INTERNATIONAL AUDIO LABORATORIES ERLANGEN
A joint institution of Fraunhofer IIS and Universität Erlangen-Nürnberg

Annotations and Analyses in Computational Musicology: Separate it or not?

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Possibilities and Limitations of Digital Annotation Tools for Audio-Visual Material with a focus on Sound and Music

Mainz, May 2–4, 2022

Friedrich-Alexander-Universität Erlangen-Nürnberg

Fraunhofer IIS

Meinard Müller

- Mathematics (Diplom/Master)
  Computer Science (PhD)
  Information Retrieval (Habilitation)

universitätbonn

- Since 2012: Professor
  Semantic Audio Processing

FAU

- Former President of the International Society for
  Music Information Retrieval (MIR)

ISMIR

- IEEE Fellow for contributions to Music Signal Processing

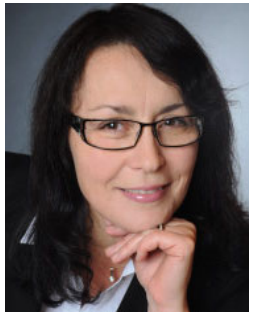
IEEE

Meinard Müller: Research Group

Semantic Audio Processing

- Christof Weiß

- Vlora Arifi-Müller



- Sebastian Rosenzweig

- Michael Krause

- Yigitcan Özer

- Simon Schwär

- Peter Meier (external)

International Audio Laboratories Erlangen

Fraunhofer IIS

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

AUDIO LABS

Friedrich-Alexander-Universität Erlangen-Nürnberg

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

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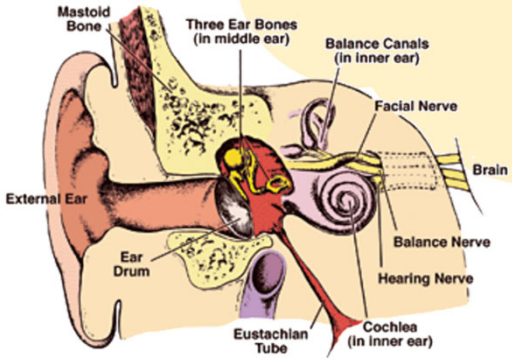
International Audio Laboratories Erlangen

Audio Coding

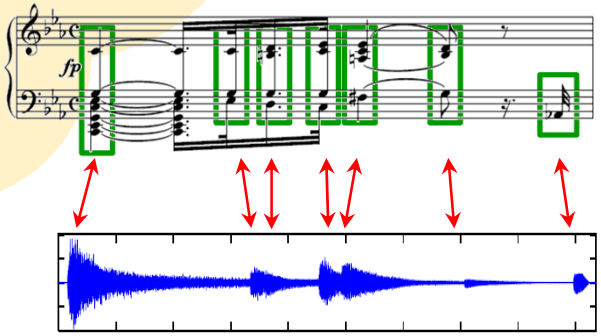
3D Audio

Audio



Psychoacoustics

Internet of Things



Music Processing

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AudioLabs – FAU

- Prof. Dr. Jürgen Herre
  Audio Coding
- Prof. Dr. Bernd Edler
  Audio Signal Analysis
- Prof. Dr. Meinard Müller
  Semantic Audio Processing
- Prof. Dr. Emanuël Habets
  Spatial Audio Signal Processing
- Prof. Dr. Nils Peters
  Audio Signal Processing
- Dr. Stefan Turowski
  Coordinator AudioLabs-FAU






