

## Neue Wege für die Musikforschung

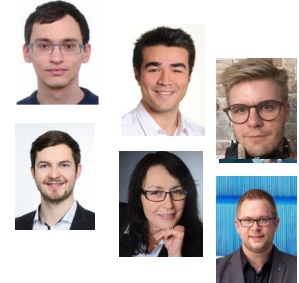
**Meinard Müller**

International Audio Laboratories Erlangen  
meinard.mueller@audiolabs-erlangen.de

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



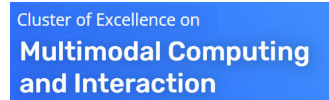
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## Multimodal Music Processing

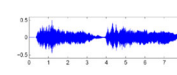
Music

## Multimodal Music Processing

Sheet Music (Image)



CD / MP3 (Audio)



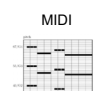
MusicXML (Text)

```
<?xml version="1.0" encoding="UTF-8" >  
<musicxml>  
  <score>  
    <staff>  
      <music></music>  
    </staff>  
  </score>  
</musicxml>
```

Dance / Motion (Mocap)



Music



Singing / Voice (Audio)



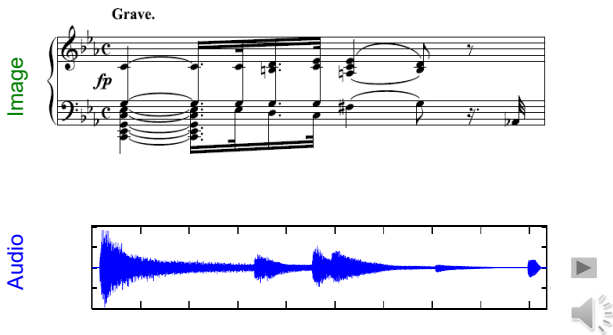
Music Film (Video)



Music Literature (Text)

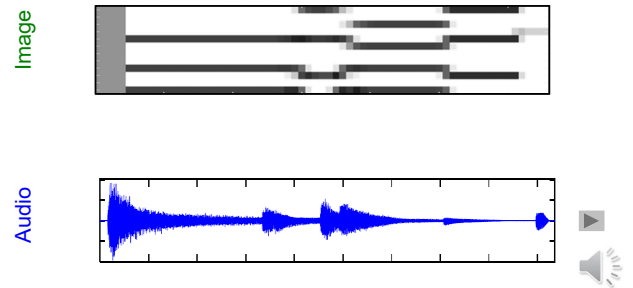


## Multimodal Music Processing



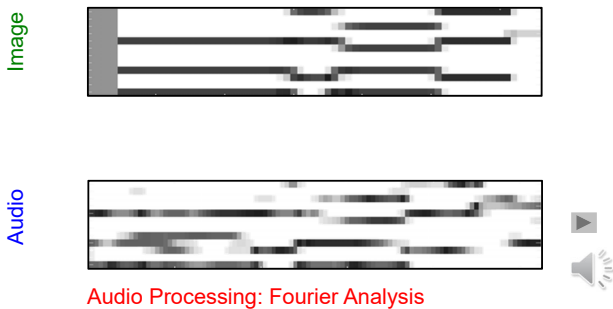
## Multimodal Music Processing

### Image Processing: Optical Music Recognition



## Multimodal Music Processing

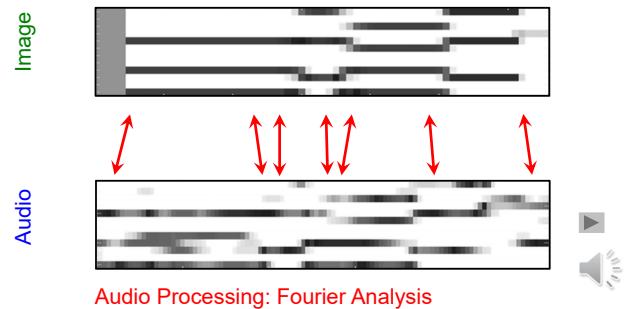
### Image Processing: Optical Music Recognition



