

Automatische Erschließung von Musikdaten

Meinard Müller

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Collegium Alexandrinum
Erlangen, 16. Januar 2025



Meinard Müller



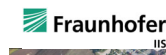
- Mathematics (Diplom/Master, 1997)
Computer Science (PhD, 2001)
Information Retrieval (Habilitation, 2007)
- Senior Researcher (2007-2012)
- Professor Semantic Audio Processing (since 2012)
- Former President of the International Society for Music Information Retrieval (MIR)
- IEEE Fellow for contributions to Music Signal Processing

Meinard Müller: Research Group

- Ben Maman
- Simon Schwär
- Johannes Zeitler
- Peter Meier
- Sebastian Strahl
- Uli Berendes
- Ching-Yu Chiu (Sunny)
- Vlora Arifi-Müller
- Stefan Balke
- Yigitcan Ozer
- Michael Krause
- Christof Weiß
- Sebastian Rosenzweig
- Frank Zalkow
- Hendrik Schreiber
- Christian Dittmar
- Stefan Balke
- Jonathan Driedger
- Thomas Prätzlich
- ...



International Audio Laboratories Erlangen



- Fraunhofer Institute for Integrated Circuits IIS
- Largest Fraunhofer institute with ≈ 1000 members
- Applied research for sensor, audio, and media technology

- Friedrich-Alexander Universität Erlangen-Nürnberg (FAU)
- One of Germany's largest universities with ≈ 40,000 students
- Strong Technical Faculty

International Audio Laboratories Erlangen

Audio

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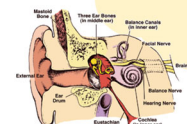
Audio Coding



3D Audio



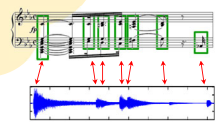
Audio



Psychoacoustics



Internet of Things



Music Processing

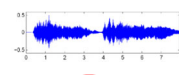


Music Information Retrieval (MIR)

Sheet Music (Image)



CD / MP3 (Audio)



