

Musik trifft Informatik in Dagstuhl

Meinard Müller

International Audio Laboratories Erlangen
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Festkolloquium

32 Jahre Informatik in Schloss Dagstuhl

24. Juni 2022

Meinard Müller: Research Group

- Christof Weiß
- Vlora Arifi-Müller
- Sebastian Rosenzweig
- Michael Krause
- Yigitcan Özer
- Simon Schwär
- Peter Meier (external)



Meinard Müller



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



- Senior Researcher (2007-2012)
Max-Planck Institute, Saarland



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



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- Mathematics (Diplom/Master, 1997)
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Cluster of Excellence on
**Multimodal Computing
and Interaction**

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



Multimodal Music Processing



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

2011, January 23 – 28, Dagstuhl Seminar 11041

Organizers:

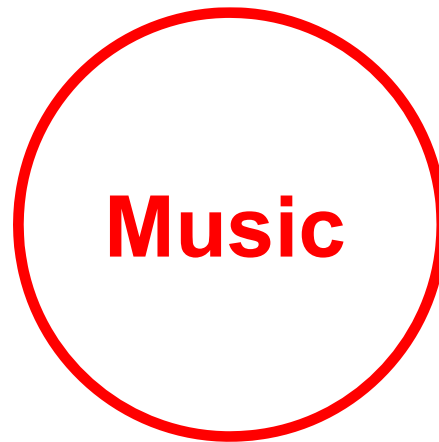
Simon Dixon (Queen Mary University of London, GB)

Masataka Goto (AIST – Ibaraki, JP)

Meinard Müller (MPI Informatik, DE)



Multimodal Music Processing

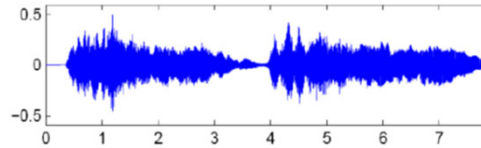


Multimodal Music Processing

Sheet Music (Image)



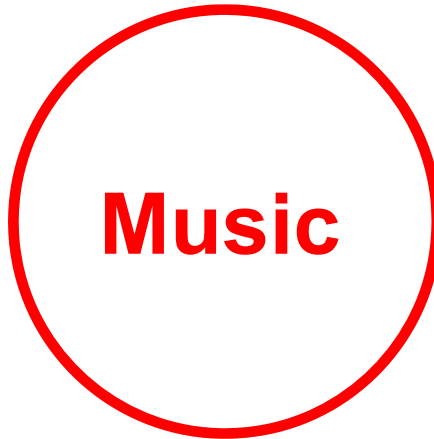
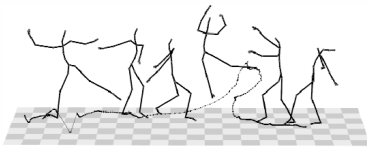
CD / MP3 (Audio)