Music

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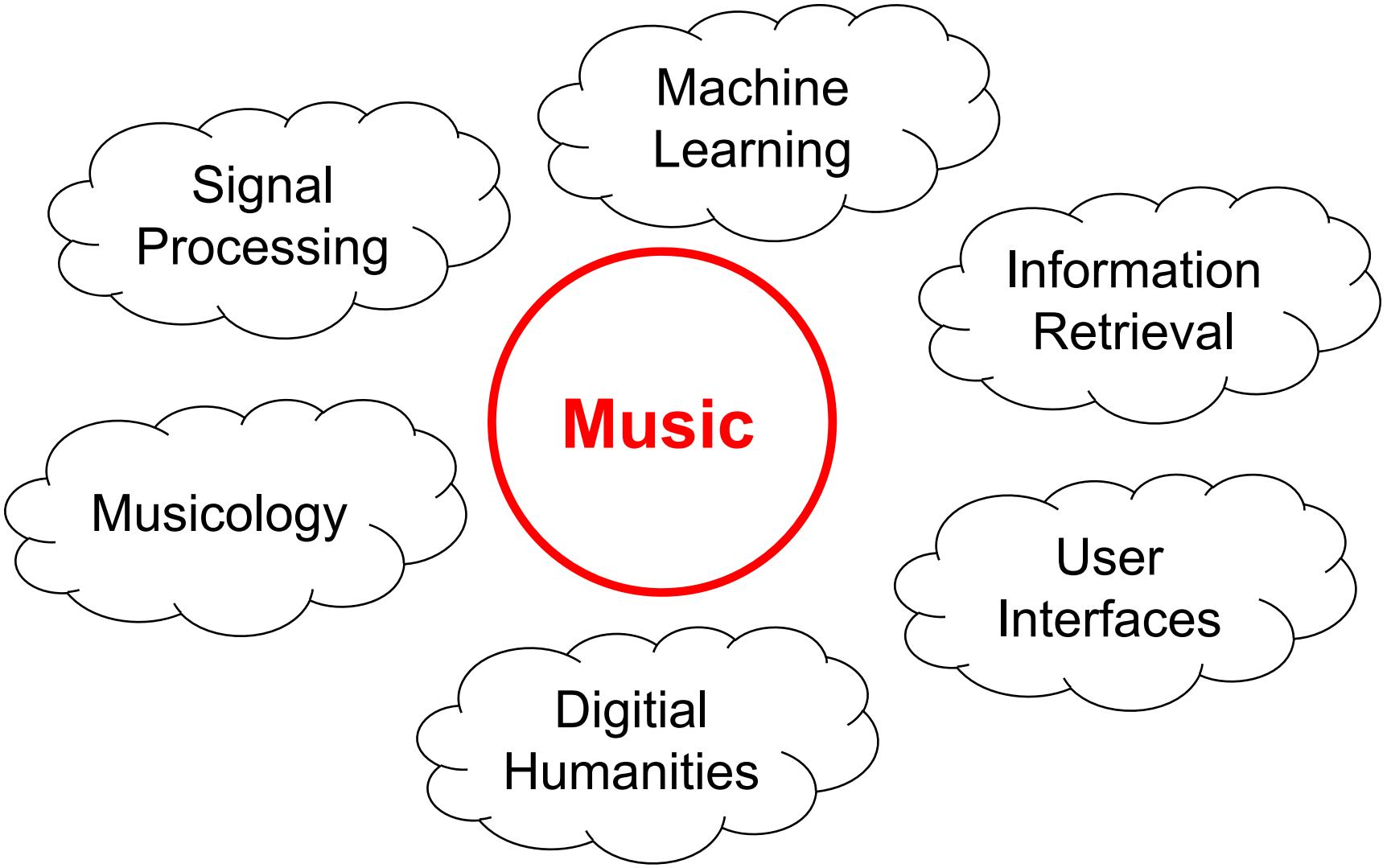
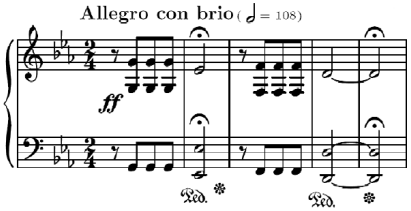
Music Information Retrieval (MIR)

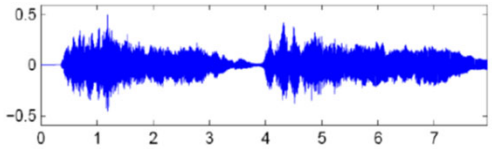


Music Information Retrieval (MIR)

Sheet Music (Image)



CD / MP3 (Audio)



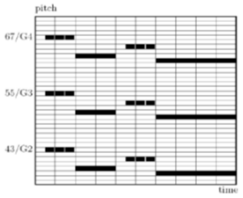
MusicXML (Text)

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

Dance / Motion (Mocap)

Music

MIDI



Singing / Voice (Audio)

Music Film (Video)

Music Literature (Text)

