

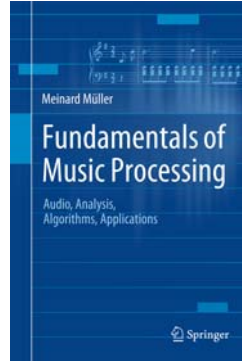
Meisterklasse HfM Karlsruhe
Music Information Retrieval
Harmony Analysis

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

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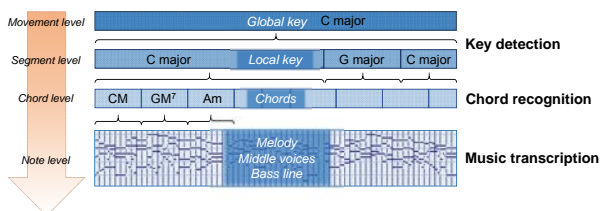
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Dissertation: Tonality-Based Style Analysis

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

Ouverture zu Fidelio Ludwig van Beethoven

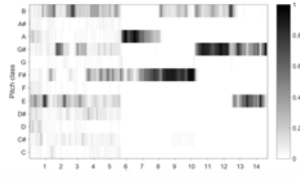
L. van Beethoven,
 Fidelio, Overture,
 Slovak Philharmonic

Recall: Chroma Representations

- Orchestra



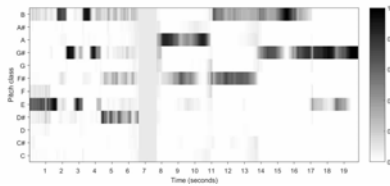
L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



- Piano



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

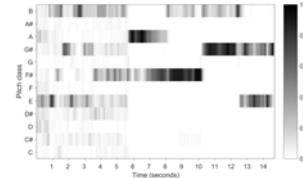


Recall: Chroma Representations

- Orchestra



L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



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

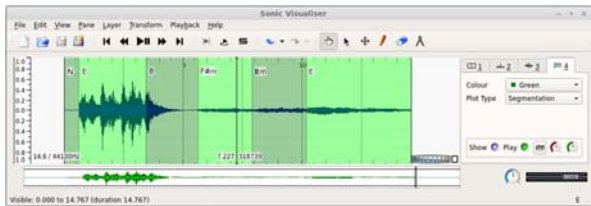
Müller / Ewert, *Towards Timbre-Invariant Audio Features for Harmony-Based Music*, IEEE TASLP, 2010

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

Tonal Structures: Chords

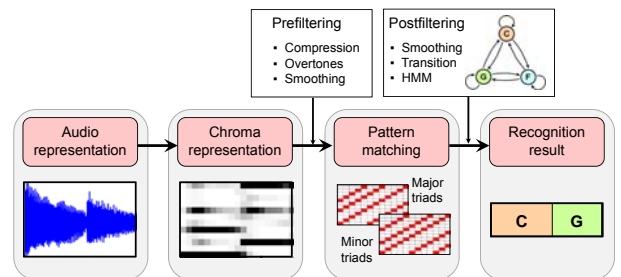
- Chord recognition

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

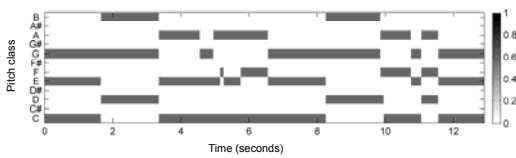


Sonic Visualizer, Chordino Vamp Plugin
(Queen Mary University of London)