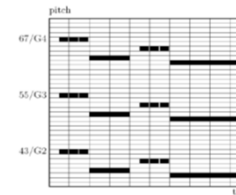
MusicXML (Text)

```
<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)

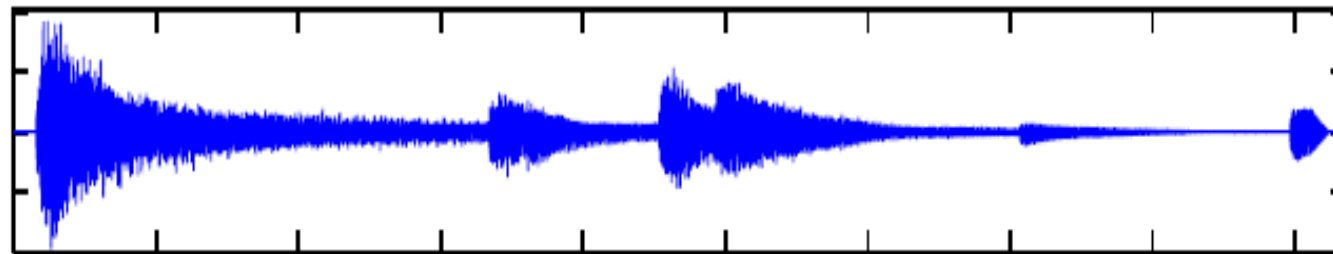


Multimodal Music Processing

Image



Audio



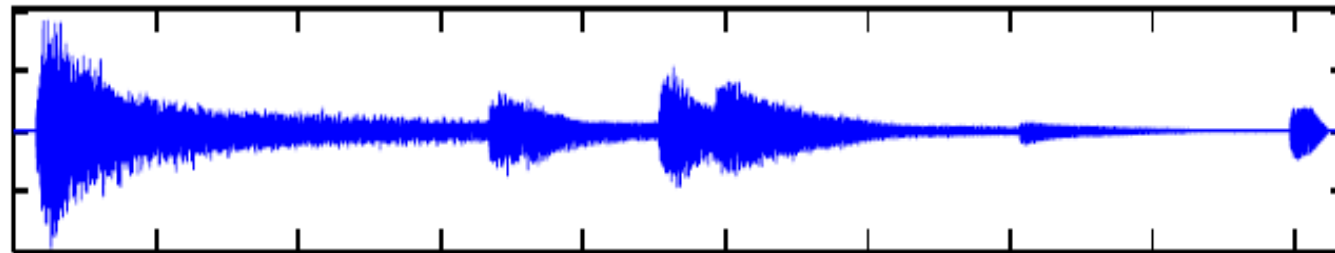
Multimodal Music Processing

Image Processing: Optical Music Recognition

Image



Audio



Multimodal Music Processing

Image Processing: Optical Music Recognition

Image



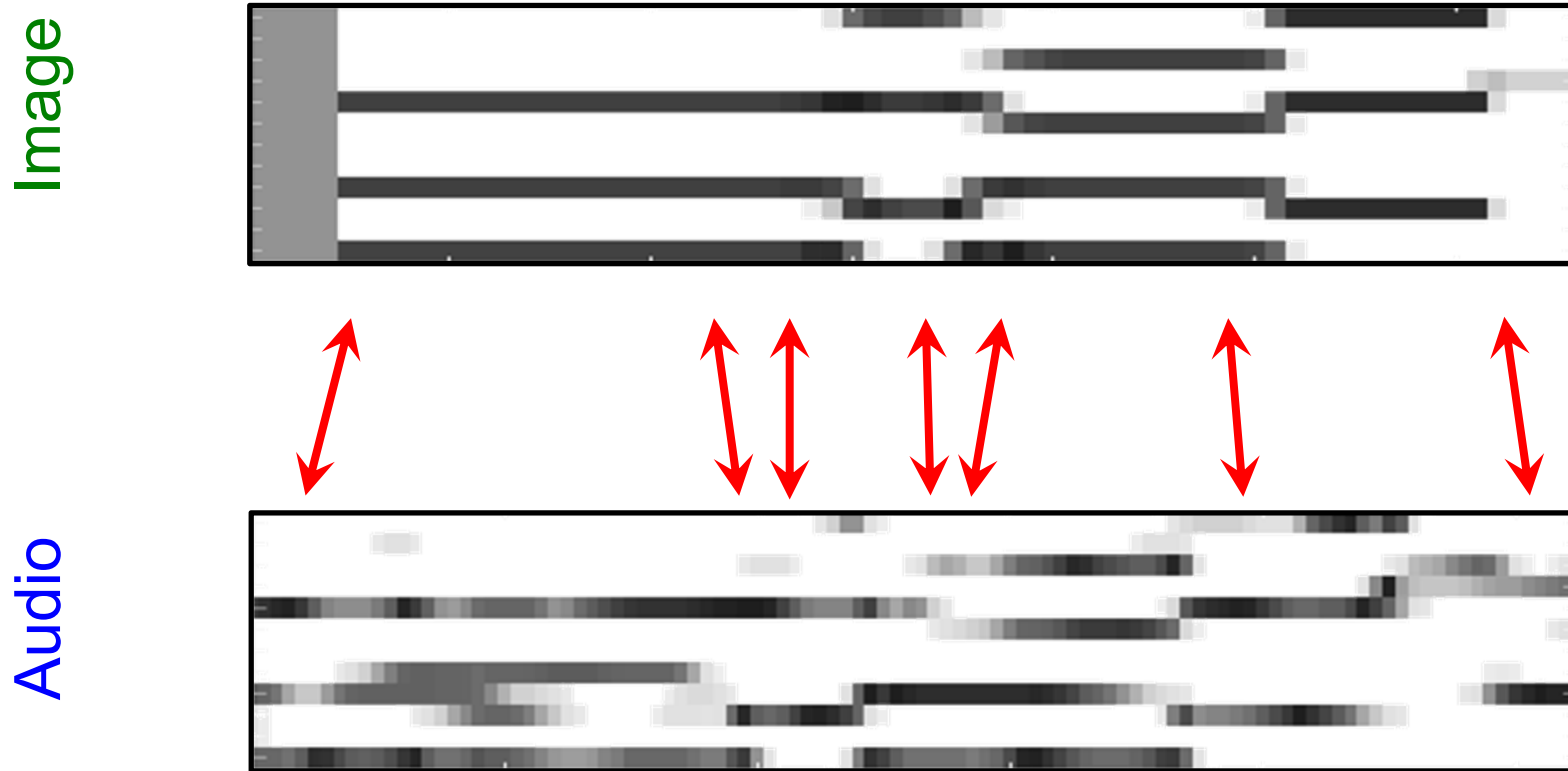
Audio



Audio Processing: Fourier Analysis

Multimodal Music Processing

Image Processing: Optical Music Recognition



Audio Processing: Fourier Analysis

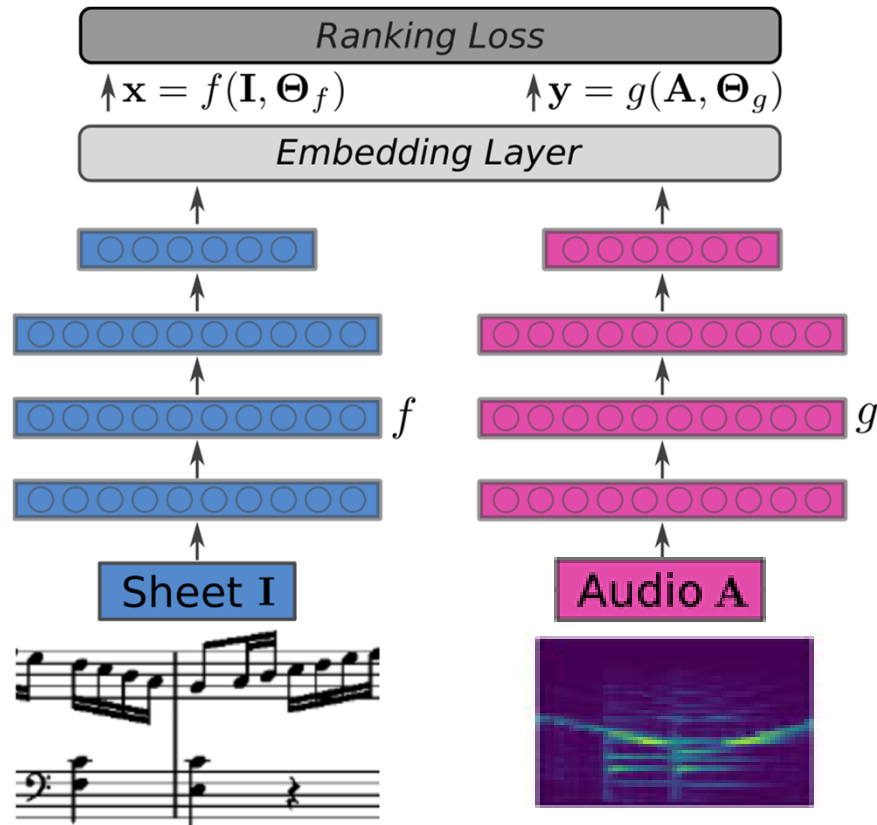
Multimodal Music Processing

The image displays a software interface for music processing, divided into two main sections: ScoreViewer and AudioViewer.

ScoreViewer: This window shows a musical score for Beethoven's Piano Sonatas, specifically 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). There are also buttons for "Score Following On", "Play", and "Stop".

AudioViewer: This window shows a playlist for "Beethoven - Piano Sonatas-Alfred Brendel". The playlist includes tracks 03 through 11, with track 11 selected. The interface includes navigation controls for Disc (1 / 11), Track (11 / 11), and Time (00:00.00 / 4:30.35). There are also buttons for "Play" and "Stop".

Multimodal Music Processing



- Deep learning
- Embedding techniques
- Music transcription
- Lyrics alignment
- ...

Multimodal Music Processing



Marc
Herbstritt

Thank you!

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



Computational Audio Analysis



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

2013, November 3 – 8, Dagstuhl Seminar 13451

Organizers:

Shrikanth S. Narayanan (USC, US)

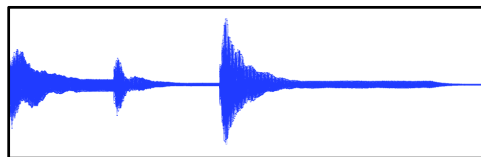
Björn Schuller (TU München, DE)

Meinard Müller (FAU, DE)



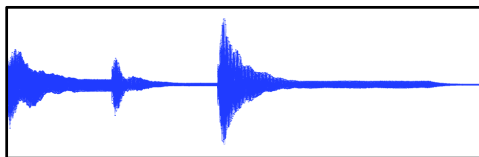
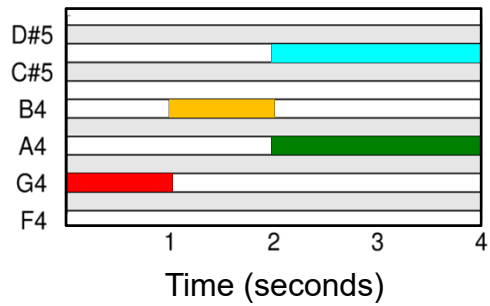
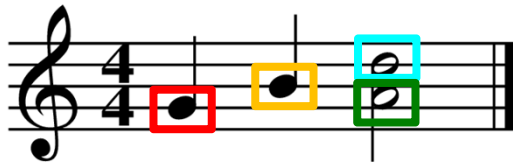
Computational Audio Analysis

Score-informed audio decomposition