### Audio Processing: Fourier Analysis

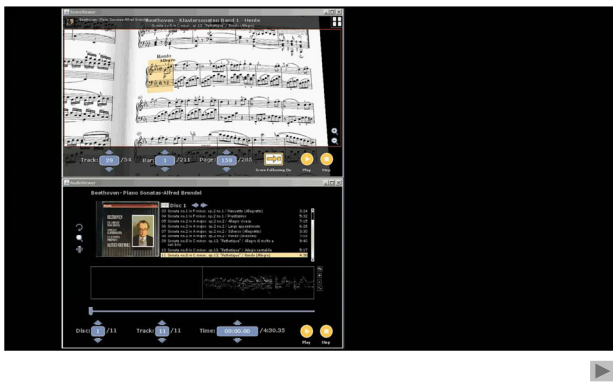
## Multimodal Music Processing

### Image Processing: Optical Music Recognition



### Audio Processing: Fourier Analysis

## Multimodal Music Processing



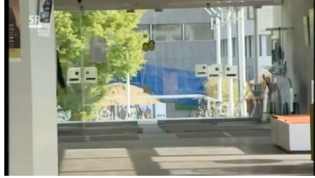
## Multimodal Music Processing

- 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

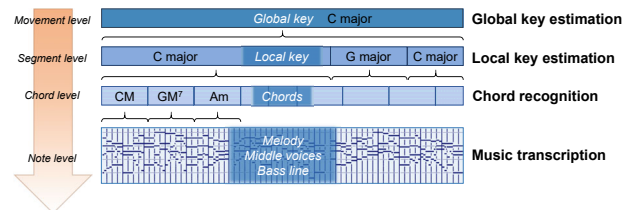
## Computational Musicology

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



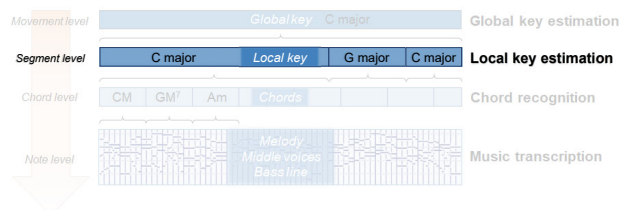
## Harmony Analysis

- 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

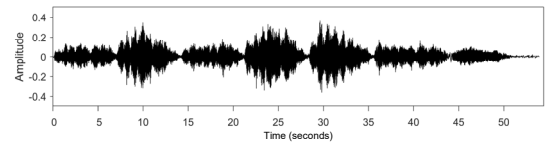
Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)  
Score representation (piano reduction)

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

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

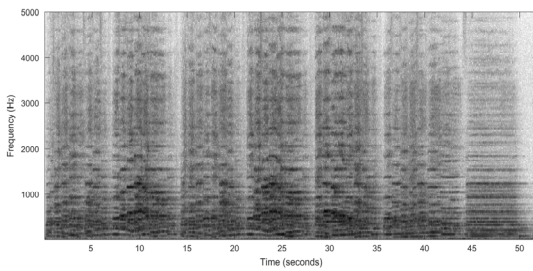
## Local Key Estimation

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



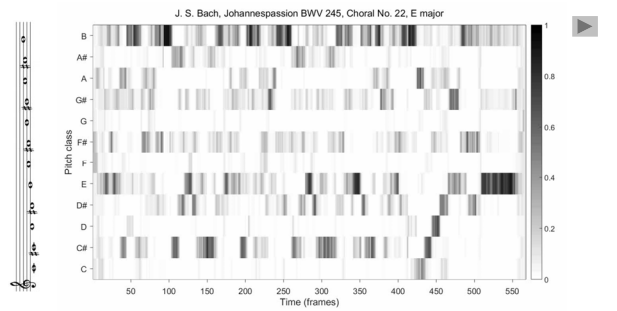
## Local Key Estimation

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



## Local Key Estimation

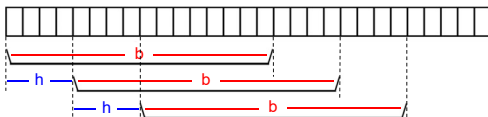
Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)  
Recording (Scholars Baroque Ensemble, Naxos 1994) **Chromagram**



