

Neue Wege für die Musikforschung

Meinard Müller

International Audio Laboratories Erlangen
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Festkolloquium

70 Jahre Musikforschung an der UoS

11. November 2022

Meinard Müller: Research Group

- Michael Krause
- Yigitcan Özer
- Simon Schwär
- Johannes Zeitler
- Vlora Arifi-Müller
- Peter Meier (external)



Meinard Müller



- Mathematics (Diplom/Master, 1997)
Computer Science (PhD, 2001)
Information Retrieval (Habilitation, 2007)

Universität Bonn



- Senior Researcher (2007-2012)

MPI für Informatik, Saarland



- Professor Semantic Audio Processing (since 2012)

Universität Erlangen-Nürnberg



Meinard Müller



- Mathematics (Diplom/Master, 1997)
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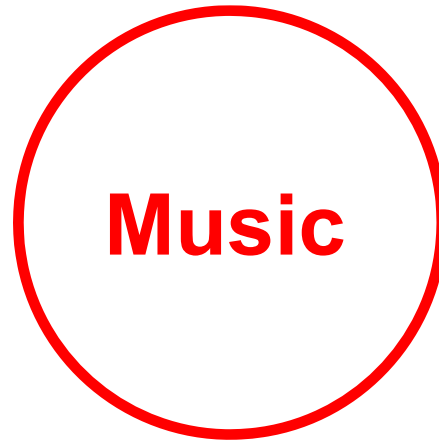
- Senior Researcher (2007-2012)
MPI für Informatik, Saarland

Cluster of Excellence on
**Multimodal Computing
and Interaction**

- Professor Semantic Audio Processing (since 2012)
Universität Erlangen-Nürnberg



Multimodal Music Processing

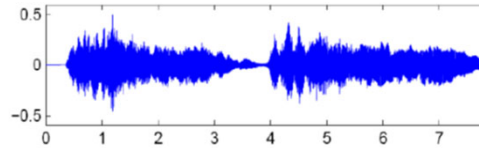


Multimodal Music Processing

Sheet Music (Image)



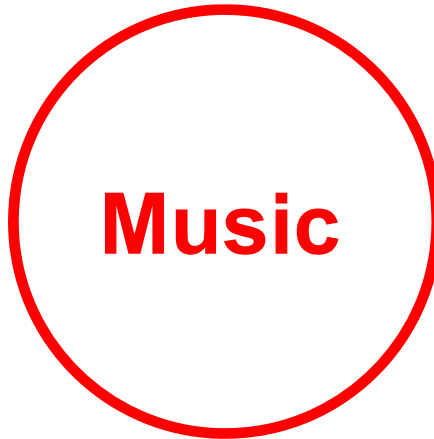
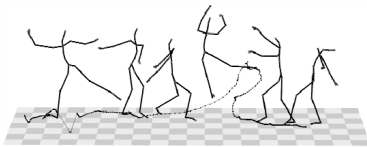
CD / MP3 (Audio)



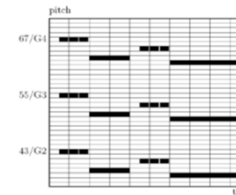
MusicXML (Text)

```
<note>  
  <pitch>  
    <step>E</step>  
    <alter>-1</alter>  
    <octave>4</octave>  
  </pitch>  
  <duration>2</duration>  
  <type>half</type>  
</note>
```

Dance / Motion (Mocap)



MIDI



Singing / Voice (Audio)



Music Film (Video)



Music Literature (Text)

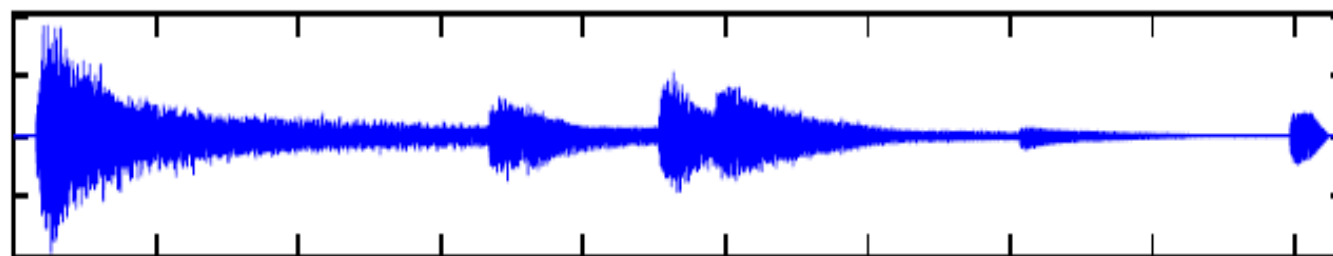


Multimodal Music Processing

Image



Audio



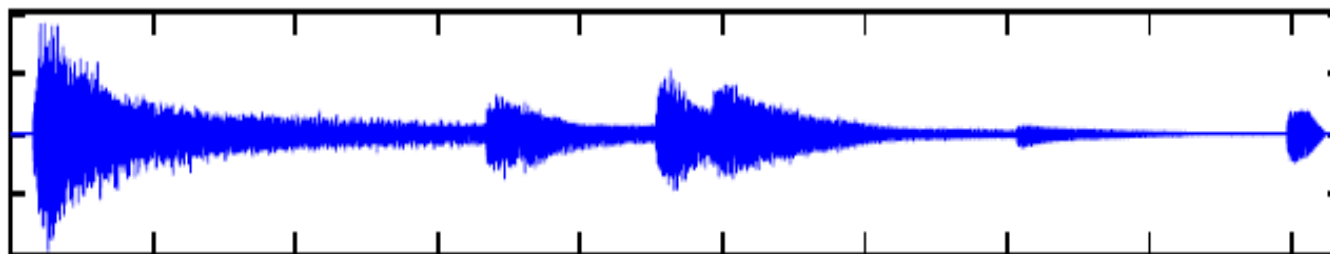
Multimodal Music Processing

Image Processing: Optical Music Recognition

Image



Audio



Multimodal Music Processing

Image Processing: Optical Music Recognition

Image



Audio



Audio Processing: Fourier Analysis

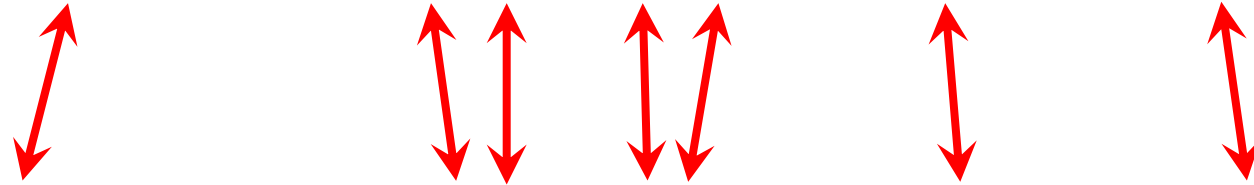
Multimodal Music Processing

Image Processing: Optical Music Recognition

Image



Audio



Audio Processing: Fourier Analysis

Multimodal Music Processing

The image displays a multimodal music processing interface with two main windows: ScoreViewer and AudioViewer.

ScoreViewer: Shows a musical score for Beethoven's Piano Sonata no. 8 in C minor, op. 13 "Pathétique" / Rondo (Allegro). The score is displayed in a multi-staff format. The interface includes navigation controls for Track (29 / 54), Bar (1 / 211), and Page (159 / 285). It also features a "Score Following On" indicator and "Play" and "Stop" buttons.

AudioViewer: Shows a track list for "Beethoven - Piano Sonatas-Alfred Brendel". The track list includes:

| Track | Duration |
|--|----------|
| 03 Sonata no.1 in F minor, op.2 no.1 / Menuetto (Allegretto) | 3:24 |
| 04 Sonata no.1 in F minor, op.2 no.1 / Prestissimo | 5:32 |
| 05 Sonata no.2 in A major, op.2 no.2 / Allegro vivace | 7:15 |
| 06 Sonata no.2 in A major, op.2 no.2 / Largo appassionato | 6:28 |
| 07 Sonata no.2 in A major, op.2 no.2 / Scherzo (Allegretto) | 3:30 |
| 08 Sonata no.2 in A major, op.2 no.2 / Rondo (Grazioso) | 7:03 |
| 09 Sonata no.6 in C minor, op.13 "Pathétique" / Allegro di moto e con brio | 9:40 |
| 10 Sonata no.8 in C minor, op.13 "Pathétique" / Adagio cantabile | 5:17 |
| 11 Sonata no.8 in C minor, op.13 "Pathétique" / Rondo (Allegro) | 4:20 |

The AudioViewer interface also includes navigation controls for Disc (1 / 11), Track (11 / 11), and Time (00:00.00 / 4:30.35). It features a "Play" and "Stop" button and a waveform visualization.

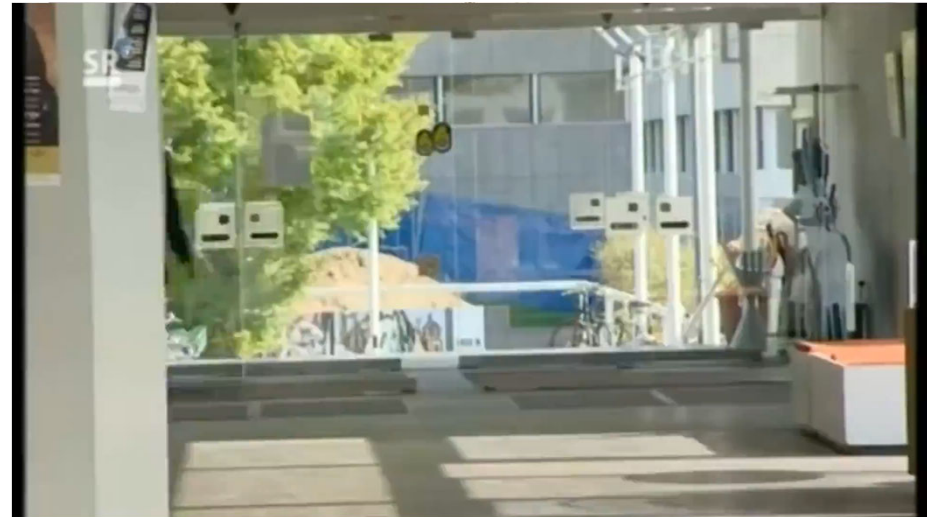
Multimodal Music Processing

- Cooperation Agreement (2009)
 - Wolfgang Bogler
 - Thomas Duis
 - Hans-Peter Seidel
- Experiments with Player Piano
- User Interfaces
- Saarland Music Data (SMD)



Multimodal Music Processing

- Cooperation Agreement (2009)
 - Wolfgang Bogler
 - Thomas Duis
 - Hans-Peter Seidel
- Experiments with Player Piano
- User Interfaces
- Saarland Music Data (SMD)



Computational Musicology

- Cooperation: Rainer Kleinertz
- Harmony-based structural analysis
- Visualization techniques
- Exploration of interdisciplinary research



Verena Konz, Meinard Müller, Rainer Kleinertz:
**A Cross-Version Chord Labelling Approach for
Exploring Harmonic Structures –
A Case Study on Beethoven's Appassionata**
Journal of New Music Research, 42(1): 61–77, 2013



Computational Musicology

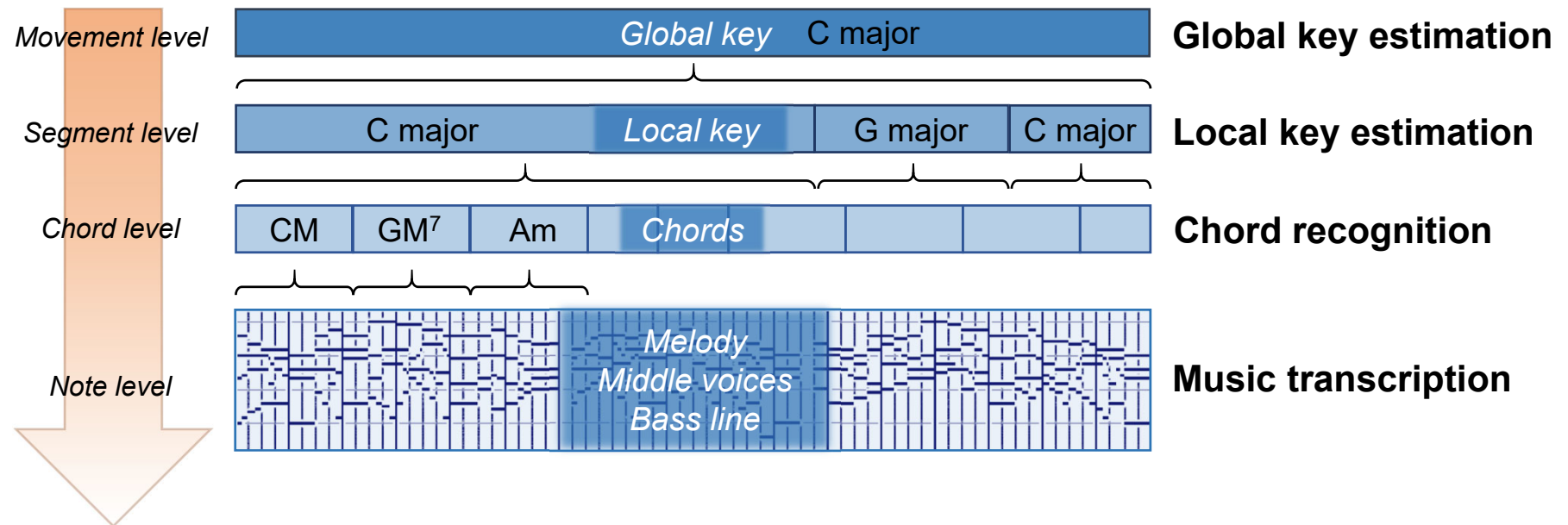


- Cooperation: Rainer Kleinertz
- Harmony-based structural analysis
- Visualization techniques
- Exploration of interdisciplinary research
- Since 2014: DFG-funded project



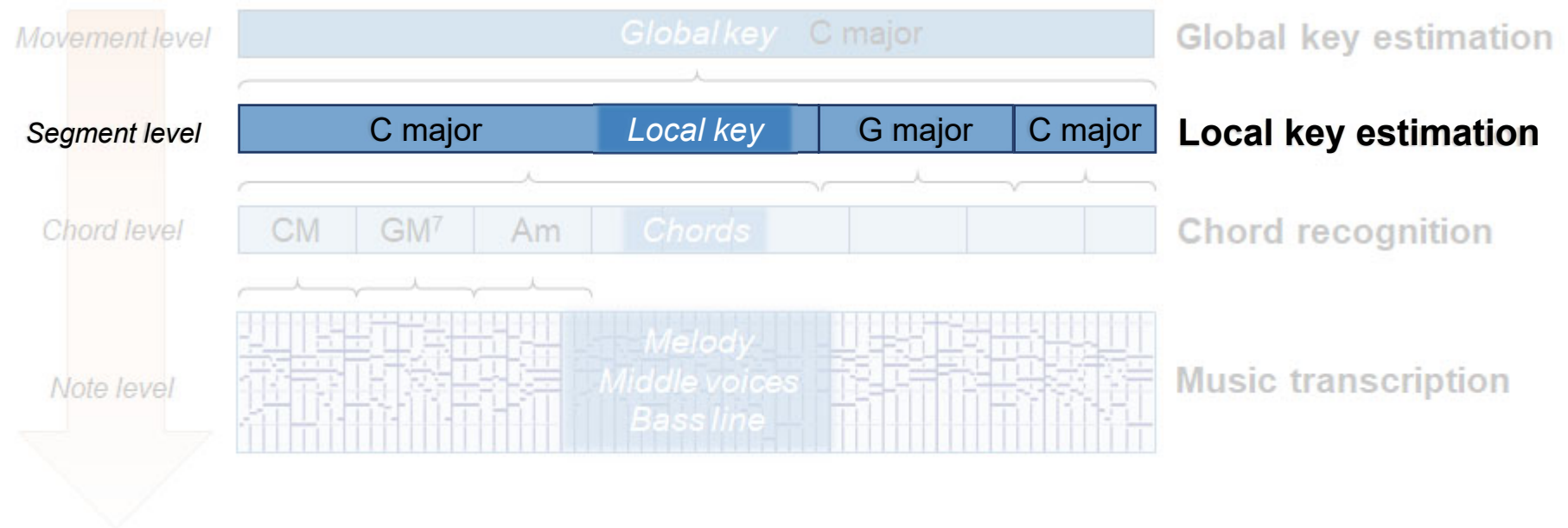
Harmony Analysis

- Different concepts
- Different temporal levels



Harmony Analysis

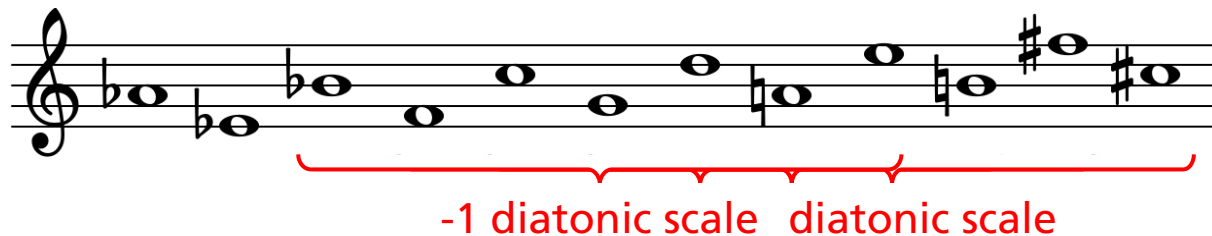
- Different concepts
- Different temporal levels



Local Key Estimation

Assumption: Music based on **diatonic scales**

- Heptatonic scales
- Ordering of scales according to the circle of fifths
- Each scale consists of chain of six perfect fifth
- Fifth-neighboring scales share 6 of 7 notes



Local Key Estimation

Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
Score representation (piano reduction)

The image shows a piano reduction of a choral piece by J.S. Bach. It consists of two systems of music. Each system has a treble and bass staff. The key signature is three sharps (F#, C#, G#) and the time signature is 4/4. The lyrics are written below the notes.