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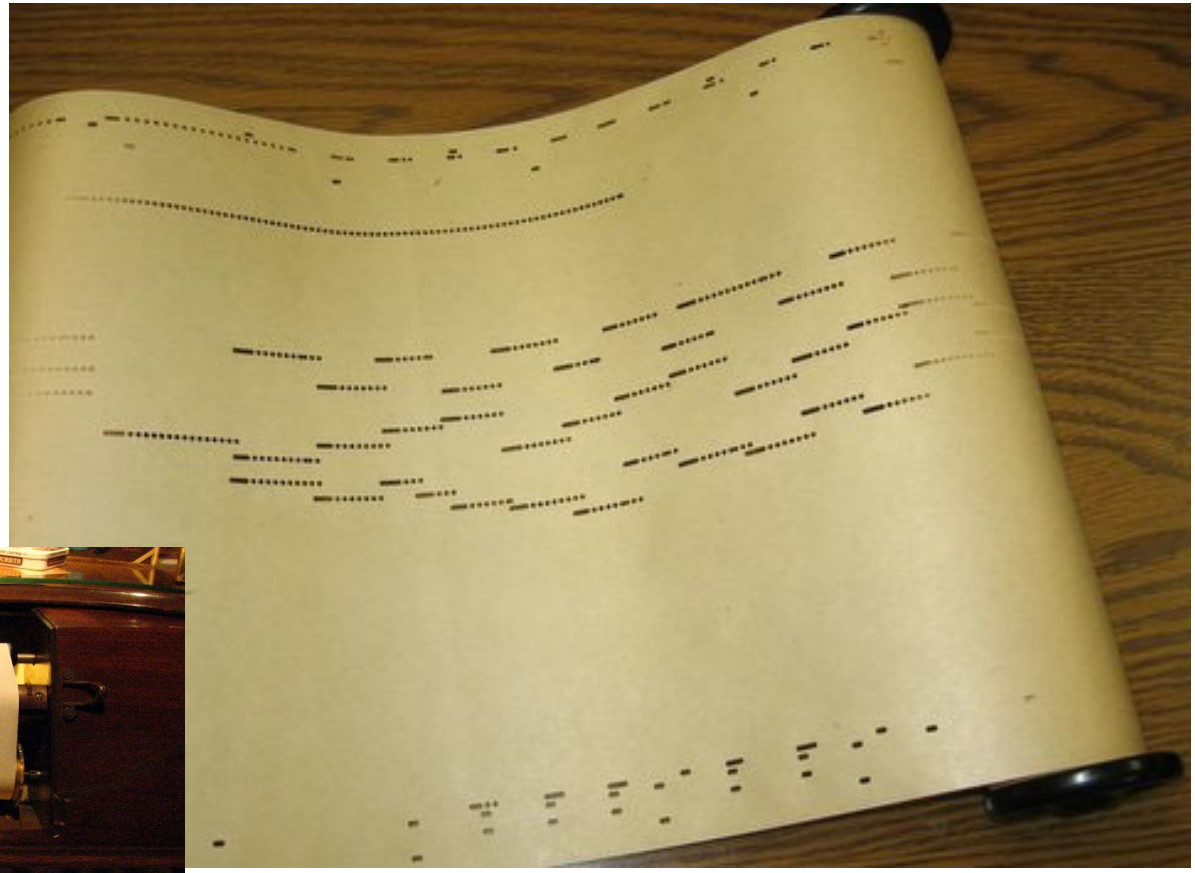
Piano Roll Representation (1900)



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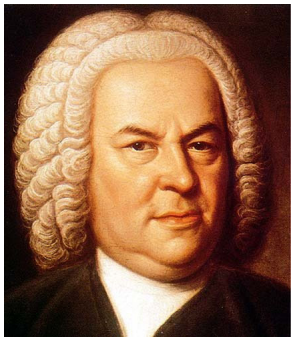
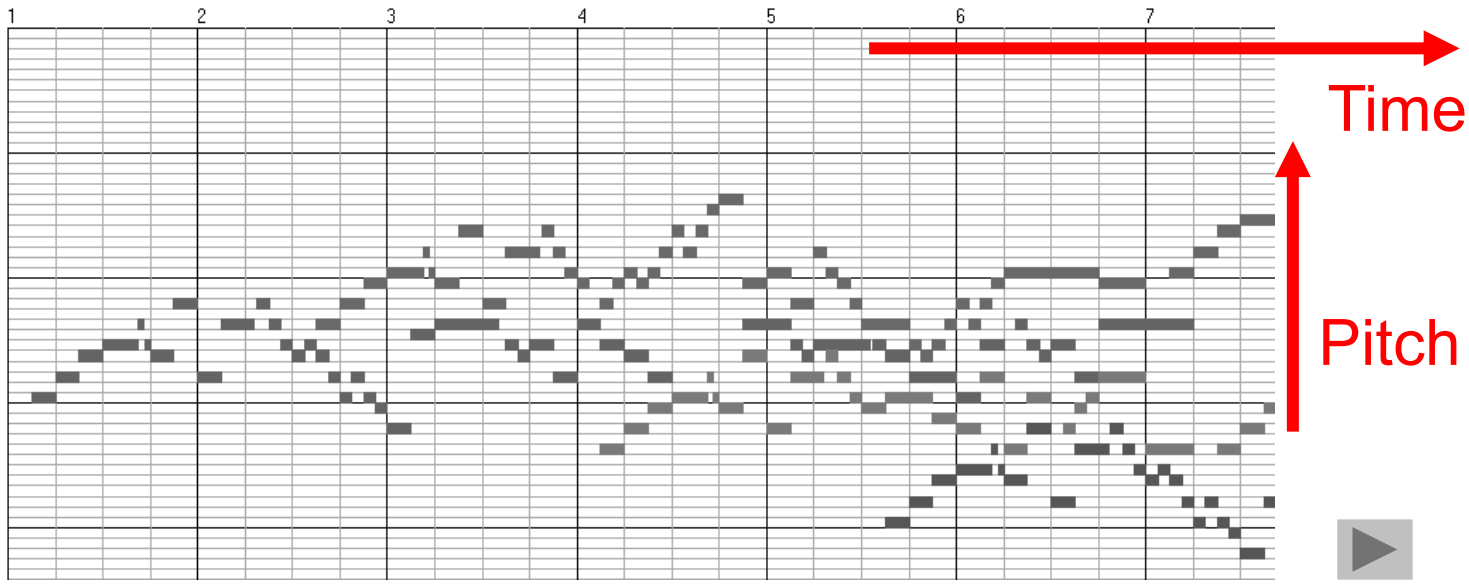
Piano Roll Representation