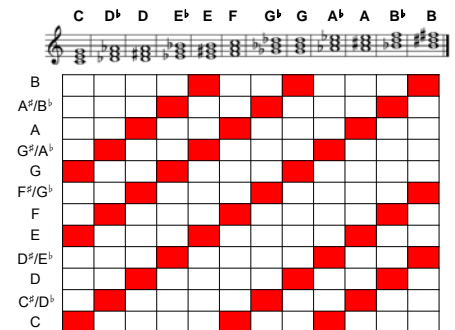
Tonal Structures: Chords



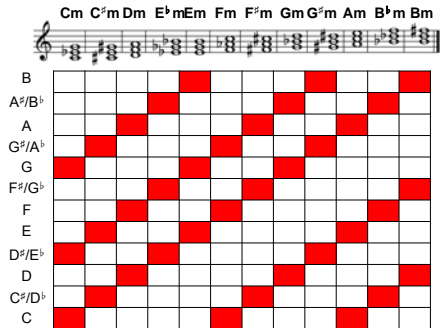
Tonal Structures: Chords



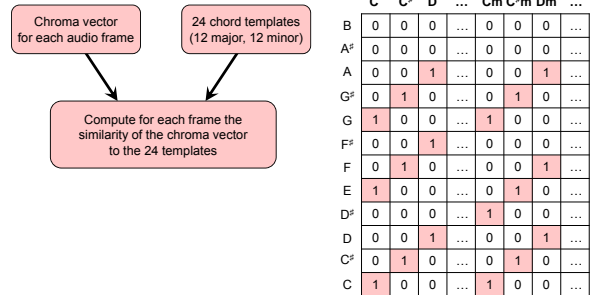
Chord Recognition: Basics



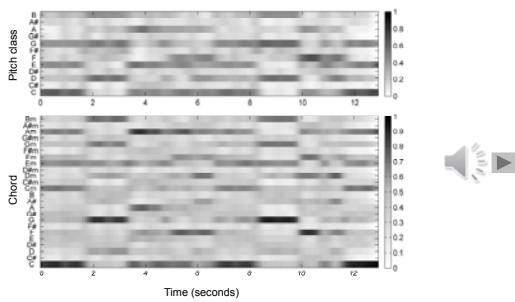
Chord Recognition: Basics



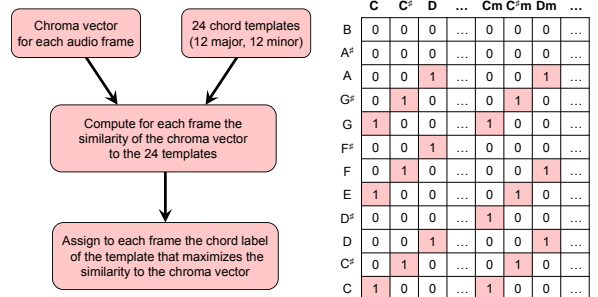
Chord Recognition: Template Matching



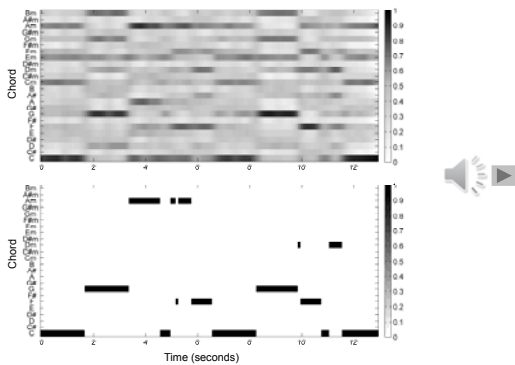
Chord Recognition: Template Matching



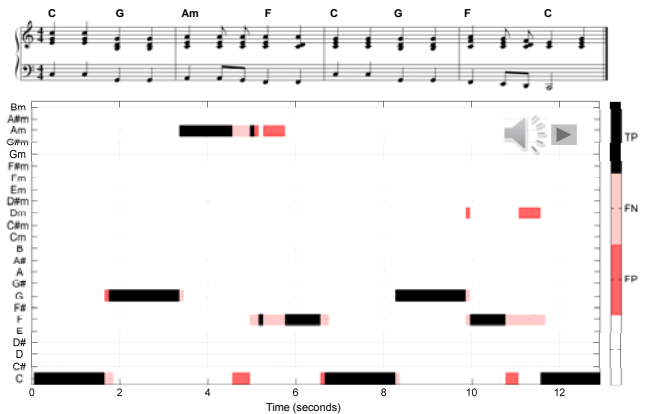
Chord Recognition: Label Assignment



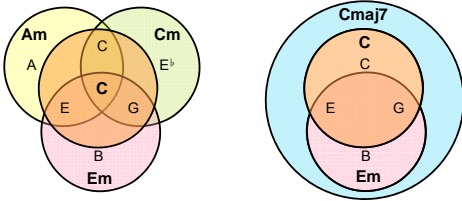
Chord Recognition: Label Assignment



Chord Recognition: Evaluation

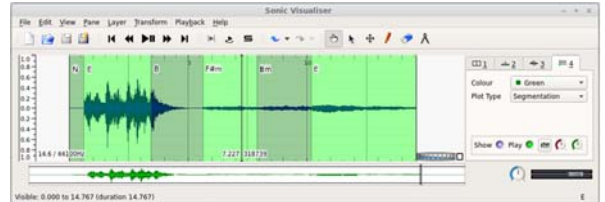


Chord Recognition: Challenges



Tonal Structures: Chords

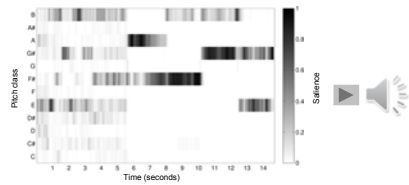
- Chord recognition
 - Typically: Feature extraction, pattern matching, filtering (HMM)
 - „Out-of-the-box“ solutions



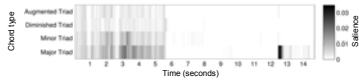
Sonic Visualizer, Chordino Vamp Plugin
(Queen Mary University of London)

Tonal Structures: Chord & Interval Categories

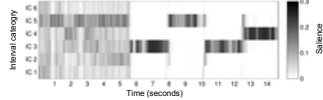
- Chromagram



- Chord type



- Interval categories



Tonal Structures: Final Chord

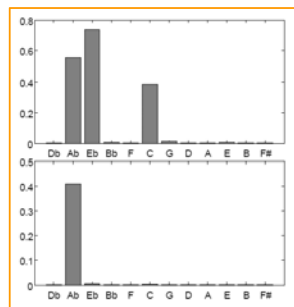
- Global key detection – typical approach:
 - Full piece chroma statistics
 - Template matching
- Idea: Use particular role of **final chord**



Tonal Structures: Final Chord

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

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



Tonal Structures: Final Chord

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

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



- 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

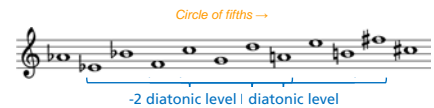
- State-of-the-art
 - Learning of pitch class profiles
 - Weighting of beginning and ending sections (15 seconds)