## Local Key Estimation

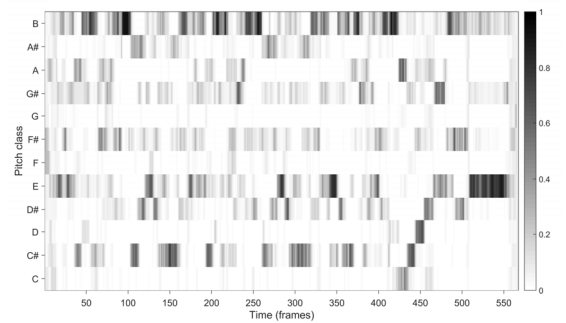
Summarize pitch class (chroma) content over a certain time period

- Feature smoothing
- Parameters: blocksize  $b$  and hopsize  $h$



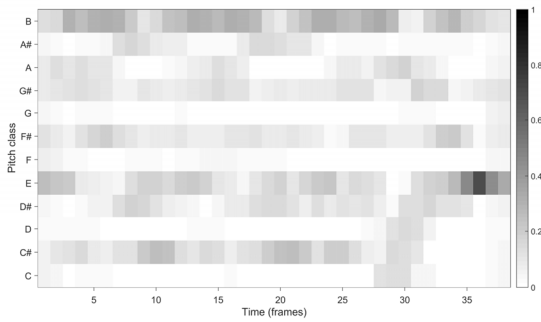
## Local Key Estimation

Chromagram



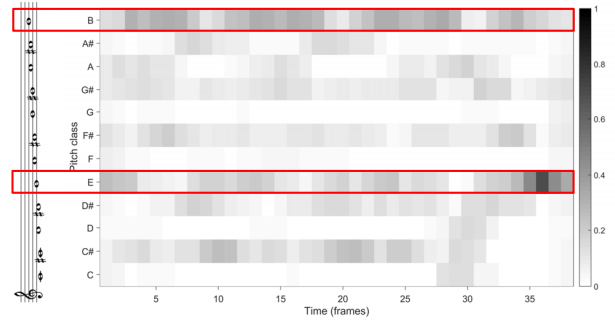
## Local Key Estimation

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



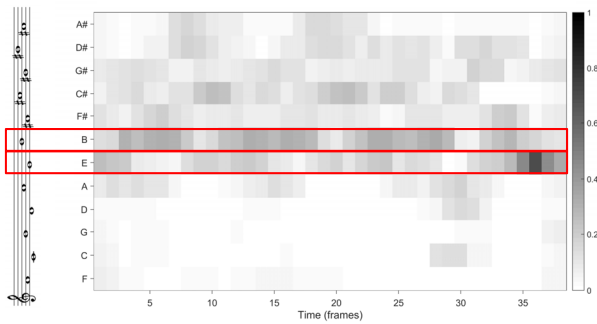
## Local Key Estimation

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



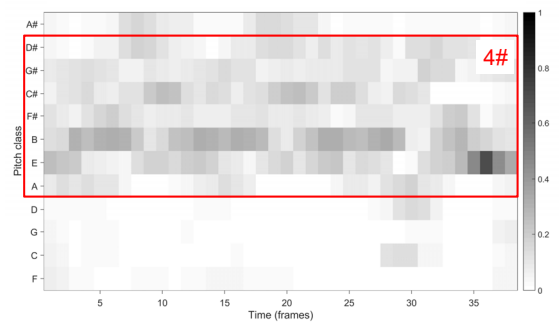
## Local Key Estimation

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



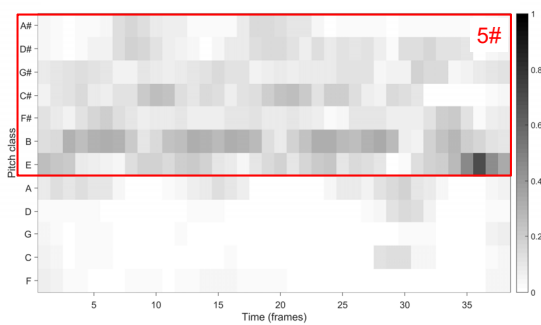
## Local Key Estimation

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



## Local Key Estimation

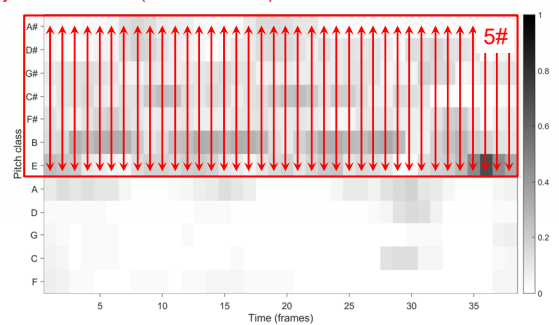