J.S. Bach, C-Major Fuge

(Well Tempered Piano, BWV 846)



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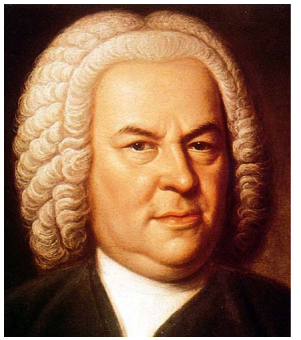
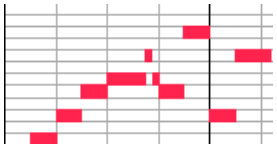
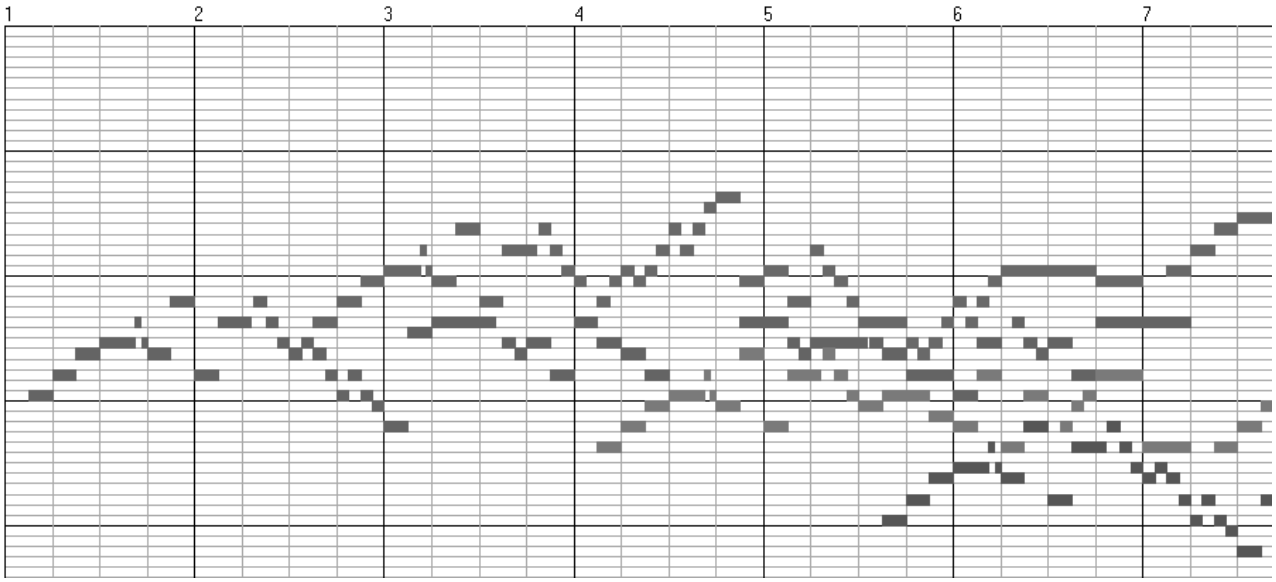
Piano Roll Representation



Query:



