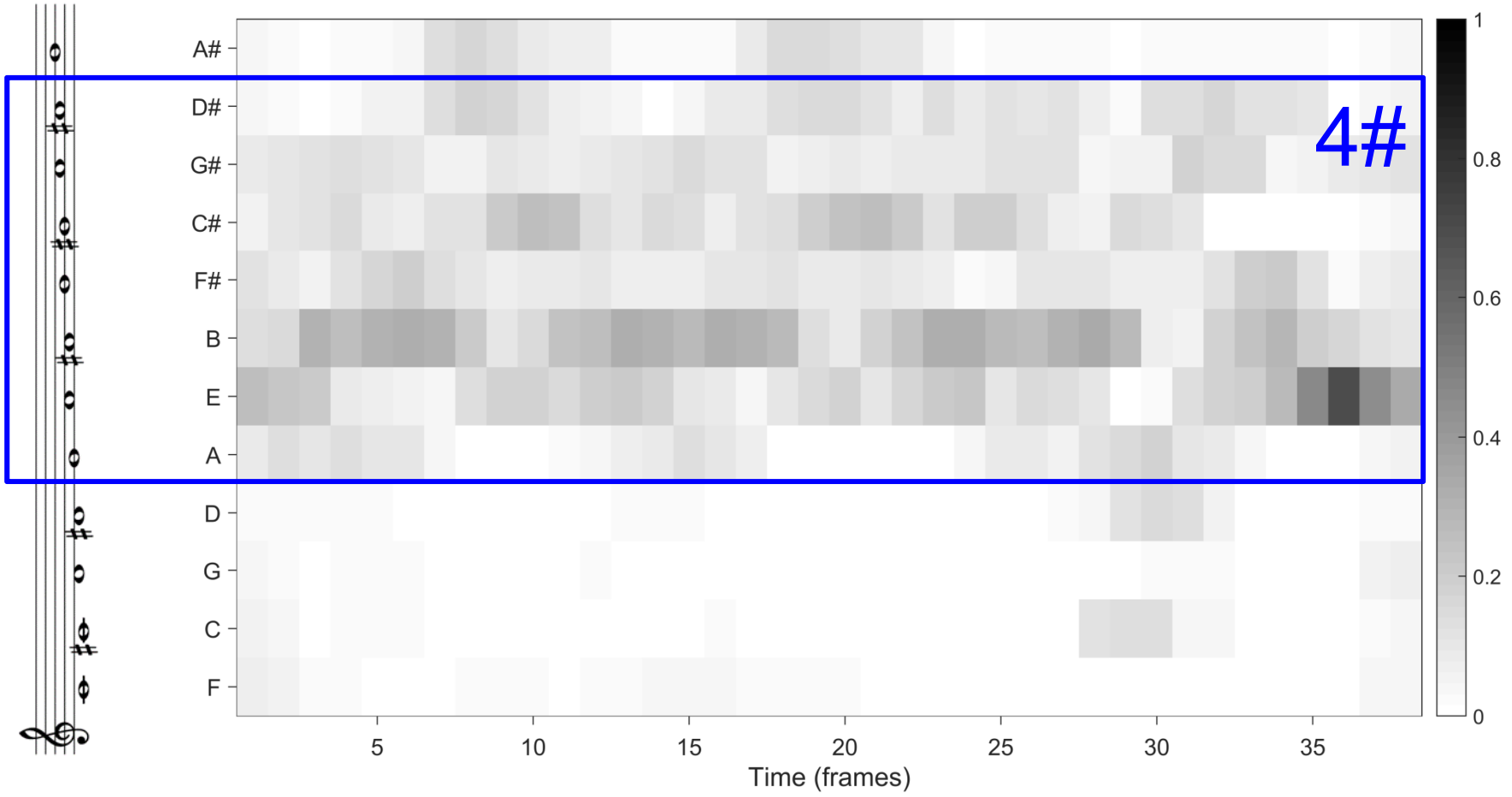
Tonal Structures: Local Diatonic Scales

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



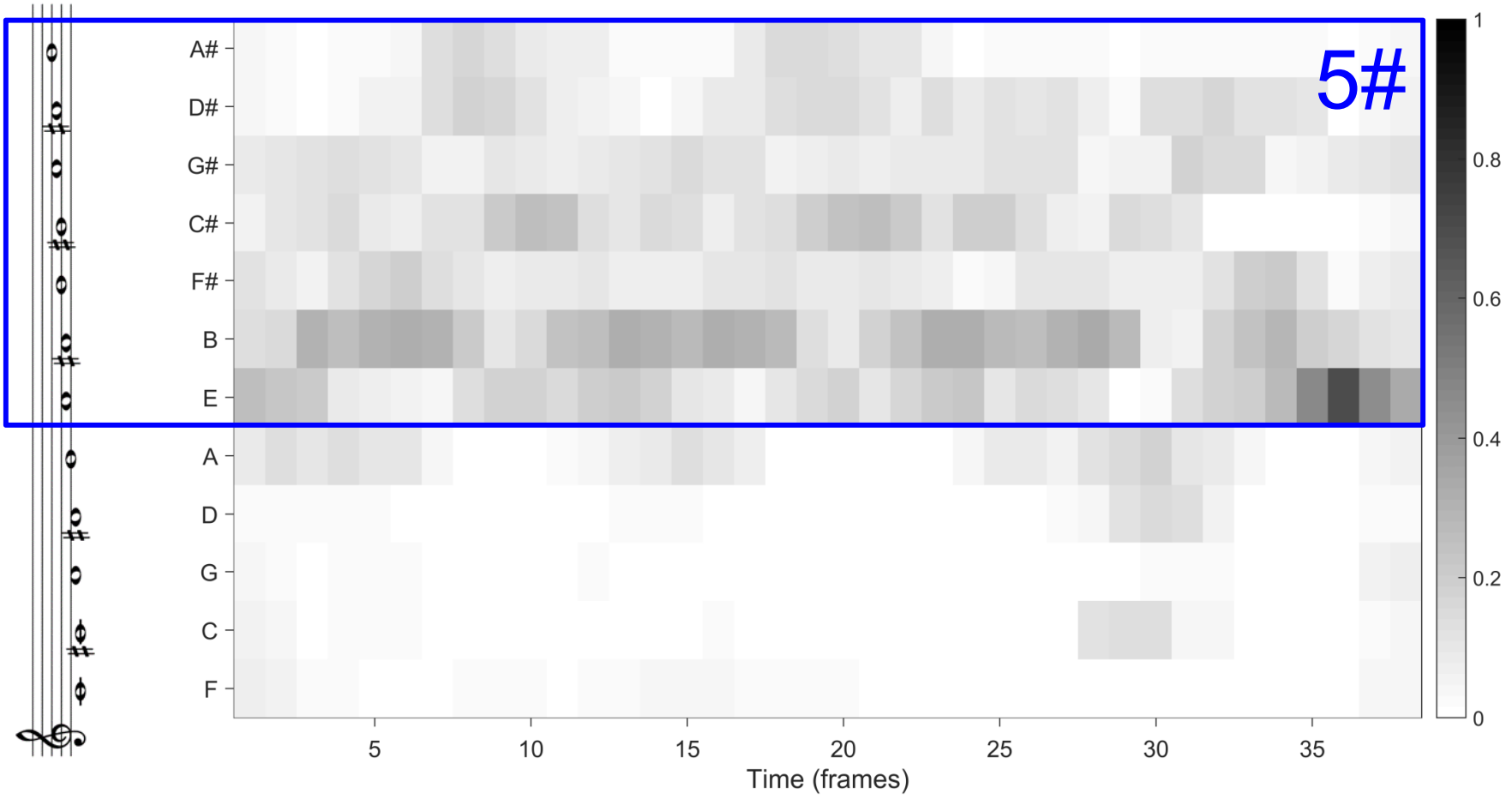
Tonal Structures: Local Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation (7 fifths)