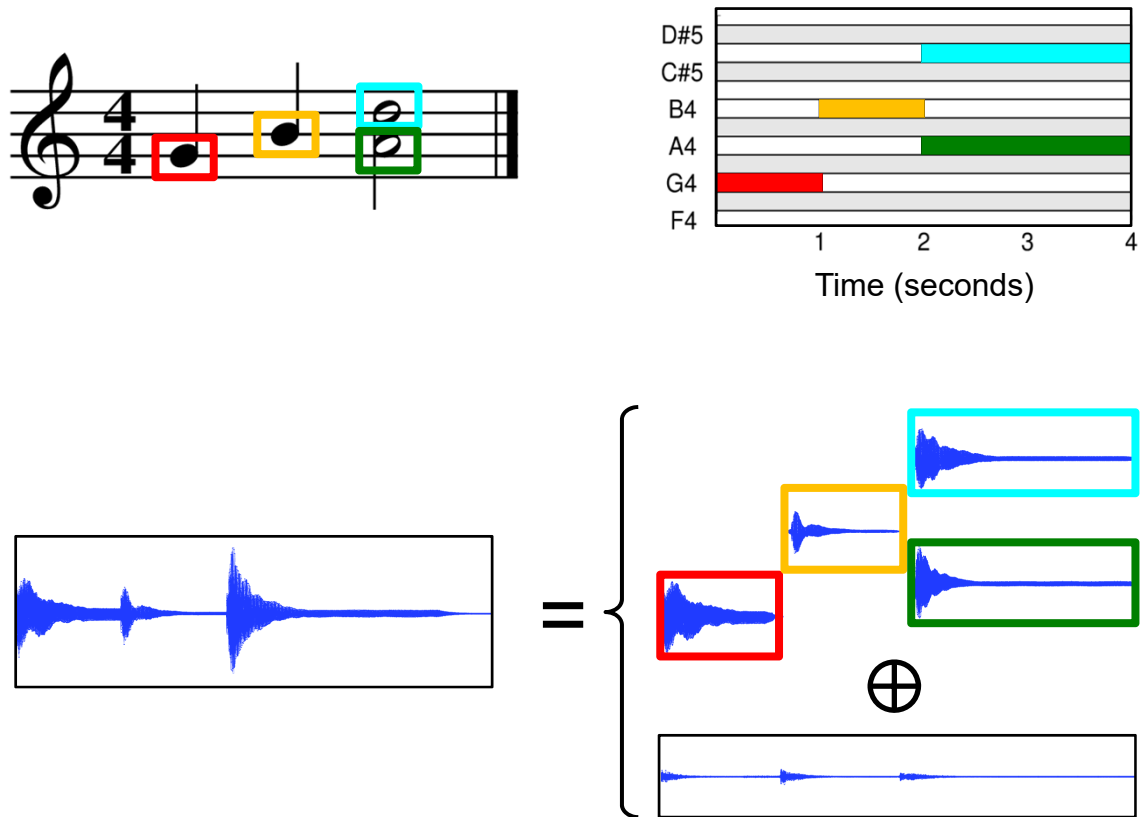
Computational Audio Analysis

Score-informed audio decomposition



Computational Audio Analysis

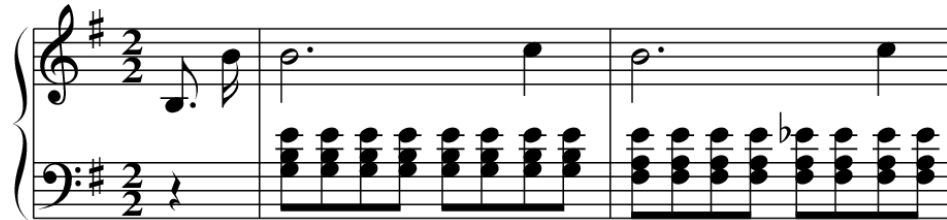
Score-informed audio decomposition



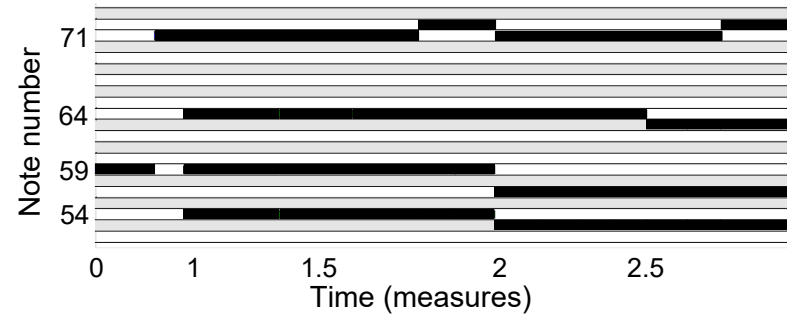
Computational Audio Analysis

Score-informed audio decomposition

Sheet music



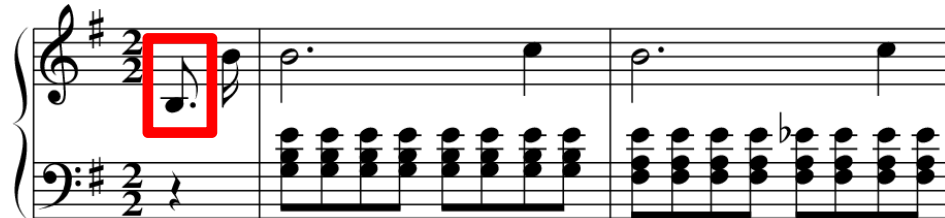
Piano roll



Computational Audio Analysis

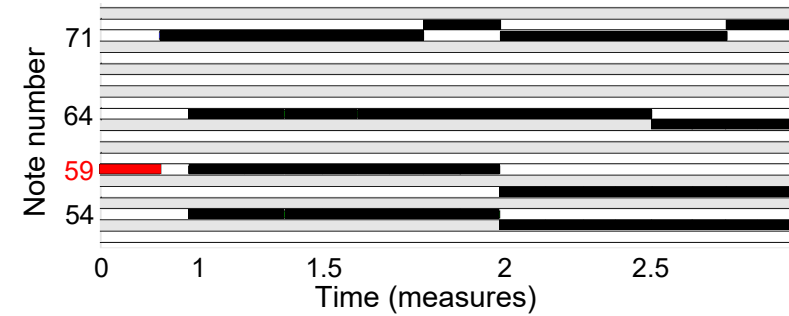
Score-informed audio decomposition

Sheet music



$p = 59$

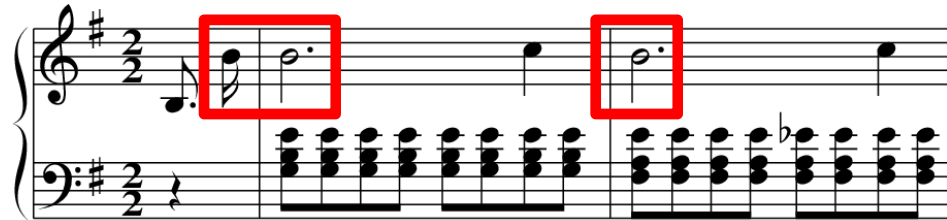
Piano roll



Computational Audio Analysis

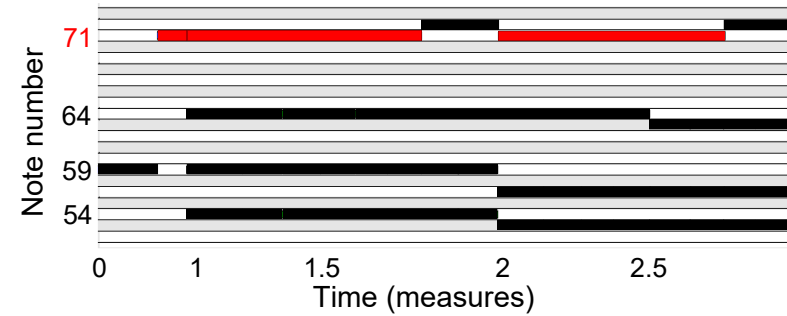
Score-informed audio decomposition

Sheet music



$p = 71$

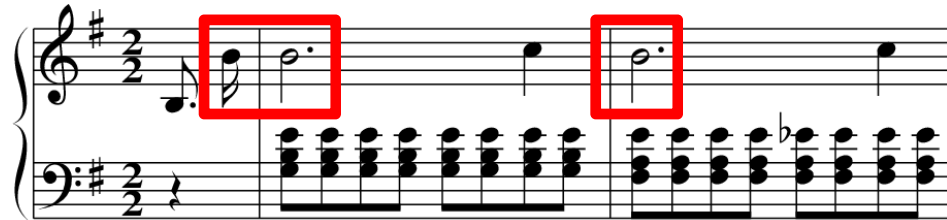
Piano roll



Computational Audio Analysis

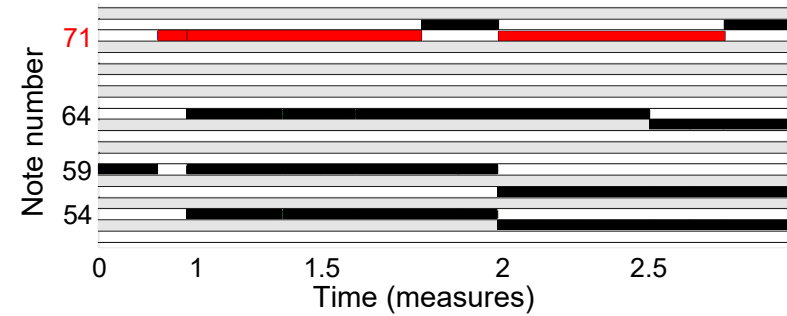
Score-informed audio decomposition

Sheet music

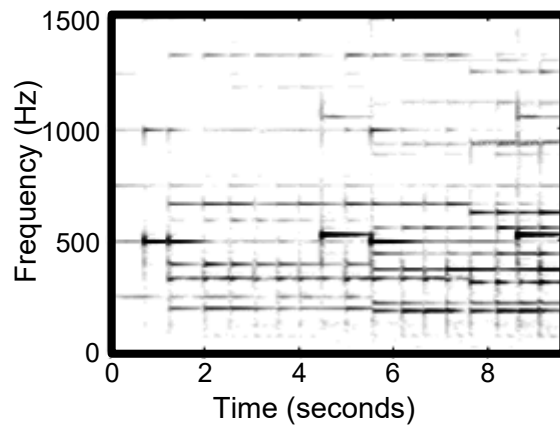


$p = 71$

Piano roll



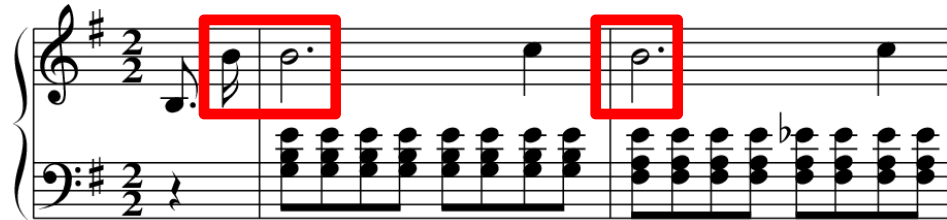
Spectrogram



Computational Audio Analysis

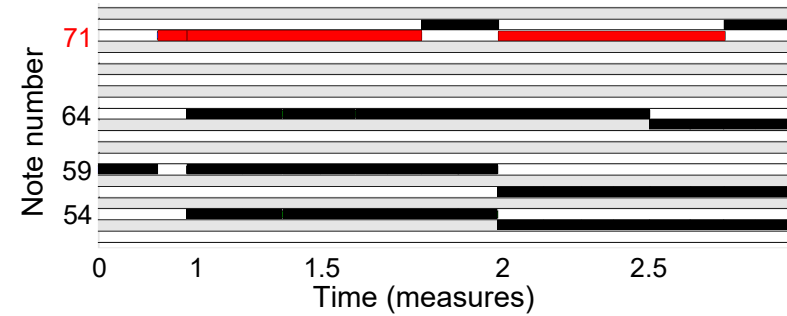
Score-informed audio decomposition

Sheet music

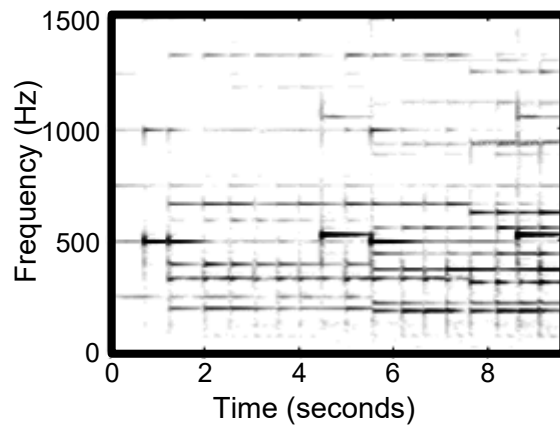


$p = 71$

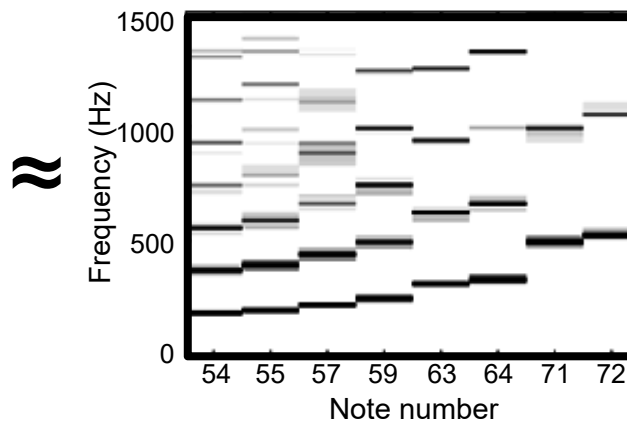
Piano roll



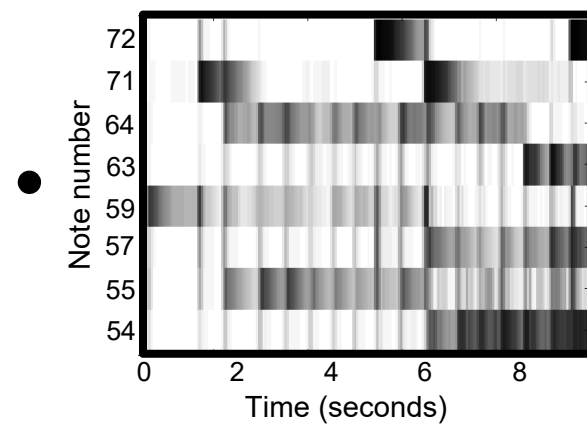
Spectrogram



Spectral patterns



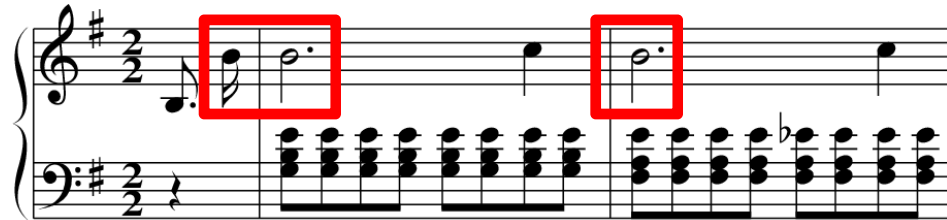
Activity patterns



Computational Audio Analysis

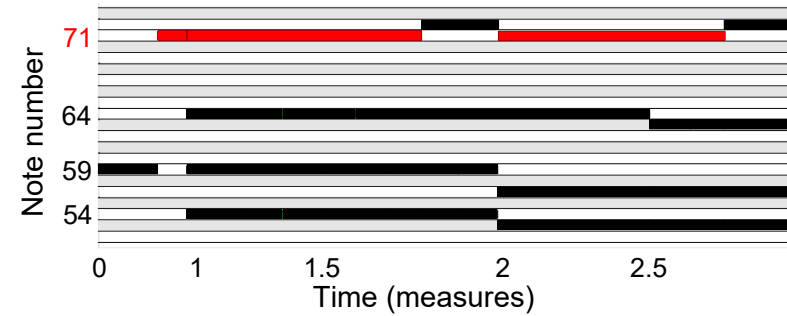
Score-informed audio decomposition

Sheet music

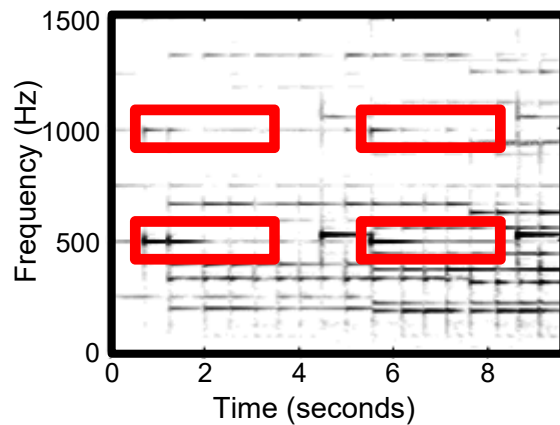


$p = 71$

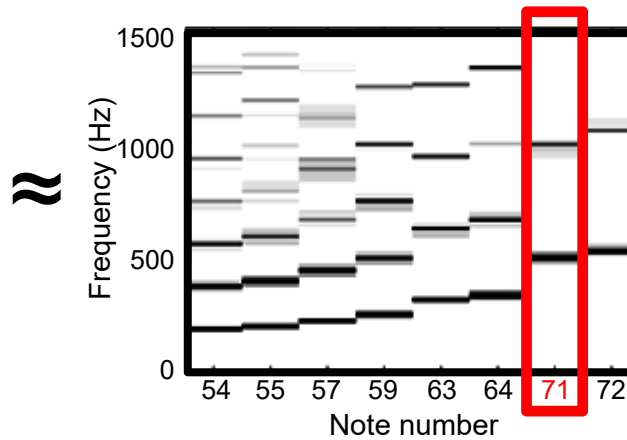
Piano roll



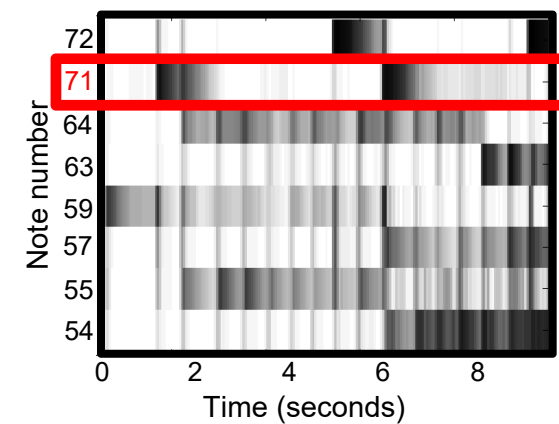
Spectrogram



Spectral patterns

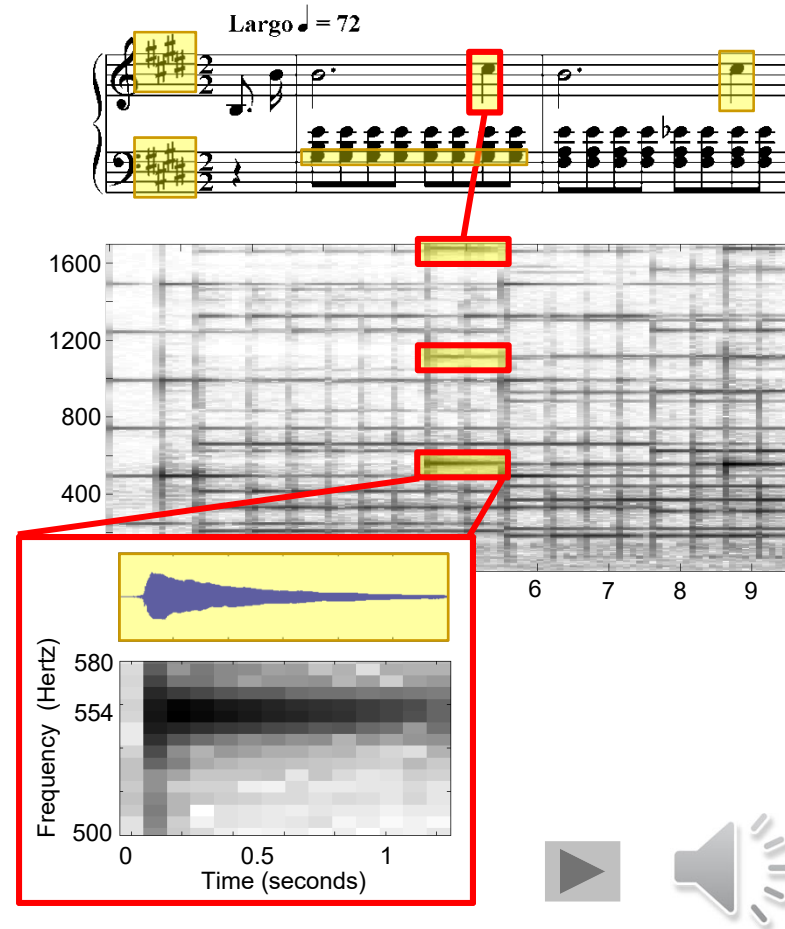
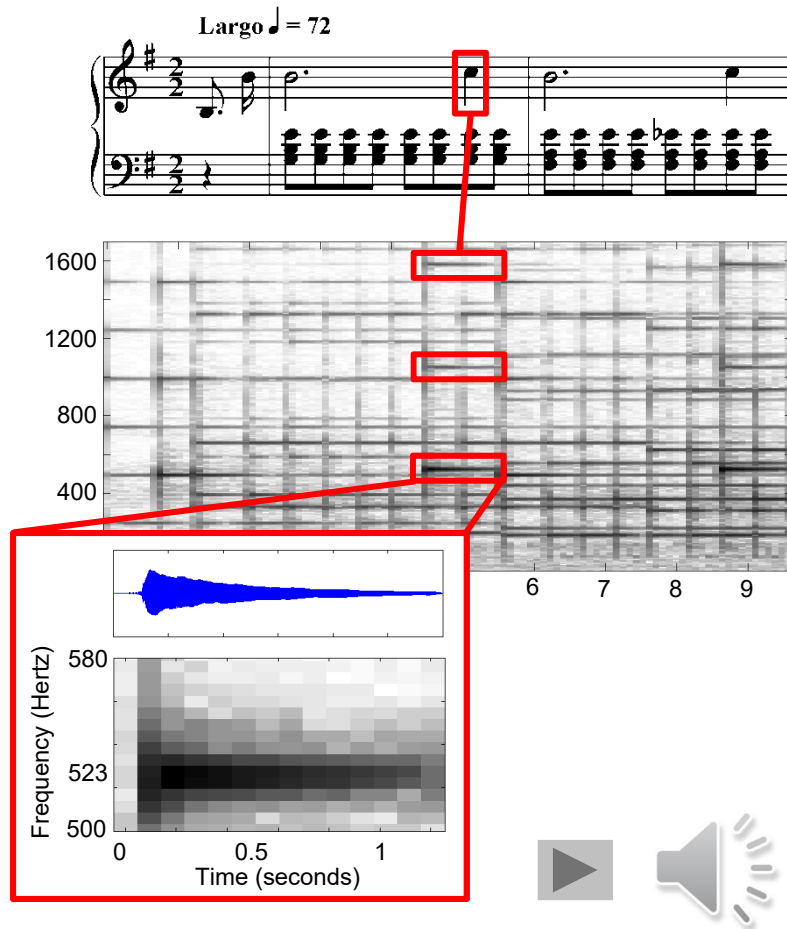


Activity patterns



Computational Audio Analysis

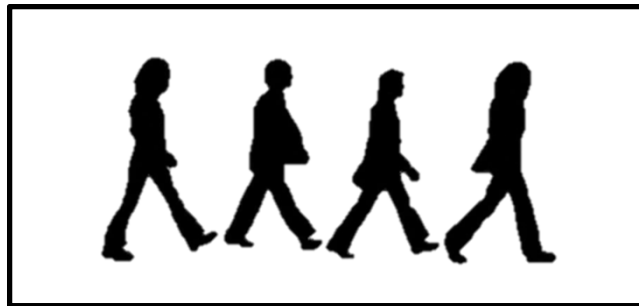
Score-informed audio decomposition



Computational Audio Analysis

Audio mosaicing (style transfer)

Target signal: Beatles–Let it be



Source signal: Bees



Mosaic signal: **Let it Bee**

Computational Audio Analysis