Summarize pitch class content according to **diatonic scales**



## Local Key Estimation

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

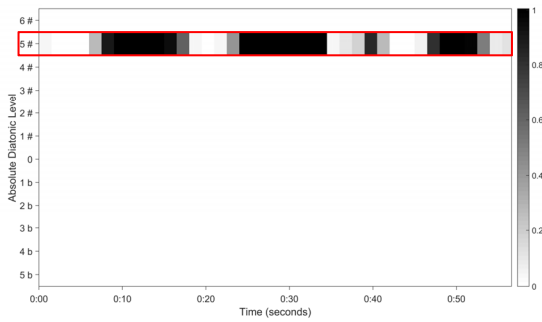
Multiply chroma values (in each column)



## Local Key Estimation

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

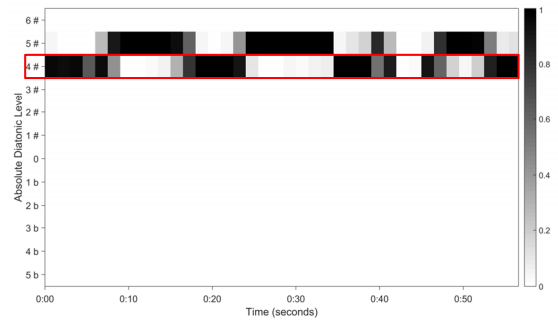
Multiply chroma values



## Local Key Estimation

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

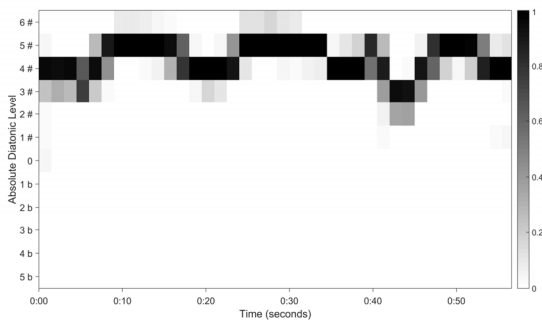
Multiply chroma values



## Local Key Estimation

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

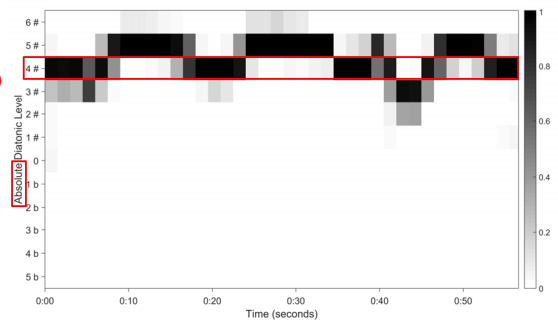
Multiply chroma values



## Local Key Estimation

Normalize representation relative to **global key**

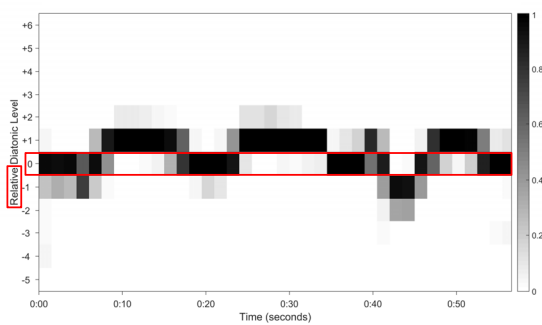
4 #  
(E major)