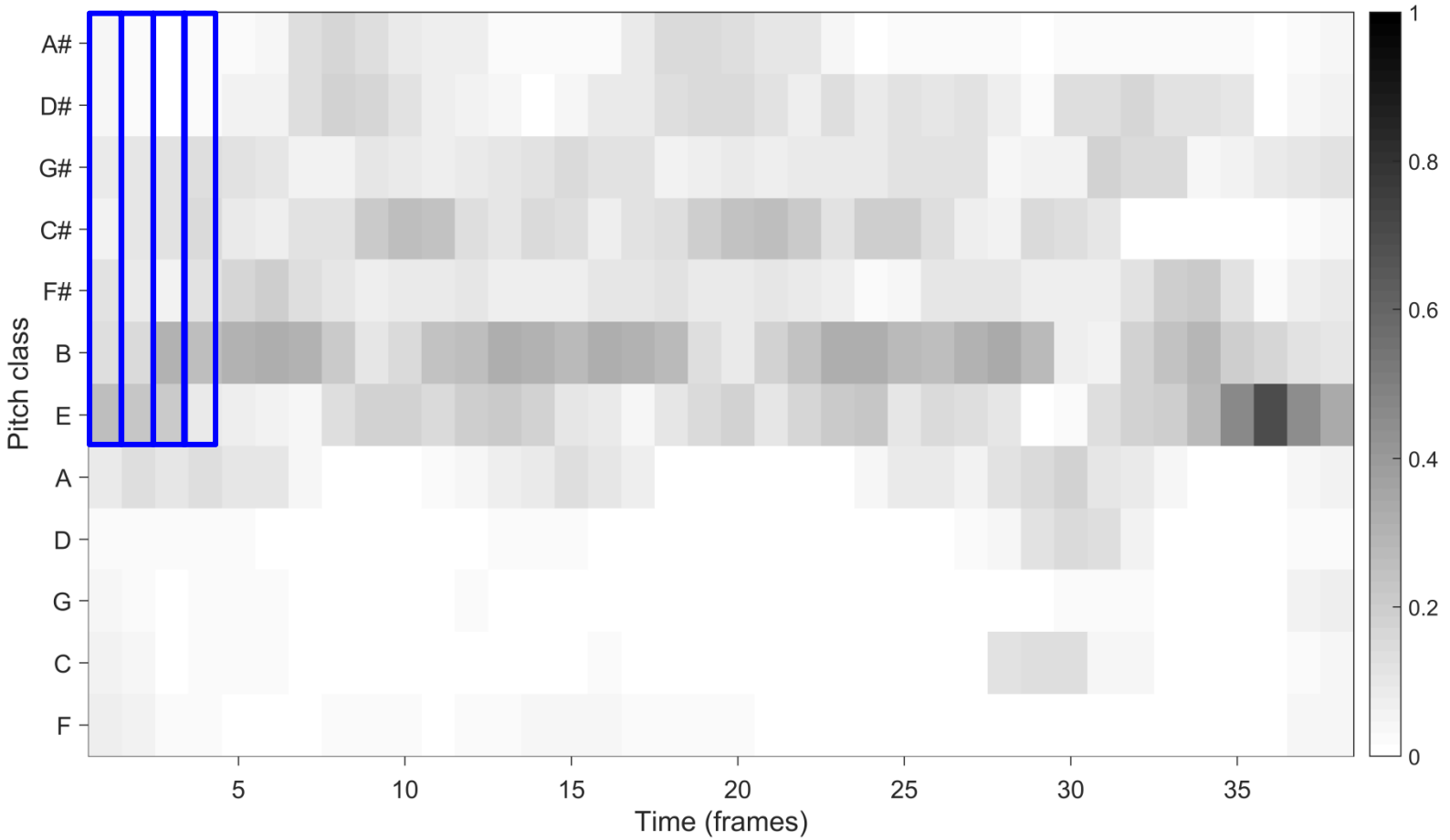
Tonal Structures: Local Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation (7 fifths)