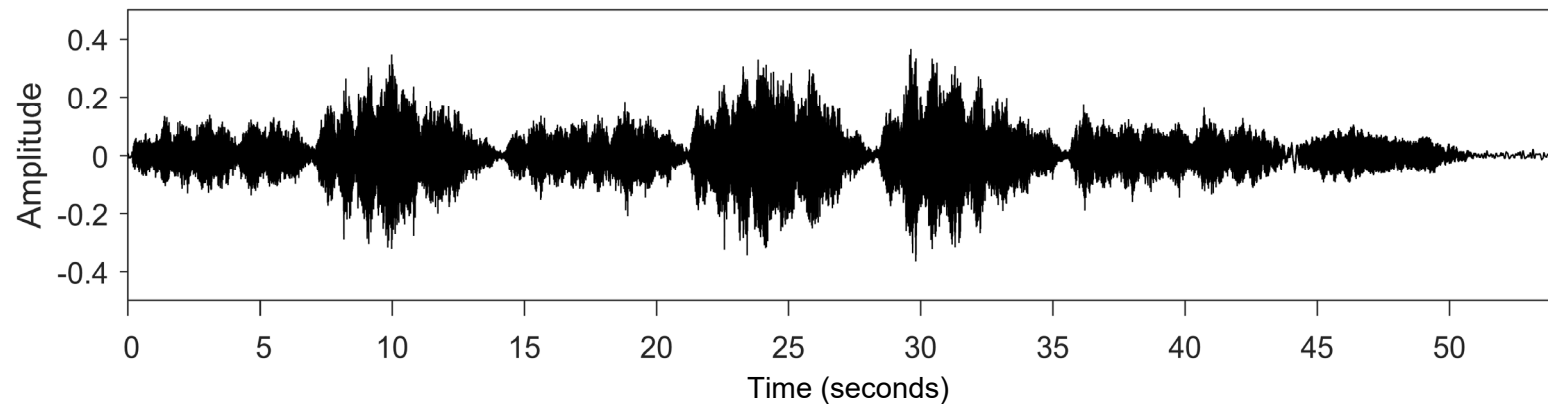
System 1:
Durch dein Ge-fäng-nis, Got-tes Sohn, muß uns die Frei-heit kom-men;
Dein Ker-ker ist der Gna-den-thron, die Frei-statt al-ler From-men;

System 2:
9
Denn gingst du nicht die Knecht-schaft ein, müßt uns-re Knecht-schaft e-wig sein.

Local Key Estimation

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

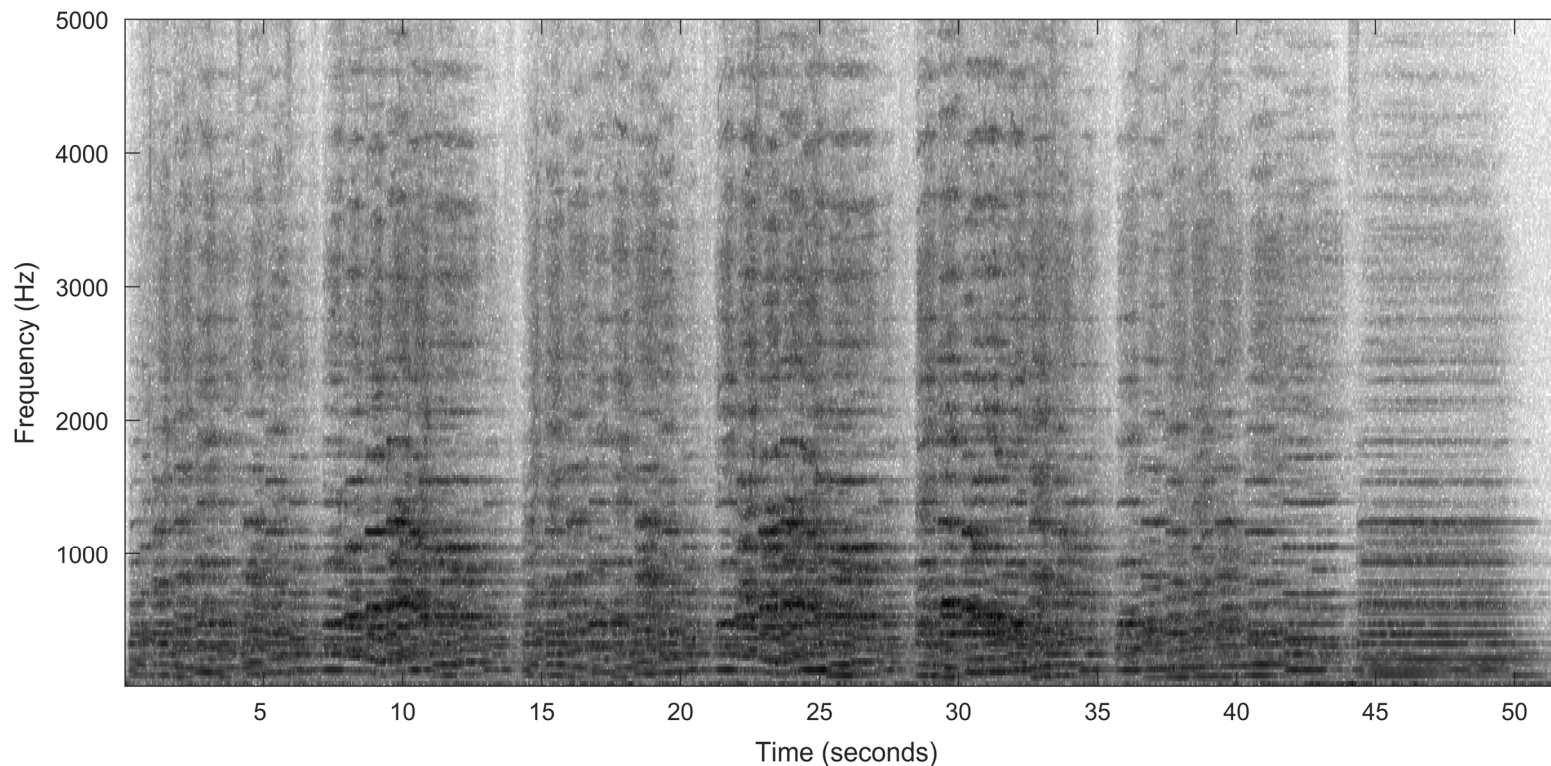
Waveform



Local Key Estimation

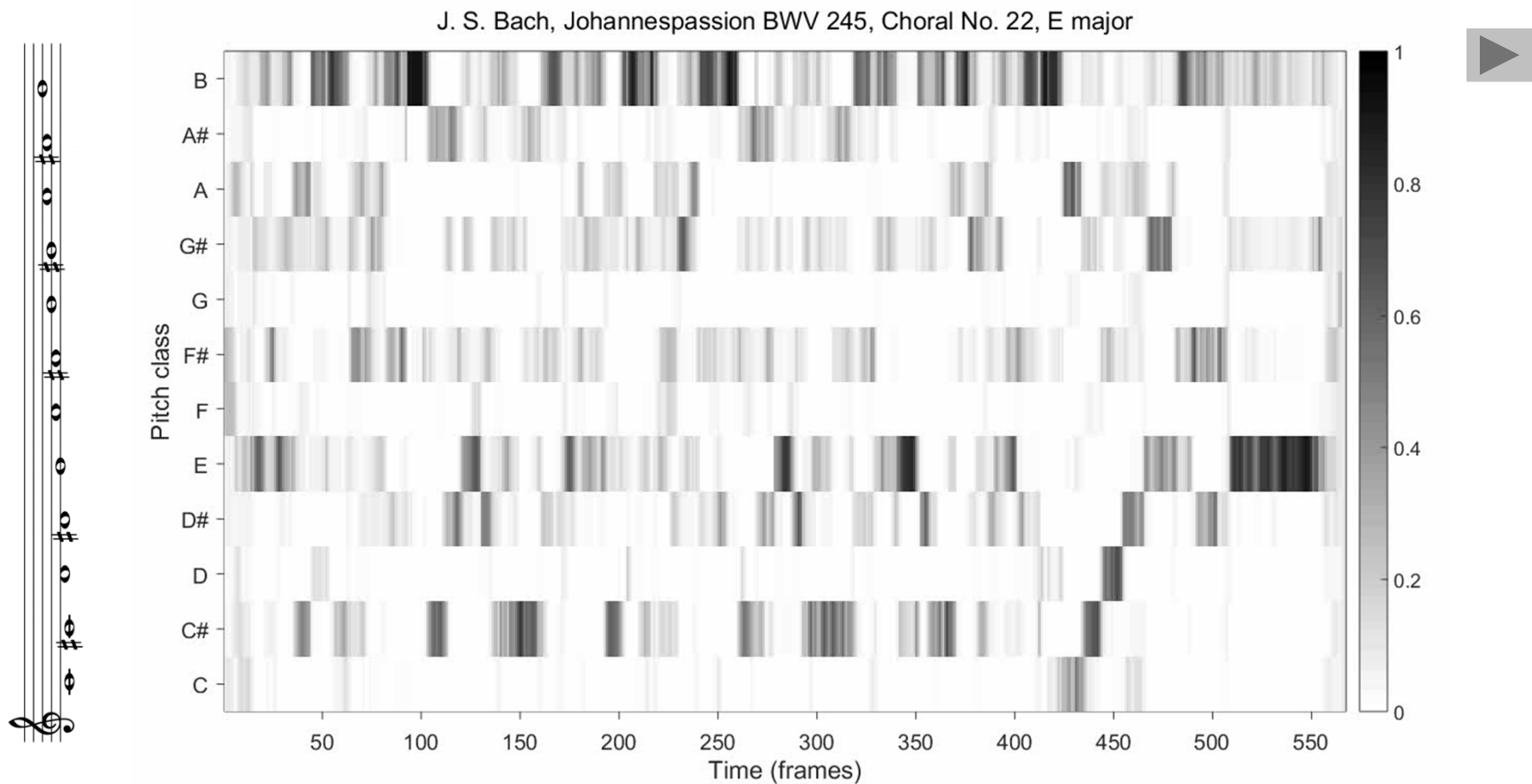
Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
Recording (Scholars Baroque Ensemble, Naxos 1994)

Spectrogram



Local Key Estimation

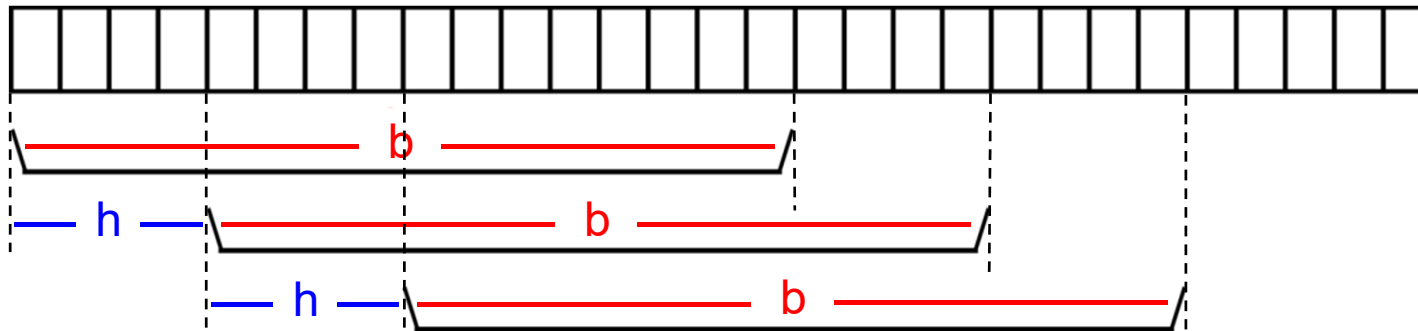
Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)
Recording (Scholars Baroque Ensemble, Naxos 1994) **Chromagram**



Local Key Estimation

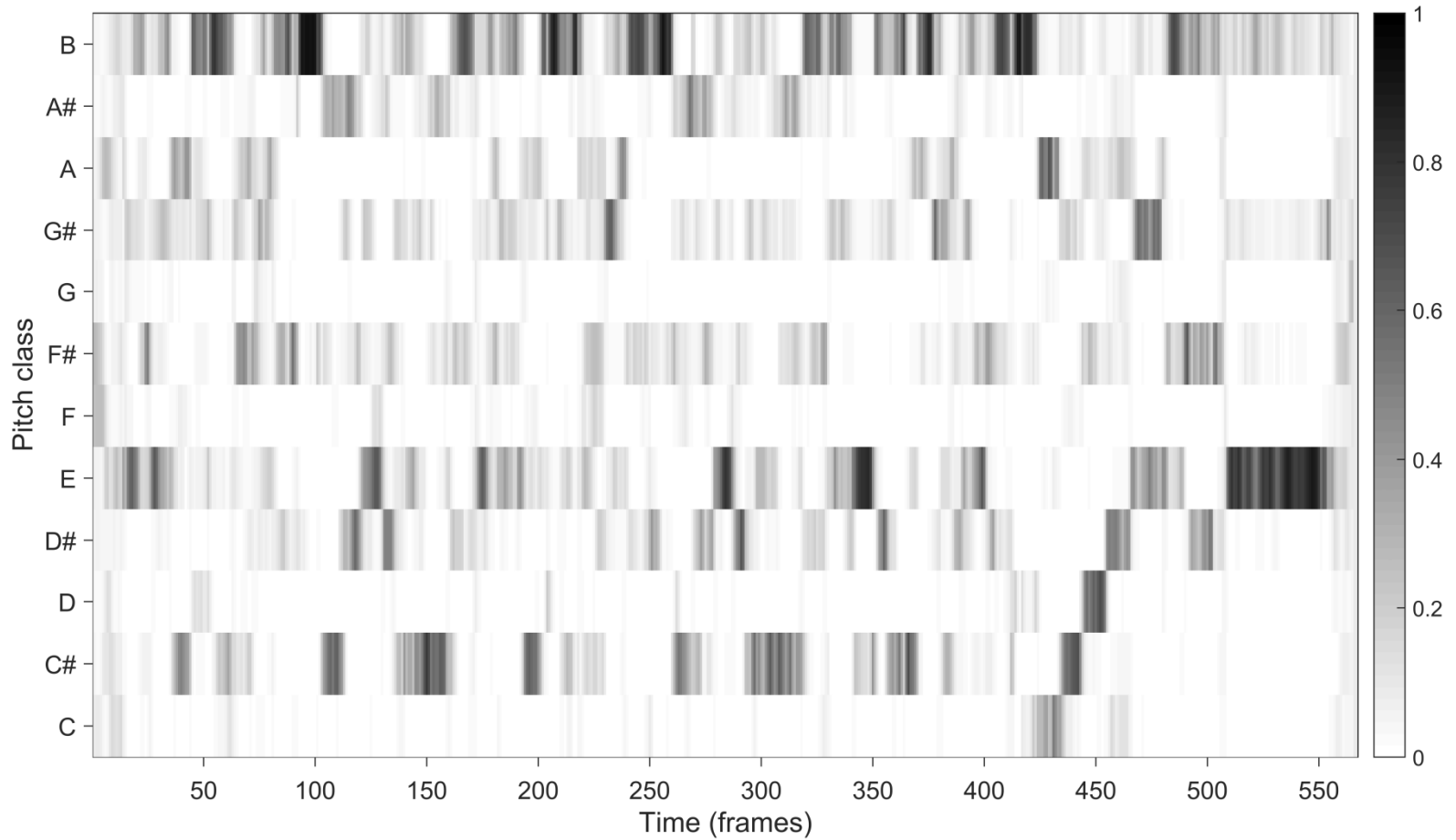
Summarize pitch class (chroma) content over a certain time period