- Decomposing complex audio scenes
- Source separation
- Understanding acoustic, linguistic, or musical properties
- Extracting emotion-related parameters (e.g., stress, confidence, frustration)
- ...

Computational Audio Analysis



Roswitha
Bardohl



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Saarbrücken, 23. Oktober 2013

Schloss Dagstuhl: Können Computersysteme Emotionen erkennen?

Thank you!



Deutschlandfunk

Zwischentöne für Computer

06.11.2013

Computational Music Structure Analysis



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

2016, February 28 – March 4, Dagstuhl Seminar 16092

Organizers:

Juan Pablo Bello (New York University, US)

Elaine Chew (Queen Mary University of London, GB)






Meinard Müller (FAU, DE)



Computational Music Structure Analysis

Example: Carl Maria von Weber: “Der Freischütz”



Variations	Performance
	Kleiber C. , 1973 
Tempo	Elmendorff, 1944 
Language	Penin (fr.), 1998 
Key	Orlov (russ.), 1946 
Sound quality	Gui (it.), 1957 



Computational Music Structure Analysis

Example: Carl Maria von Weber: "Der Freischütz" (No. 4)

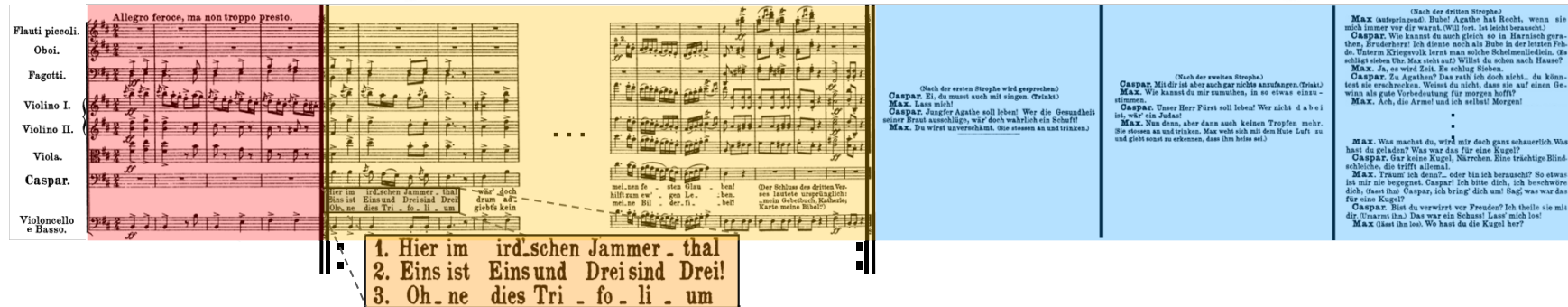
Introduction



Stanzas



Dialogues

Flauti piccoli.
Oboi.
Fagotti.
Violino I.
Violino II.
Viola.
Caspar.
Violoncello e Basso.

Allegro feroce, ma non troppo presto.

1. Hier im ird'schen Jammer - thal
2. Eins ist Eins und Drei sind Drei!
3. Oh - ne dies Tri - fo - li - um

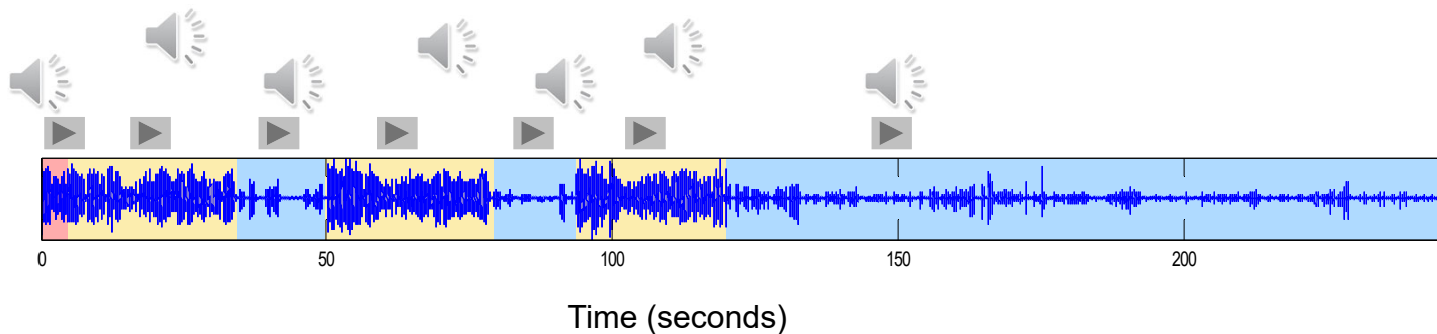
(Nach der ersten Strophe wird gesprochen)
Caspar. Ei, du mußt auch mit singen. (Trinkt)
Max. Lach mich!

(Nach der zweiten Strophe)
Caspar. Mit dir ist aber auch gar nichts anzufangen. (Trinkt)
Max. Wie kannst du mir summen, in so etwas einstimmen.
Caspar. User Herr Fürst soll leben! Wer nicht d a bei ist, war ein Jäger!
Max. Nun denn, aber dann auch keinen Tropfen mehr, ge - stessen an und trinken. Max weht sich mit dem Hute Luft zu und gibt sonst zu erkennen, dass ihm heiss sei.)

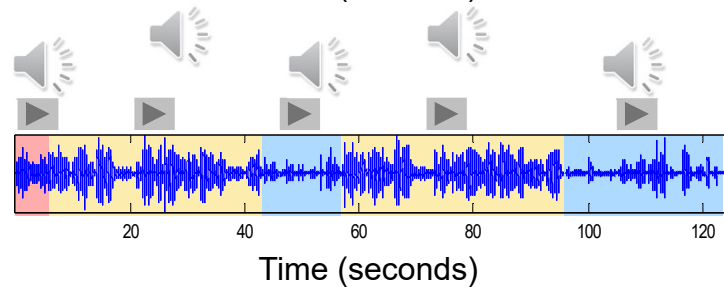
(Nach der dritten Strophe)