MusicXML (Text)

```
<musicxml>  
<score>  
<staff>  
<note>  
<pitch>  
<duration>  
<type>  
</note>  
</staff>  
</score>
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Dance / Motion (Mocap)



Music

MIDI



Singing / Voice (Audio)



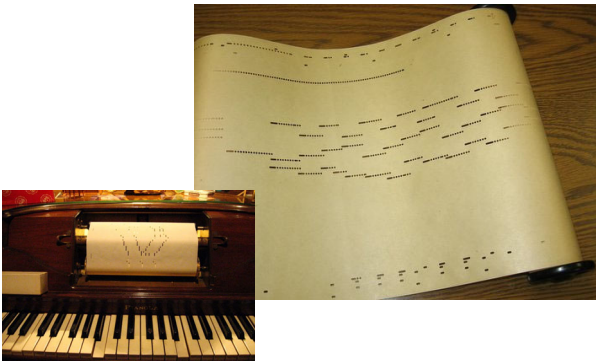
Music Film (Video)



Music Literature (Text)

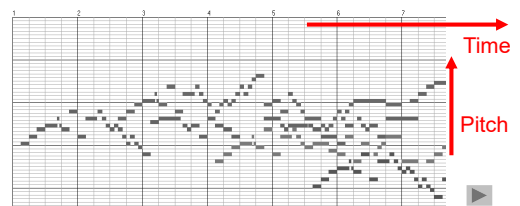


Piano Roll Representation (1900)



Piano Roll Representation

J.S. Bach, C-Major Fuge
(Well Tempered Piano, BWV 846)

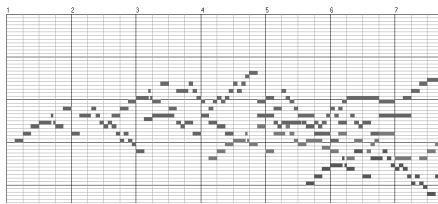


Piano Roll Representation

Query:

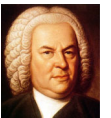


Goal: Find all occurrences of the query



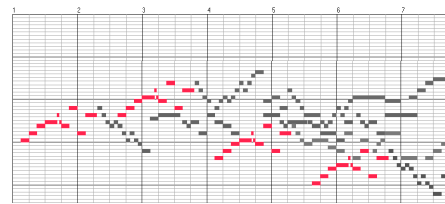
Piano Roll Representation

Query:

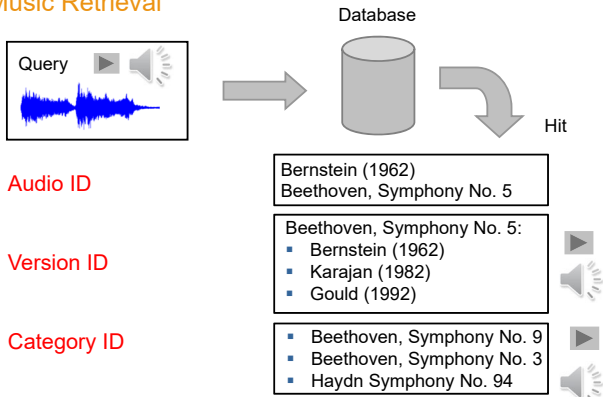


Goal: Find all occurrences of the query

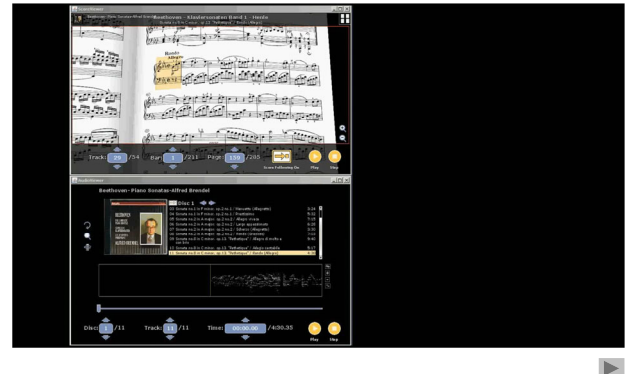
Matches:



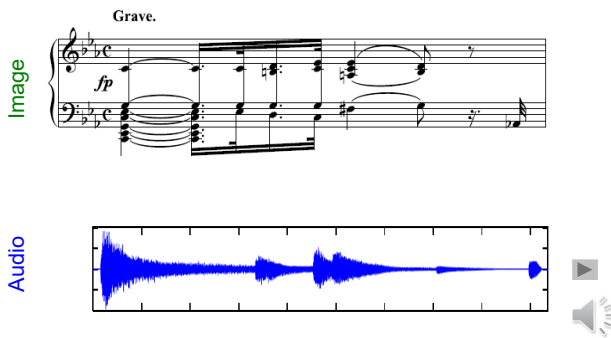
Music Retrieval



Music Synchronization

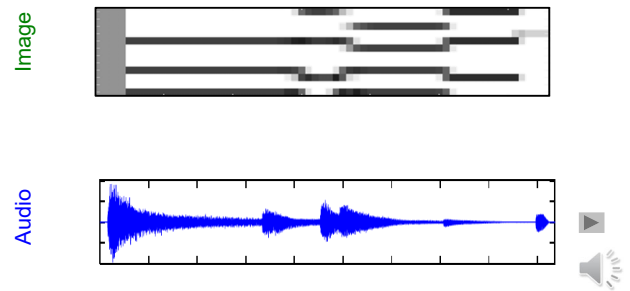


Music Synchronization: Image-Audio



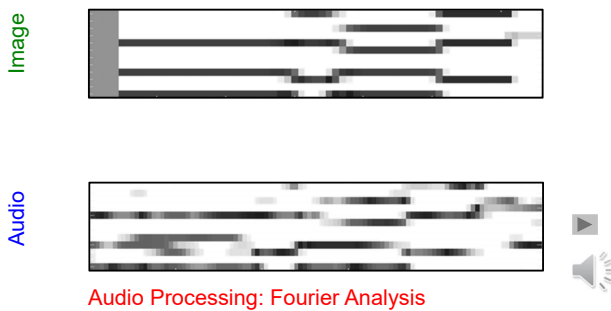
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition



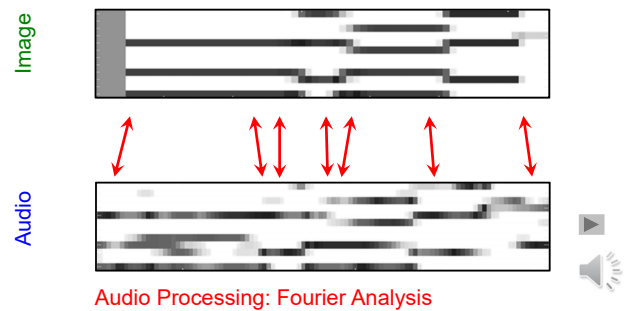
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

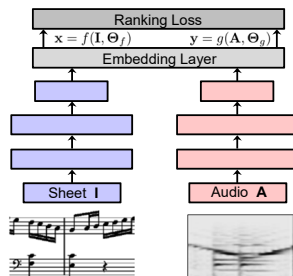


Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

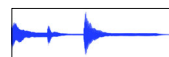


Music Synchronization: Image-Audio

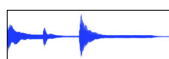
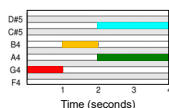


- Deep learning
- Embedding techniques
- Weak annotations
- Loss functions
- ...

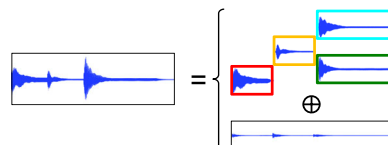
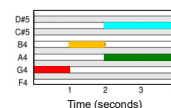