## Local Key Estimation

Normalize representation relative to **global key**

4 #  
(E major)

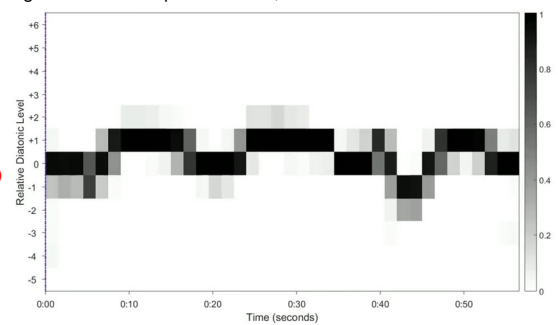


## Local Key Estimation

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

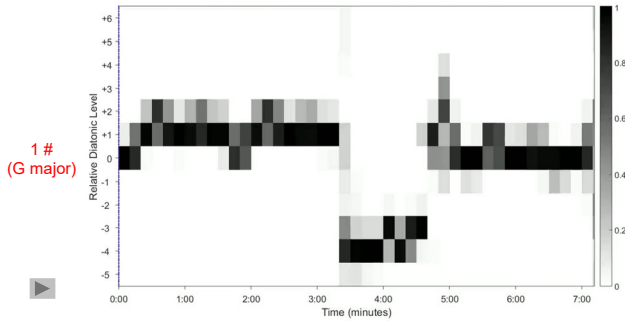
Recording: Scholars Baroque Ensemble, Naxos 1994

4 #  
(E major)



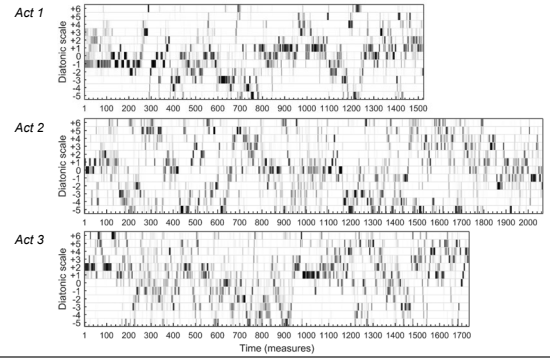
## Local Key Estimation

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



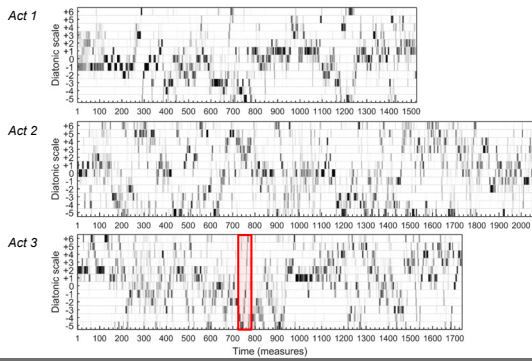
## Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



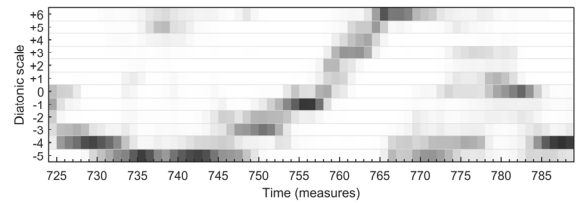
## Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



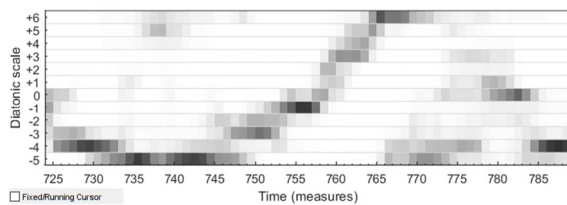
## Local Key Estimation

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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- Mark Gotham  
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