Goal: Find all occurrences of the query



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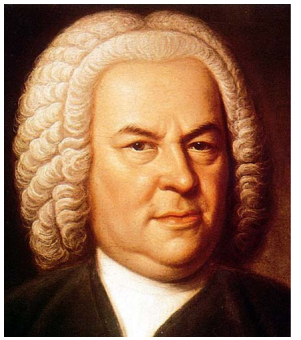
Piano Roll Representation



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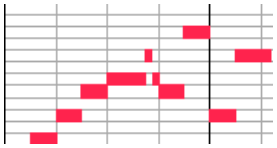
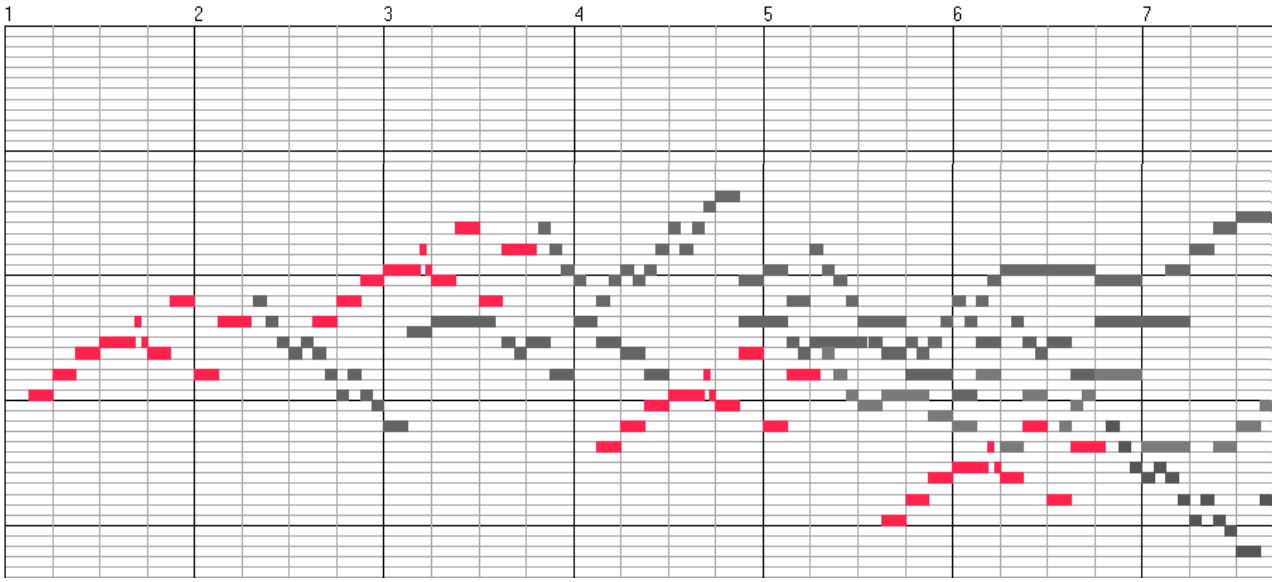


Goal: Find all occurrences of the query

Matches:



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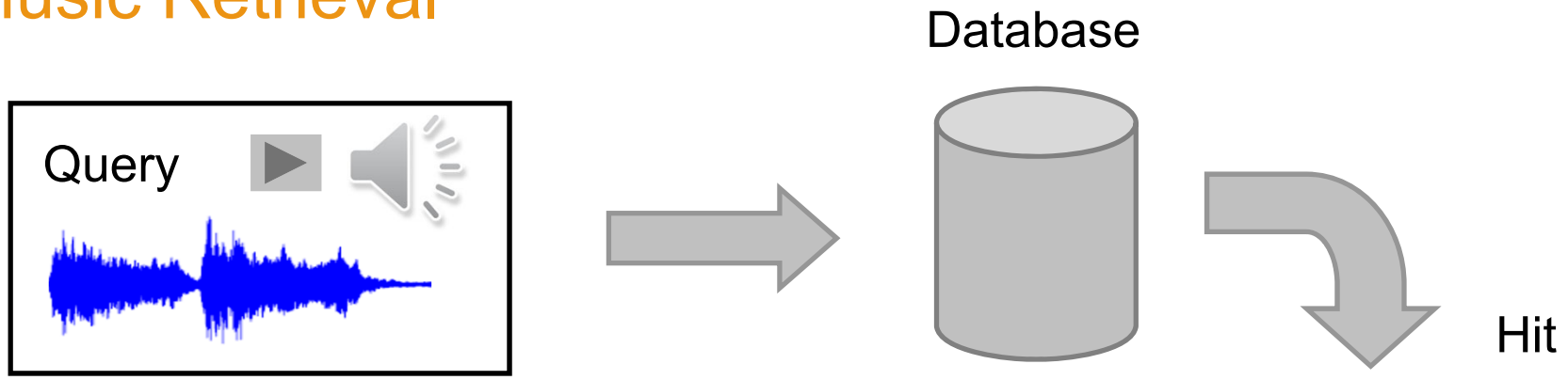
Music Retrieval