Max. Aufspringend: Hui! Agathe hat Recht, wenn sie mich immer vor dir warst. (Will fort. Ist leicht besessen.)
Caspar. Wie kannst du auch gleich so in Harnisch geraten, Bräutigam! Ich diene noch als Bute in der letzten Pöckel. Unsere Kriegsvolk lernt man solche Schellenleiden. Du schickst ihnen die Max nicht aus! Willst du schon nach Hause?
Max. Ja, es wird Zeit. Es schlag Stöben.
Caspar. Zu Agathe! Das reißt ich doch nicht... du kümmerst sie erschröcken. Weinst du nicht, dass sie auf einem Gewin als gute Vorbedeutung für morgen hofft?
Max. Ach, die Ärmer! und ich selbst! Morgen!

Max. Was machst du, wirf mir doch ganz schauerlich. Was hast du geladen? Was war das für eine Kugel?
Caspar. Gar keine Kugel, Narren. Eine trachtige Blindschlange, die trifft allemal.
Max. Trauer! ich deutet... oder bist du besessen? So etwas ist mir nie begegnet. Caspar! Ich bitte dich, ich beschwöre dich, lass ihn Caspar, ich bring' dich um! Sag, was war das für eine Kugel?
Caspar. Hast du verwirrt vor Freude? Ich theile sie mit dir. (Warnt ihn.) Das war ein Schuss! Lauf' mich los!
Max. (lässt ihn los.) Wo hast du die Kugel her?

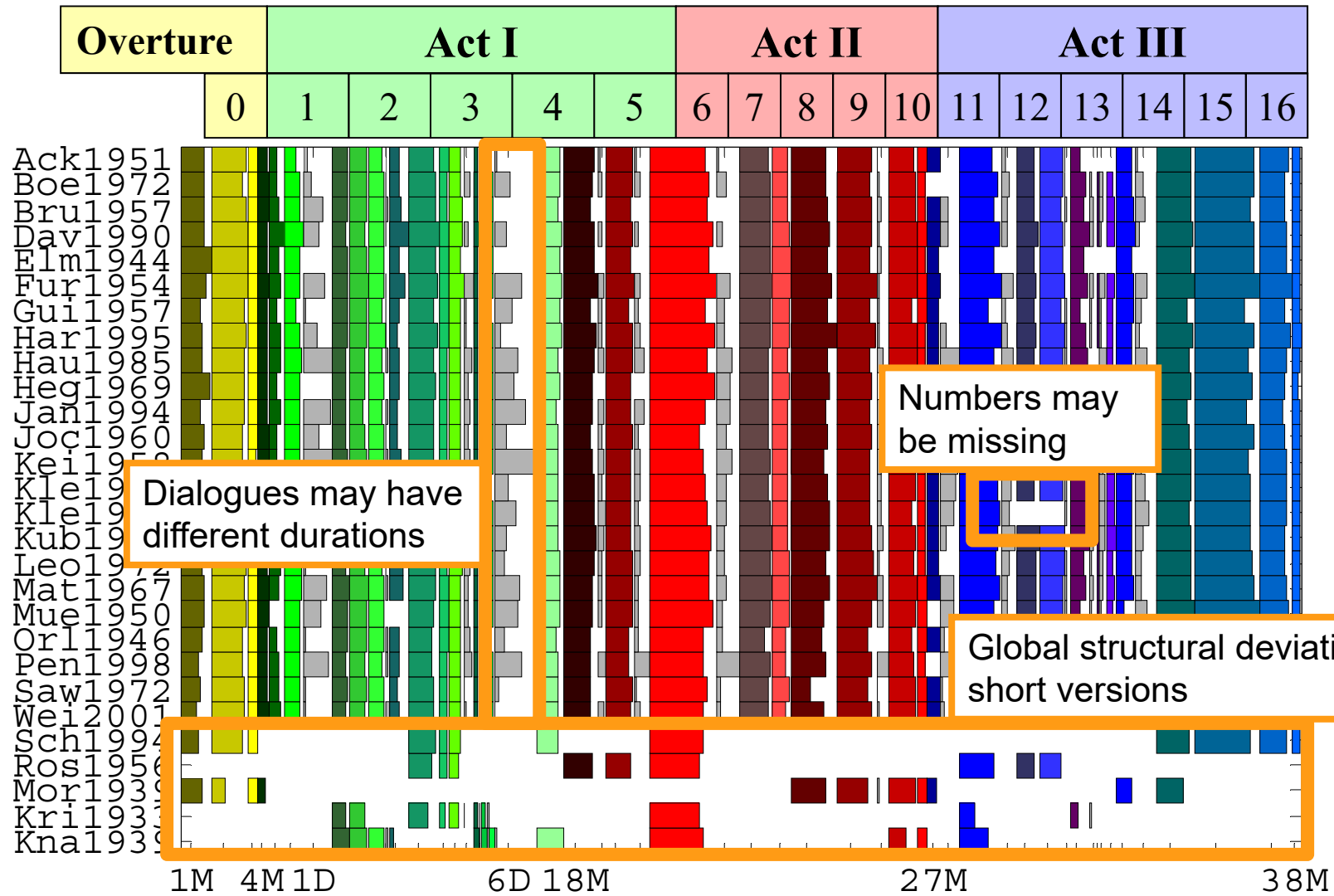
Kleiber



Ackermann



Computational Music Structure Analysis



Computational Music Structure Analysis

- Extraction of musical form
- Finding (nearly) repeating patterns
- Instrument detection and classification
- Language detection
- Detection of musical keys, chords, ...
- Detection of time signature, tempo, measures, beats, ...
- ...

Computational Music Structure Analysis



Susanne
Bach-
Bernhard



Heike
Clemens



Simone
Schilke



Jutka
Gasiorowski



Michael
Wagner

Thank you!

Computational Methods for Melody and Voice Processing in Music Recordings



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

2019, January 27 – February 1, Dagstuhl Seminar 19052

Organizers:

Emilia Gómez (UPF – Barcelona, ES)

Yi-Hsuan Yang (Academica Sinica – Taipei, TW)

Meinard Müller (FAU, DE)

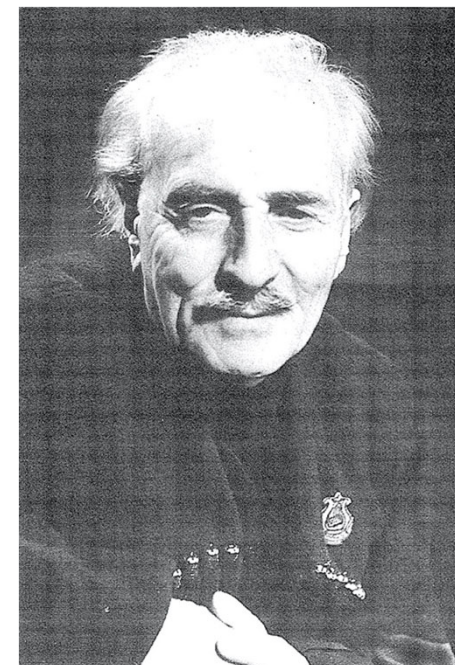


Computational Methods for Melody and Voice Processing in Music Recordings

Example: Erkomaishvili corpus