- Feature smoothing
- Parameters: blocksize b and hopsize h



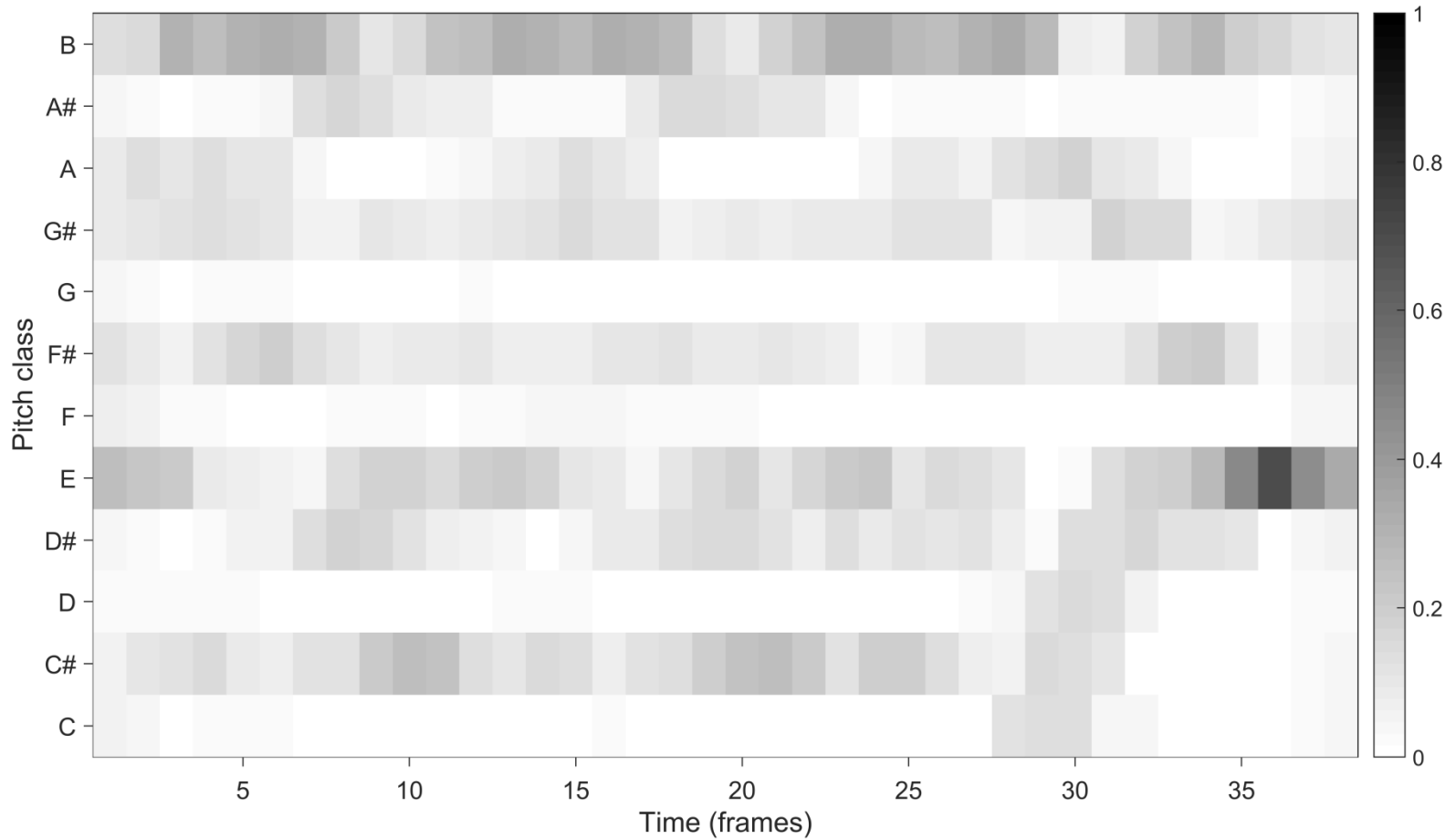
Local Key Estimation

Chromagram



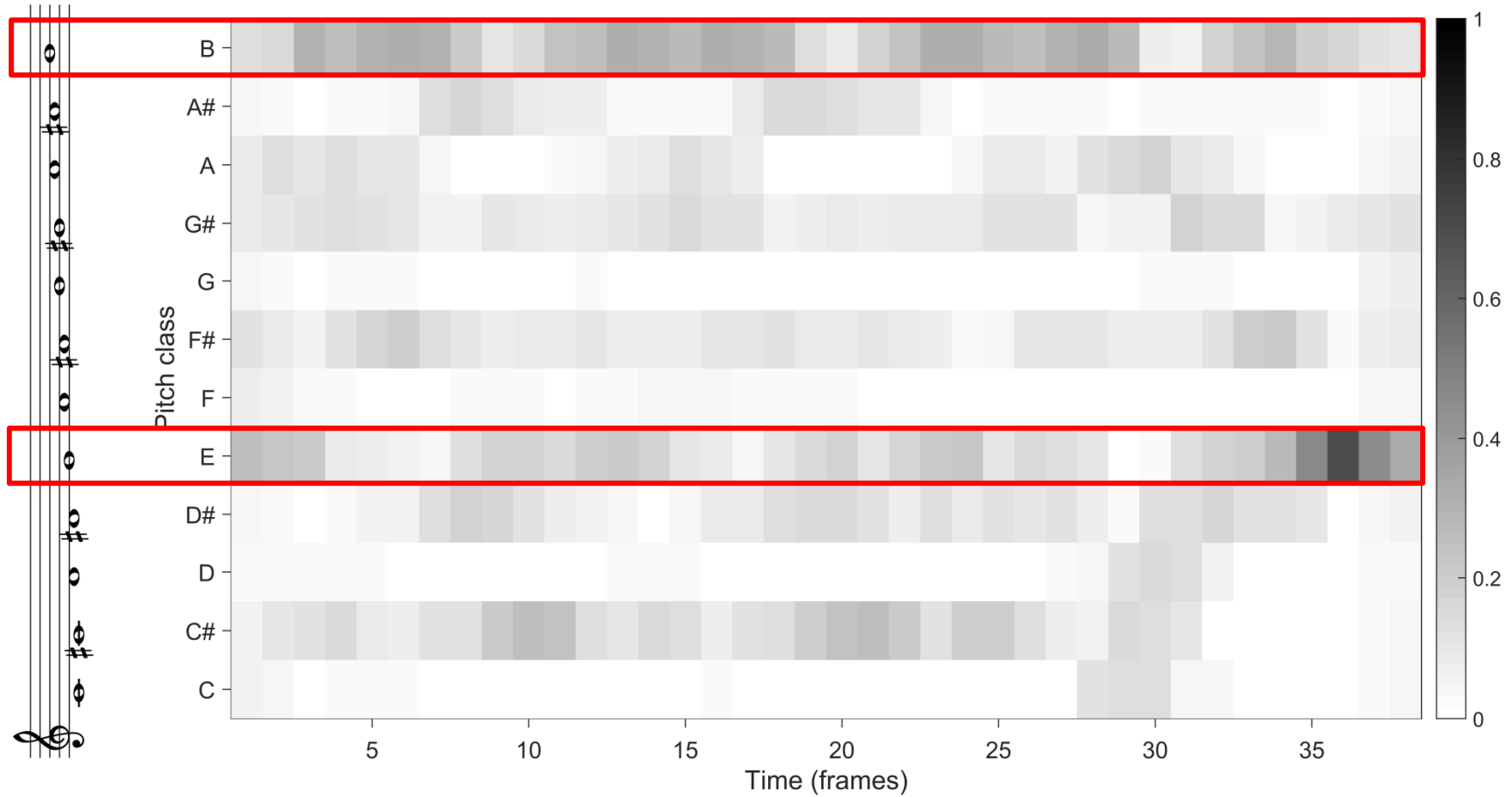
Local Key Estimation

Chromagram after smoothing ($b = 42$, $h = 15$)



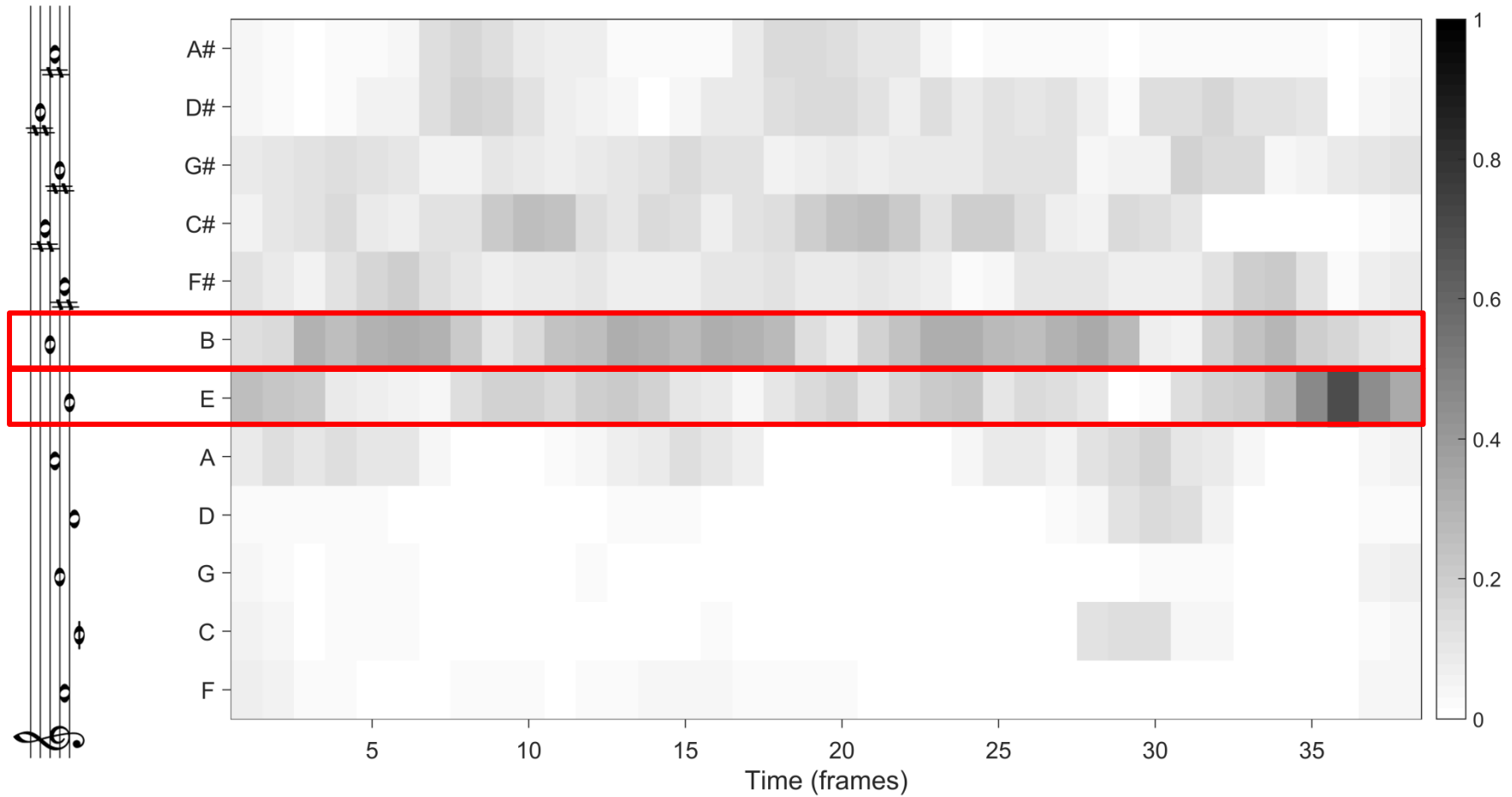
Local Key Estimation

Arrange pitch classes according to **perfect fifth series**



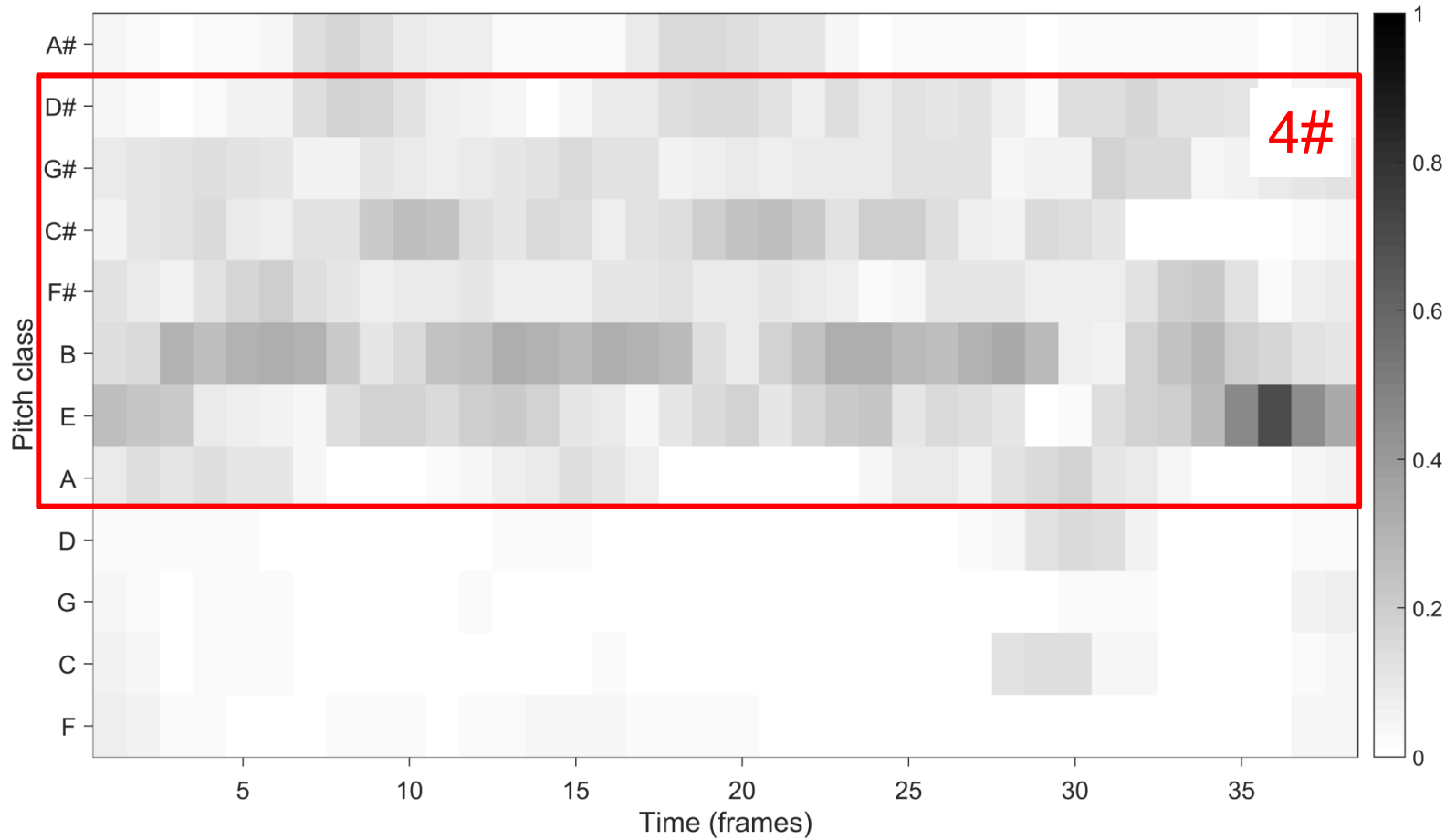
Local Key Estimation

Arrange pitch classes according to **perfect fifth series**



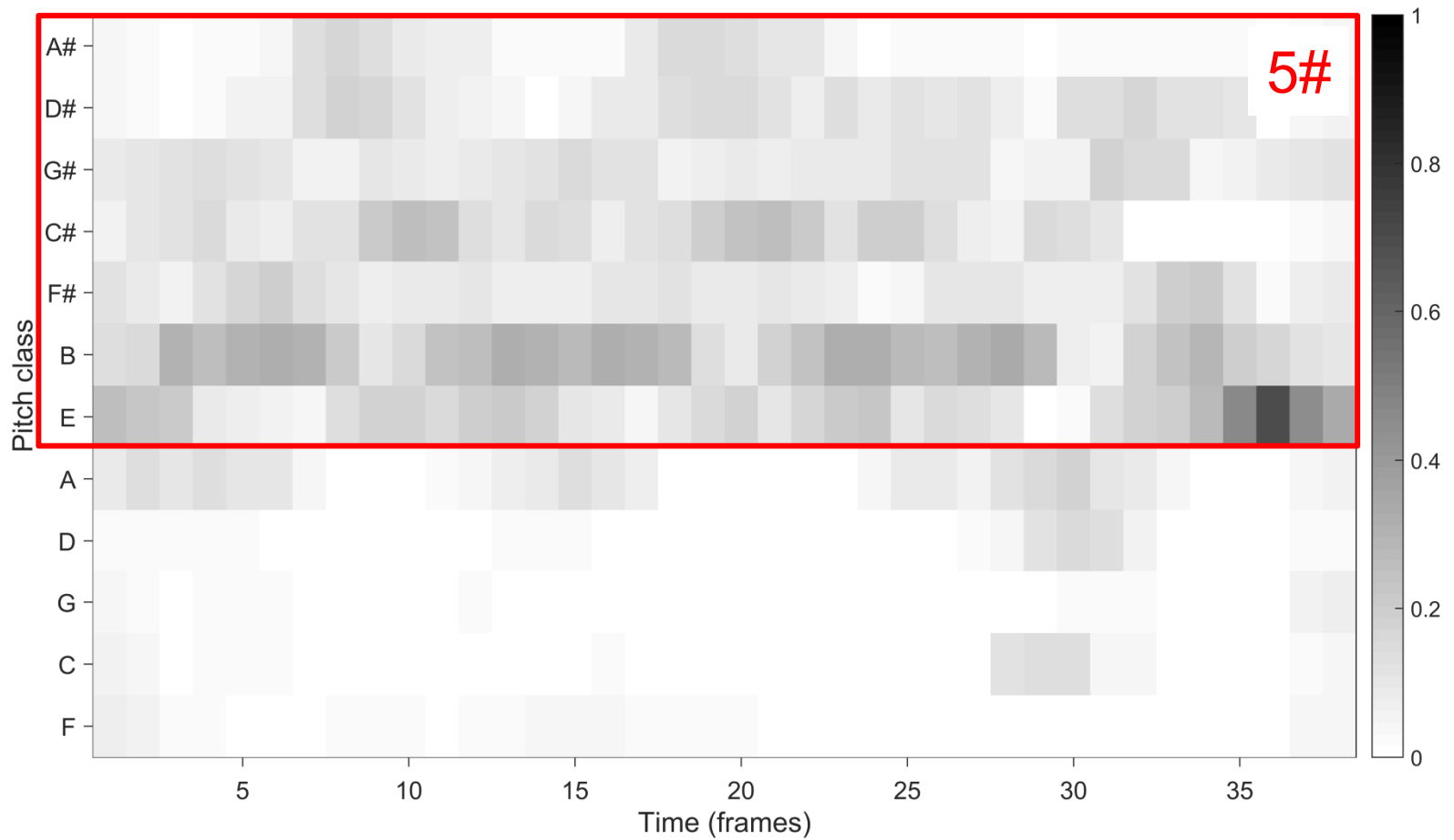
Local Key Estimation

Summarize pitch class content according to **diatonic scales**



Local Key Estimation

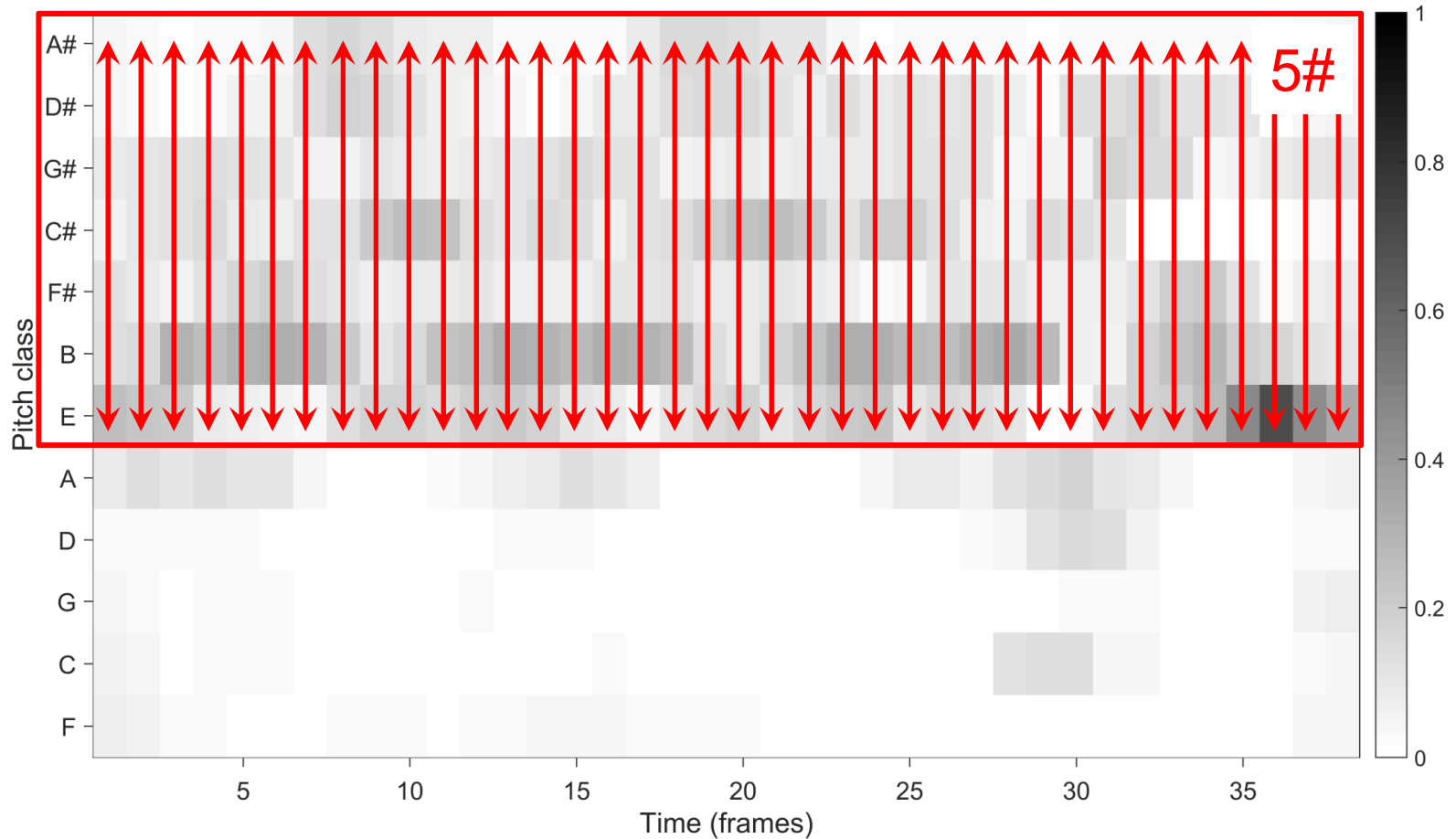
Summarize pitch class content according to **diatonic scales**