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

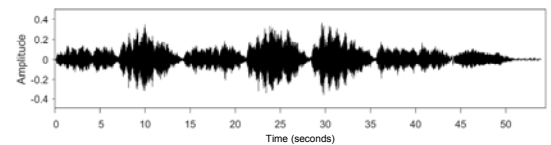


Tonal Structures: Local Diatonic Scales

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

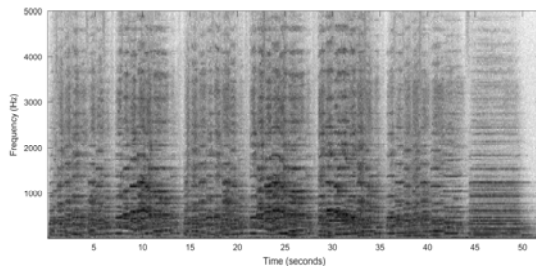
Tonal Structures: Local Diatonic Scales

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



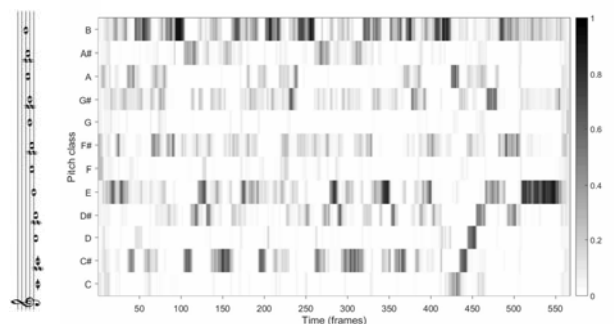
Tonal Structures: Local Diatonic Scales

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



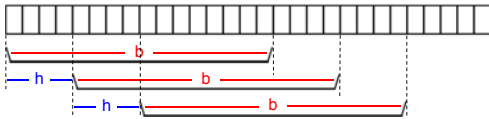
Tonal Structures: Local Diatonic Scales

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



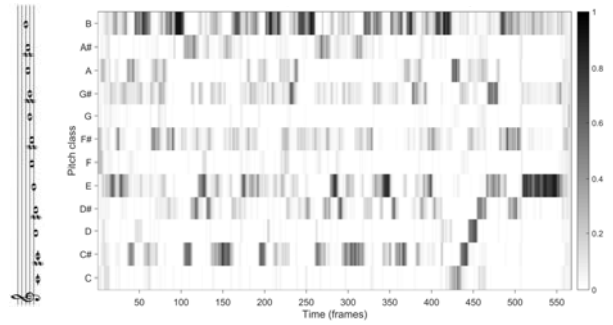
Tonal Structures: Local Diatonic Scales

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



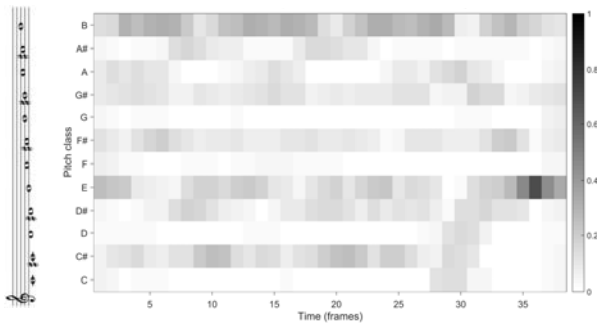
Tonal Structures: Local Diatonic Scales

- Choral (Bach)



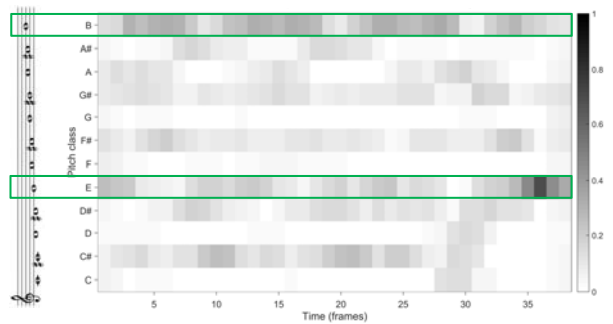
Tonal Structures: Local Diatonic Scales

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



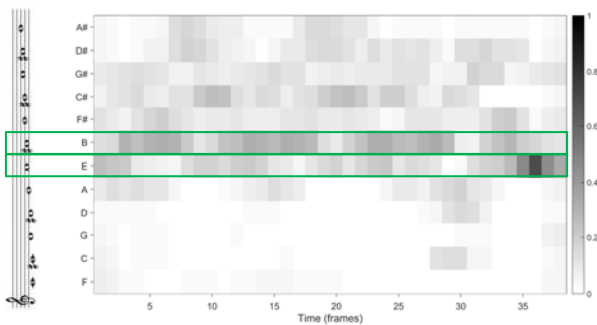
Tonal Structures: Local Diatonic Scales

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



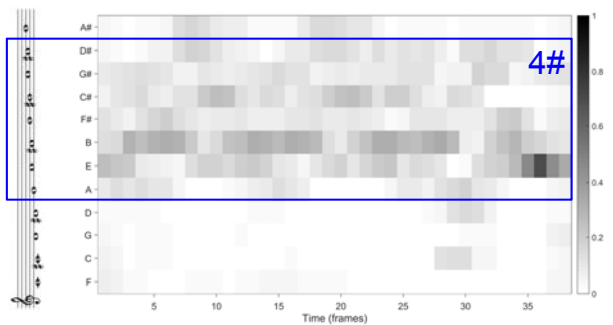
Tonal Structures: Local Diatonic Scales

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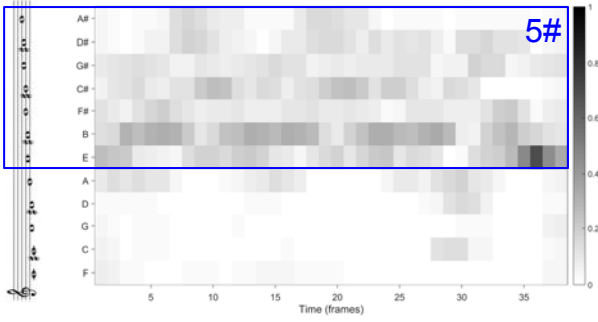
Tonal Structures: Local Diatonic Scales