Audio ID

Bernstein (1962)
Beethoven, Symphony No. 5

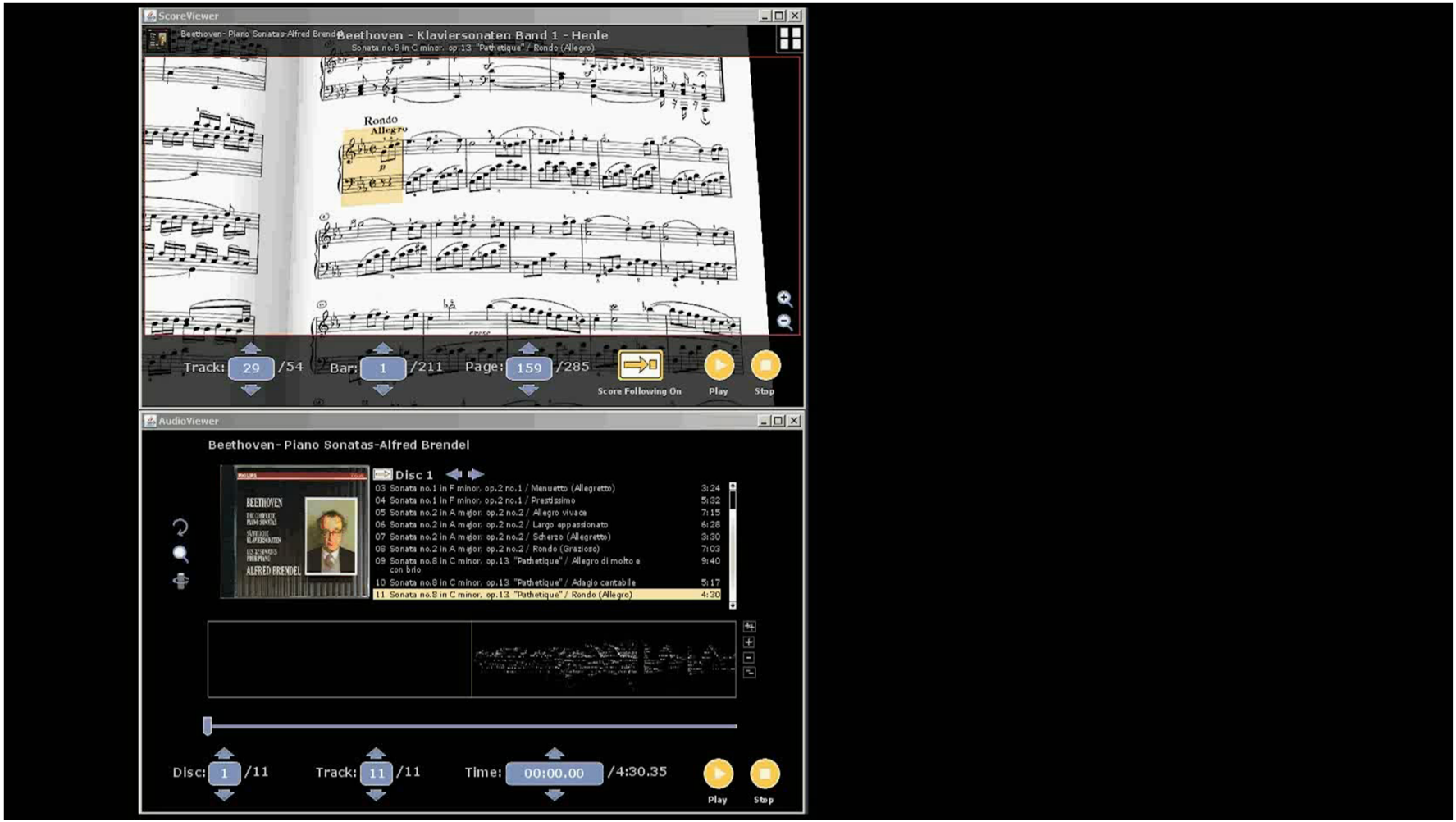
Version ID

Beethoven, Symphony No. 5:
- Bernstein (1962)
- Karajan (1982)
- Gould (1992)