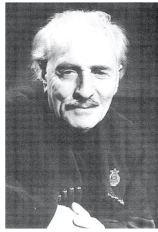




## Traditional Georgian Vocal Music

Example: Erkomaishvili corpus

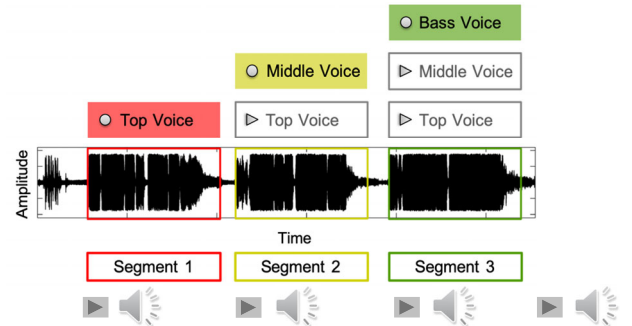
- Collection of traditional three-voice Georgian songs
- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)
- Recordings of 100 songs using tape recorders (1966)



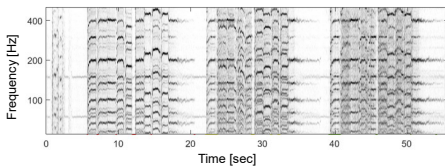
*"Original masterpieces of Georgian musical thinking."* (Shugliashvili, 2014)

## Traditional Georgian Vocal Music

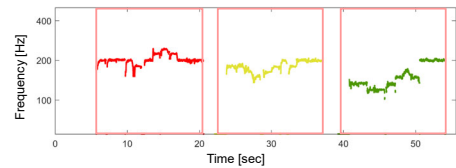
Example: Erkomaishvili corpus



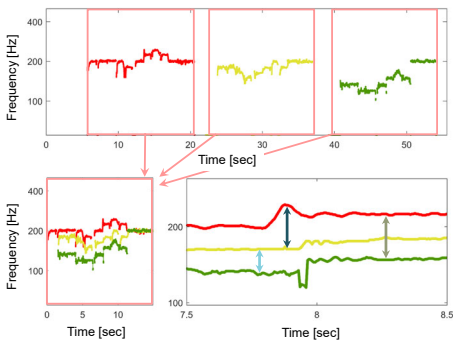
## Traditional Georgian Vocal Music



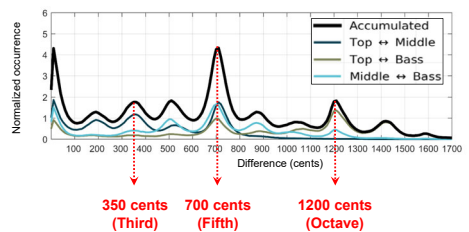
## Traditional Georgian Vocal Music



## 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)

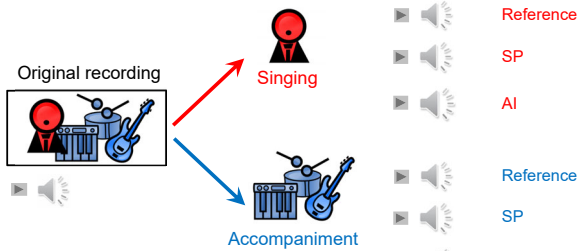
Honorary doctorate (2022)  
State Conservatory of Georgia

**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

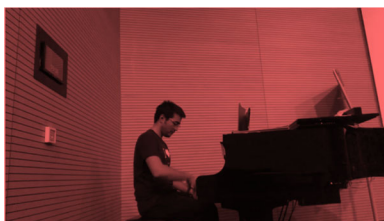
- Yigitcan Özer
- PhD student in engineering
- Pianist