Score-Informed Audio Decomposition



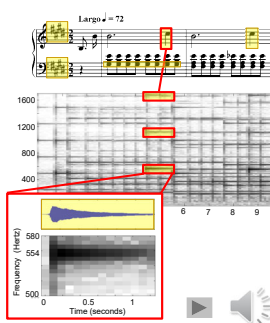
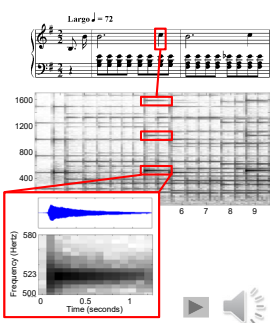
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition



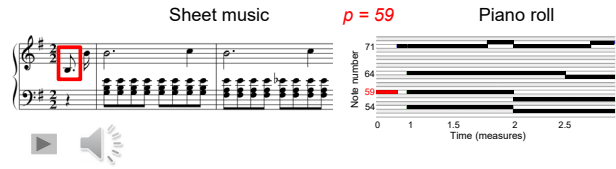
Score-Informed Audio Decomposition



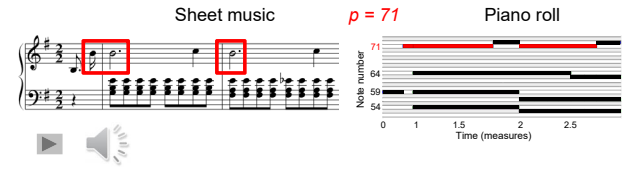
Score-Informed Audio Decomposition



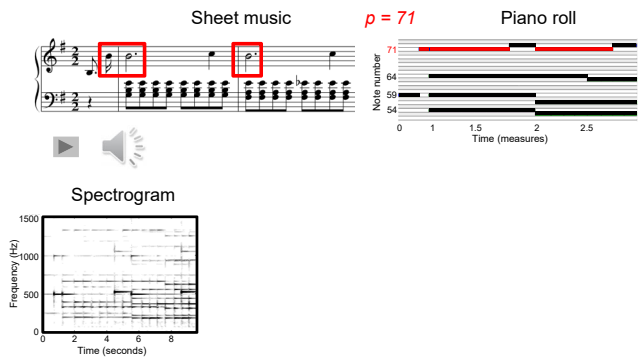
Score-Informed Audio Decomposition



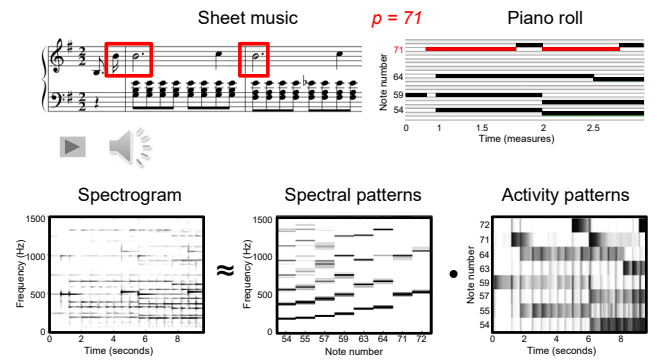
Score-Informed Audio Decomposition



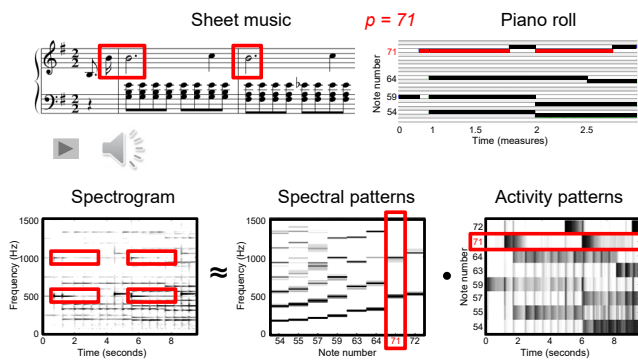
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

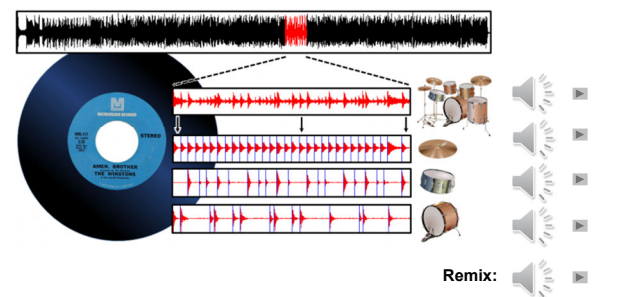


Score-Informed Audio Decomposition



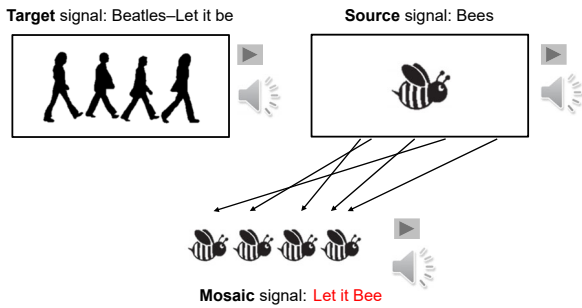
Score-Informed Audio Decomposition

Informed Drum-Sound Decomposition



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)



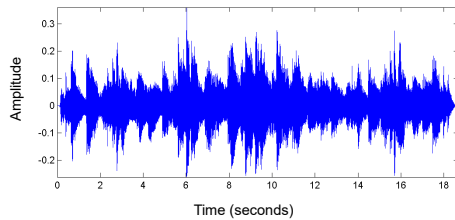
Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

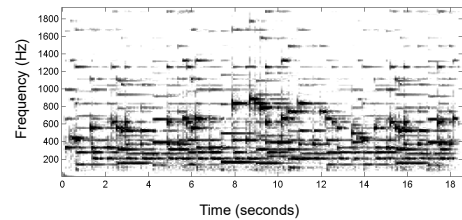
- Waveform



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram
- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal
- Polyphony

Source Separation

- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”

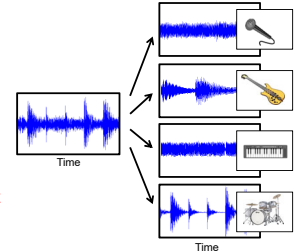


Source Separation

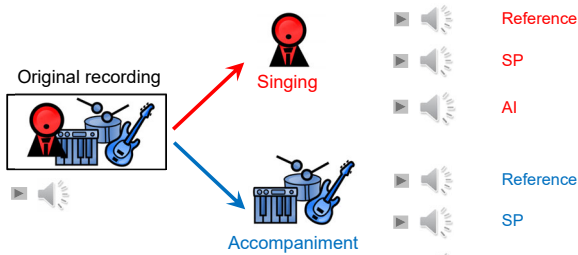
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- "Cocktail party effect"
- Several input signals
- Sources are assumed to be statistically independent

Source Separation (Music)

- Main melody, accompaniment, drum track
- Instrumental voices
- Individual note events
- Only mono or stereo
- Sources are often highly dependent