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



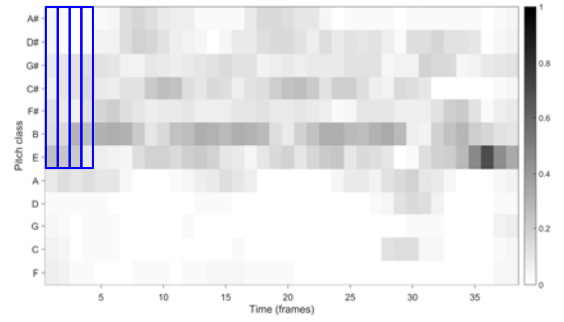
Tonal Structures: Local Diatonic Scales

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



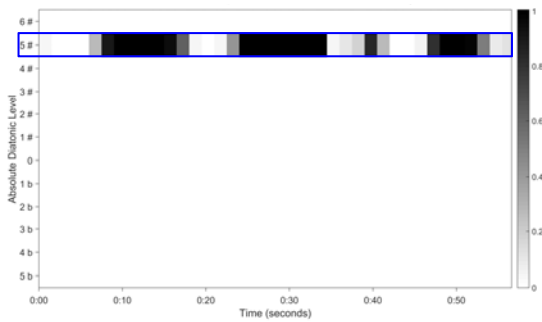
Tonal Structures: Local Diatonic Scales

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



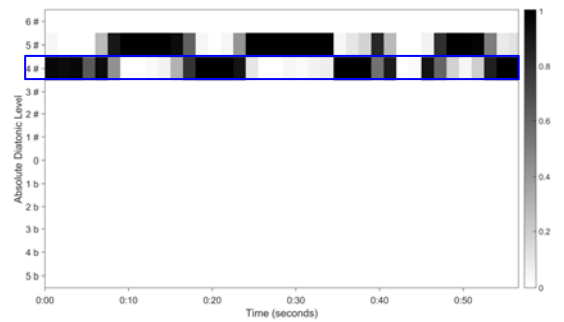
Tonal Structures: Local Diatonic Scales

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



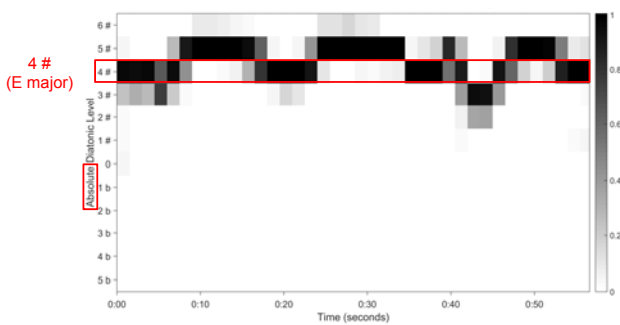
Tonal Structures: Local Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation



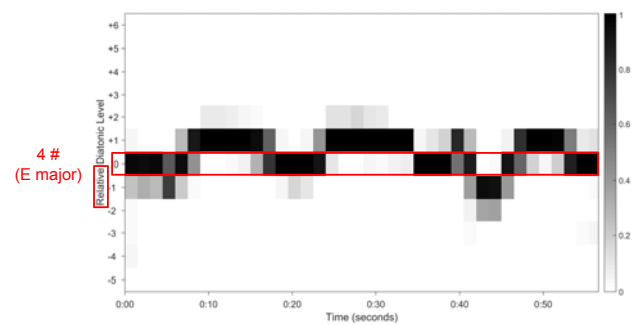
Tonal Structures: Local Diatonic Scales

- Choral (Bach) — Diatonic Scale Estimation



Tonal Structures: Local Diatonic Scales

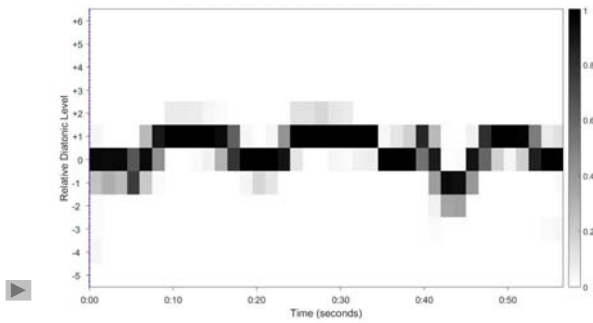
- Choral (Bach) — Diatonic Scale Estimation: Shift to global key



Tonal Structures: Local Diatonic Scales

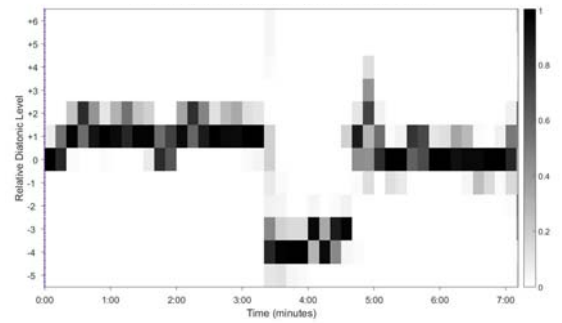
- Choral (Bach) — $0 \triangle 4\#$

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



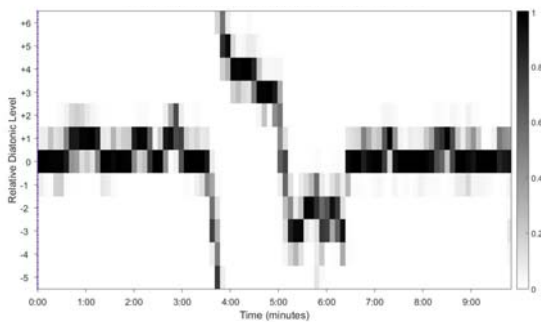
Tonal Structures: Local Diatonic Scales

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



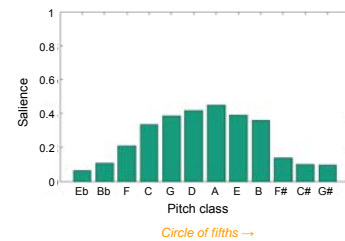
Tonal Structures: Local Diatonic Scales

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



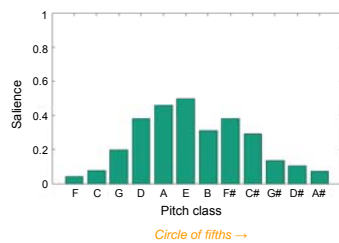
Tonal Structures: Complexity

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



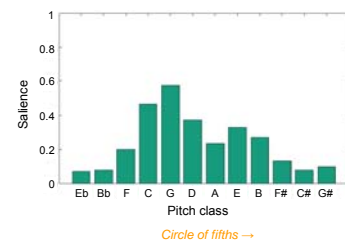
Tonal Structures: Complexity

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



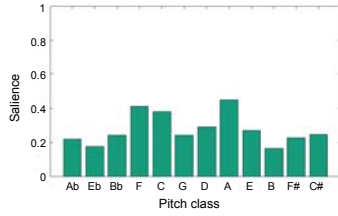
Tonal Structures: Complexity

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



Tonal Structures: Complexity

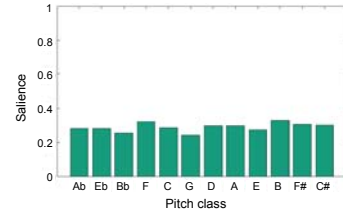
- Global chroma statistics (audio)
- 1883 – J. Brahms, Symphony No. 3, 1. Allegro con brio (F major)