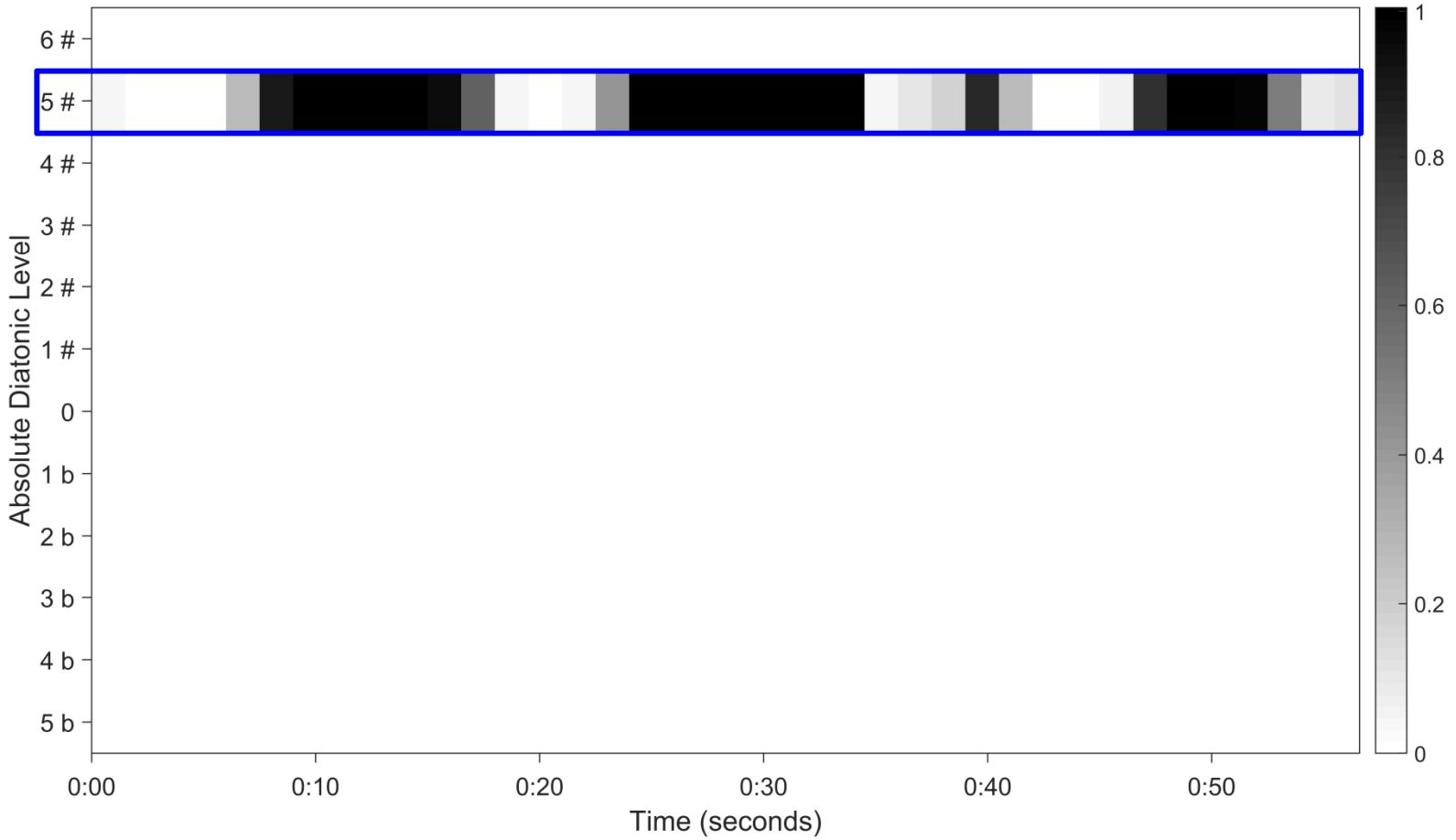
Tonal Structures: Local Diatonic Scales

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



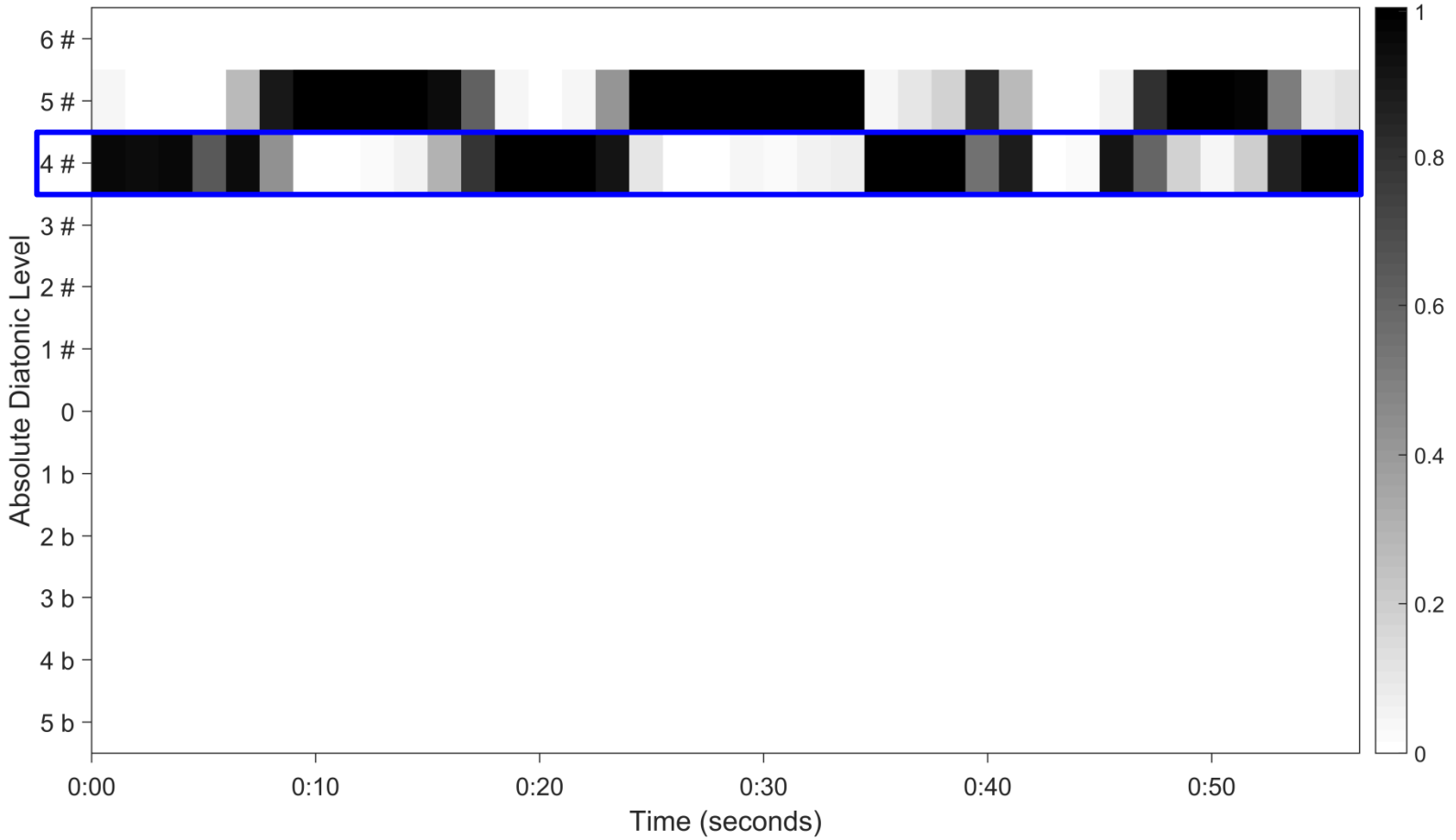
Tonal Structures: Local Diatonic Scales

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



Tonal Structures: Local Diatonic Scales

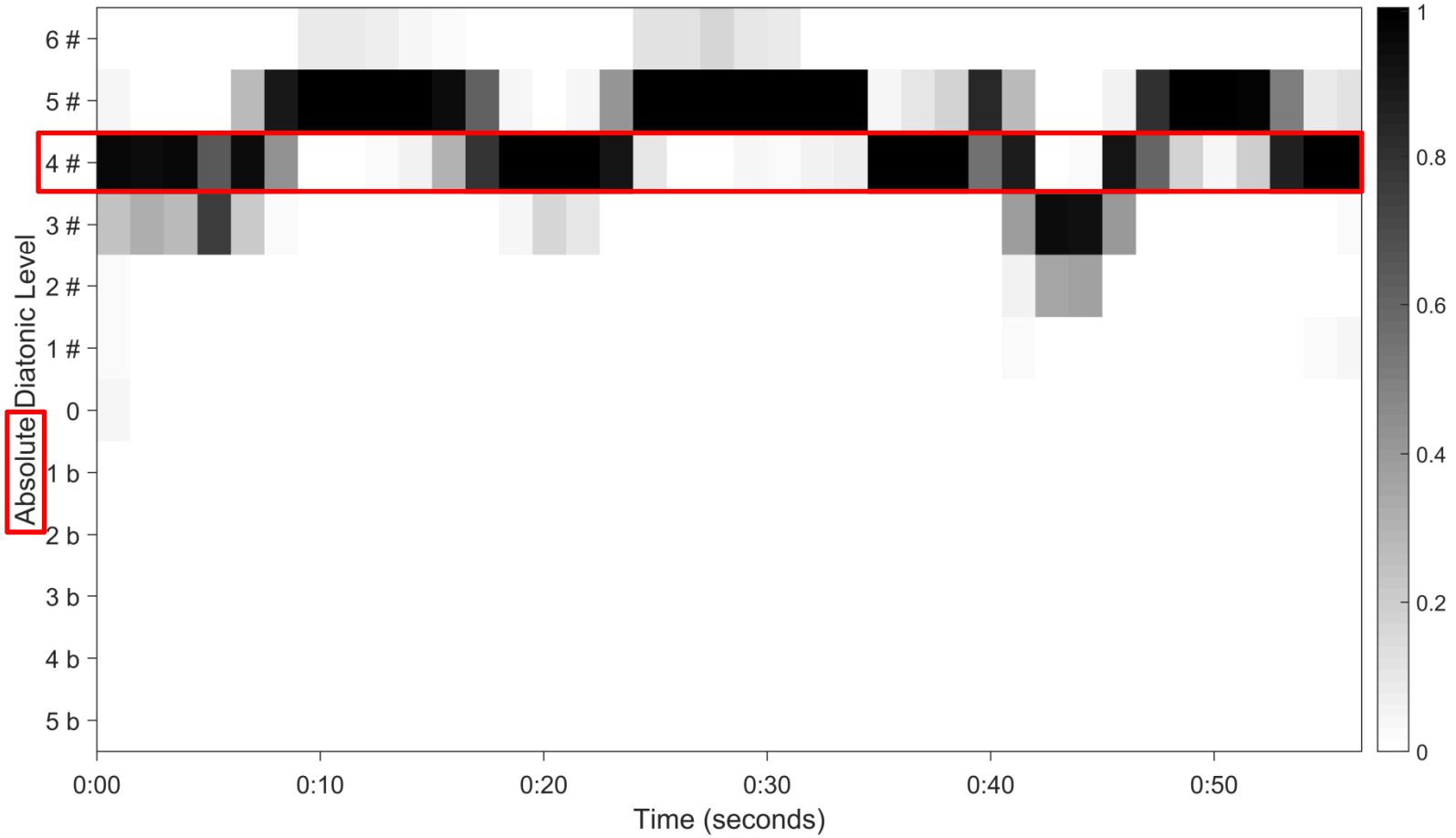
- Choral (Bach) — Diatonic Scale Estimation



Tonal Structures: Local Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation

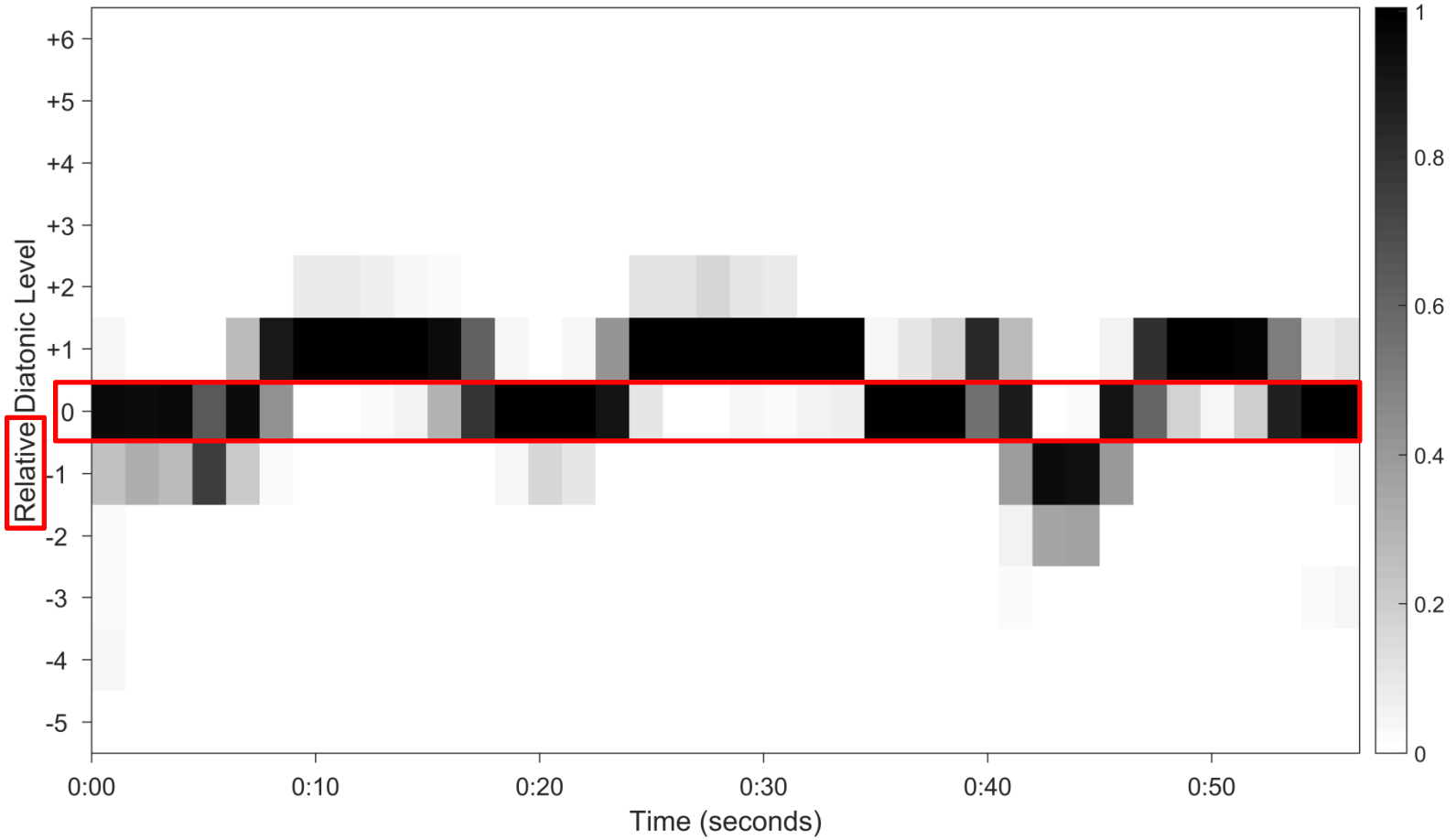
4 #
(E major)