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

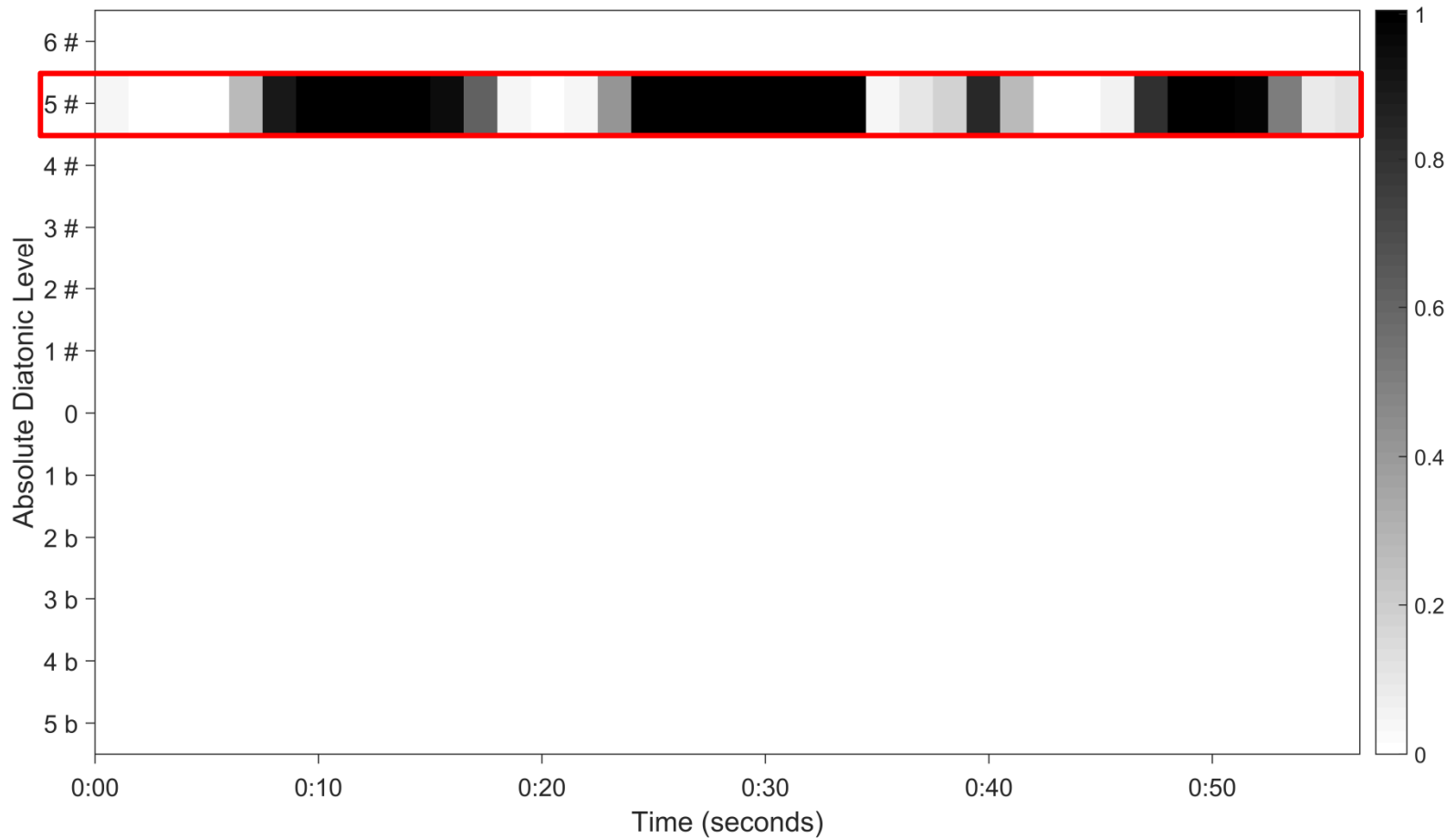
Multiply chroma values (in each column)



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

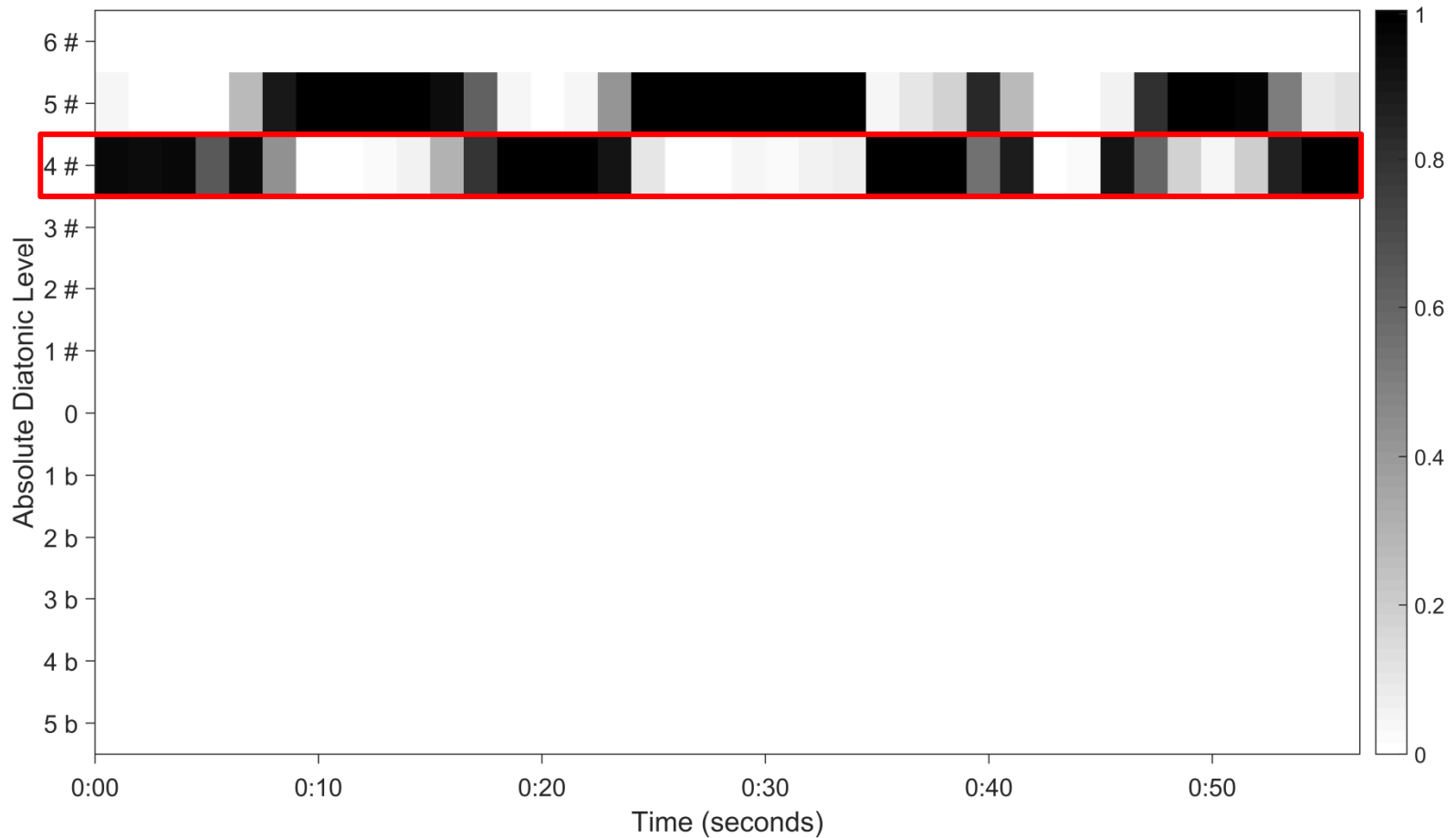
Multiply chroma values



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

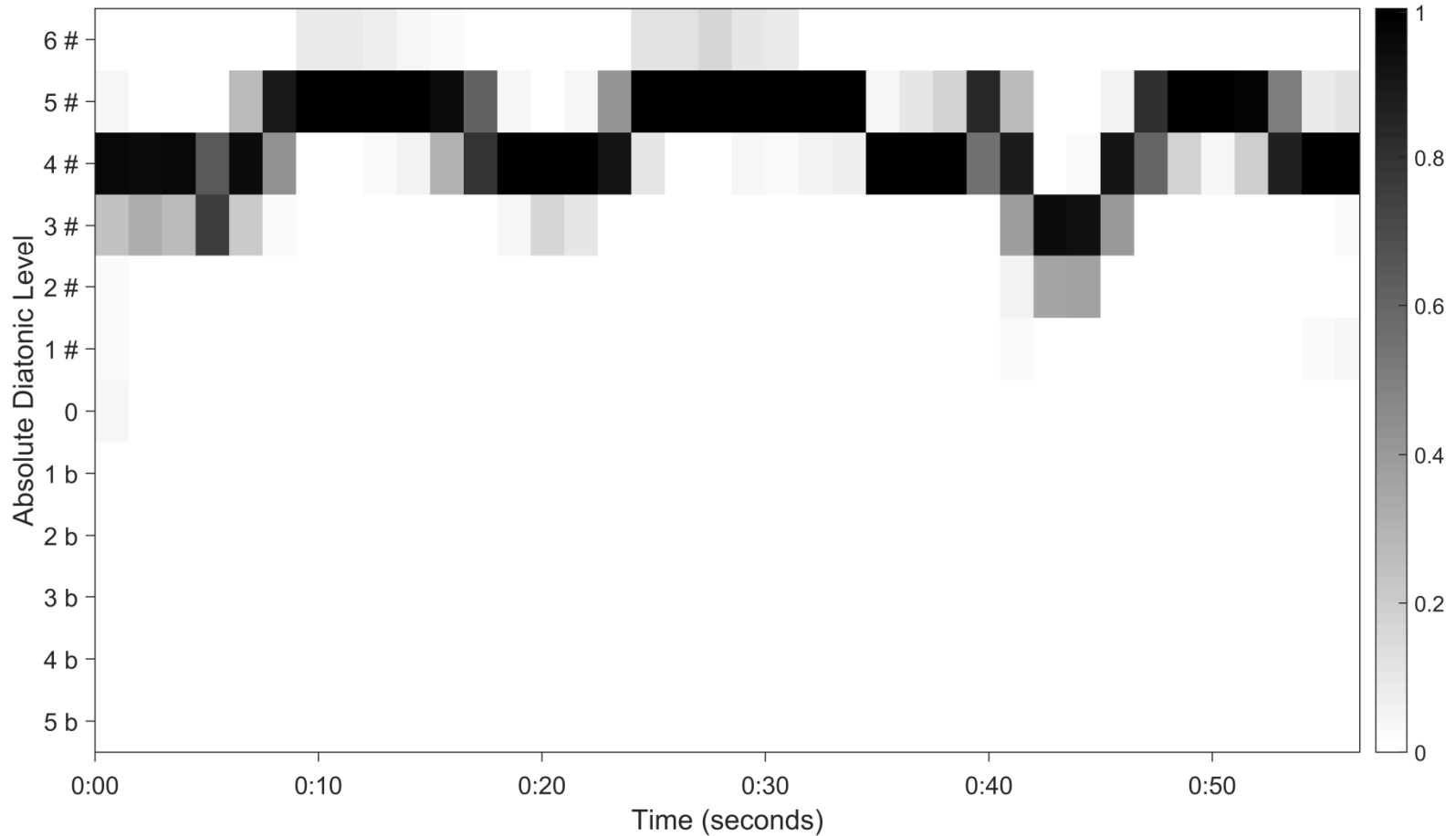
Multiply chroma values



Local Key Estimation

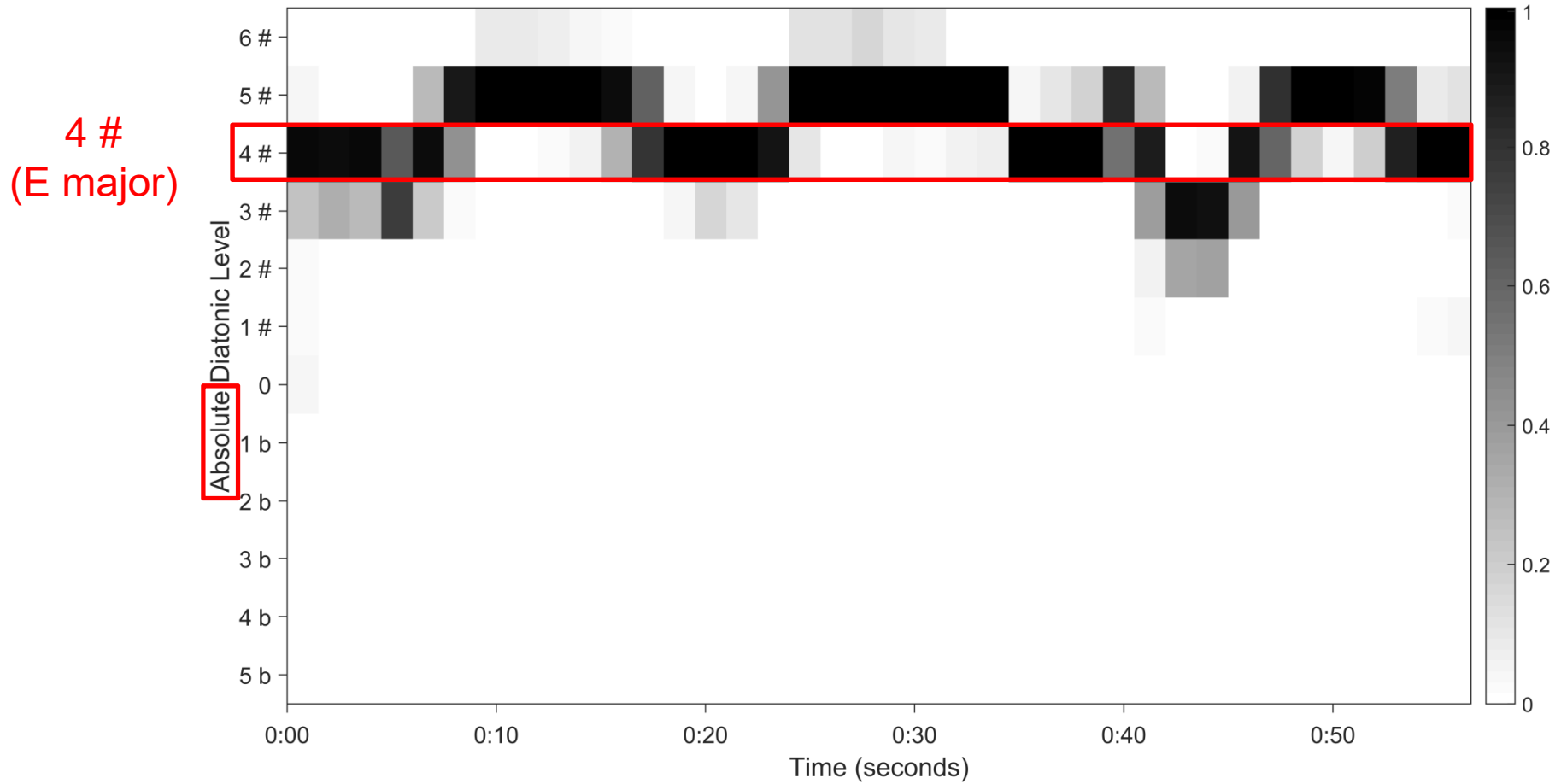
Summarize pitch class content according to **diatonic scales**