Circle of fifths →

Tonal Structures: Complexity

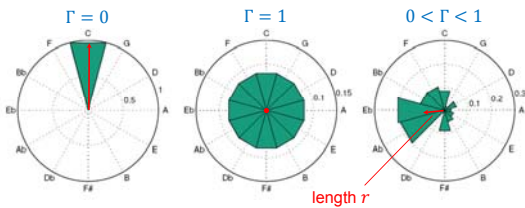
- Global chroma statistics (audio)
- 1940 – A. Webern, Variations for Orchestra op. 30



Circle of fifths →

Tonal Structures: Complexity

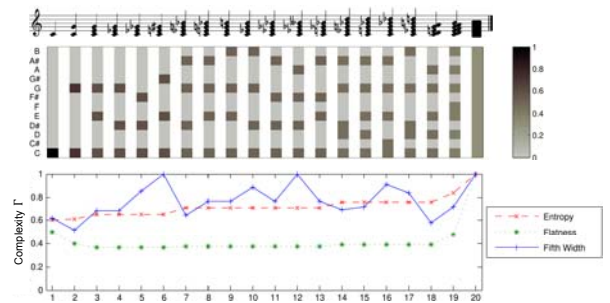
- Realization of complexity measure Γ
 - Entropy / Flatness measures
 - Distribution over Circle of Fifths



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

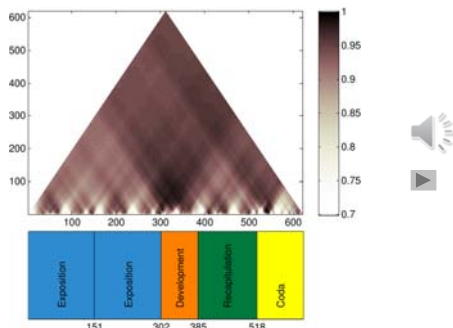
- Relating to different time scales!

Tonal Structures: Complexity



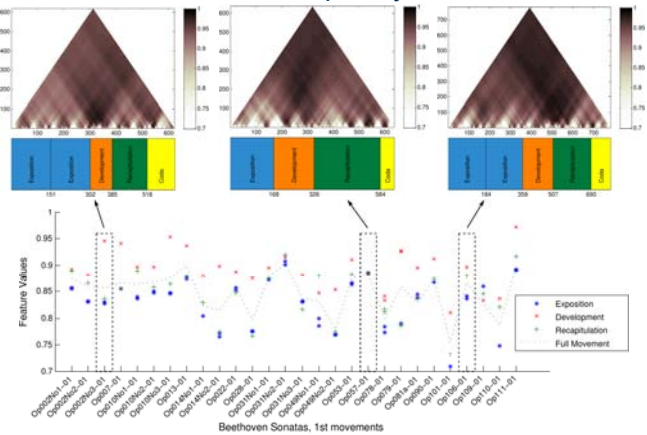
Weiss / Müller, Quantifying and Visualizing Tonal Complexity, CIM 2014

Tonal Structures: Complexity

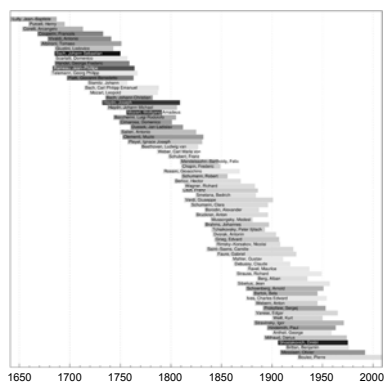


L. van Beethoven
Sonata Op. 2, No. 3
1st movement

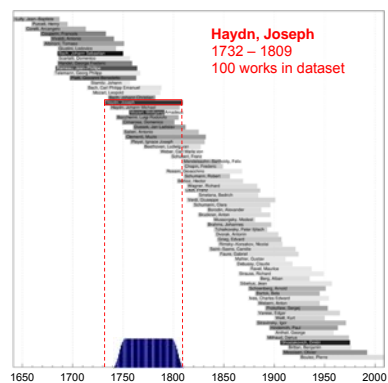
Tonal Structures: Complexity



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