Tonal Structures: Local Diatonic Scales

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

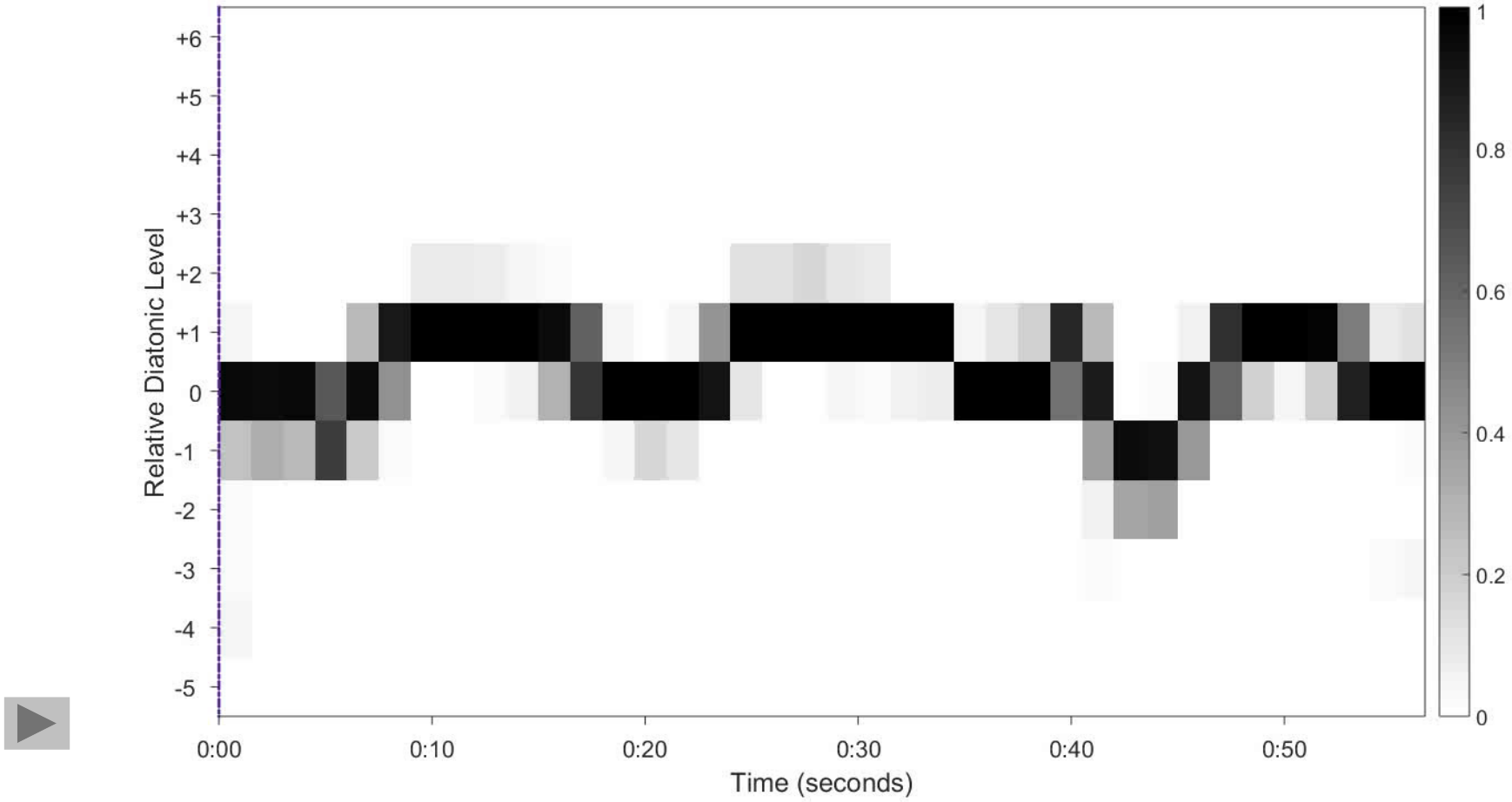
4 #
(E major)