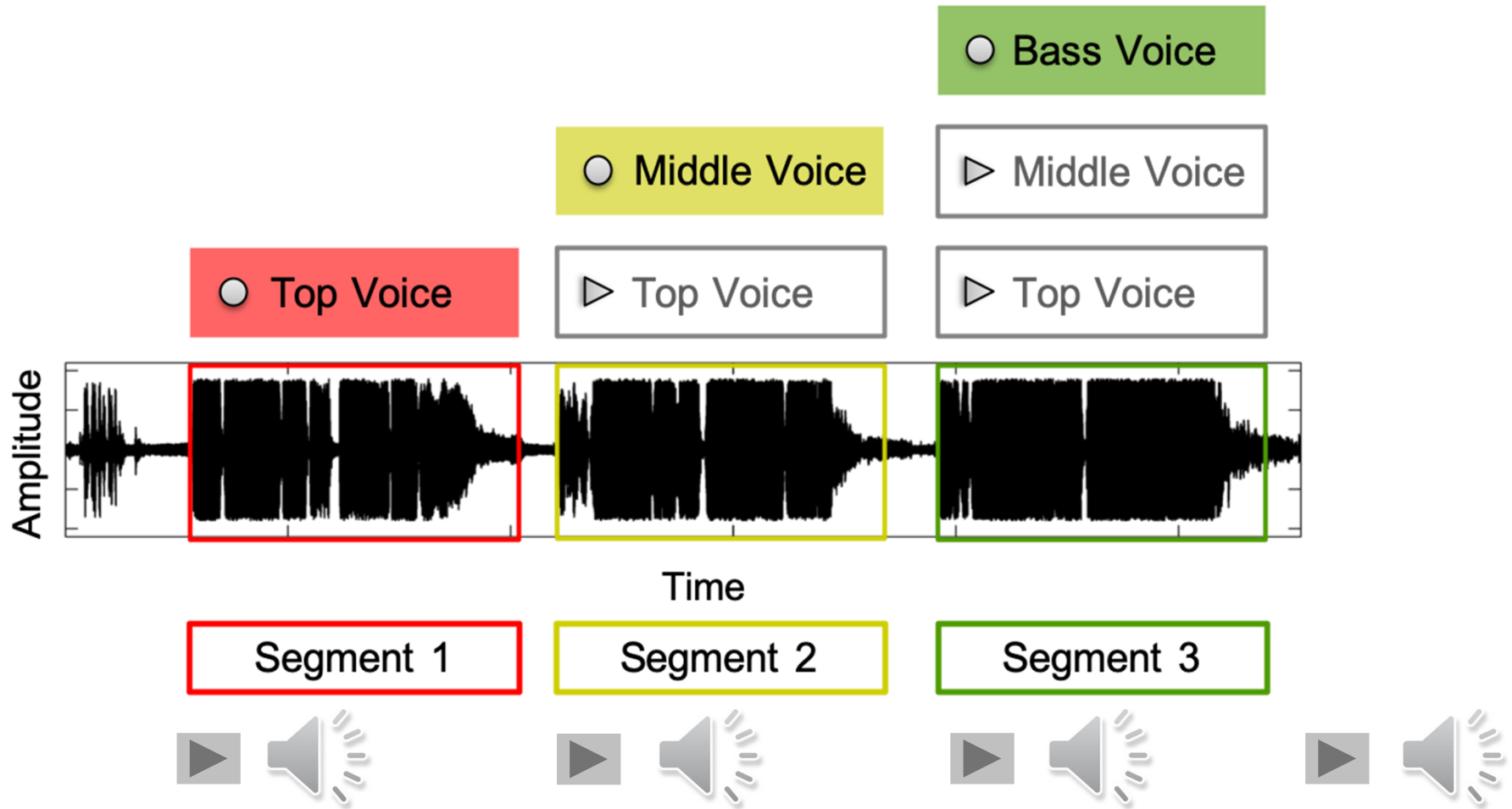
- Collection of traditional three-voice Georgian songs
- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)
- Recordings of 100 songs using tape recorders (1966)

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

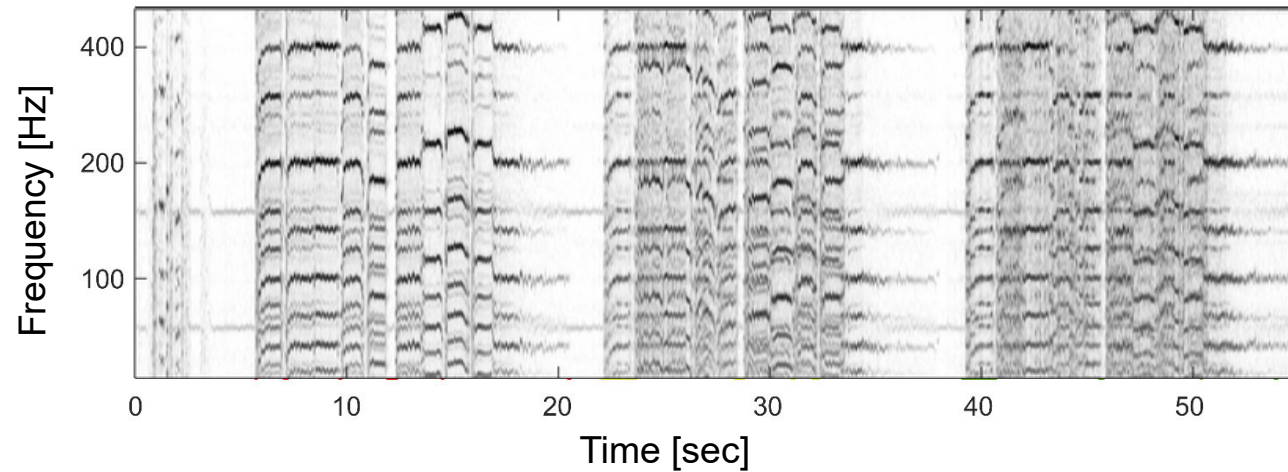


Computational Methods for Melody and Voice Processing in Music Recordings

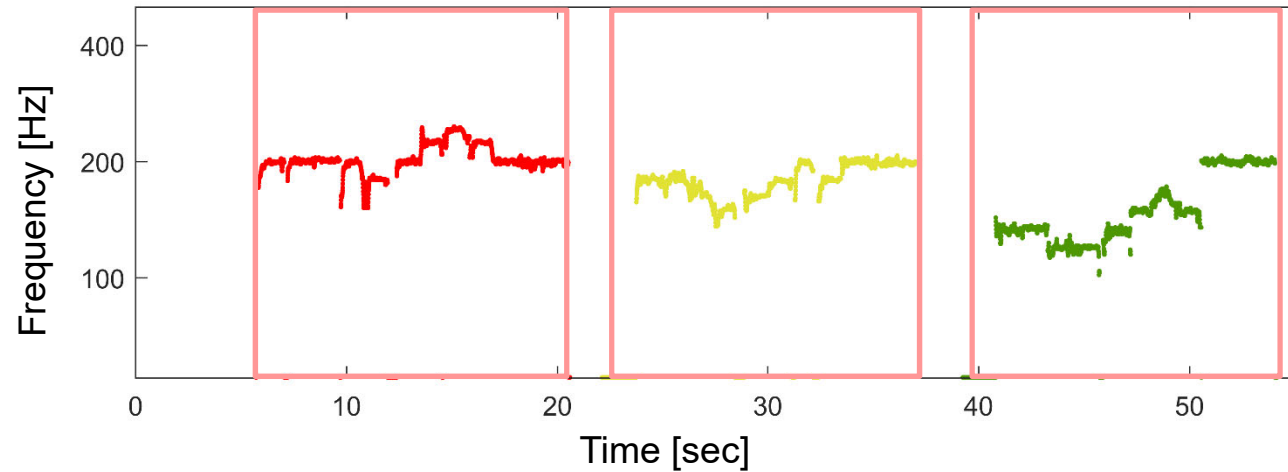
Example: Erkomaishvili corpus



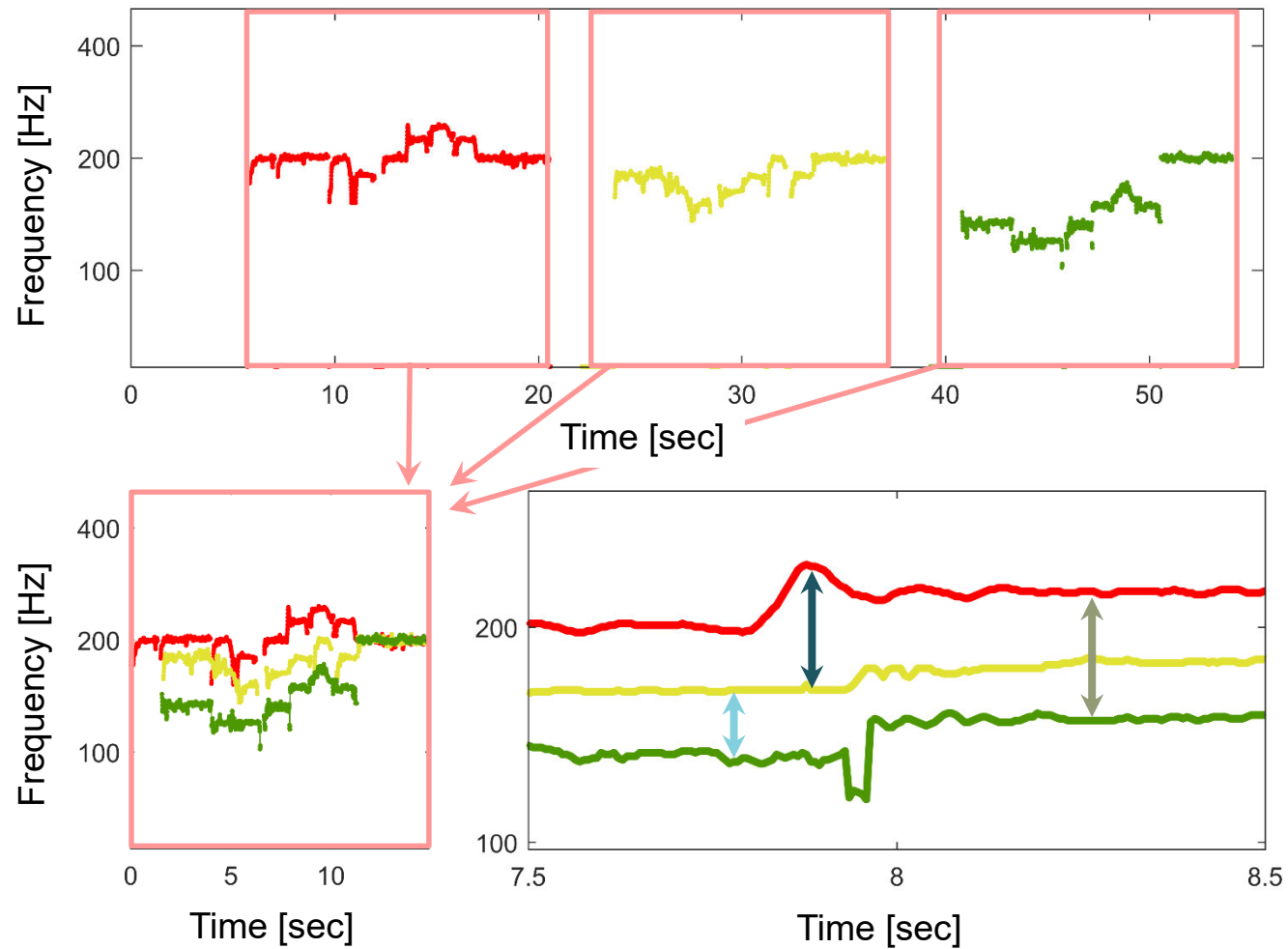
Computational Methods for Melody and Voice Processing in Music Recordings



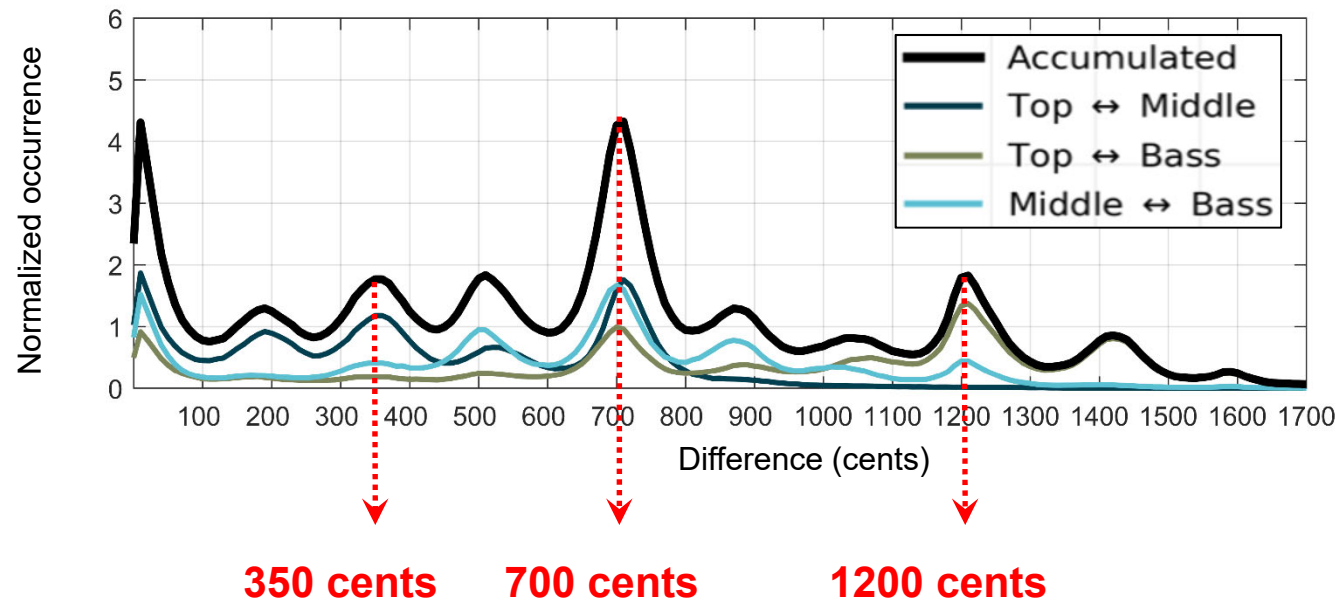
Computational Methods for Melody and Voice Processing in Music Recordings



Computational Methods for Melody and Voice Processing in Music Recordings



Computational Methods for Melody and Voice Processing in Music Recordings



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

Computational Methods for Melody and Voice Processing in Music Recordings



Computational Methods for Melody and Voice Processing in Music Recordings



Room
Microphone

Allegro moderato

Soprano *p* Lo - cus i - ste a De - o fa - ctus est, *mf* lo - cus i - ste a De - o *f*

Alto *p* Lo - cus i - ste a De - o fa - ctus est, *mf* lo - cus i - ste a De - o *f*

Tenor *p* Lo - cus i - ste a De - o fa - ctus est, *mf* lo - cus i - ste a De - o *f*

Bass *p* Lo - cus i - ste a De - o fa - ctus est, *mf* lo - cus i - ste a De - o *f*



Computational Methods for Melody and Voice Processing in Music Recordings

Michael Gerke



Thank you!



Saarbrücken, 25. August 2020

SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Dagstuhler Gesänge für die Wissenschaft

Forschung und Lehre, 28.08.2020

Chor aus Wissenschaftlern will Beitrag zur KI-Forschung leisten

Internationale Forschende aus Musikwissenschaft und Informatik zeichneten zu Forschungszwecken Gesänge auf. Davon sollen KI-Studien profitieren.

Deep Learning and Knowledge Integration for Music Audio Analysis



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

2022, February 20 – 25, Dagstuhl Seminar 22082