Multiply chroma values



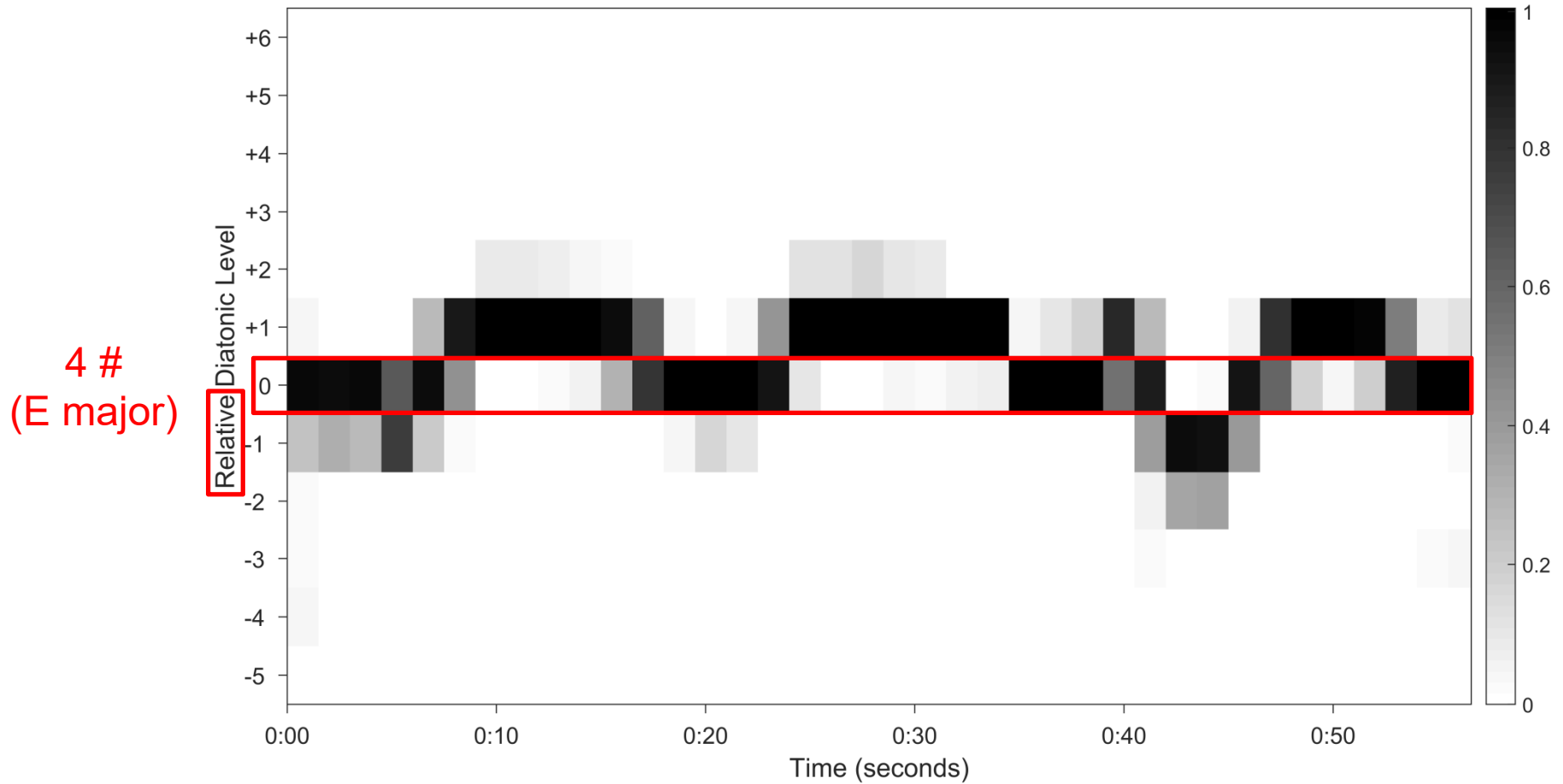
Local Key Estimation

Normalize representation relative to **global key**



Local Key Estimation

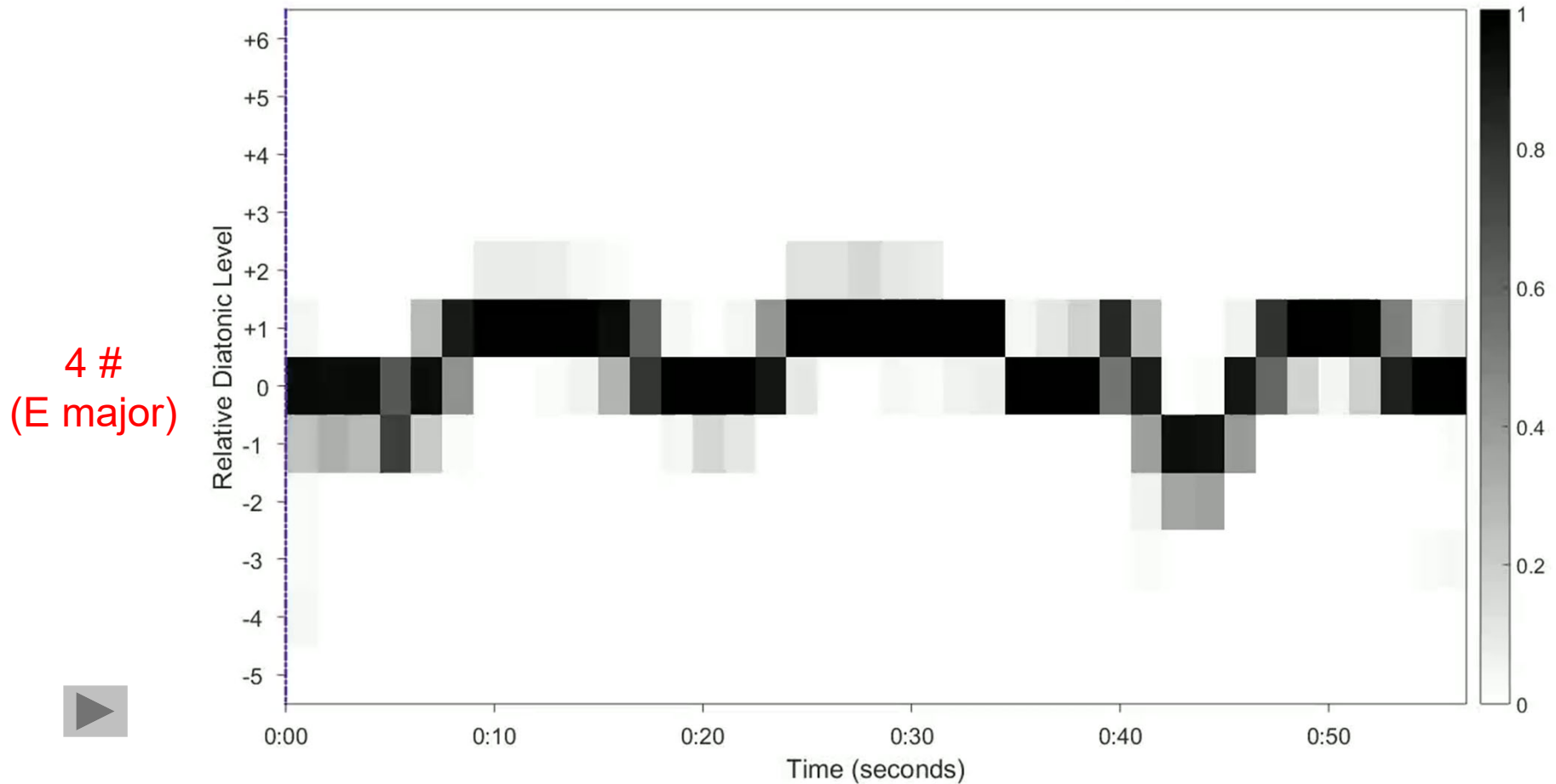
Normalize representation relative to **global key**



Local Key Estimation

J.S. Bach: Choral "Durch Dein Gefängnis" (*Johannespassion*)

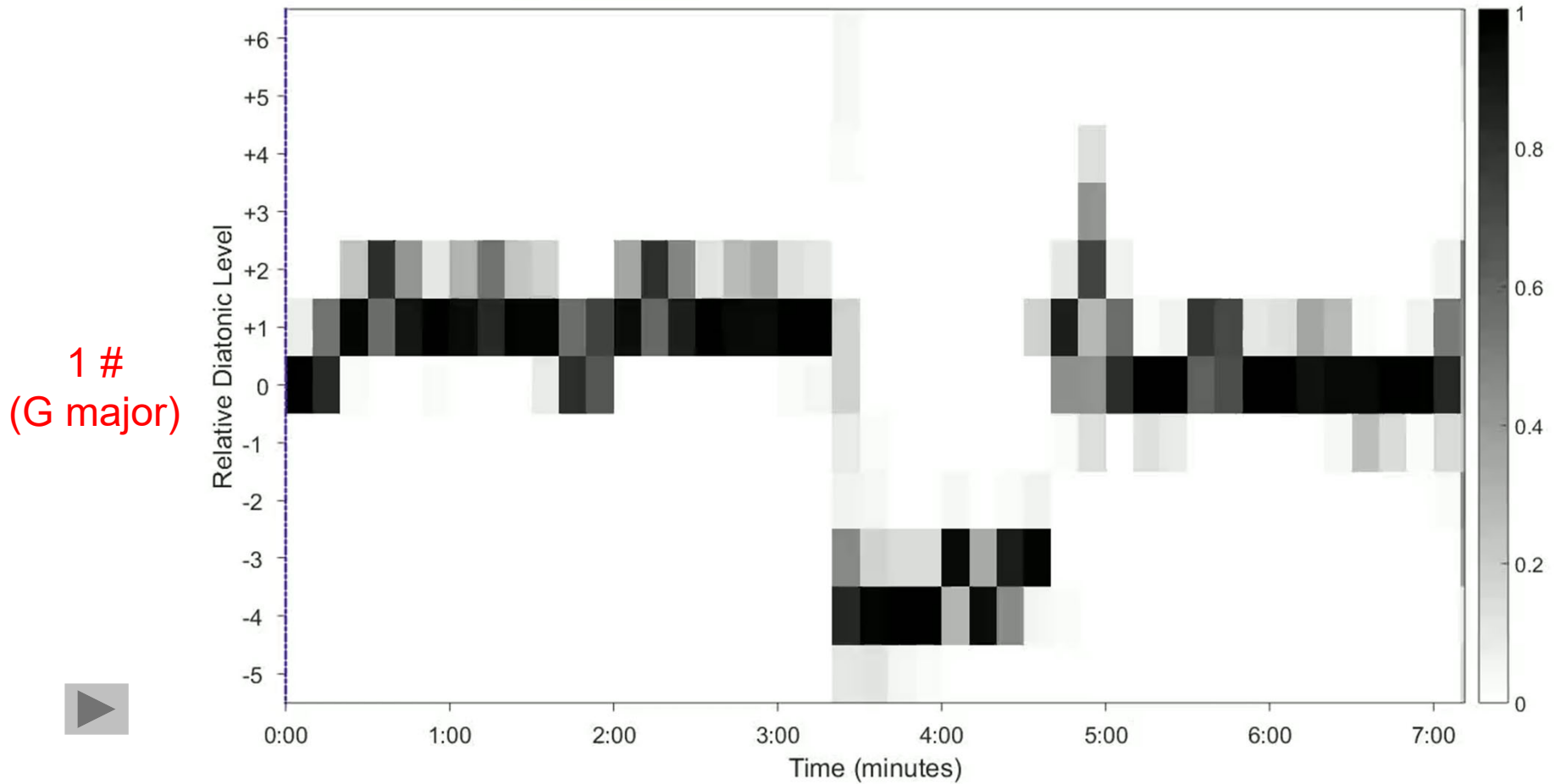
Recording: Scholars Baroque Ensemble, Naxos 1994



Local Key Estimation

L. v. Beethoven: Piano Sonata No. 10 (Op. 14 Nr. 2), 1. Allegro

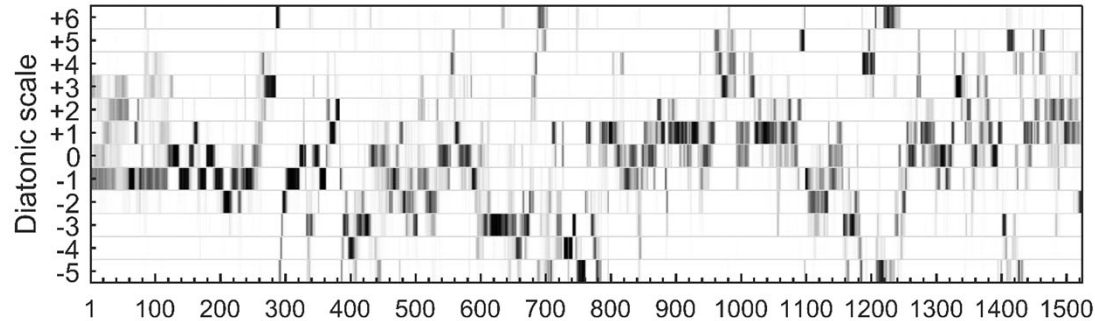
Recording: Barenboim, EMI 1998



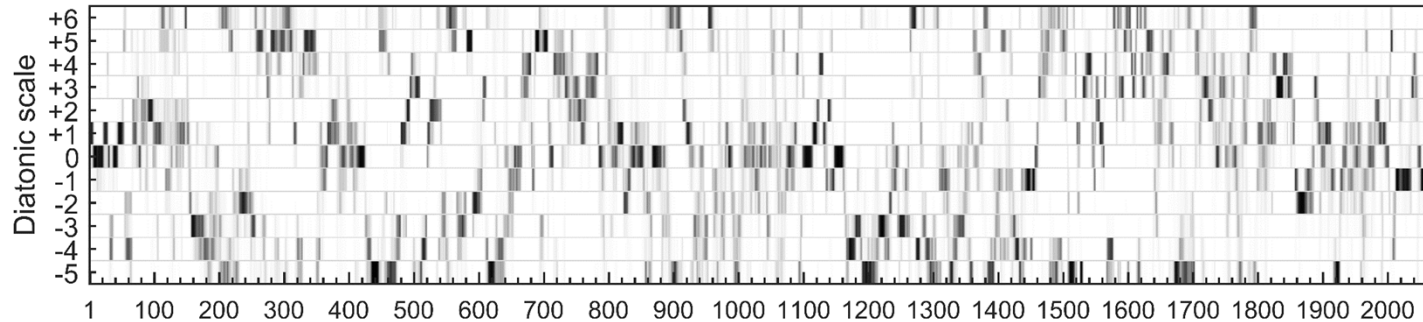
Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)

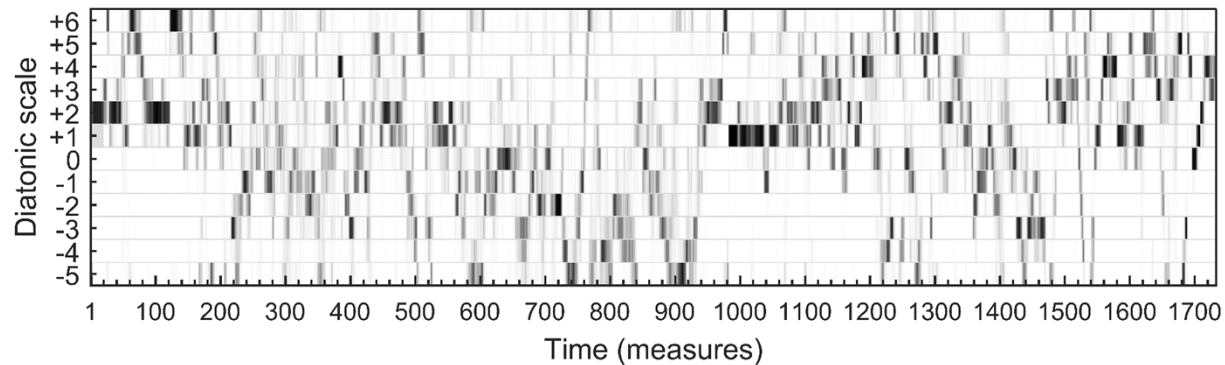
Act 1



Act 2



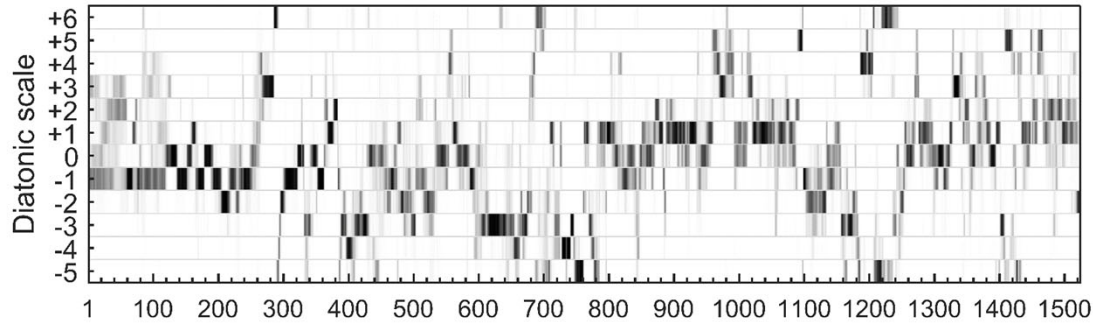
Act 3



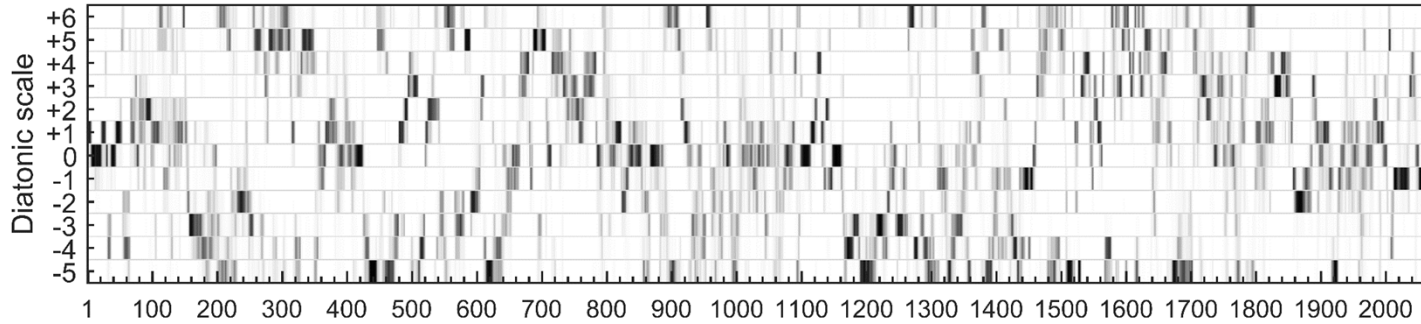
Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)

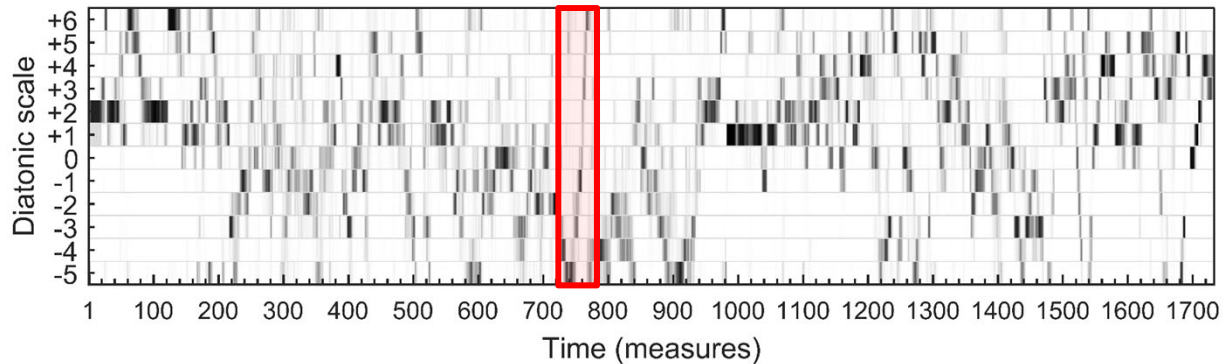
Act 1



Act 2



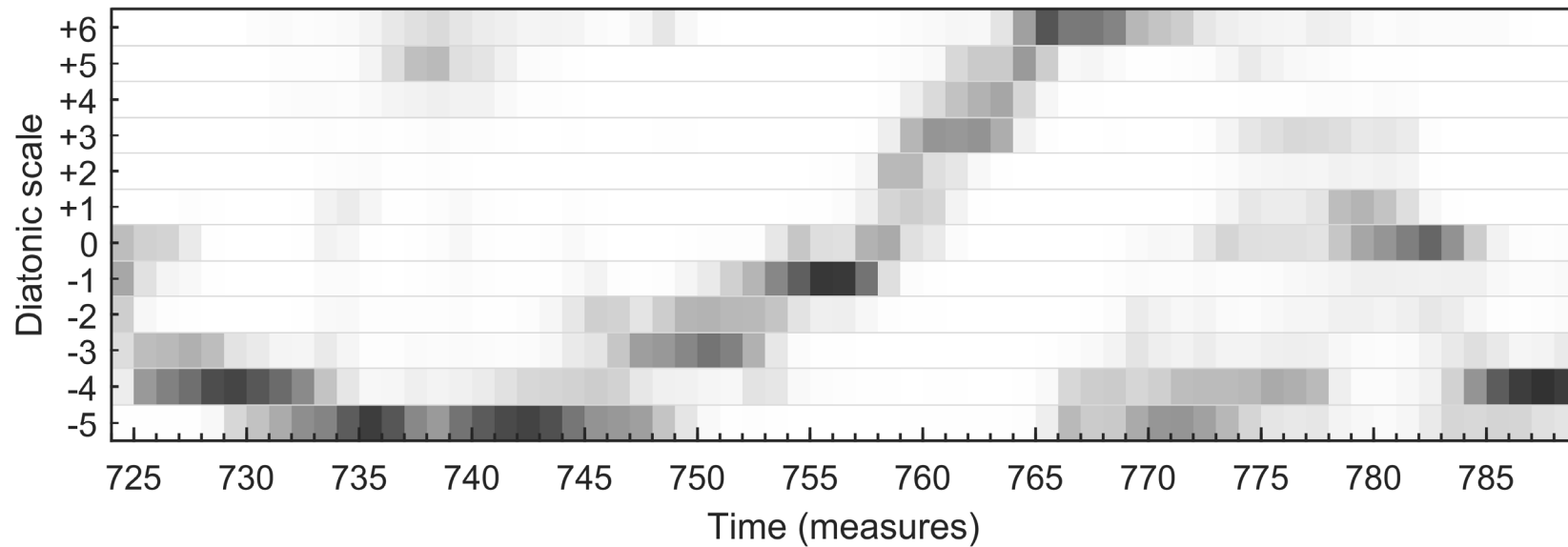
Act 3



Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)