## Computational Audio Analysis

Source separation

- Yigitcan Özer
- PhD student in engineering
- Pianist



**Only Piano!**



**Where is the orchestra?**



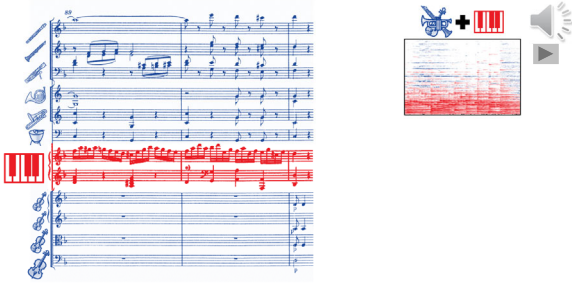
## Computational Audio Analysis

Source separation



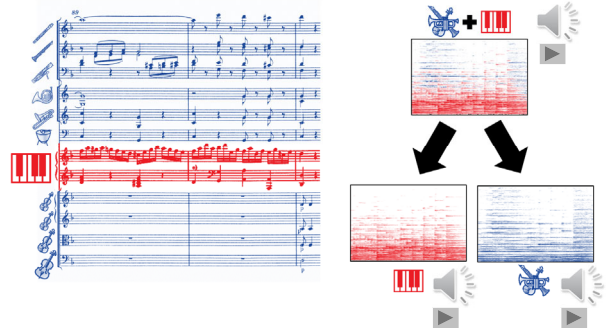
## Computational Audio Analysis

Source separation



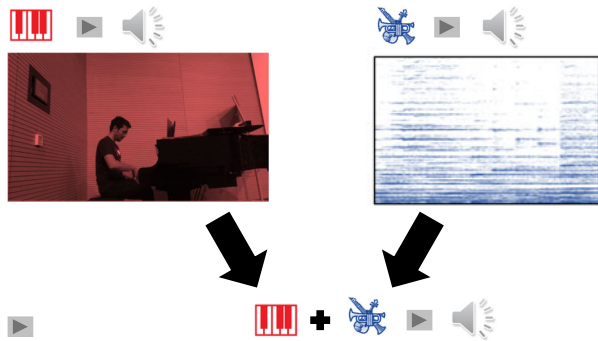
## Computational Audio Analysis

Source separation



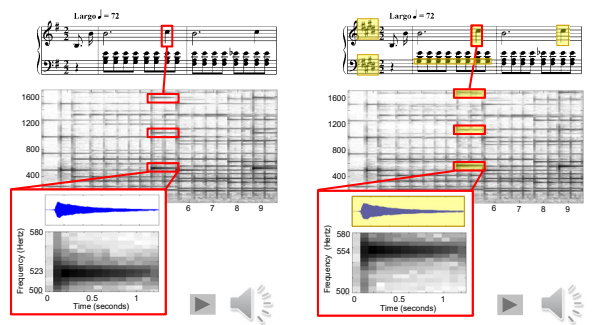
## Computational Audio Analysis

Source separation



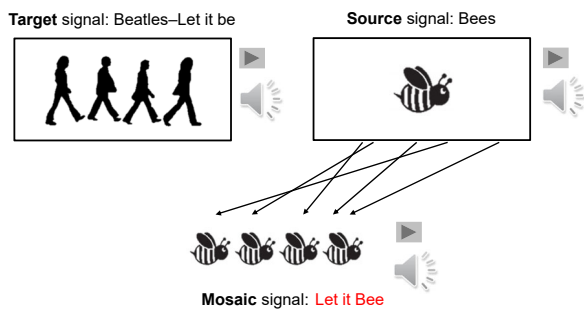
## Computational Audio Analysis

Score-informed audio decomposition



## Computational Audio Analysis

Audio mosaicing (style transfer)



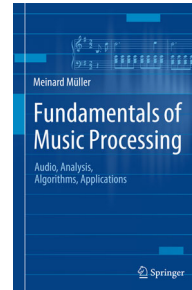
## Computational Audio Analysis

- 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.

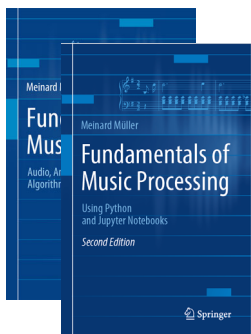
## Fundamentals of Music Processing (FMP)



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

Accompanying website:  
[www.music-processing.de](http://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

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

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2nd edition  
Meinard Müller  
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

- 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#.YOhEQqzaUk>
- 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>

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## 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>