Organizers:

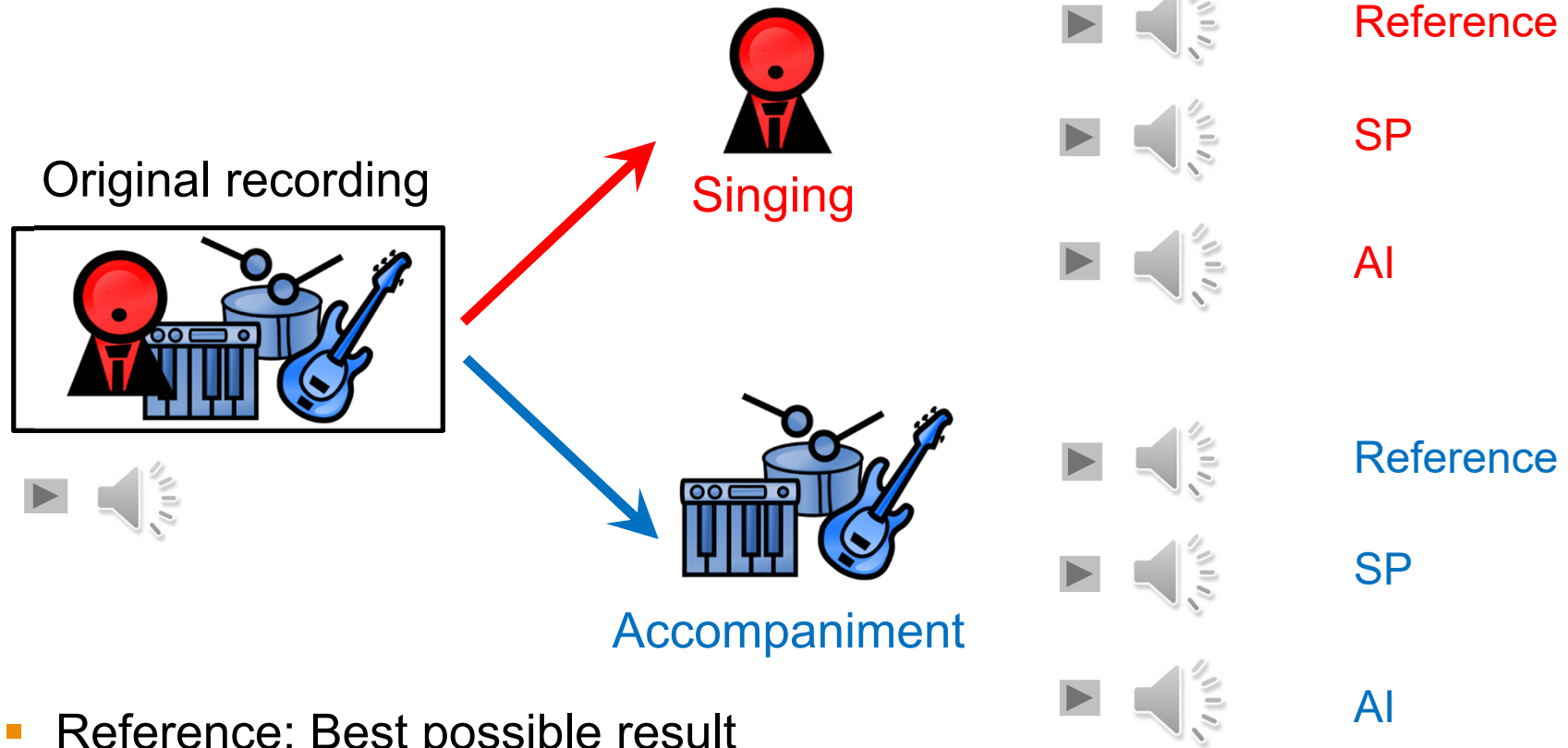
Rachel Bittner (Spotify – Paris, FR)

Juhan Nam (KAIST – Daejeon, KR)

Meinard Müller (FAU, DE)



Deep Learning and Knowledge Integration for Music Audio Analysis



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

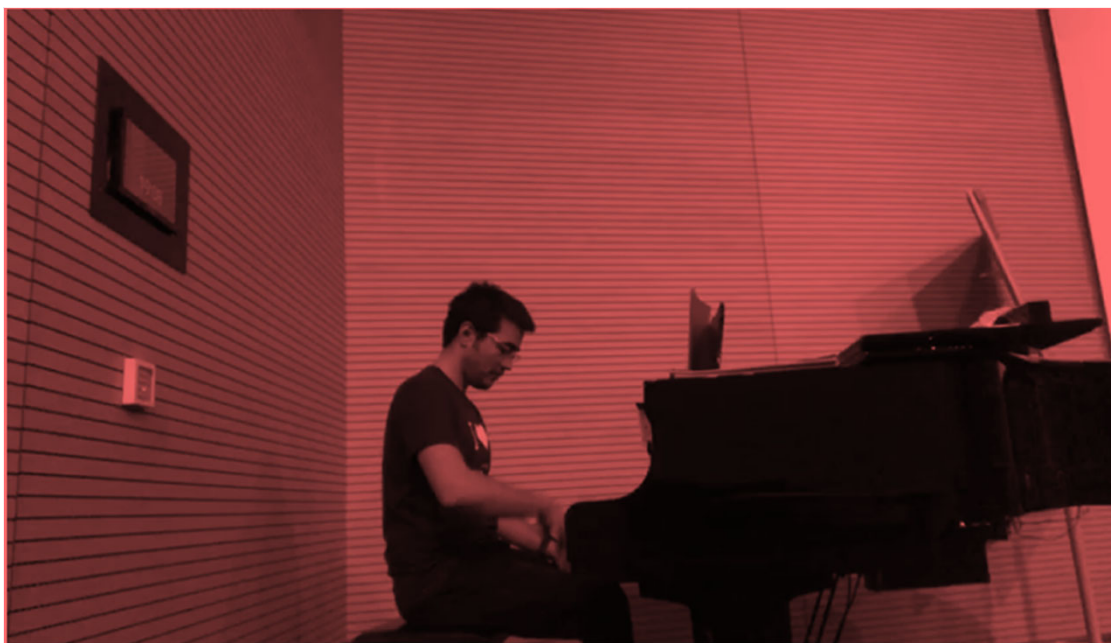
Deep Learning and Knowledge Integration for Music Audio Analysis

- Yigitcan Özer
- PhD student in engineering
- Pianist



Deep Learning and Knowledge Integration for Music Audio Analysis

- Yigitcan Özer
- PhD student in engineering
- Pianist



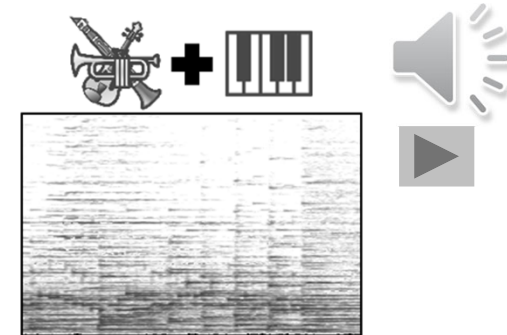
Only Piano!



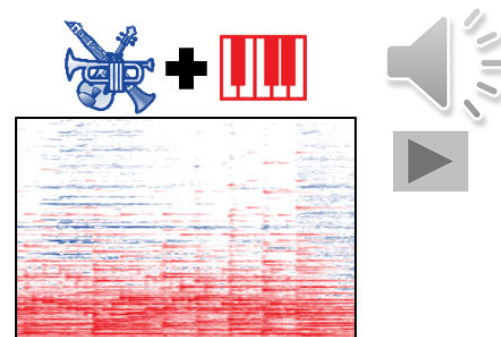
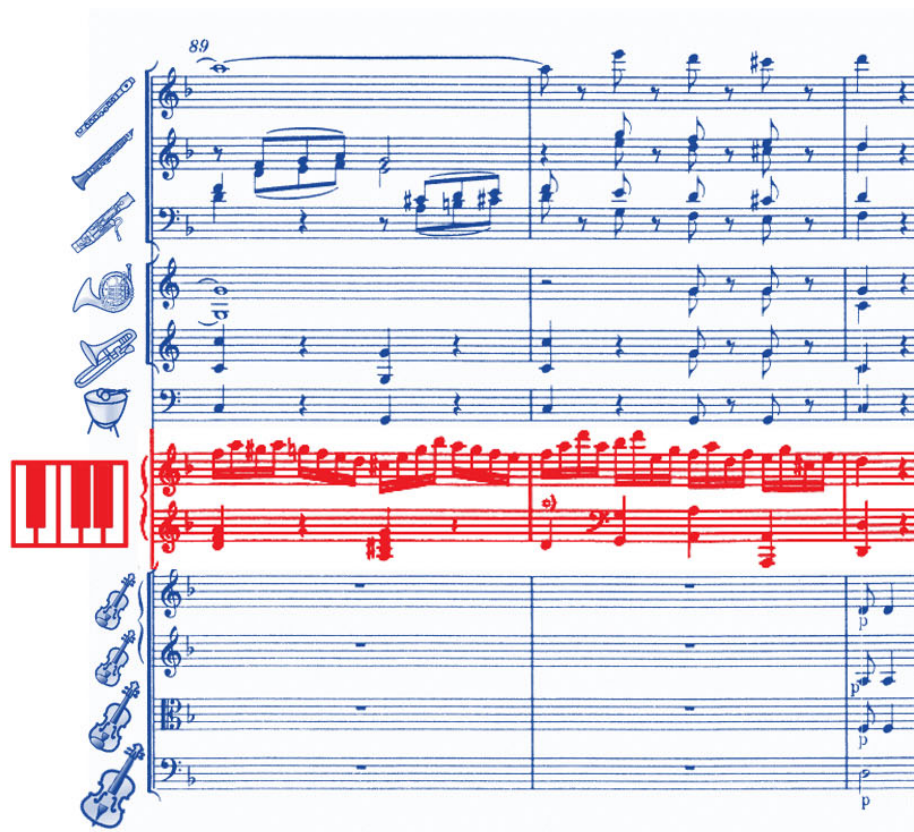
Where is the orchestra?



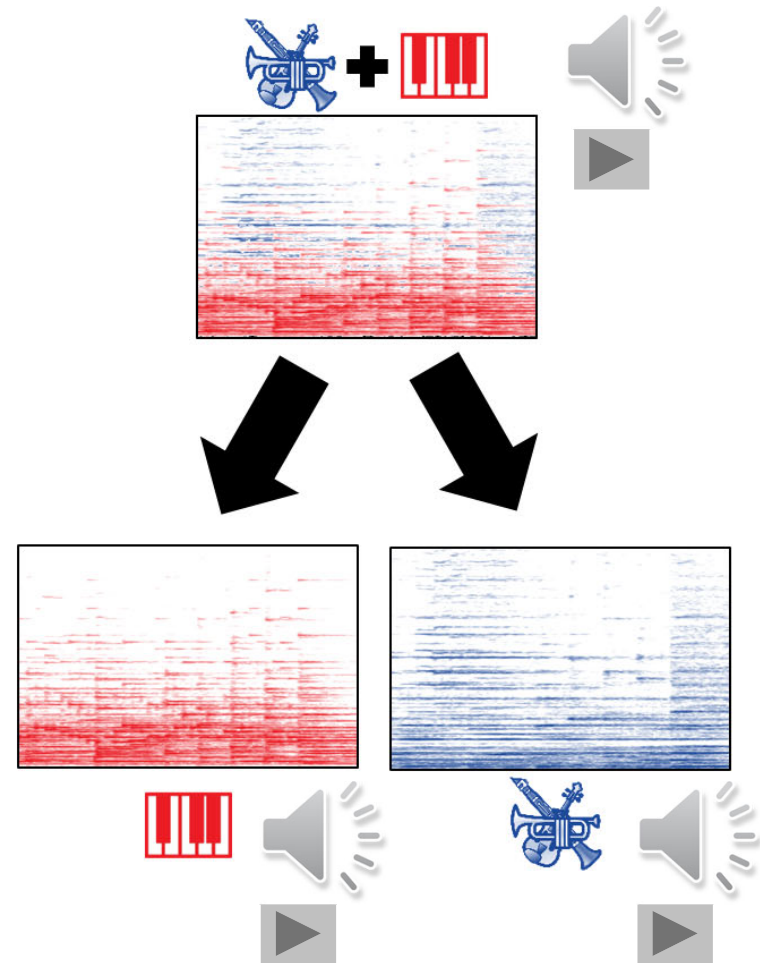
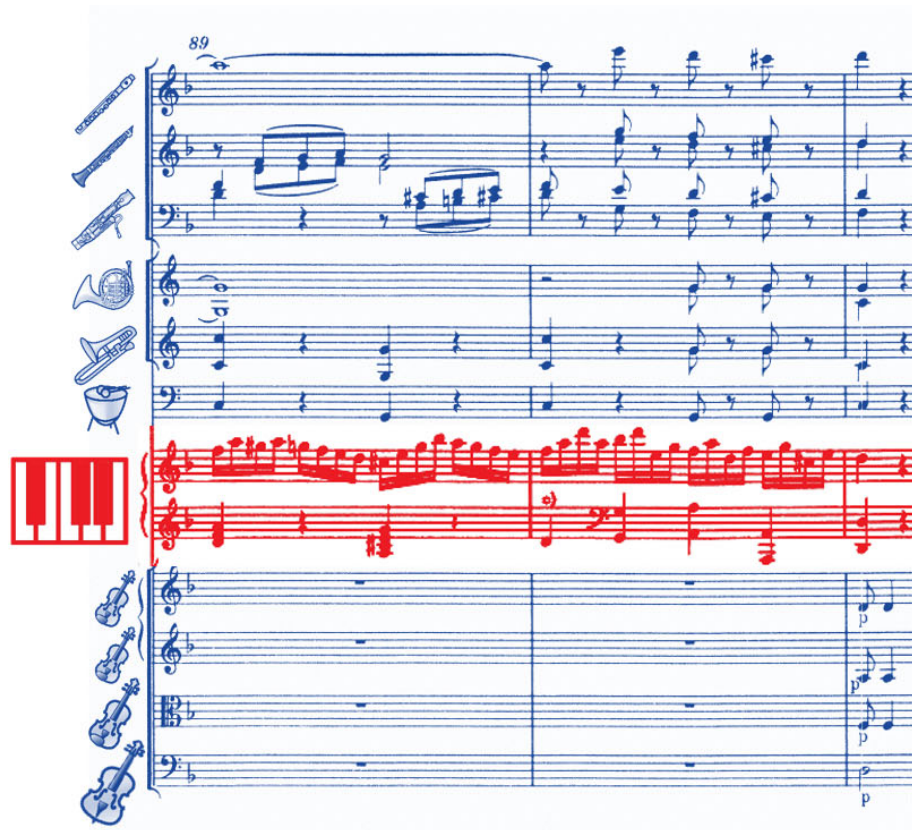
Deep Learning and Knowledge Integration for Music Audio Analysis



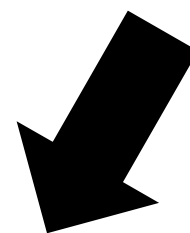
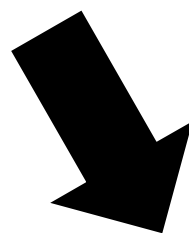
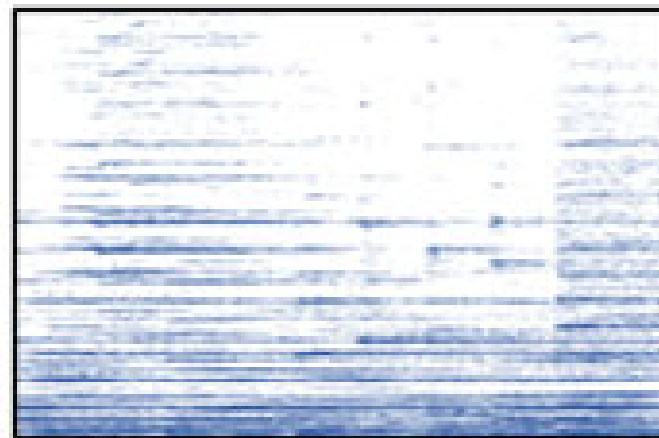
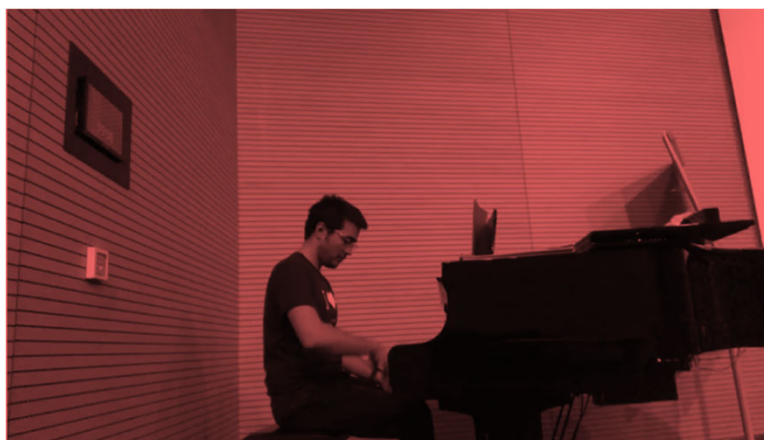
Deep Learning and Knowledge Integration for Music Audio Analysis



Deep Learning and Knowledge Integration for Music Audio Analysis



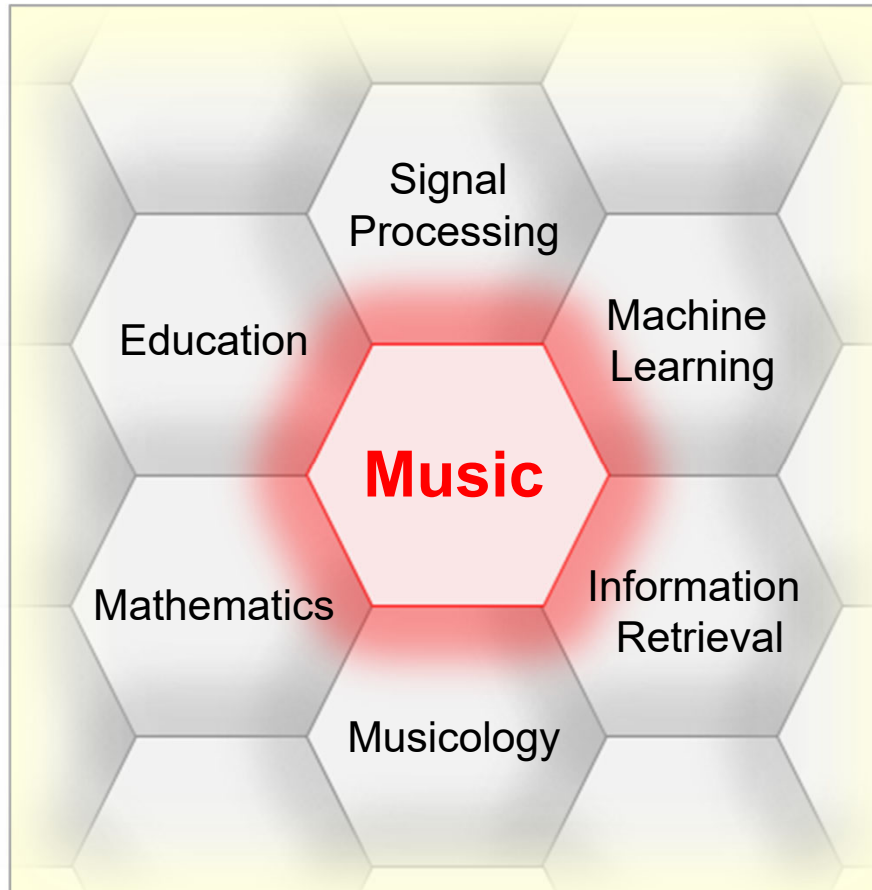
Deep Learning and Knowledge Integration for Music Audio Analysis



Deep Learning and Knowledge Integration for Music Audio Analysis

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

Musik trifft Informatik in Dagstuhl



- Music is a ubiquitous and vital part of our lives
- Digital music services: Spotify, Pandora, iTunes, ...
- Music yields intuitive entry point to support and motivate education in technical disciplines
- Music bridges the gap between engineering, computer science, mathematics, and the humanities

Musik trifft Informatik in Dagstuhl



Reinhard
Wilhelm



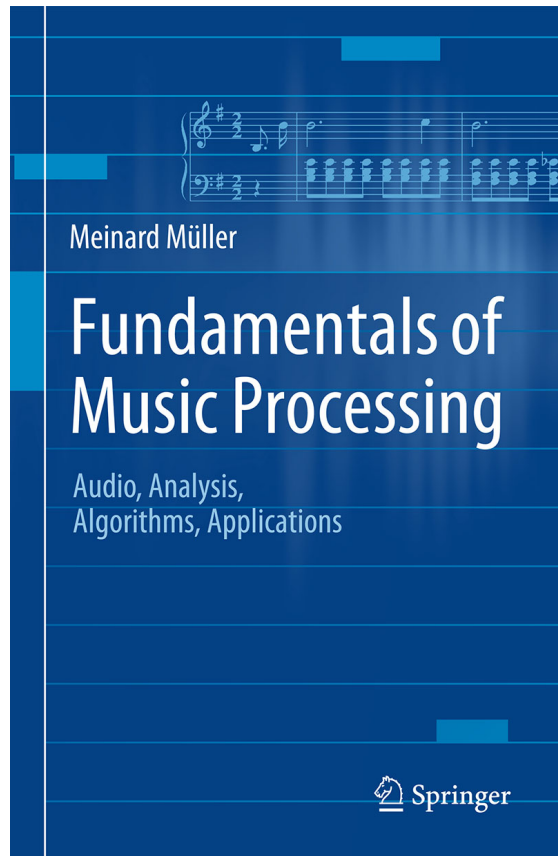
Raimund
Seidel



SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Thank you!

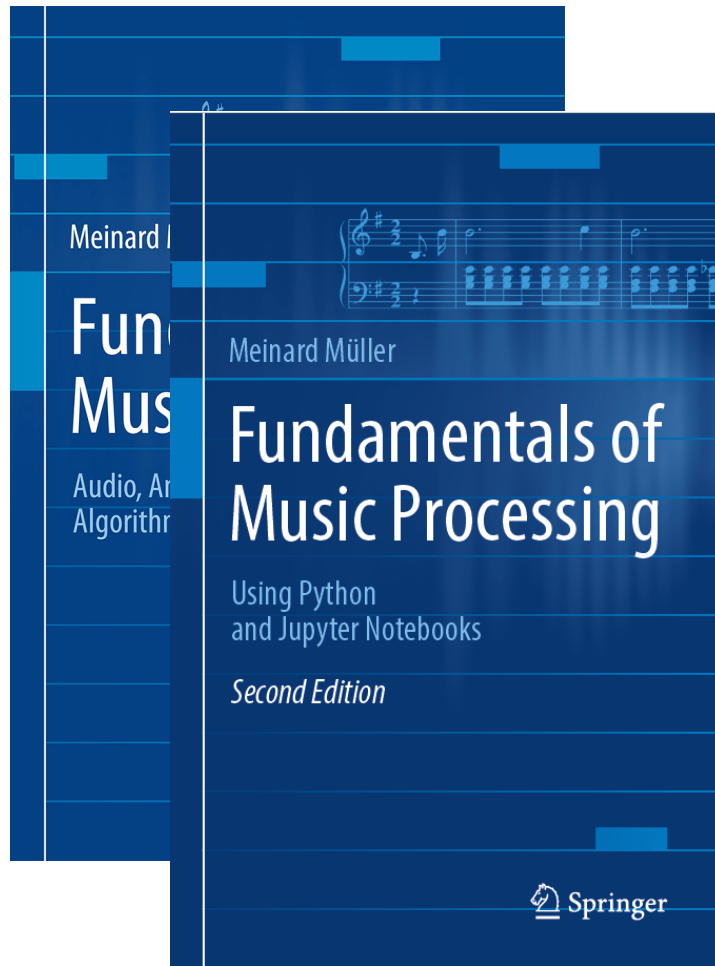
Fundamentals of Music Processing (FMP)



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