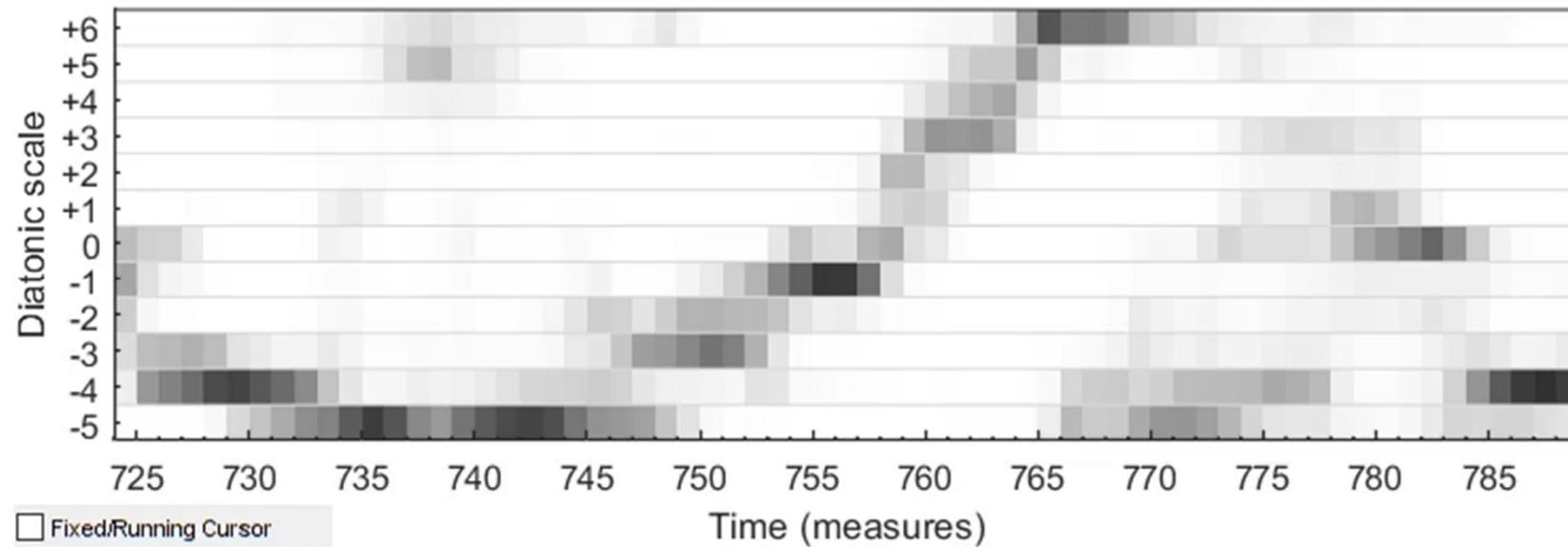
Act 3, measure 724–789 (*Wotan's punishment*)



Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)

Act 3, measure 724–789 (*Wotan's punishment*)



Interdisciplinary Dialogue

- Dagstuhl Seminar (2016):
Computational Music Structure Analysis



Interdisciplinary Dialogue

- Dagstuhl Seminar (2016):
Computational Music Structure Analysis

- GI Jahrestagung (2017):
Workshop: Musik trifft Informatik

Gesellschaft
für Informatik



Interdisciplinary Dialogue

- Dagstuhl Seminar (2016):
Computational Music Structure Analysis
- GI Jahrestagung (2017):
Workshop: Musik trifft Informatik
- Tagung (2022):
Understanding Beethoven
Musicology and Computer Science in Dialogue



Qualification

- Mark Gotham

2021: Universität des Saarlandes → TU Dortmund

Professor of Music Theory



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2021: Universität des Saarlandes → TU Dortmund

Professor of Music Theory



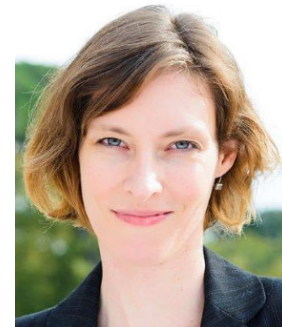
- Stephanie Klauk

2022: Habilitation, Universität des Saarlandes



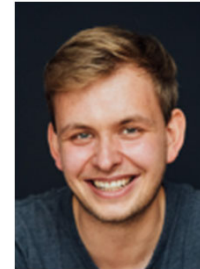
Qualification

- Mark Gotham
2021: Universität des Saarlandes → TU Dortmund
Professor of Music Theory
- Stephanie Klauk
2022: Habilitation, Universität des Saarlandes
- Christof Weiß
2022: FAU → Universität Würzburg
Professor of Computational Humanities



Computational Analysis of Traditional Georgian Vocal Music

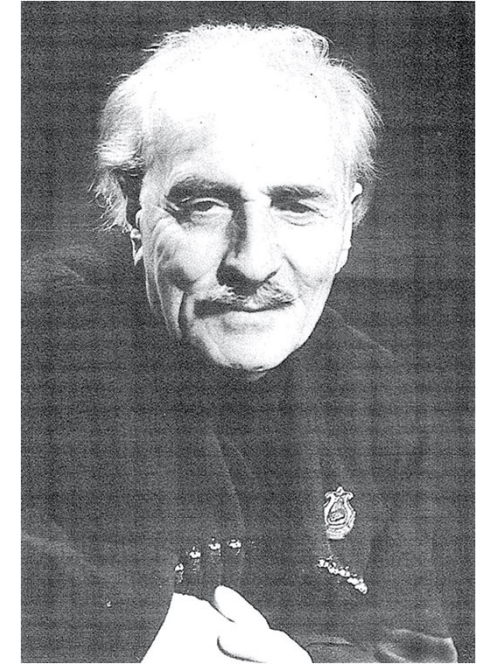
- Interdisciplinary research project
 - Prof. Dr. Frank Scherbaum (Potsdam)
 - Dr. Nana Mzhavanadze (Tbilisi)
 - Sebastian Rosenzweig (FAU)
- Objective: Tonal analysis
- 2018 – 2022: DFG-funded project



Traditional Georgian Vocal Music

Example: Erkomaishvili corpus

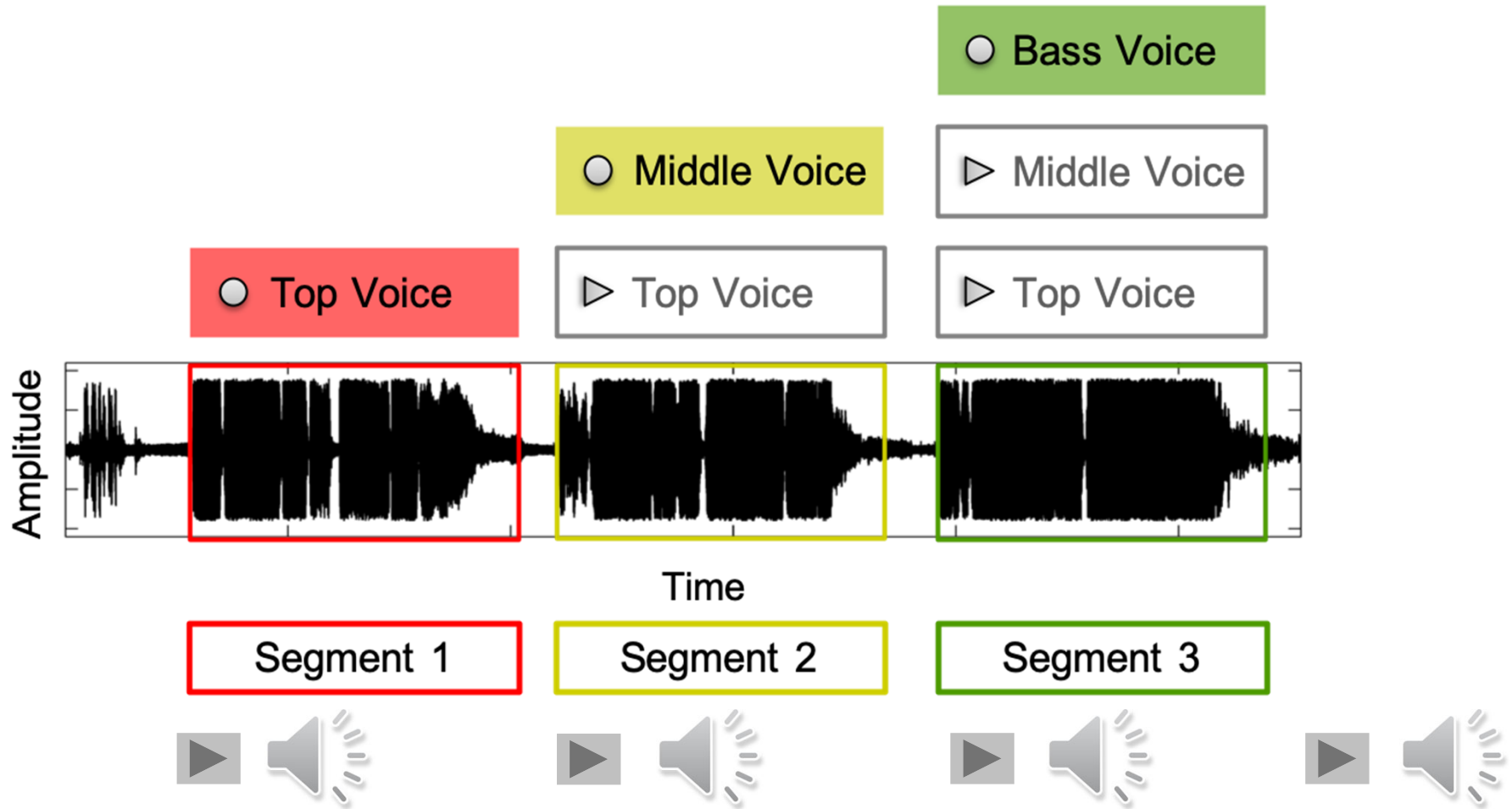
- Collection of traditional three-voice Georgian songs
- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)
- Recordings of 100 songs using tape recorders (1966)



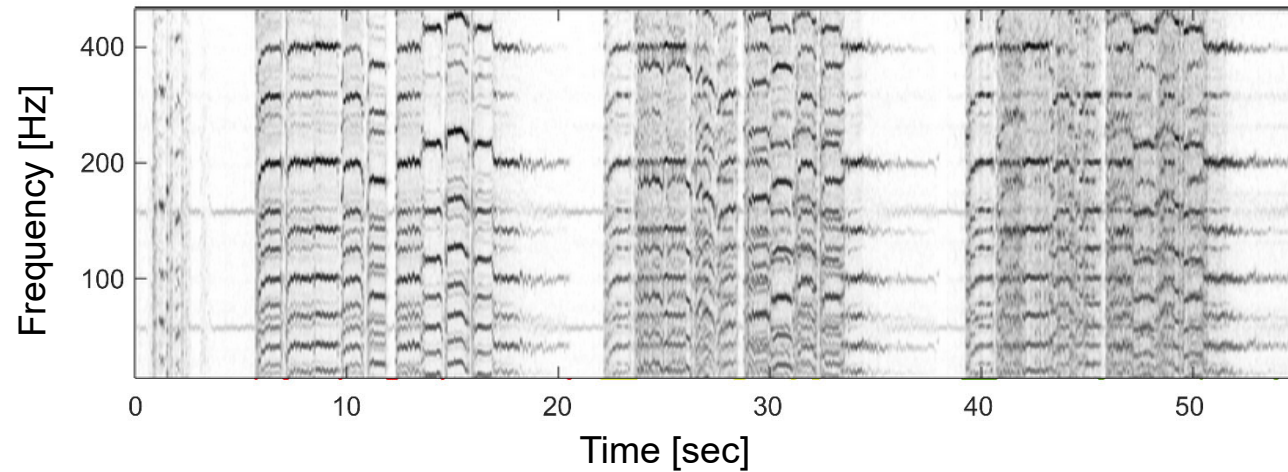
“Original masterpieces of Georgian musical thinking.” (Shugliashvili, 2014)