Tonal Structures: Local Diatonic Scales

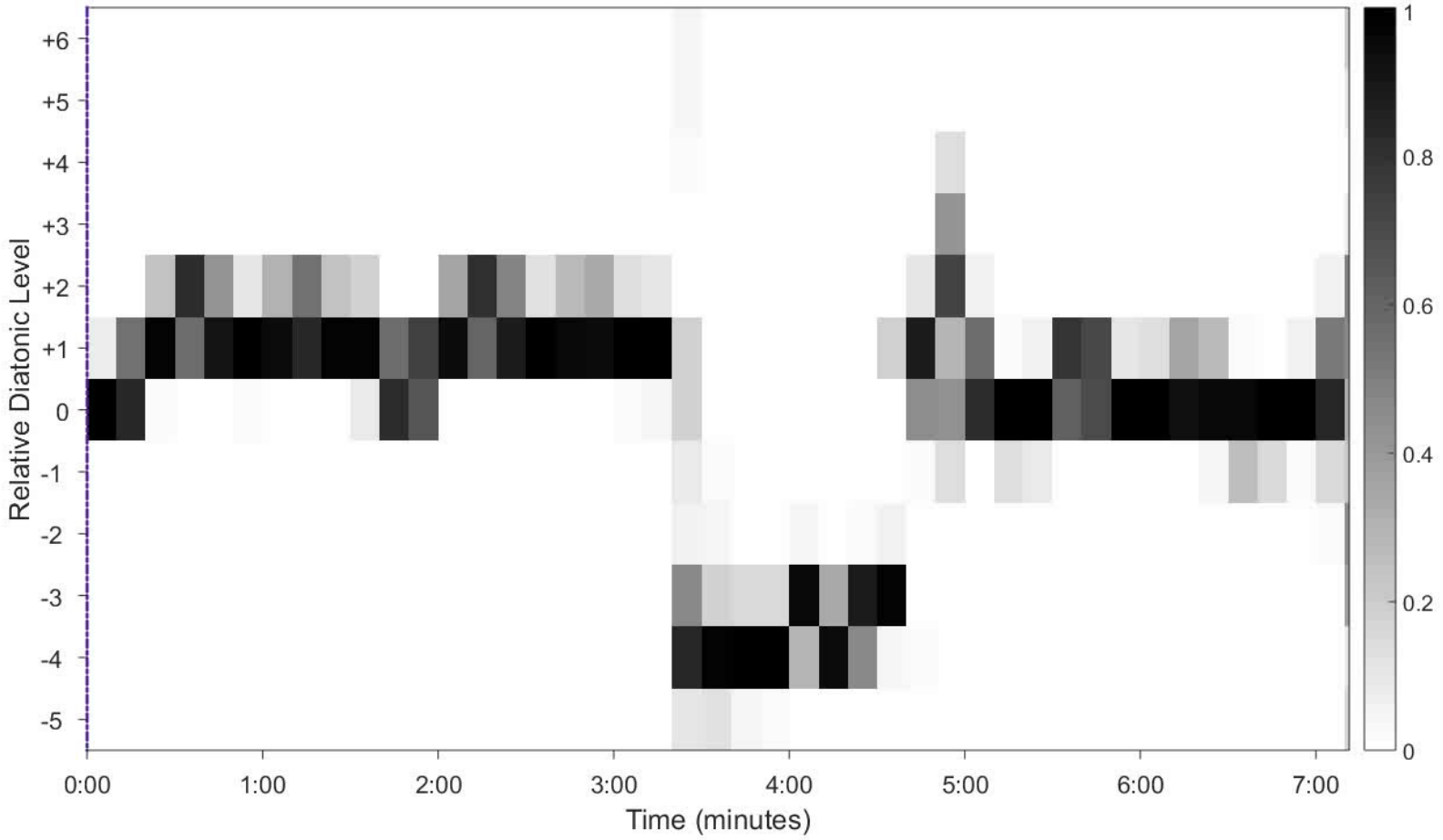
- Choral (Bach) — 0 ≙ 4#

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



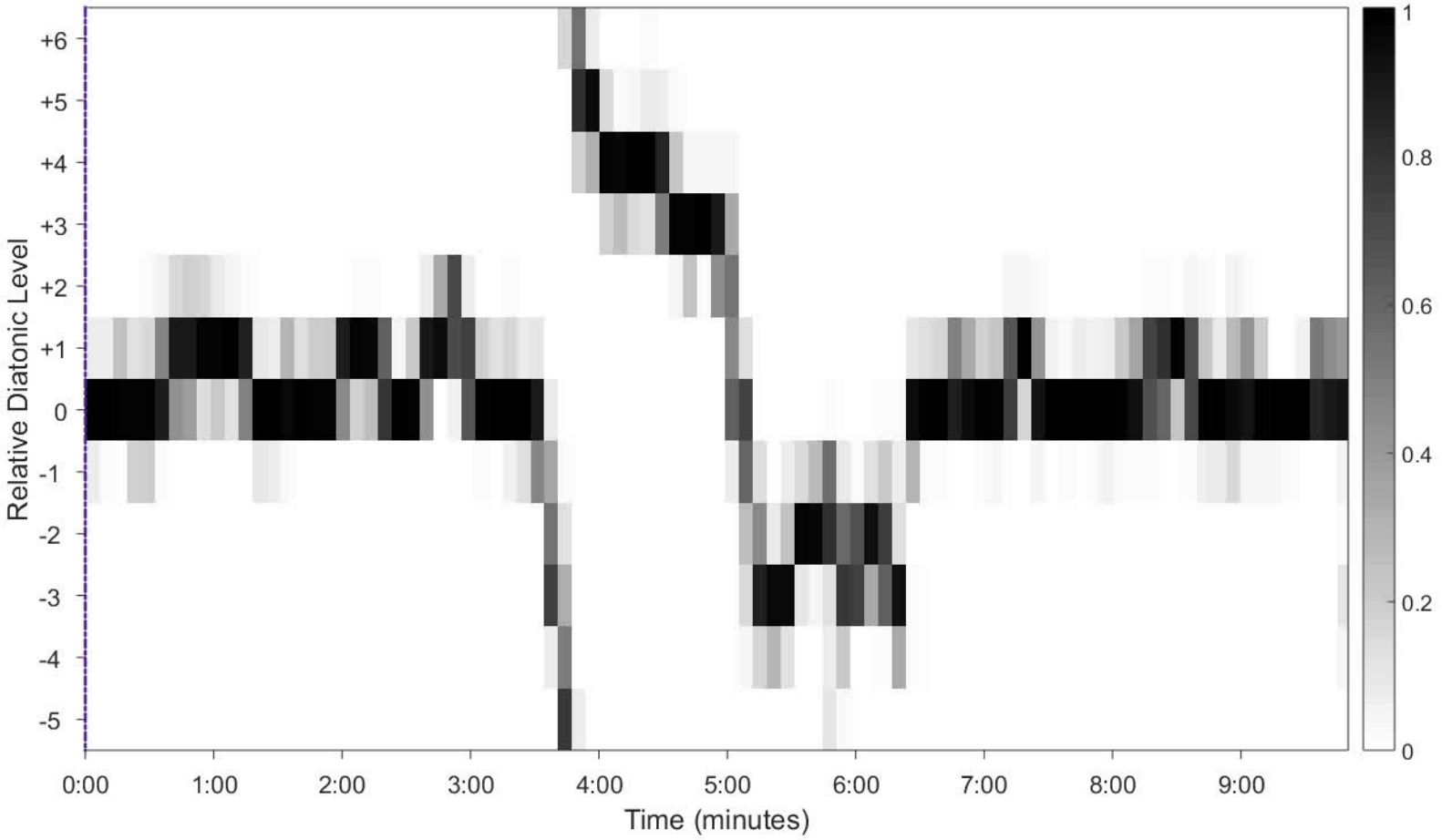
Tonal Structures: Local Diatonic Scales

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



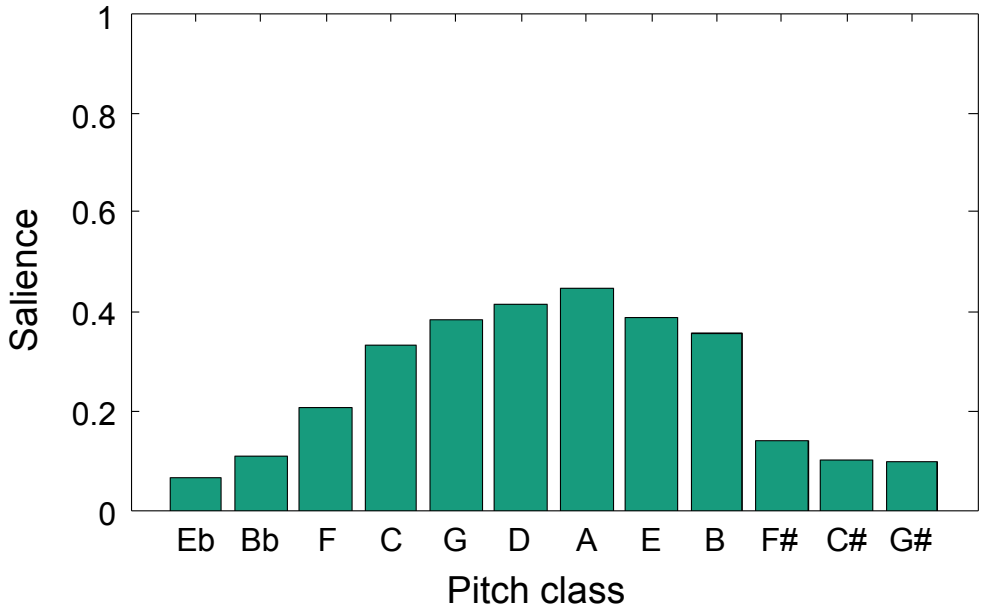
Tonal Structures: Local Diatonic Scales

- R. Wagner, *Die Meistersinger von Nürnberg*, Vorspiel — 0 ≙ 0
  (Polish National Radio Symphony Orchestra, J. Wildner, Naxos 1993)



Tonal Structures: Complexity

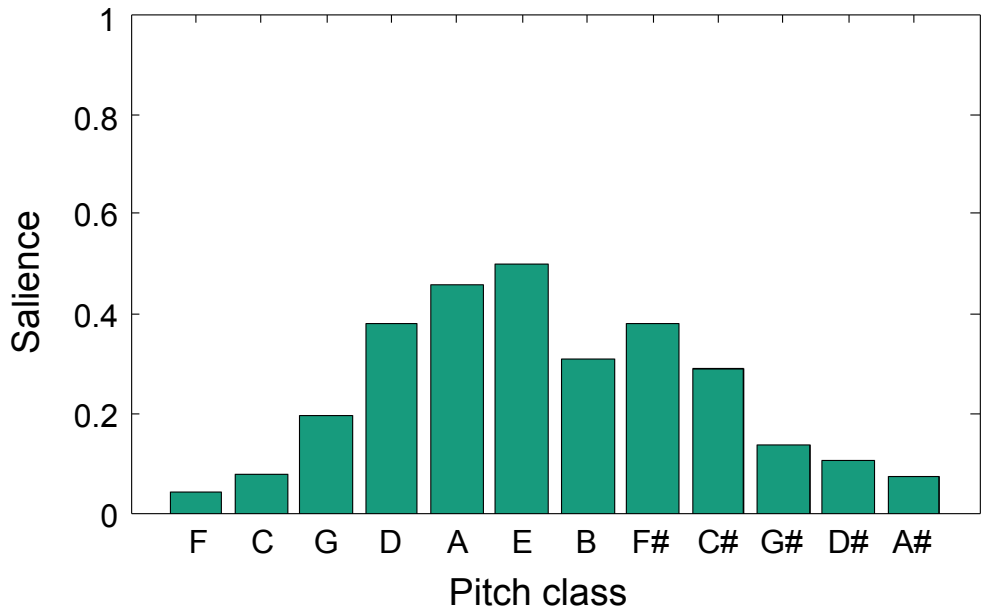
- Global chroma statistics (audio)
- **1567** – G. da Palestrina, Missa de Beata Virgine, Credo



Circle of fifths →

Tonal Structures: Complexity

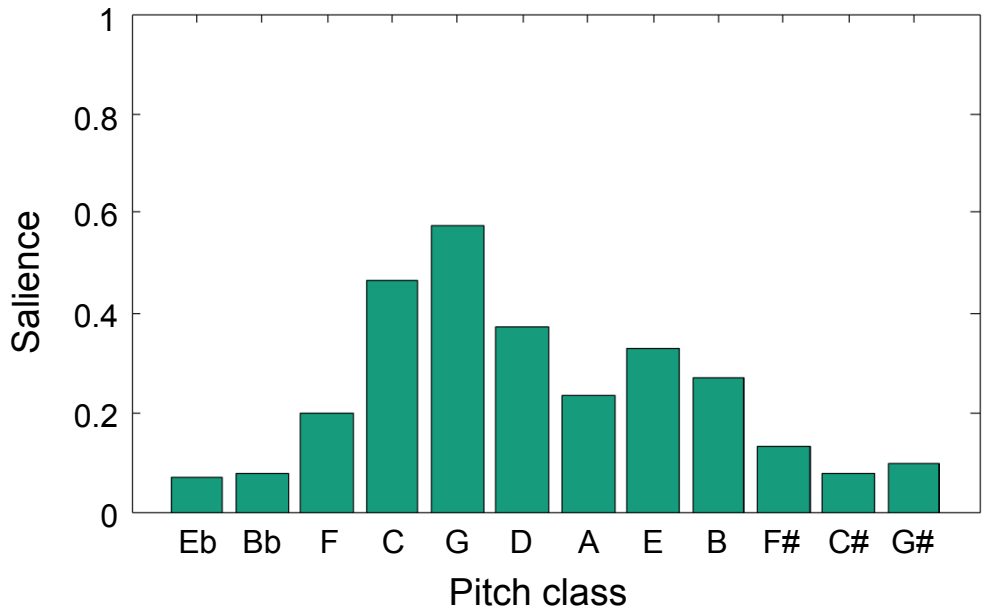
- Global chroma statistics (audio)
- **1725** – J. S. Bach, Orchestral Suite No. 4 BWV 1069, 1. Ouverture (D major)



Circle of fifths →

Tonal Structures: Complexity

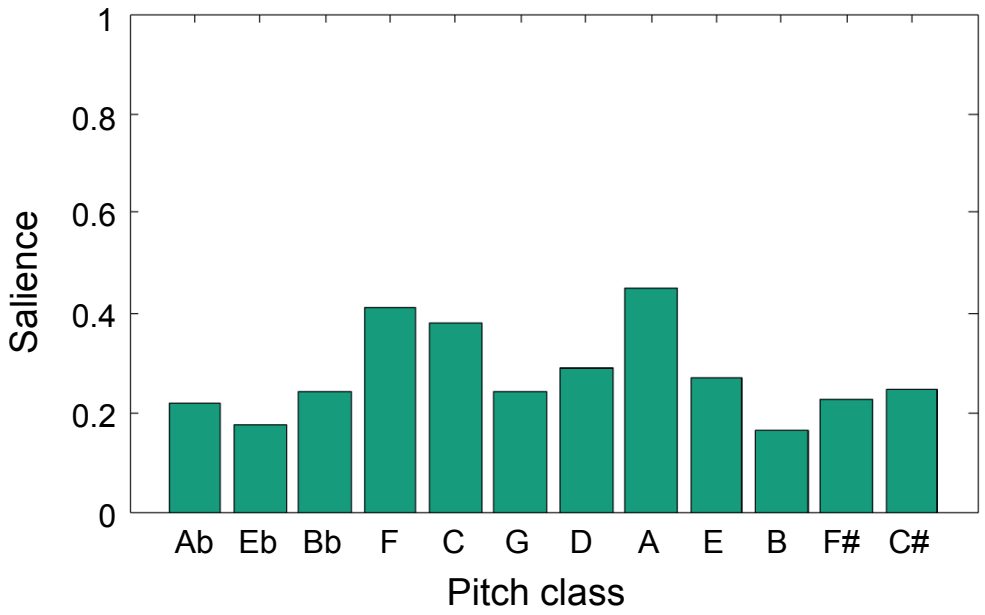
- Global chroma statistics (audio)
- **1783** – W. A. Mozart, „Linz“ symphony KV 425, 1. Adagio / Allegro (C major)