AI-Based Source Separation



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

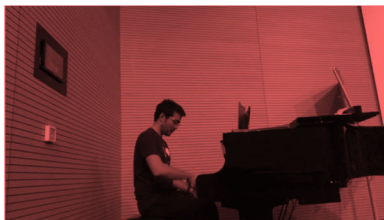
AI-Based Source Separation

- Yigitcan Özer
- PhD student in engineering
- Pianist



AI-Based Source Separation

- Yigitcan Özer
- PhD student in engineering
- Pianist



Only Piano!



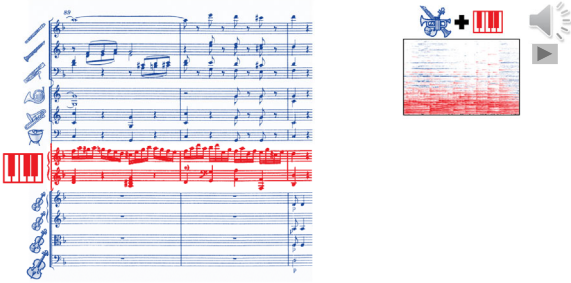
Where is the orchestra?



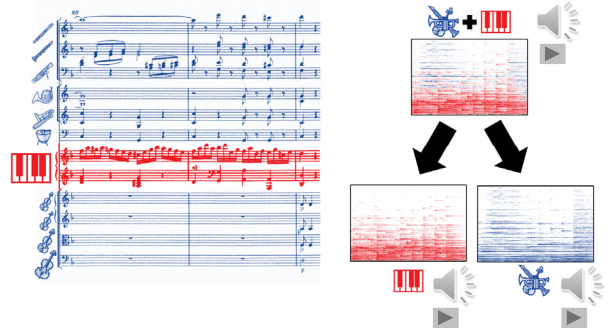
AI-Based Source Separation



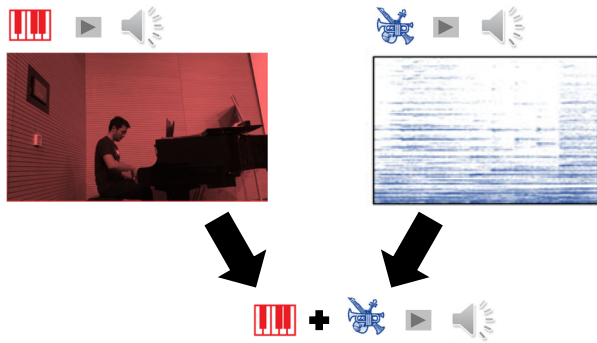
AI-Based Source Separation



AI-Based Source Separation



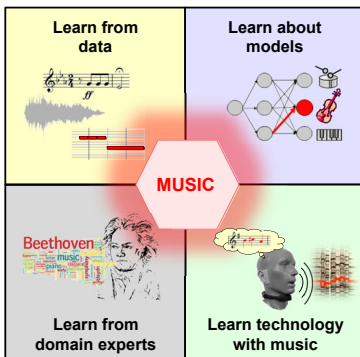
AI-Based Source Separation



AI-Based Source Separation

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

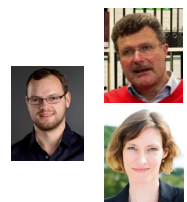
Learning with Music Signals: Technology Meets Education



- Machine learning for music signal processing
- Interpretable models and knowledge integration
- Music understanding and applications
- Interactive learning in engineering through music

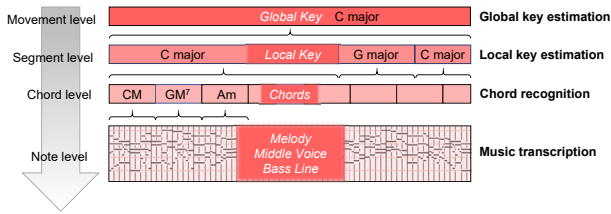
Computational Musicology

- Cooperation:
 - Rainer Kleinertz (Saarbrücken)
 - Stephanie Klauk (Saarbrücken)
 - Christof Weiß (Würzburg)
- Objectives
 - Harmony-based structural analysis
 - Beethoven Sonatas & Wagner's Ring
 - Interdisciplinary dialogue
- Since 2014: DFG-funded project



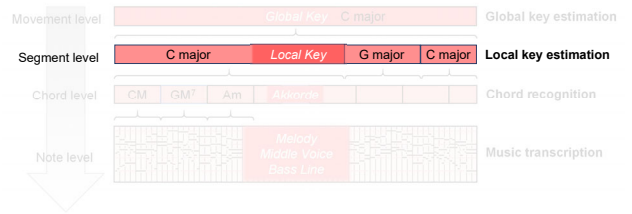
Computational Musicology: Harmony Analysis

- Different concepts
- Different temporal levels



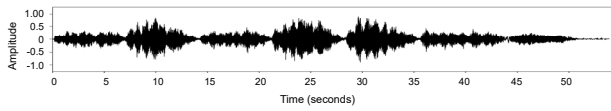
Computational Musicology: Harmony Analysis

- Different concepts
- Different temporal levels



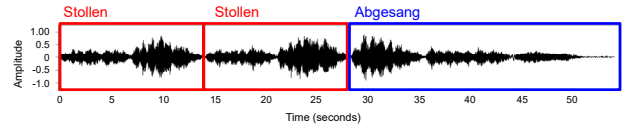