Traditional Georgian Vocal Music

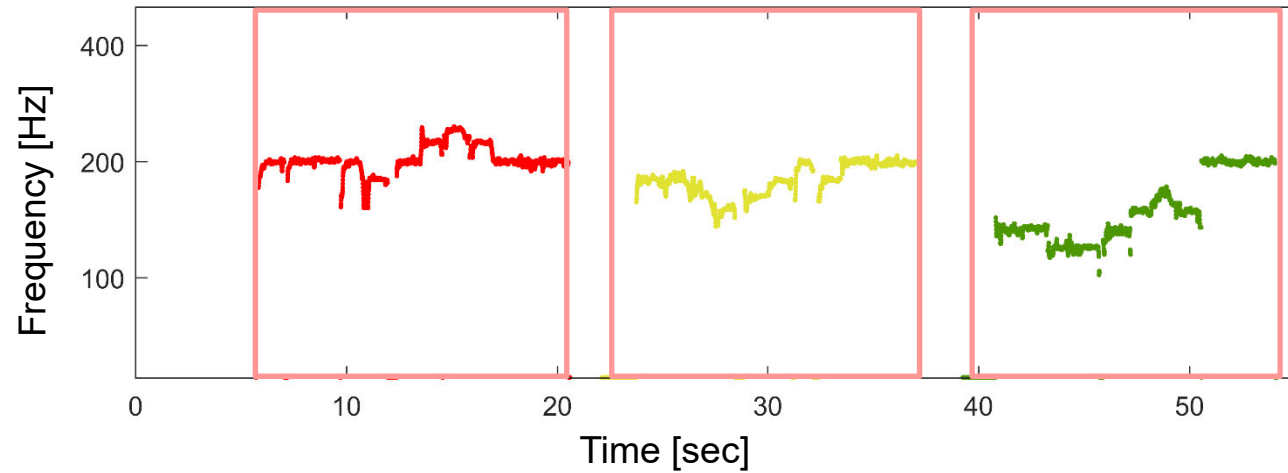
Example: Erkomaishvili corpus



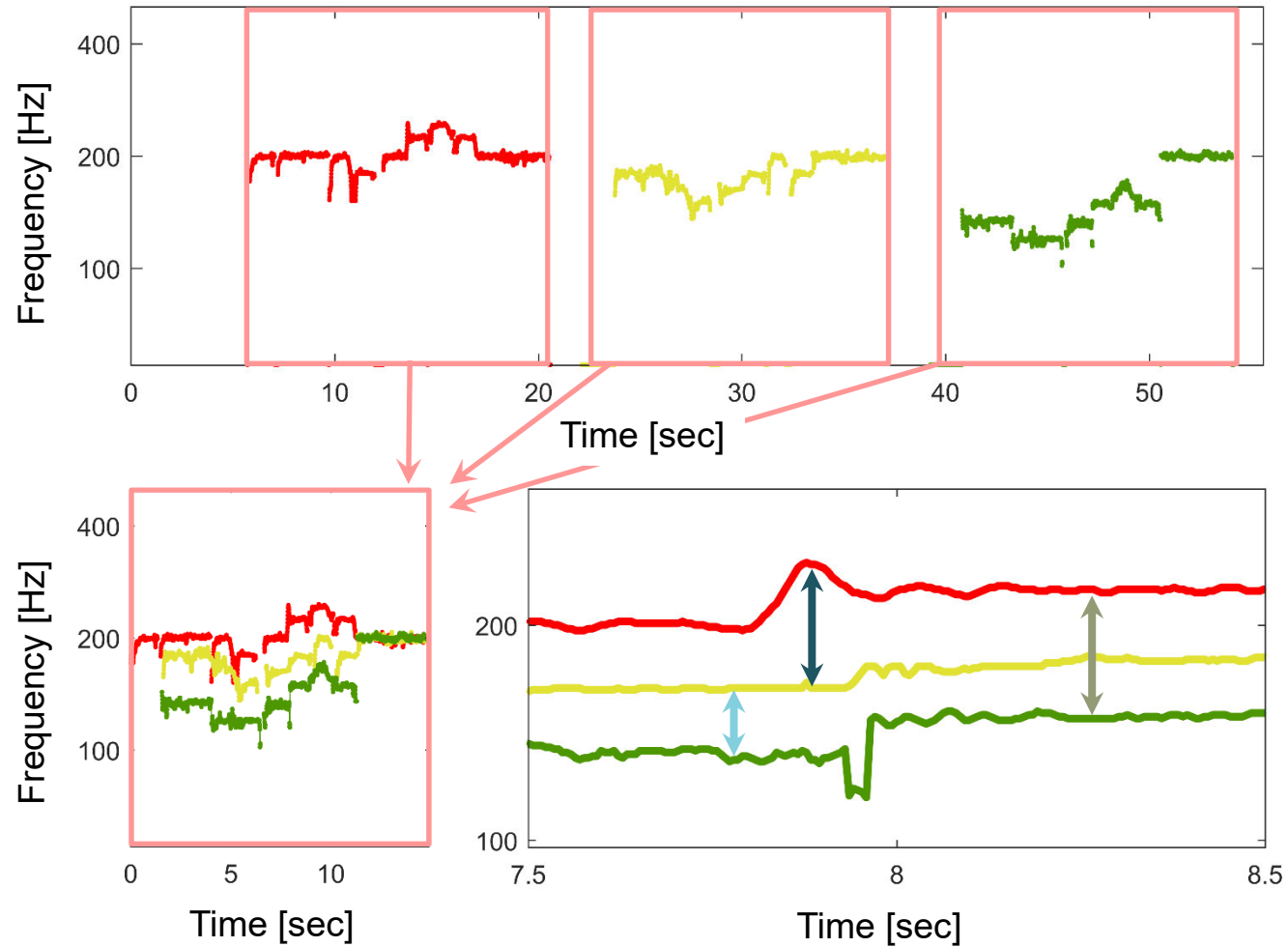
Traditional Georgian Vocal Music



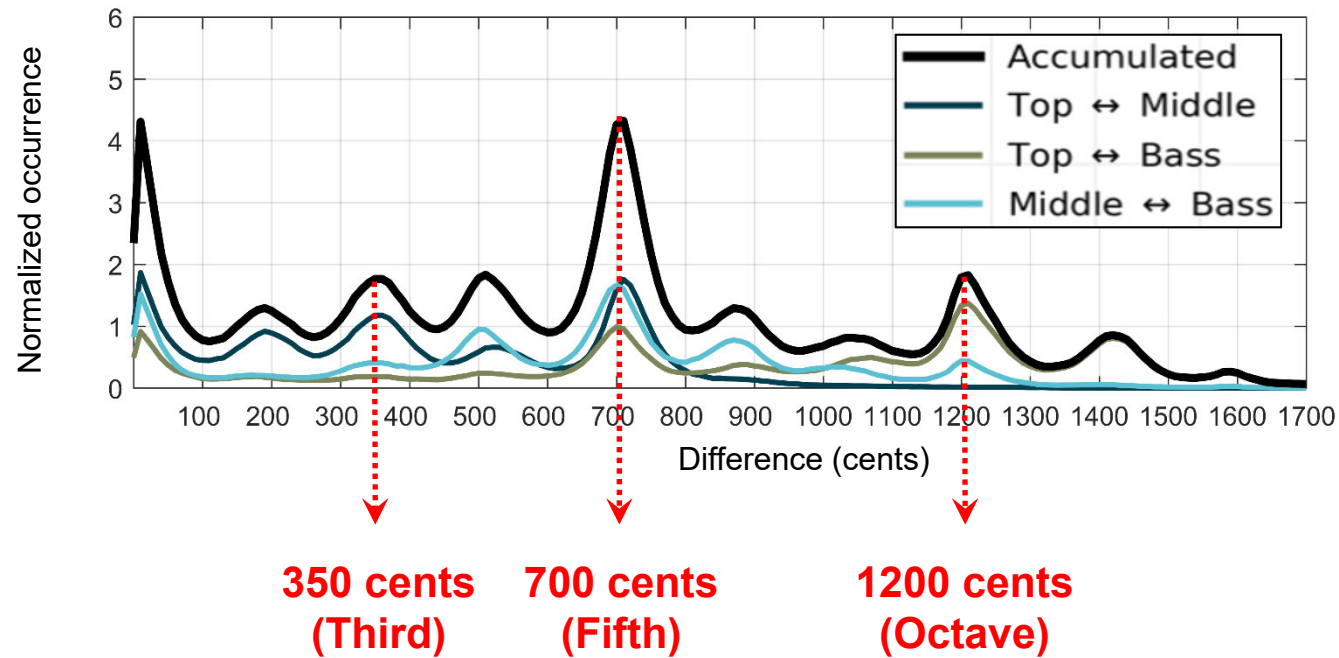
Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



- Peak at **350 cents** (between minor and major third)
- **Non-western temperament**

Traditional Georgian Vocal Music



- Recordings from field expedition in 2016
- 216 performances
- Multitrack audio + video
 - Room, **HSM**, **LRX**
- Total duration: 6 h



Room
Microphone

Traditional Georgian Vocal Music

- Musical scales
- Harmonic / melodic intervals
- Singer interaction
- Curation of music corpora
- New sensors
(larynx microphones)

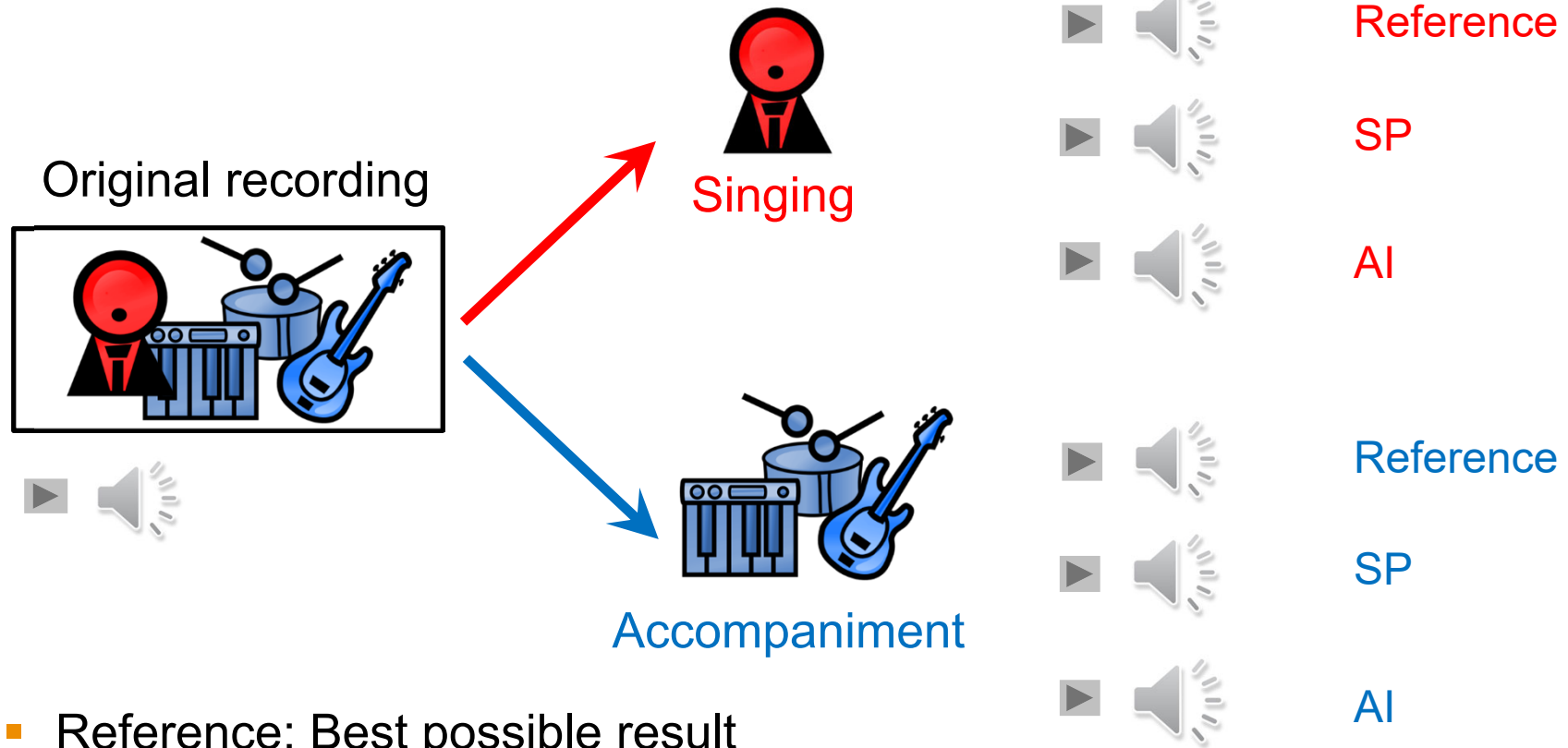
Honorary doctorate (2022)
State Conservatory of Georgia

Frank Scherbaum



Computational Audio Analysis

Source separation



- Reference: Best possible result
- SP: Using traditional signal processing
- AI: Using data-driven approach

Computational Audio Analysis

Source separation

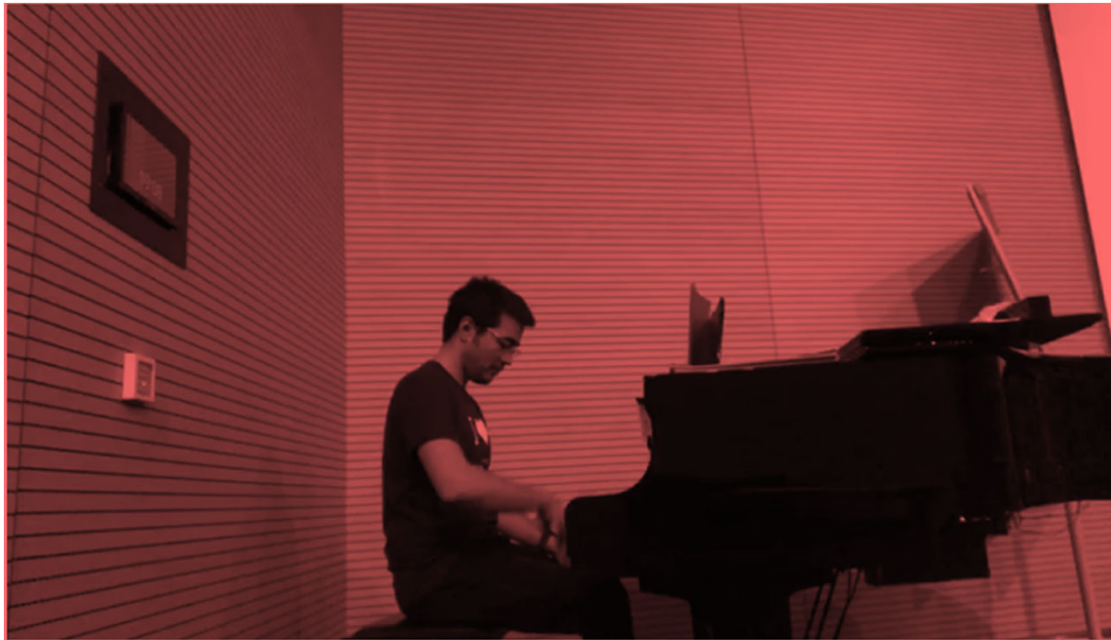
- Yigitcan Özer
- PhD student in engineering
- Pianist



Computational Audio Analysis

Source separation

- Yigitcan Özer
- PhD student in engineering
- Pianist



Only Piano!



**Where is the
orchestra?**

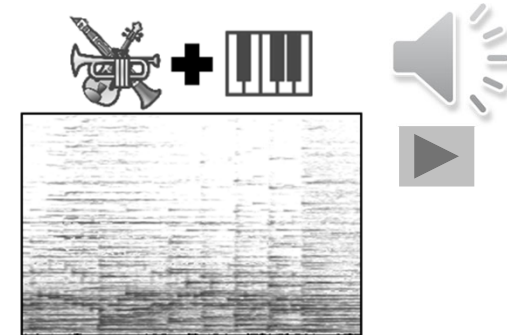


Computational Audio Analysis

Source separation

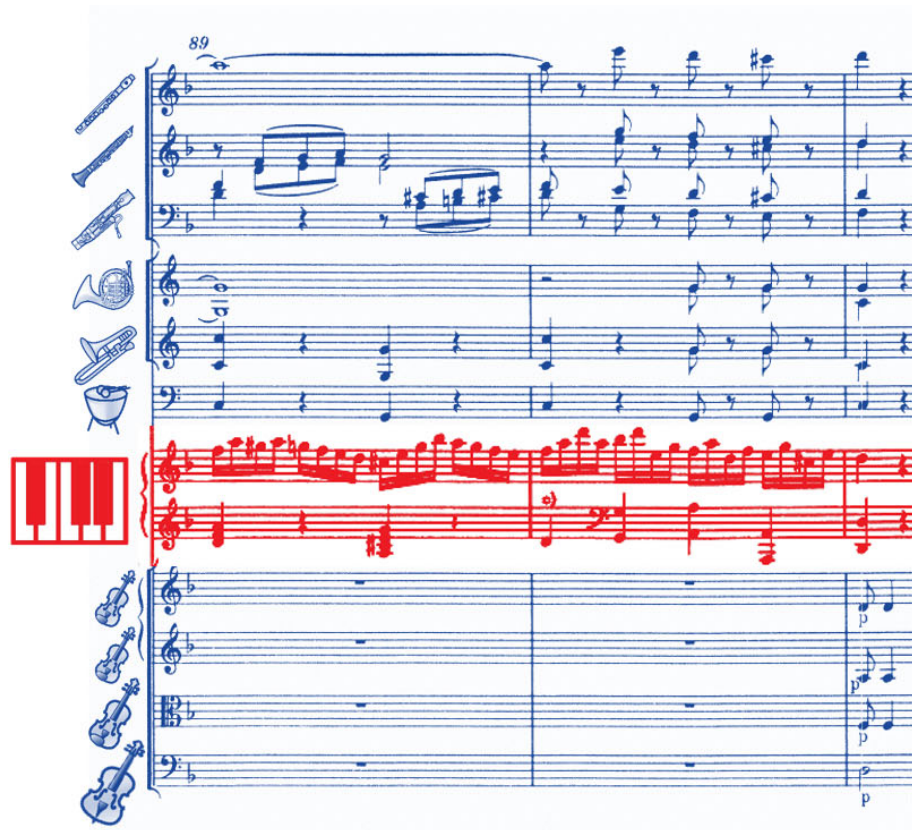


A musical score for a piece starting at measure 89. The score is written on multiple staves. To the left of the staves are icons for various instruments: two flutes, a clarinet, a trumpet, a trombone, a saxophone, a piano, a violin, and a viola. The piano part is particularly prominent, showing a complex melodic line.

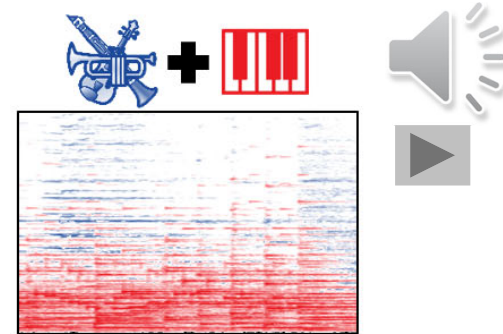


Computational Audio Analysis

Source separation

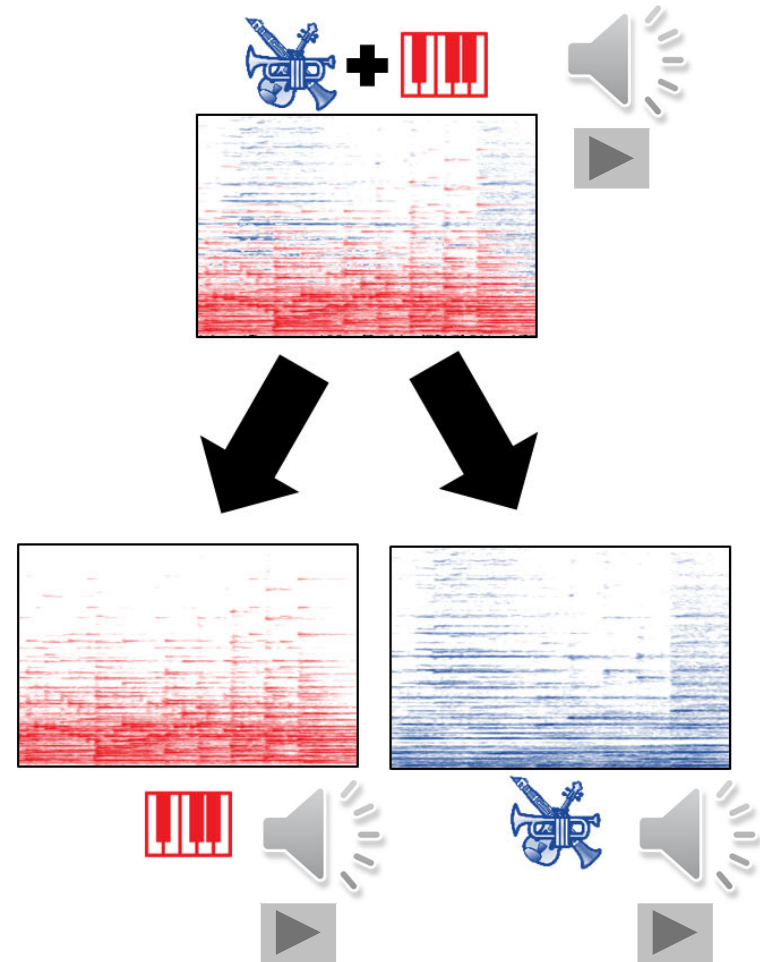
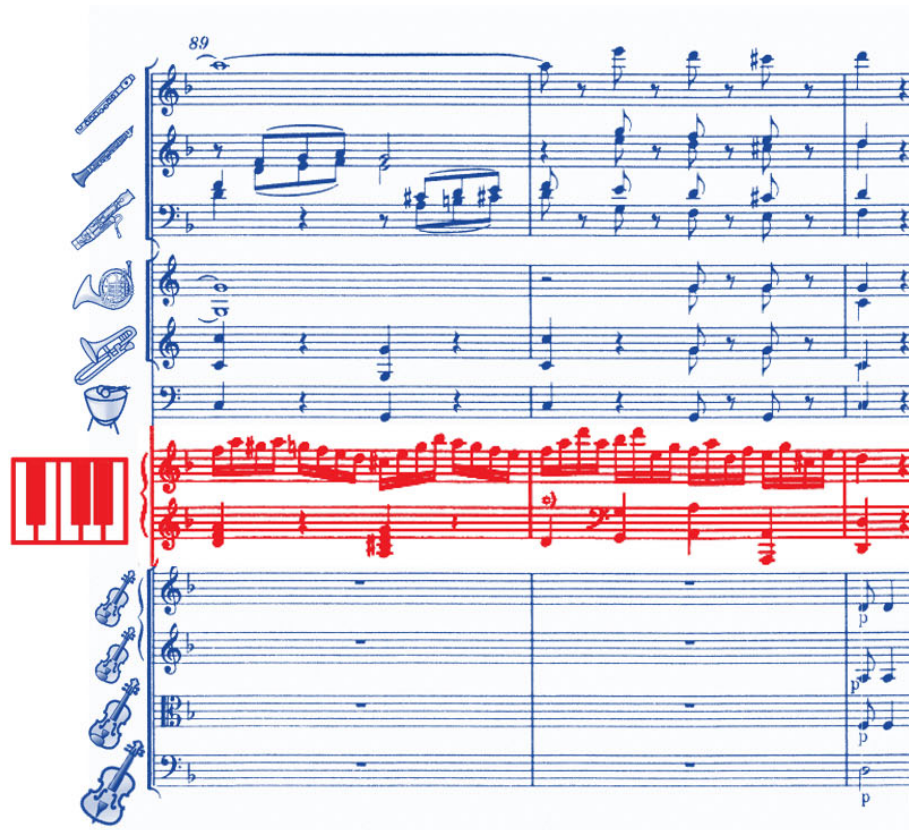


A musical score for a symphony orchestra, starting at measure 89. The score is divided into two main sections. The upper section, from measure 89 to the end, is written in blue ink and includes staves for woodwinds (flute, oboe, clarinet, bassoon), brass (trumpet, trombone, horn, tuba), and strings. The lower section, from measure 89 to the end, is written in red ink and includes a piano part. A red piano keyboard icon is positioned to the left of the piano part. The piano part shows a complex melodic line in the right hand and a supporting bass line in the left hand.