Circle of fifths →

Tonal Structures: Complexity

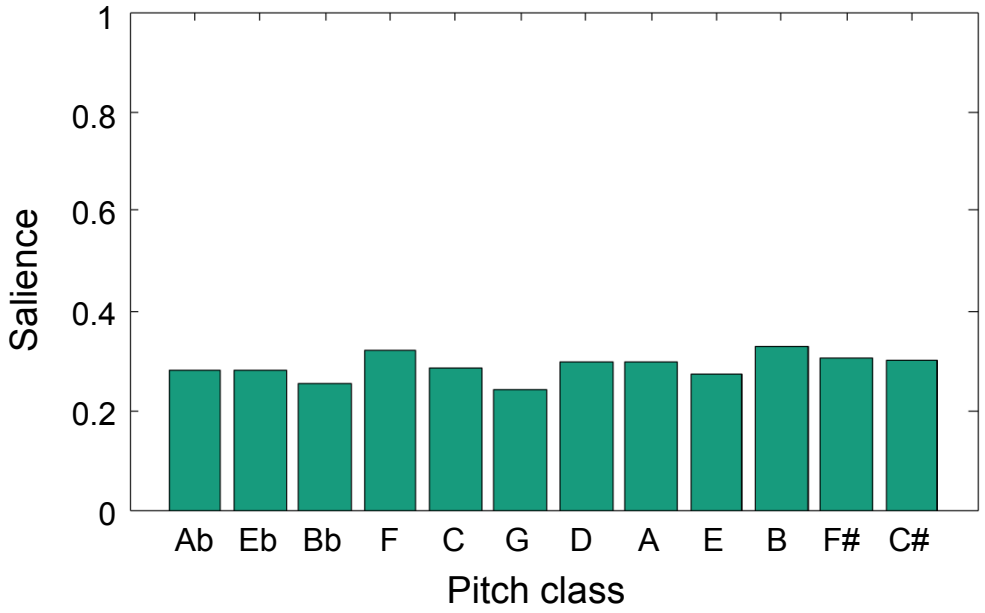
- Global chroma statistics (audio)
- **1883** – J. Brahms, Symphony No. 3, 1. Allegro con brio (F major)



Circle of fifths →

Tonal Structures: Complexity

- Global chroma statistics (audio)
- **1940** – A. Webern, Variations for Orchestra op. 30

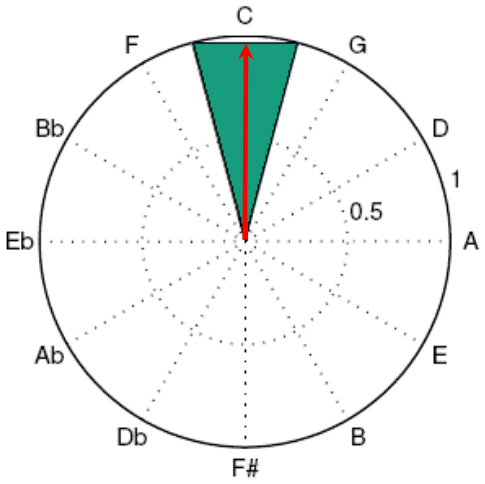


Circle of fifths →

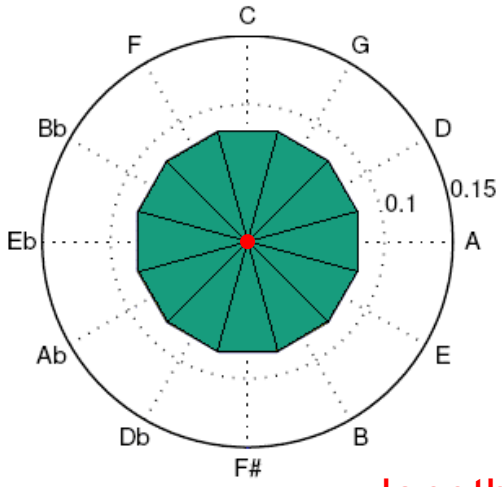
Tonal Structures: Complexity

- Realization of complexity measure Γ
  - Entropy / Flatness measures
  - Distribution over *Circle of Fifths*