Local Key Estimation

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



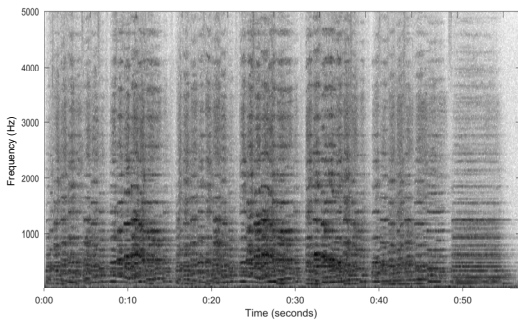
Local Key Estimation

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



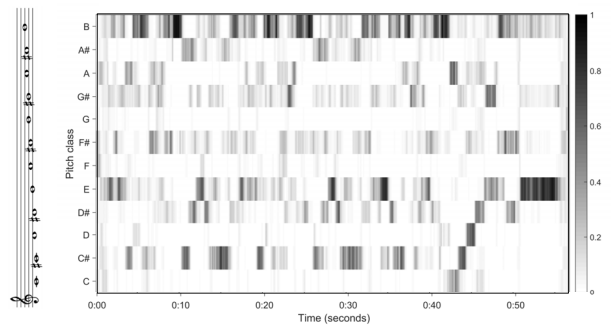
Local Key Estimation

Spectrogram



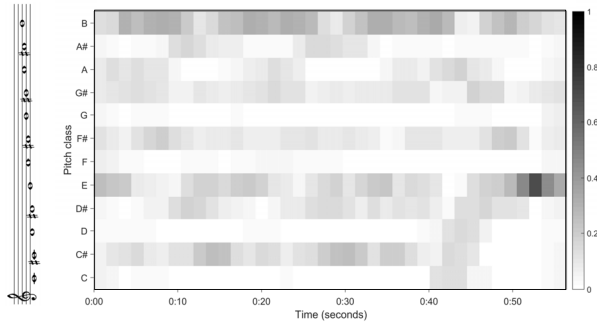
Local Key Estimation

Chromagram



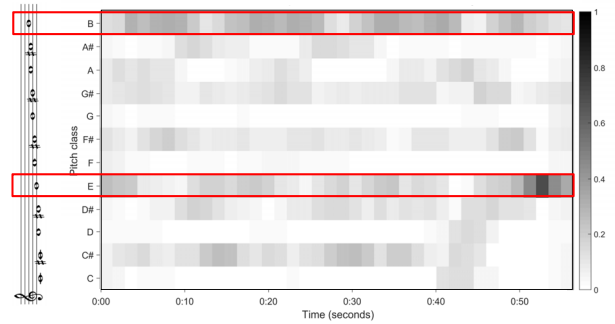
Local Key Estimation

Chromagram after smoothing



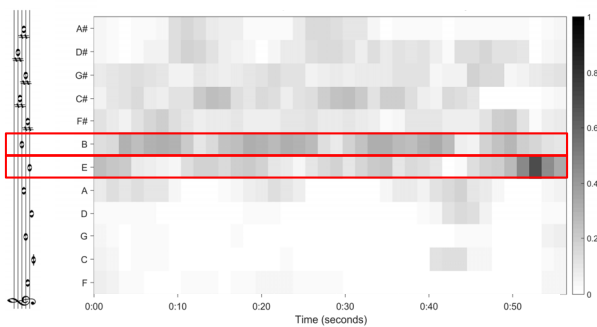
Local Key Estimation

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



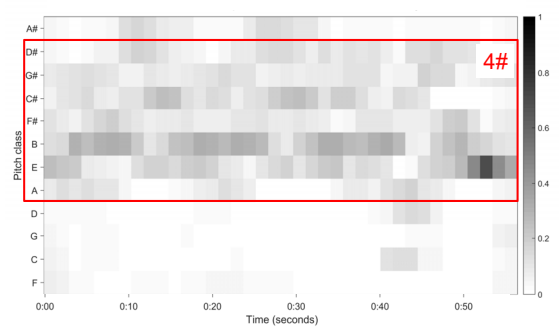
Local Key Estimation

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



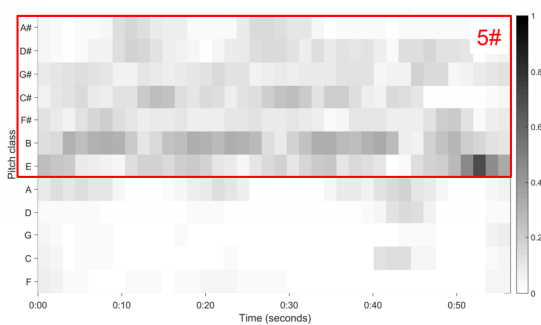
Local Key Estimation

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



Local Key Estimation

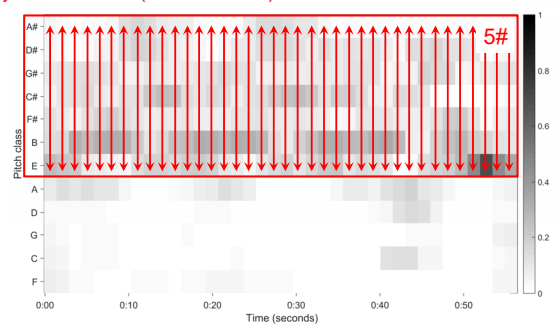
Summarize pitch class content according to **diatonic scales**



Local Key Estimation

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

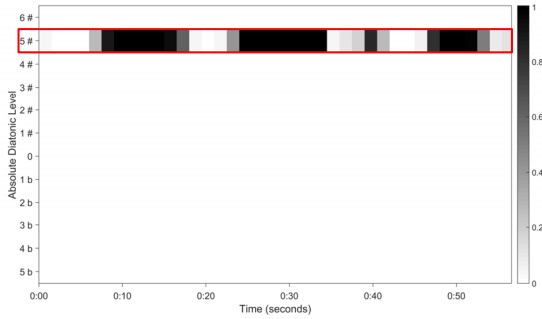
Multiply chroma values (in each column)



Local Key Estimation

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

Multiply chroma values



Automatische Erschließung
von Musikdaten

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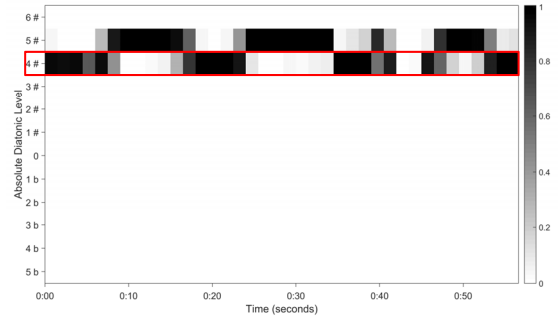
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Local Key Estimation

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

Multiply chroma values



Automatische Erschließung
von Musikdaten

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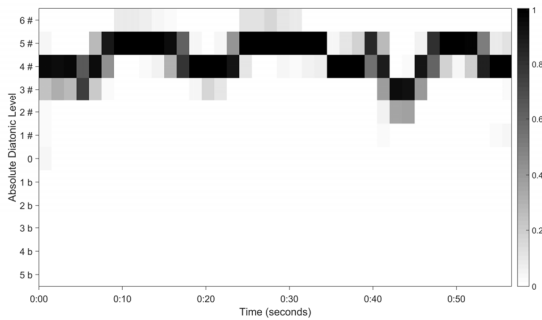