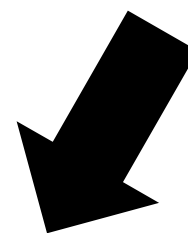
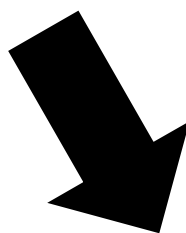
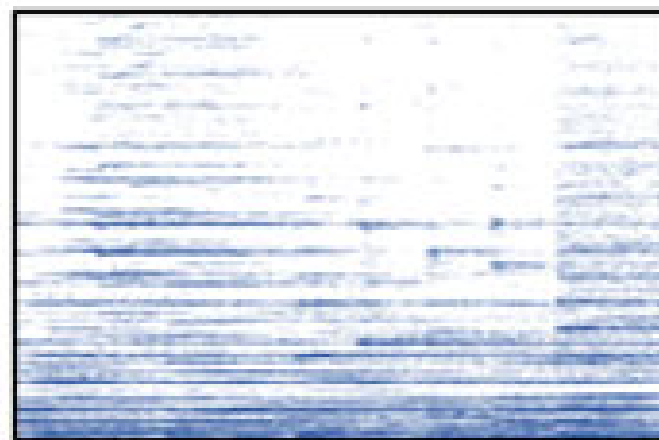
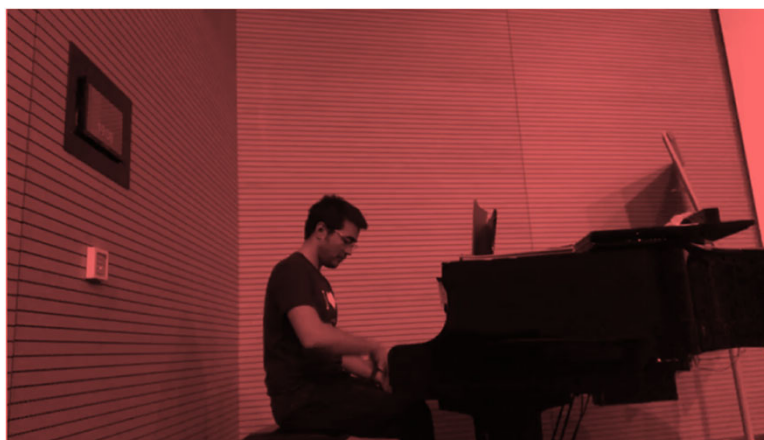
Computational Audio Analysis

Source separation



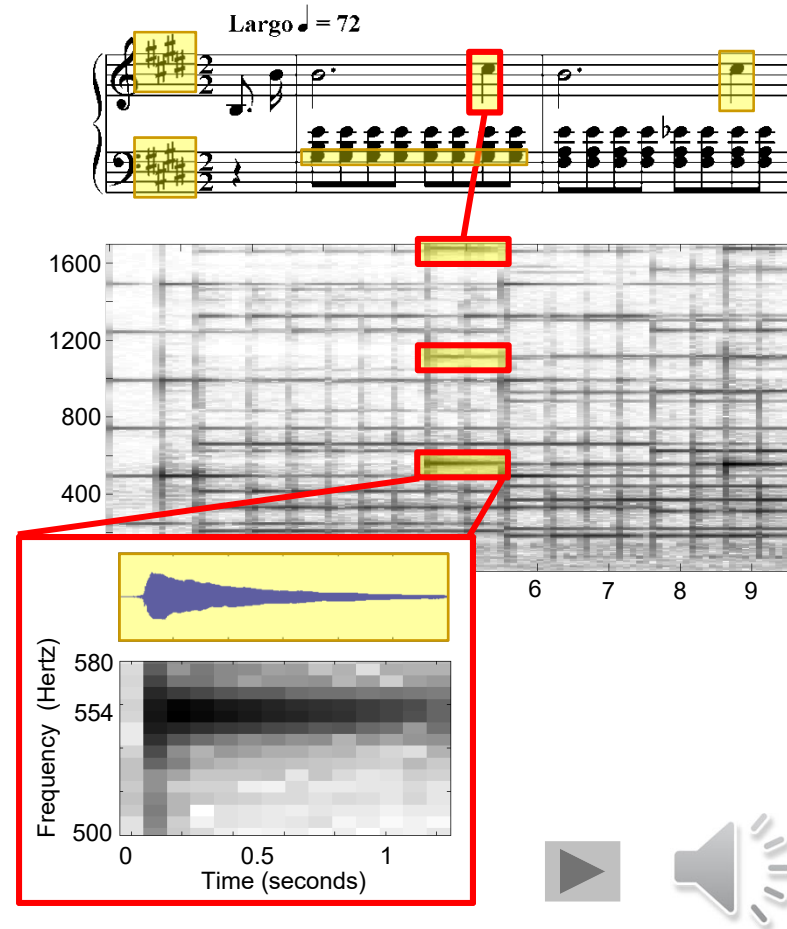
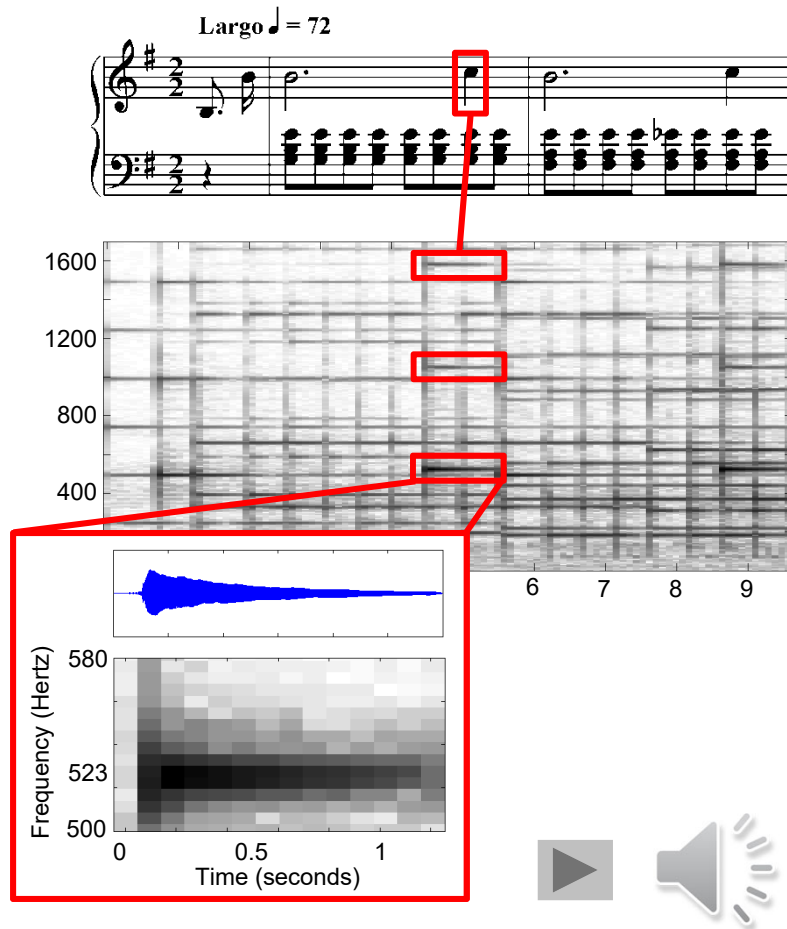
Computational Audio Analysis

Source separation



Computational Audio Analysis

Score-informed audio decomposition



Computational Audio Analysis

Audio mosaicing (style transfer)

Target signal: Beatles–Let it be



Source signal: Bees



Mosaic signal: **Let it Bee**

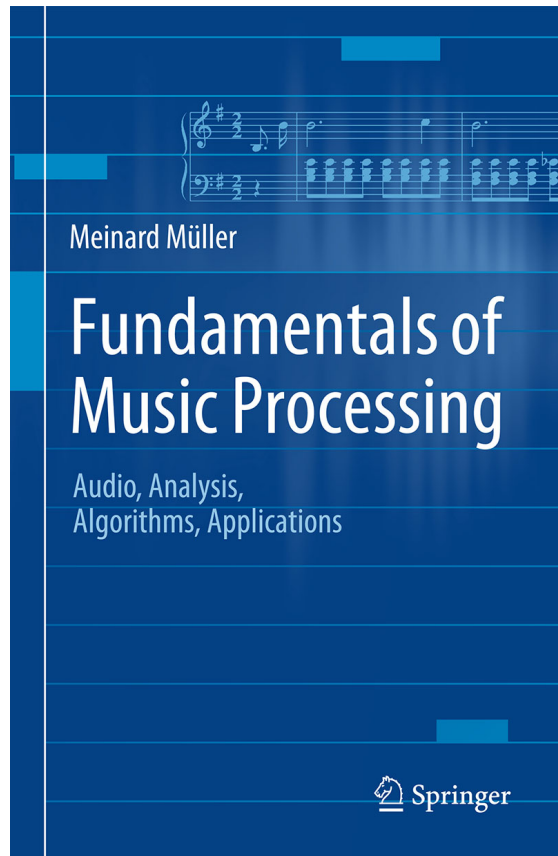
Computational Audio Analysis

- Understanding modern machine learning techniques
- Critical questioning of artificial intelligence (AI) concepts
- Developing explainable AI models
- Educating next generation of scientists
- ...

Neue Wege für die Musikforschung

Ziel soll dabei nicht die Ablösung der Historischen Musikwissenschaft durch eine wie auch immer zu definierende Musikinformatik sein, sondern vielmehr ein Dialog zwischen Historischer Musikwissenschaft und Informatik auf der Basis ihrer unterschiedlichen Voraussetzungen und Methoden.

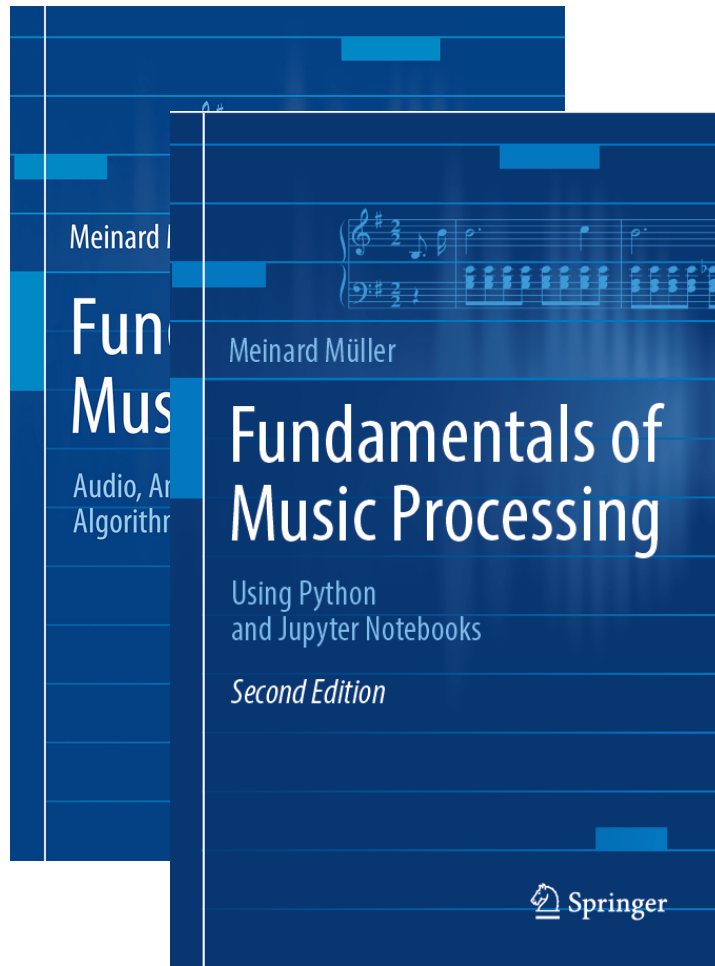
Fundamentals of Music Processing (FMP)



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
Springer, 2015

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)

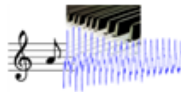

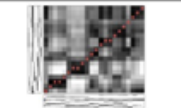
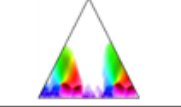
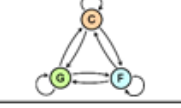
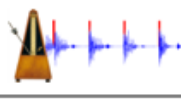
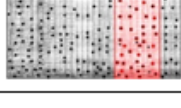
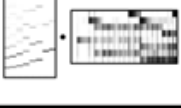


Meinard Müller
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Springer, 2015

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2nd edition
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Fundamentals of Music Processing
Using Python and Jupyter Notebooks
Springer, 2021

Fundamentals of Music Processing (FMP)

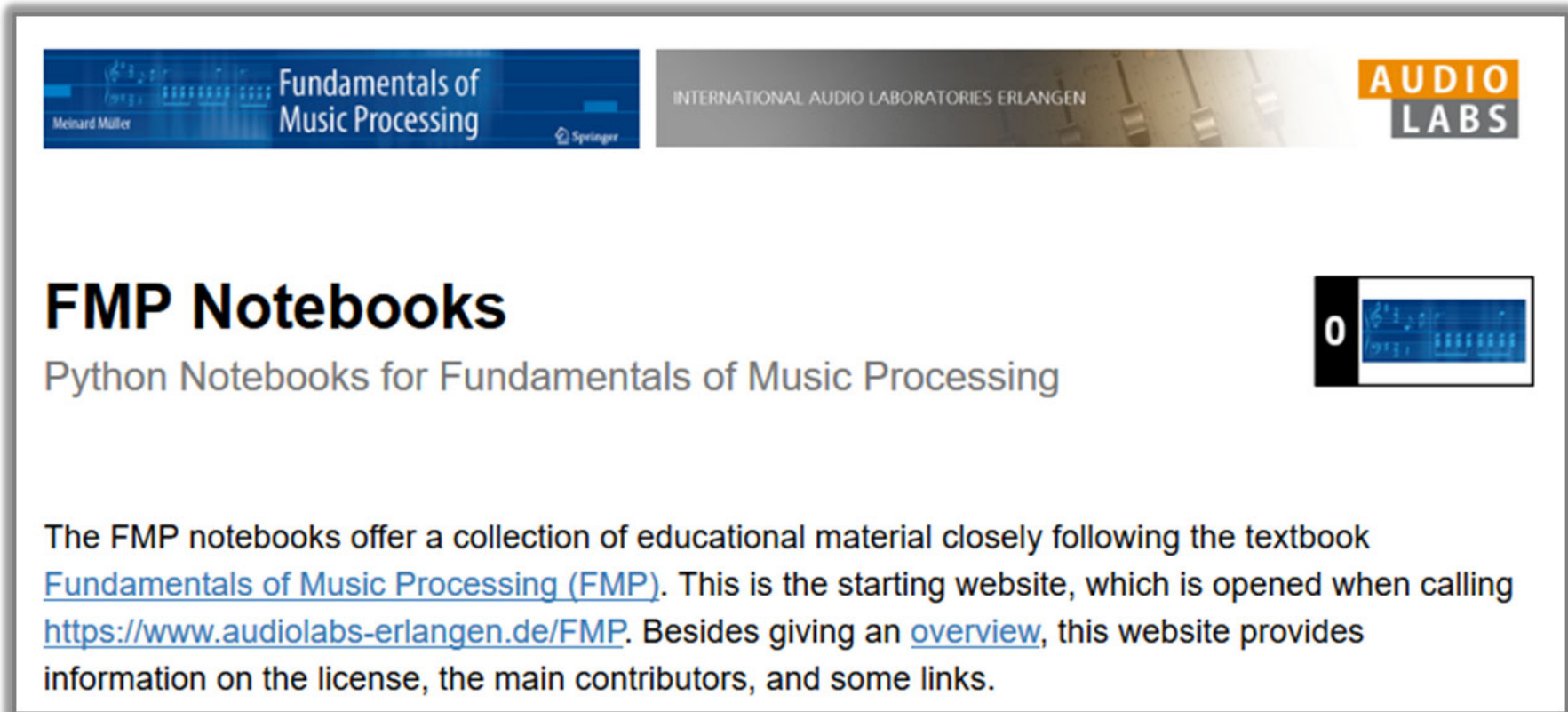
| Chapter | Music Processing Scenario |
|---------|---|
| 1 |  Music Representations |
| 2 |  Fourier Analysis of Signals |
| 3 |  Music Synchronization |
| 4 |  Music Structure Analysis |
| 5 |  Chord Recognition |
| 6 |  Tempo and Beat Tracking |
| 7 |  Content-Based Audio Retrieval |
| 8 |  Musically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

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Springer, 2021

FMP Notebooks: Education & Research



The screenshot shows the header of the FMP Notebooks website. On the left, there is a blue banner for the book 'Fundamentals of Music Processing' by Meinard Müller, published by Springer. To the right of this banner is the text 'INTERNATIONAL AUDIO LABORATORIES ERLANGEN' and the 'AUDIO LABS' logo. Below the banner, the main heading reads 'FMP Notebooks' in a large, bold, black font, followed by the subtitle 'Python Notebooks for Fundamentals of Music Processing' in a smaller, grey font. To the right of the subtitle is a small icon of a notebook with a blue cover and a white page. Below the subtitle, a paragraph of text explains that the FMP notebooks offer educational material following the textbook 'Fundamentals of Music Processing (FMP)'. It provides the starting website URL <https://www.audiolabs-erlangen.de/FMP> and mentions that the site also provides an overview, license information, and contributor details.

<https://www.audiolabs-erlangen.de/FMP>

References

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<https://www.springer.com/gp/book/9783030698072>
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<https://joss.theoj.org/papers/10.21105/joss.03326>
- Meinard Müller: An Educational Guide Through the FMP Notebooks for Teaching and Learning Fundamentals of Music Processing. Signals, 2(2): 245–285, 2021.
<https://www.mdpi.com/2624-6120/2/2/18>
- Meinard Müller and Frank Zalkow: FMP Notebooks: Educational Material for Teaching and Learning Fundamentals of Music Processing. Proc. International Society for Music Information Retrieval Conference (ISMIR): 573–580, 2019.
<https://zenodo.org/record/3527872#.YOhEQOgzaUk>
- Meinard Müller, Brian McFee, and Katherine Kinnaird: Interactive Learning of Signal Processing Through Music: Making Fourier Analysis Concrete for Students. IEEE Signal Processing Magazine, 38(3): 73–84, 2021.
<https://ieeexplore.ieee.org/document/9418542>

Resources (Group Meinard Müller)

- FMP Notebooks:

<https://www.audiolabs-erlangen.de/FMP>

- libfmp:

<https://github.com/meinardmueller/libfmp>

- synctoolbox:

<https://github.com/meinardmueller/synctoolbox>

- libtsm:

<https://github.com/meinardmueller/libtsm>

- Preparation Course Python (PCP) Notebooks:

<https://www.audiolabs-erlangen.de/resources/MIR/PCP/PCP.html>

<https://github.com/meinardmueller/PCP>