Category ID

- Beethoven, Symphony No. 9
- Beethoven, Symphony No. 3
- Haydn Symphony No. 94

Score Following



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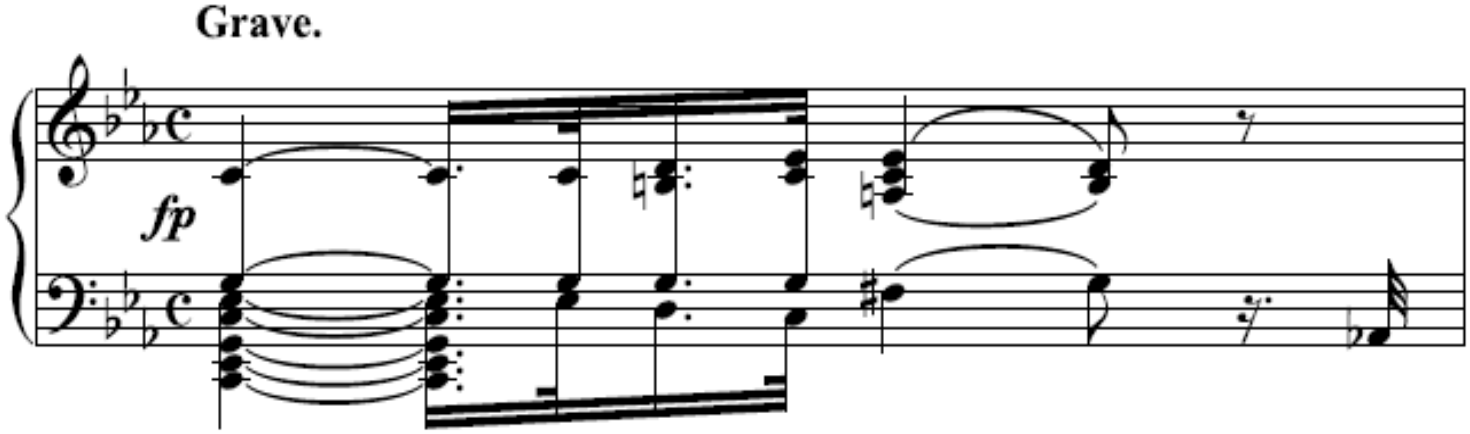
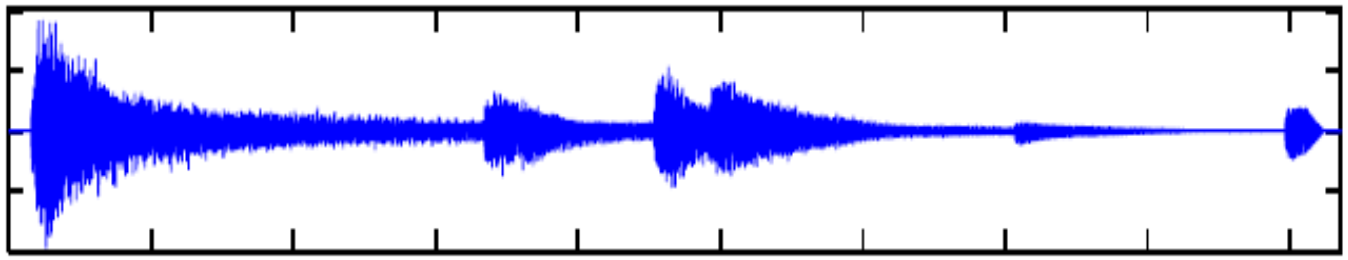
Music Synchronization: Image-Audio

Image



Audio



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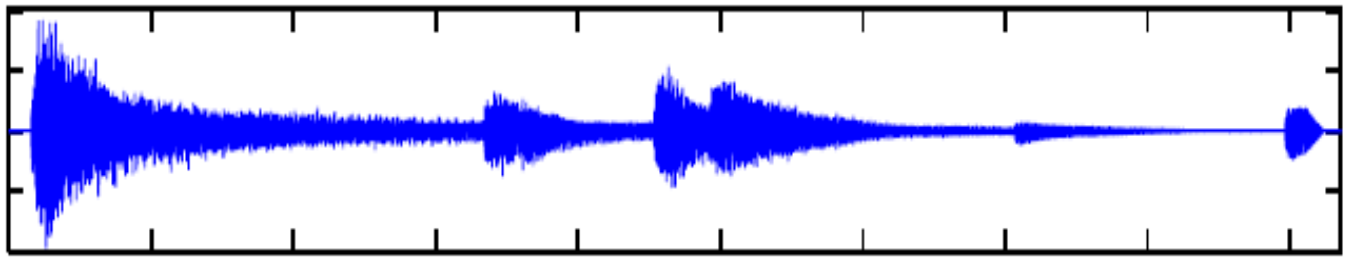
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image