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Local Key Estimation

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

Multiply chroma values



Automatische Erschließung
von Musikdaten

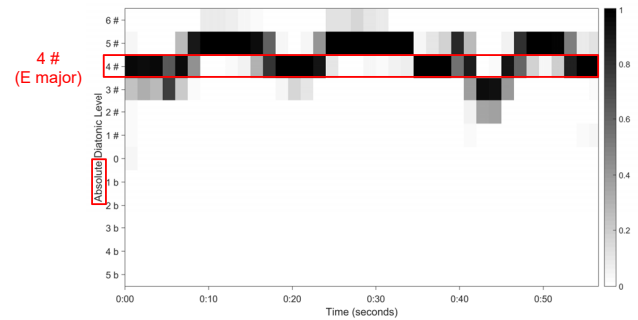
63

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Local Key Estimation

Normalize representation relative to **global key**



Automatische Erschließung
von Musikdaten

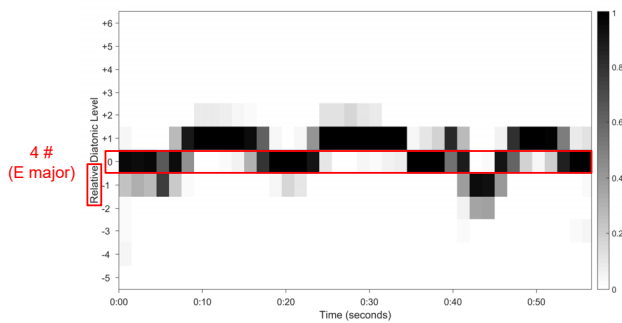
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Local Key Estimation

Normalize representation relative to **global key**



Automatische Erschließung
von Musikdaten

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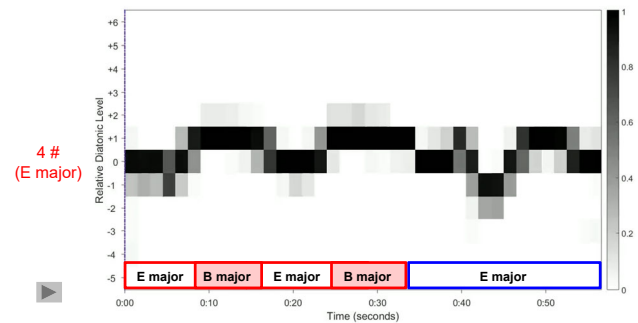
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Local Key Estimation

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

Recording: Scholars Baroque Ensemble, Naxos 1994



Automatische Erschließung
von Musikdaten

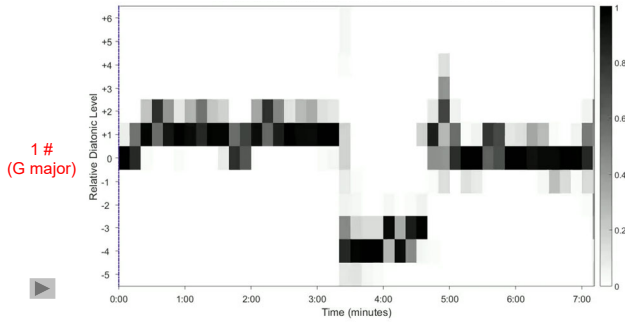
66

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Local Key Estimation

L. v. Beethoven: Piano Sonata No. 10 (Op. 14 Nr. 2), 1. Allegro
Recording: Barenboim, EMI 1998



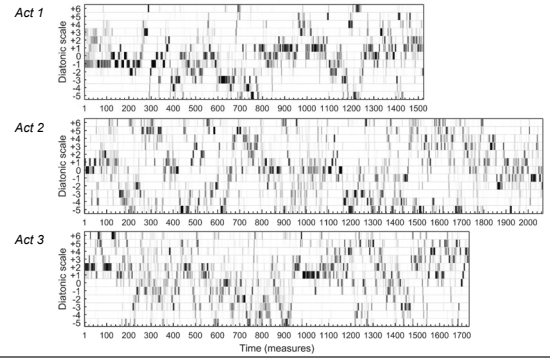
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von Musikdaten

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Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



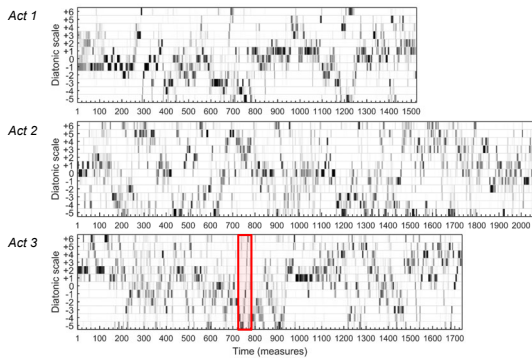
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von Musikdaten

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Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



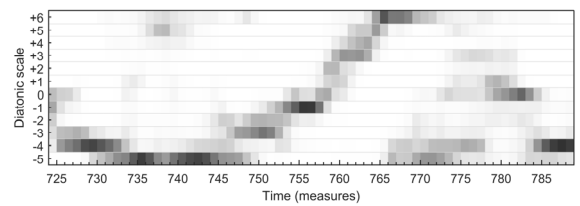