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)

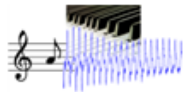

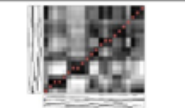

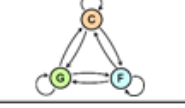
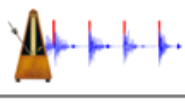
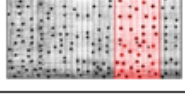
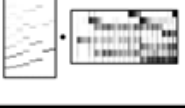


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2nd edition
Meinard Müller
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Using Python and Jupyter Notebooks
Springer, 2021

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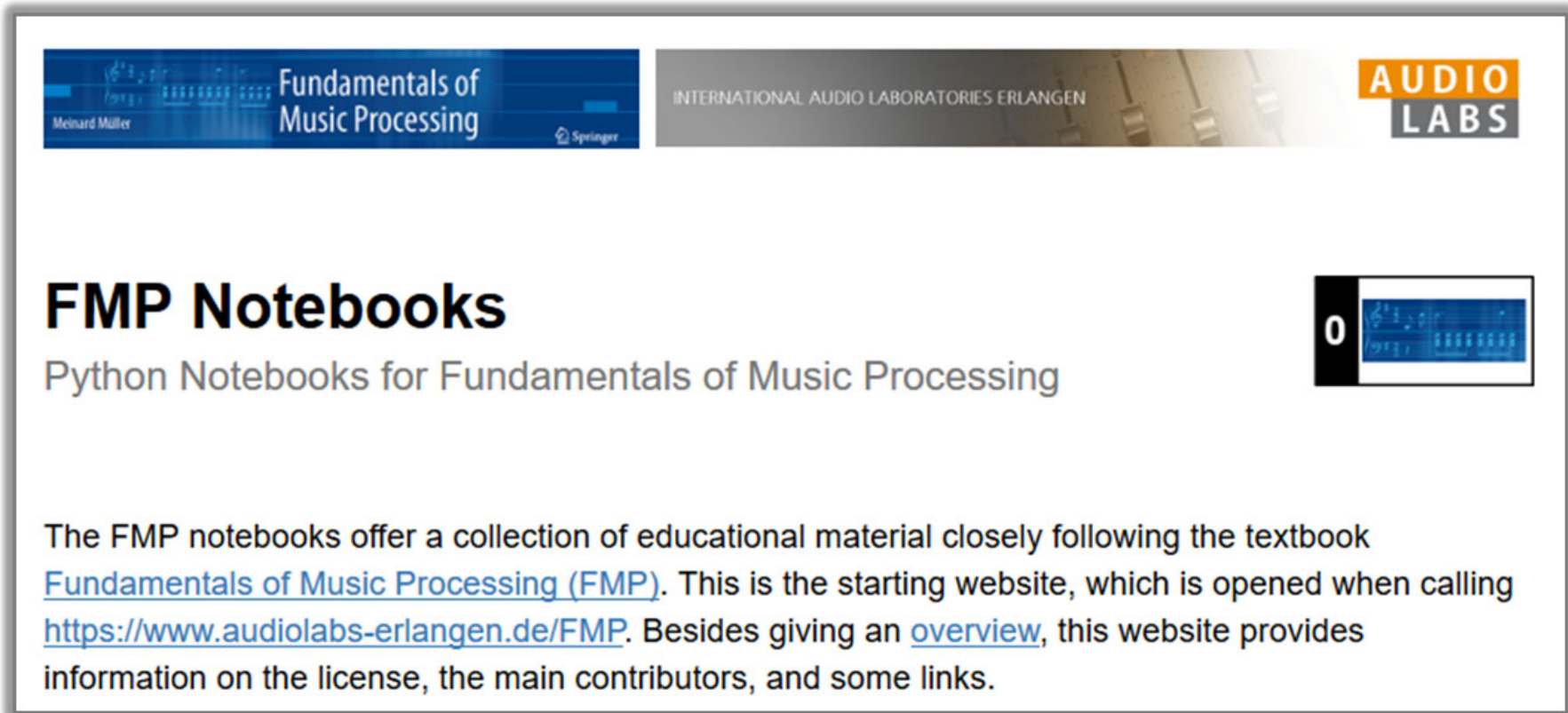
Chapter	Music Processing Scenario
1	 Music Representations
2	 Fourier Analysis of Signals
3	 Music Synchronization
4	 Music Structure Analysis
5	 Chord Recognition
6	 Tempo and Beat Tracking
7	 Content-Based Audio Retrieval
8	 Musically Informed Audio Decomposition

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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 book cover for 'Fundamentals of Music Processing' by Meinard Müller, published by Springer. In the center, it says 'INTERNATIONAL AUDIO LABORATORIES ERLANGEN'. On the right, there is the 'AUDIO LABS' logo. Below the header, the main heading is 'FMP Notebooks' in a large, bold, black font. Underneath it, the subtitle reads 'Python Notebooks for Fundamentals of Music Processing'. To the right of the subtitle is a small icon of a notebook with a blue cover and a white page, with a black circle containing the number '0' to its left. Below the subtitle, there is a paragraph of text: 'The FMP notebooks offer a collection of educational material closely following the textbook [Fundamentals of Music Processing \(FMP\)](#). 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

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<https://joss.theoj.org/papers/10.21105/joss.03326>
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<https://www.mdpi.com/2624-6120/2/2/18>
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- 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>