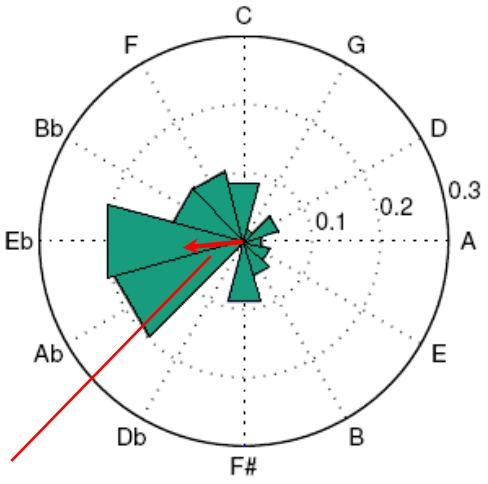
$\Gamma = 0$



$\Gamma = 1$



$0 < \Gamma < 1$

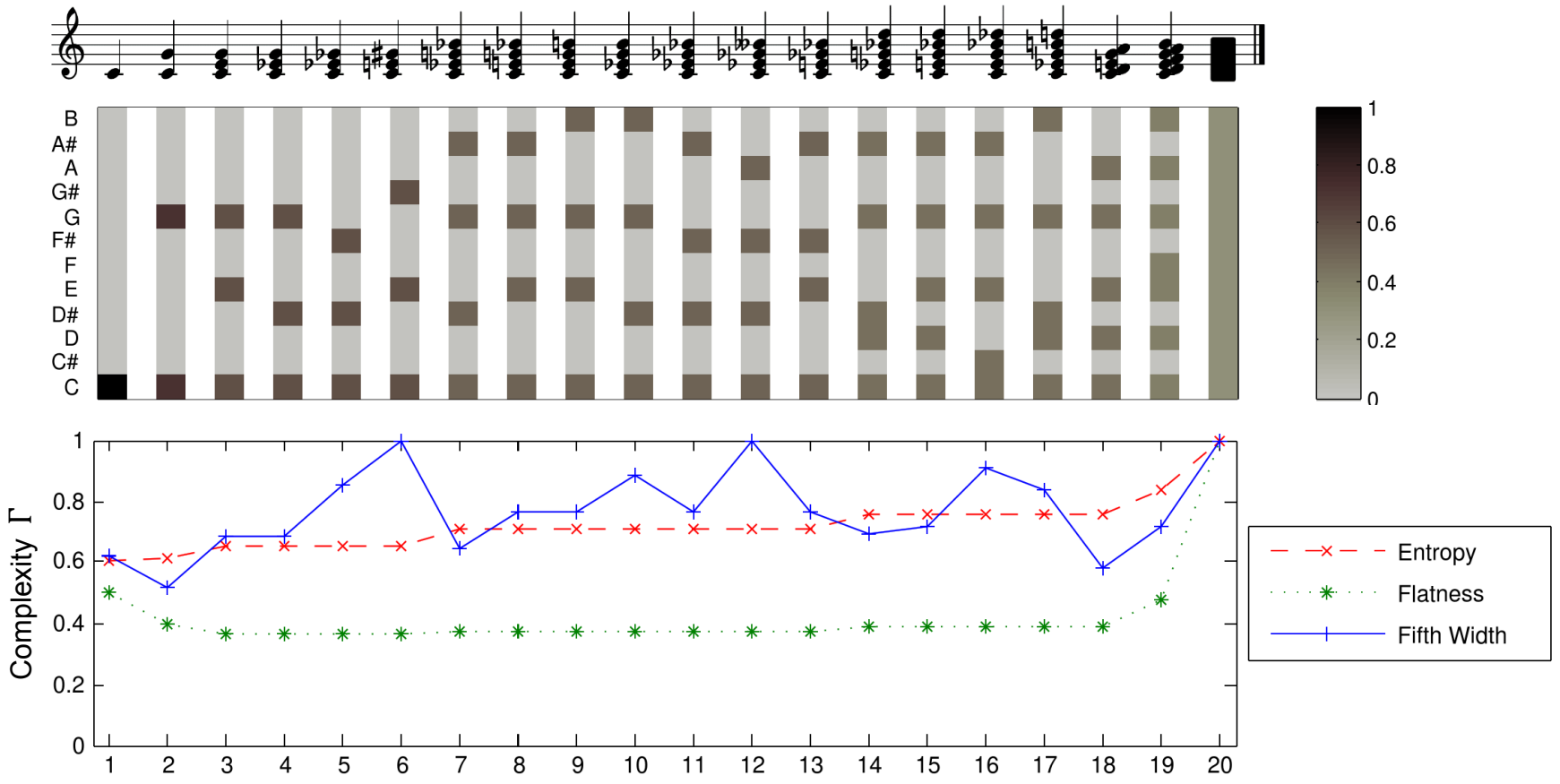


length r

$$\Gamma = \sqrt{1 - r}$$

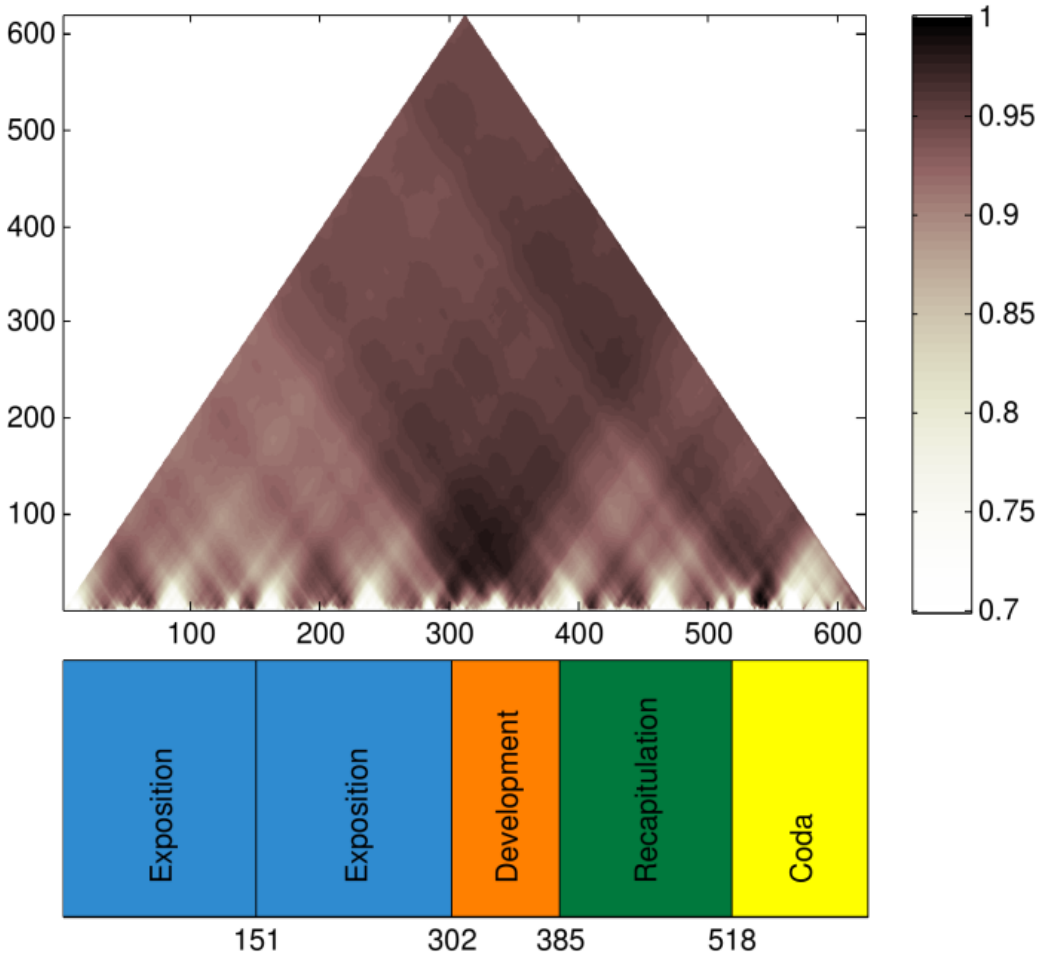
- Relating to different time scales!

Tonal Structures: Complexity



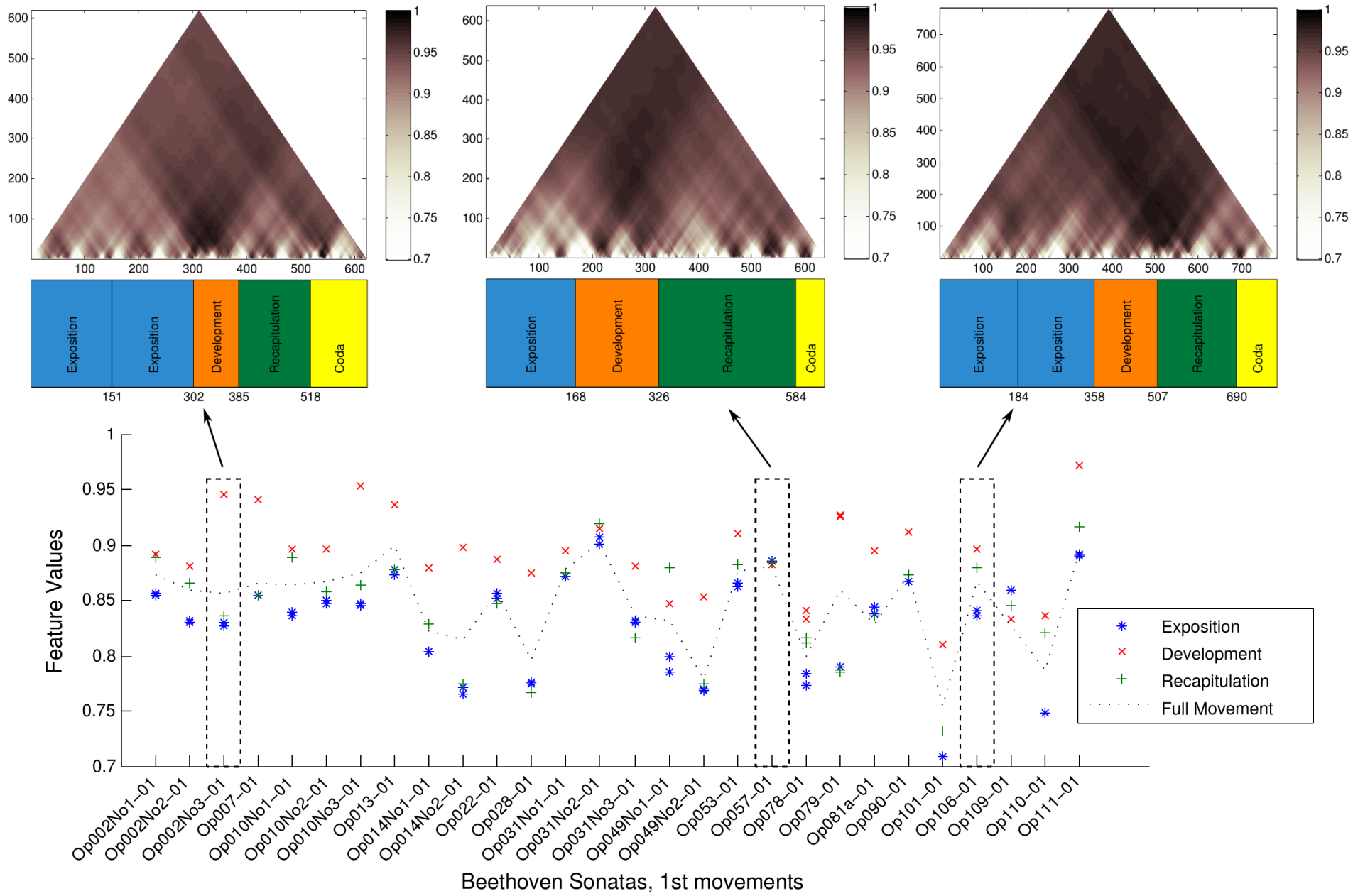
Weiss / Müller, *Quantifying and Visualizing Tonal Complexity*, CIM 2014