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von Musikdaten

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Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)
Act 3, measure 724–789 (*Wotan's punishment*)



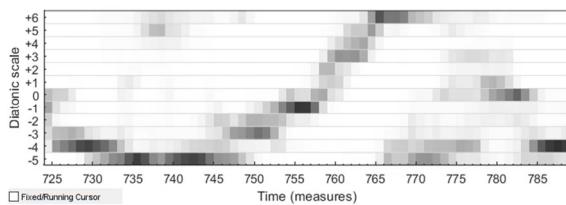
Automatische Erschließung
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Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)
Act 3, measure 724–789 (*Wotan's punishment*)



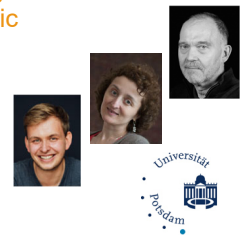
Automatische Erschließung
von Musikdaten

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Computational Ethnomusicology: 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



Automatische Erschließung
von Musikdaten

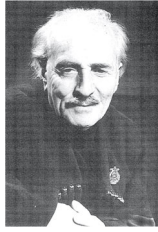
72

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AUDIO LABS

Traditional Georgian Vocal Music

Example: Erkomaishvili corpus

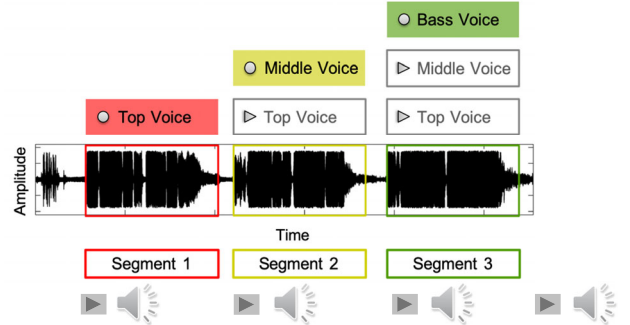
- Collection of traditional three-voice Georgian songs
- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)
- Recordings of 100 songs using tape recorders (1966)



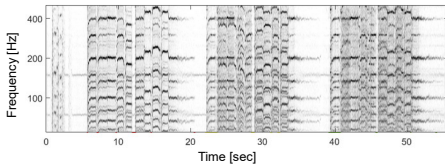
"Original masterpieces of Georgian musical thinking." (Shugliashvili, 2014)

Traditional Georgian Vocal Music

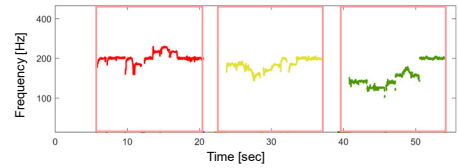
Example: Erkomaishvili corpus



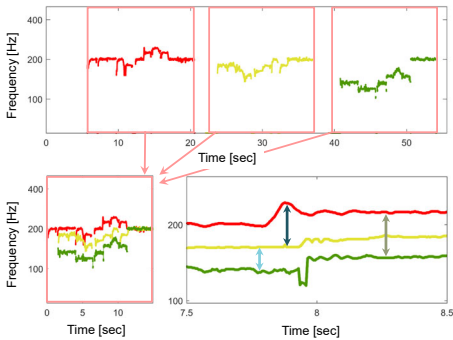
Traditional Georgian Vocal Music



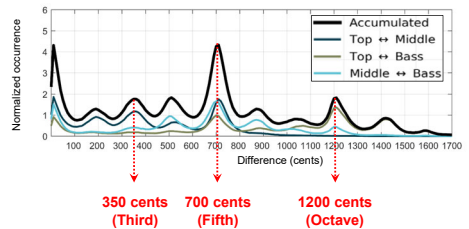
Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



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

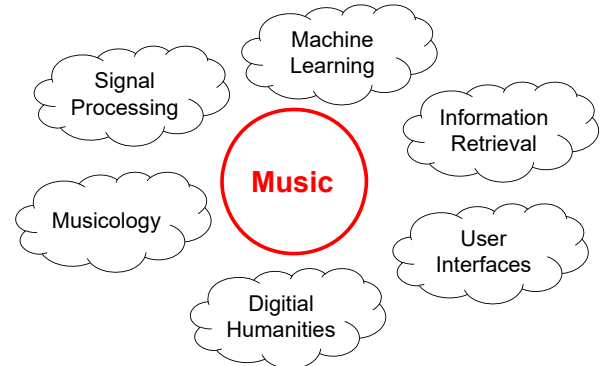
Traditional Georgian Vocal Music

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

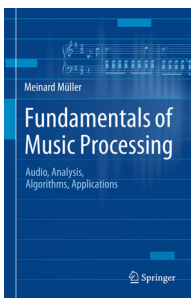


Room
Microphone

Music Information Retrieval (MIR)



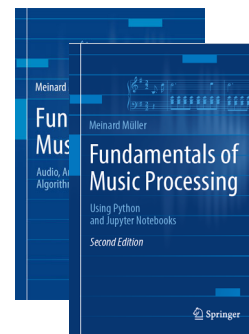
Fundamentals of Music Processing (FMP)



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

Accompanying website:
www.music-processing.de

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2nd edition
Meinard Müller
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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Fundamentals of Music Processing
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Springer, 2021

FMP Notebooks: Education & Research

FMP Notebooks
Python Notebooks for Fundamentals of Music Processing

The FMP notebooks offer a collection of educational material closely following the textbook [Fundamentals of Music Processing \(FMP\)](https://www.audiolabs-erlangen.de/FMP). This is the starting website, which is opened when calling <https://www.audiolabs-erlangen.de/FMP>. Besides giving an [overview](#), this website provides information on the license, the main contributors, and some links.

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

References (FMP Notebooks)

- Meinard Müller: Fundamentals of Music Processing – Using Python and Jupyter Notebooks. 2nd Edition, Springer, 2021.
<https://www.springer.com/gp/book/9783030698072>
- Meinard Müller and Frank Zalkow: libfmp: A Python Package for Fundamentals of Music Processing. Journal of Open Source Software (JOSS), 6(63): 1–5, 2021.
<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 Kinnaid: 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>