Tonal Structures: Complexity

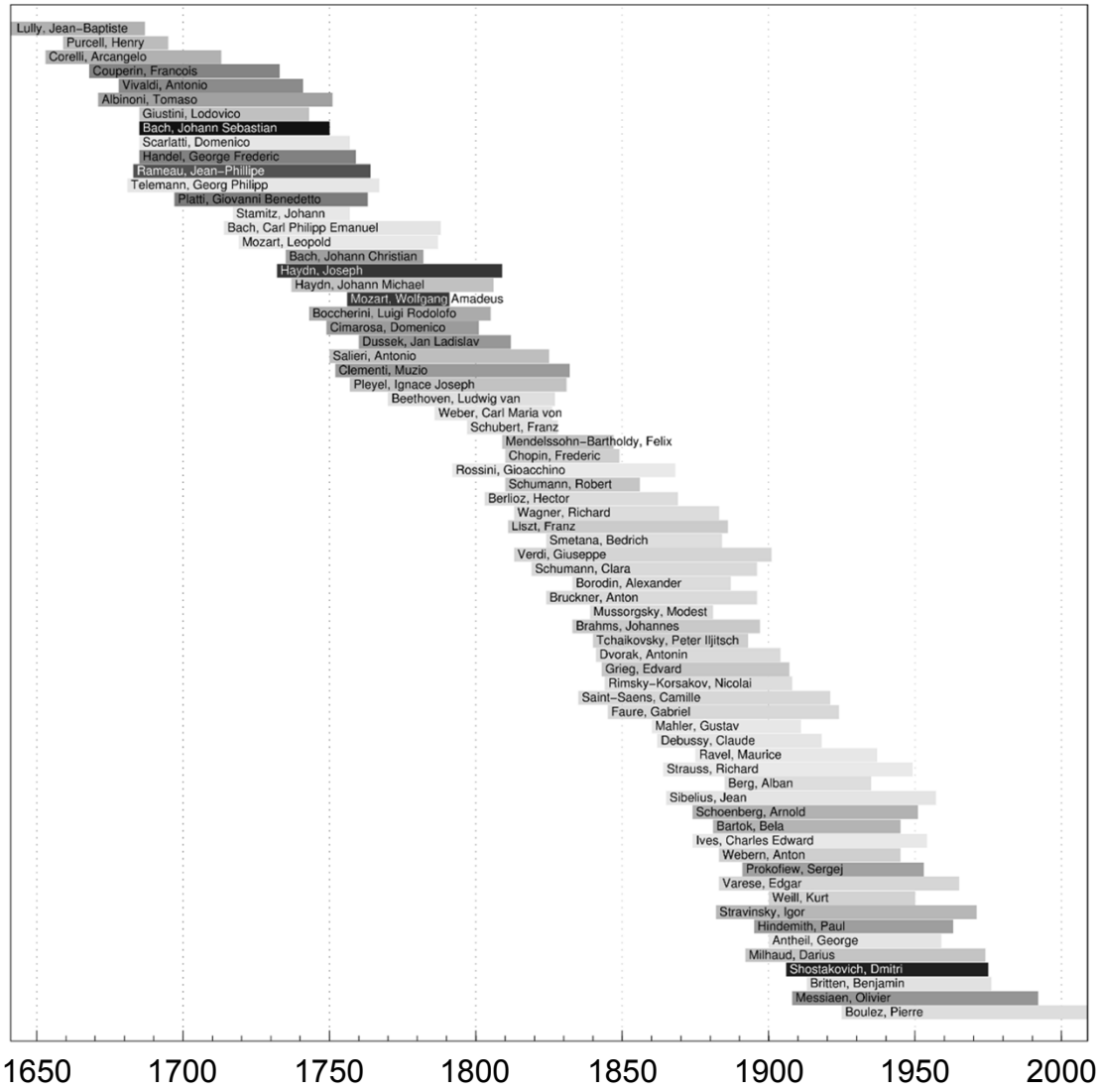


L. van Beethoven
Sonata Op. 2, No. 3
1st movement

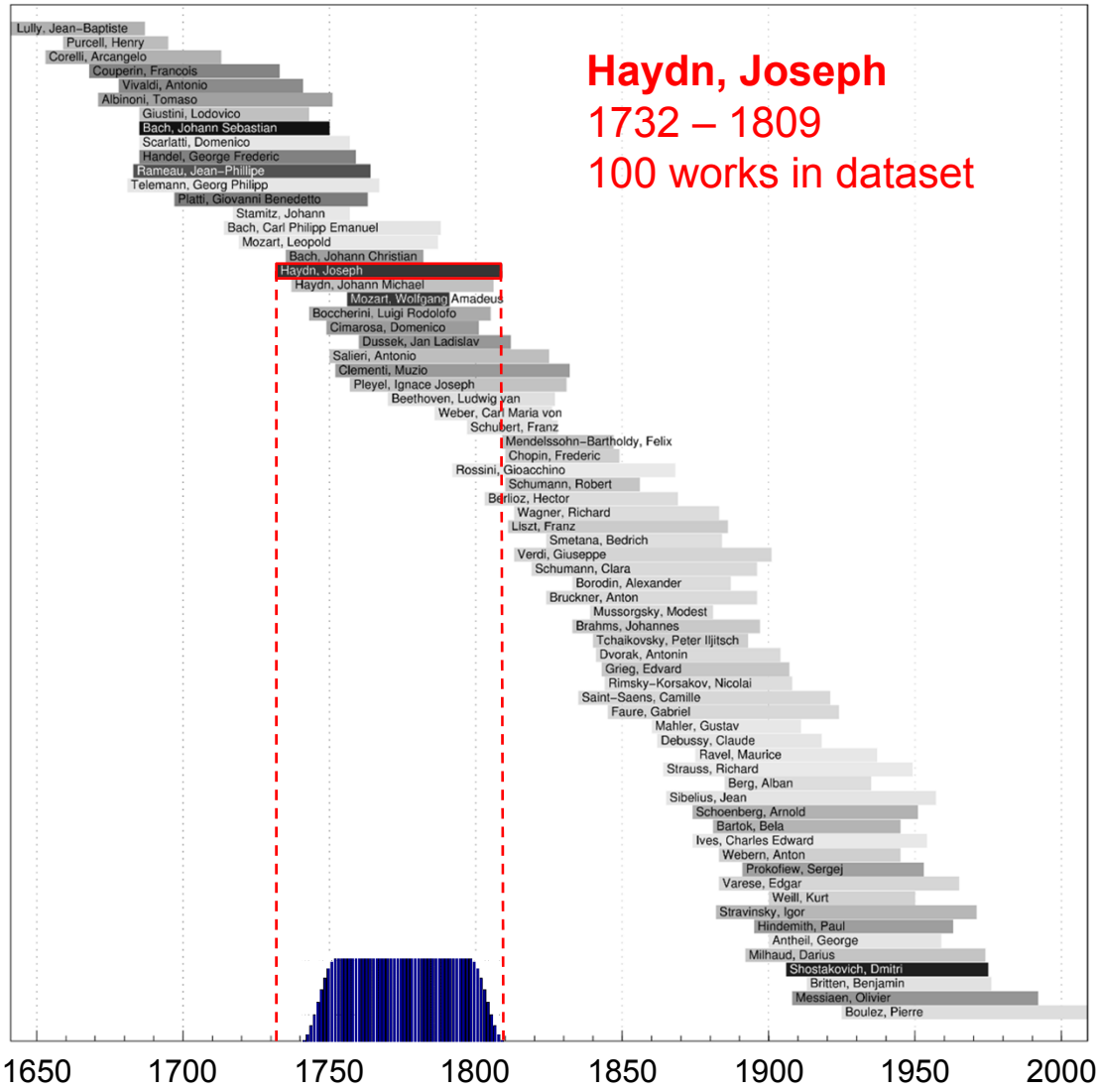
Tonal Structures: Complexity

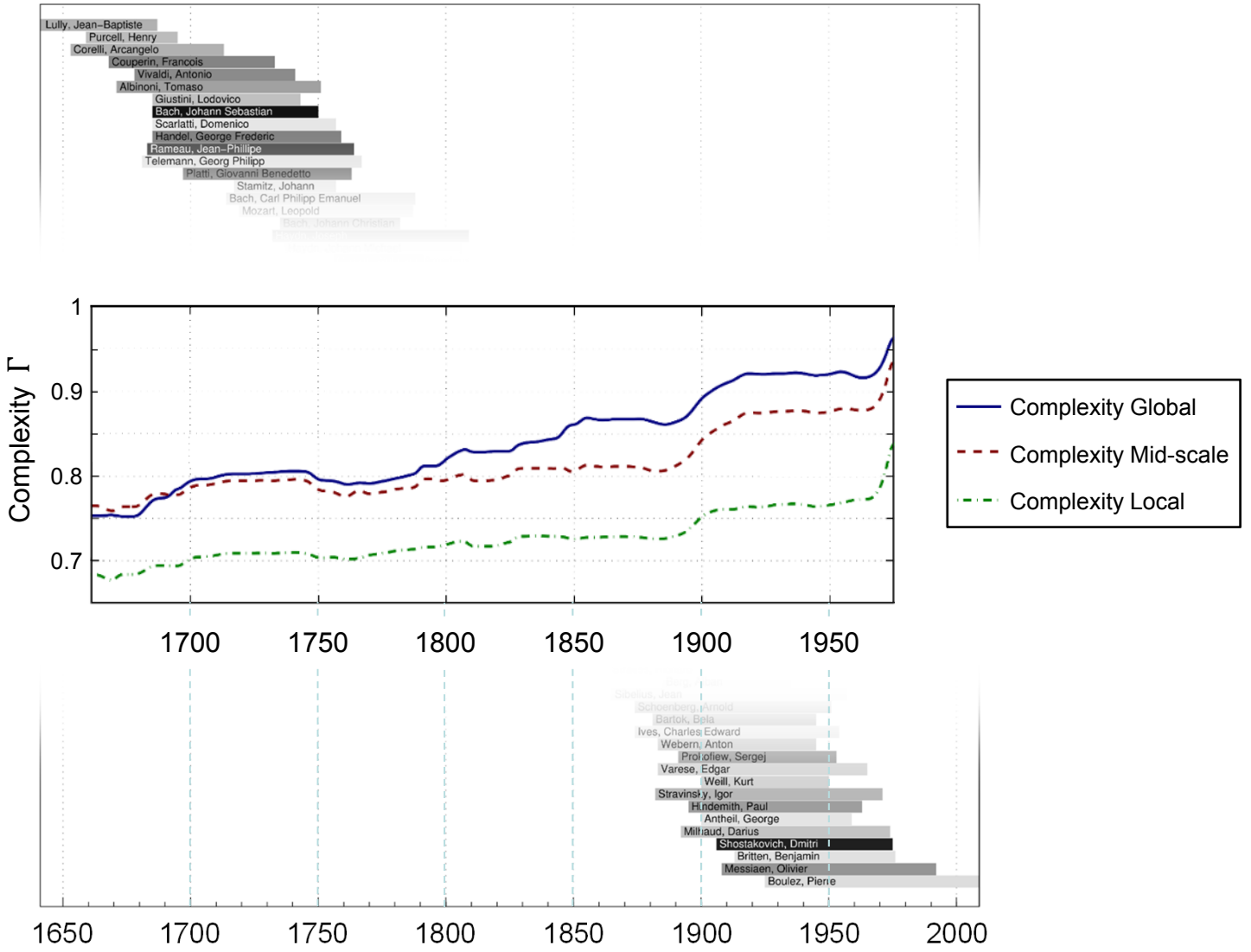


Tonal Structures: Complexity



Tonal Structures: Complexity



Haydn, Joseph
1732 – 1809
100 works in dataset

Tonal Structures: Complexity