Audio



Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

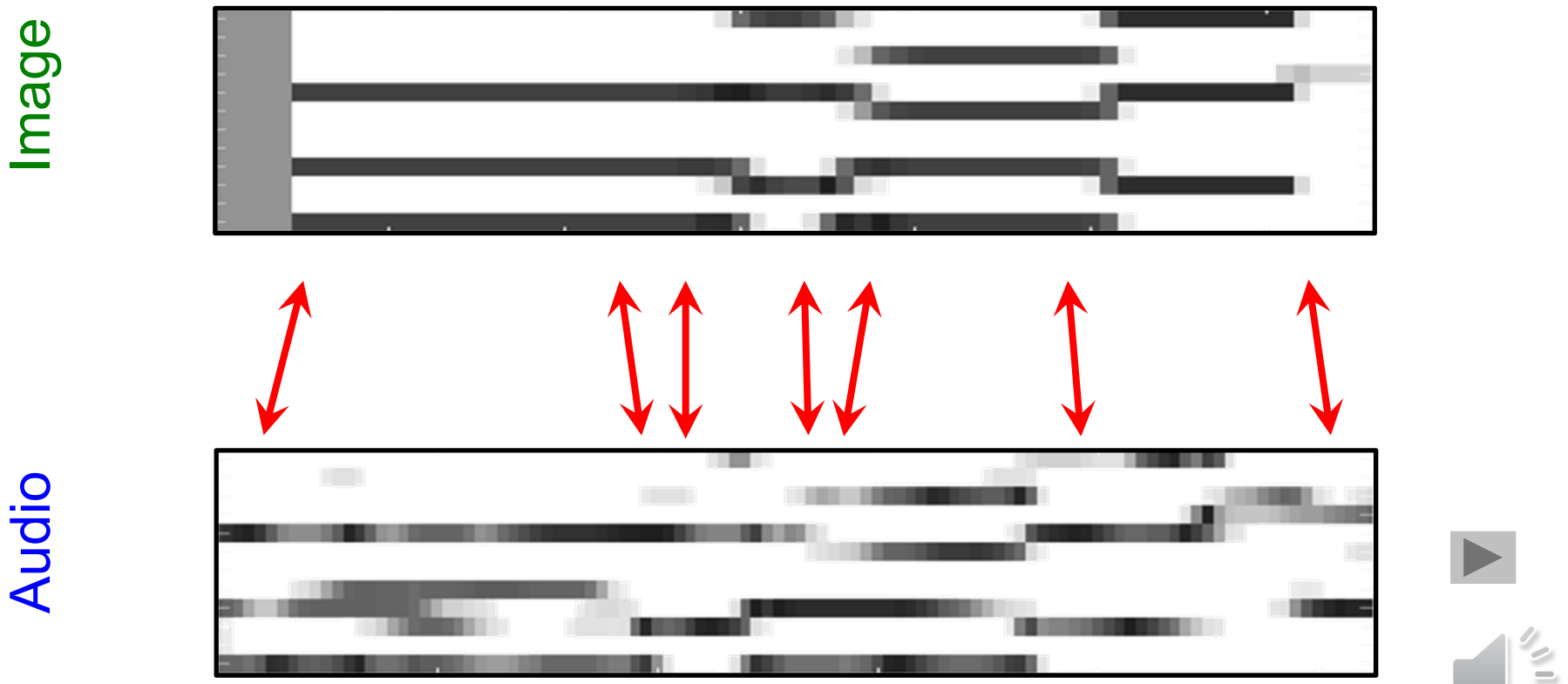
Image

Audio

Audio Processing: Fourier Analysis

Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

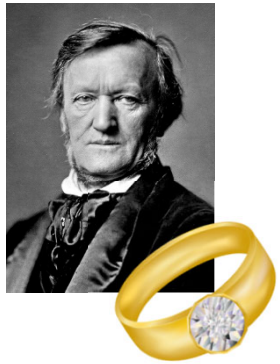


Audio Processing: Fourier Analysis

Music Scenarios

- Freischütz Digital

- Wagner's Ring



- Georgian Music

- Schubert Winterreise

Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL

- BMBF (2012 – 2016)
- Detmold/Paderborn
  (Prof. Veit, Digital Editions)
- Frankfurt
  (Prof. Betzwieser, Musicology)
- Erlangen
  (Prof. Müller, Computer Science)

Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL

- BMBF (2012 – 2016)
- Detmold/Paderborn
  (Prof. Veit, Digital Editions)
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  (Prof. Betzwieser, Musicology)
- Erlangen
  (Prof. Müller, Computer Science)

Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL

Recordings

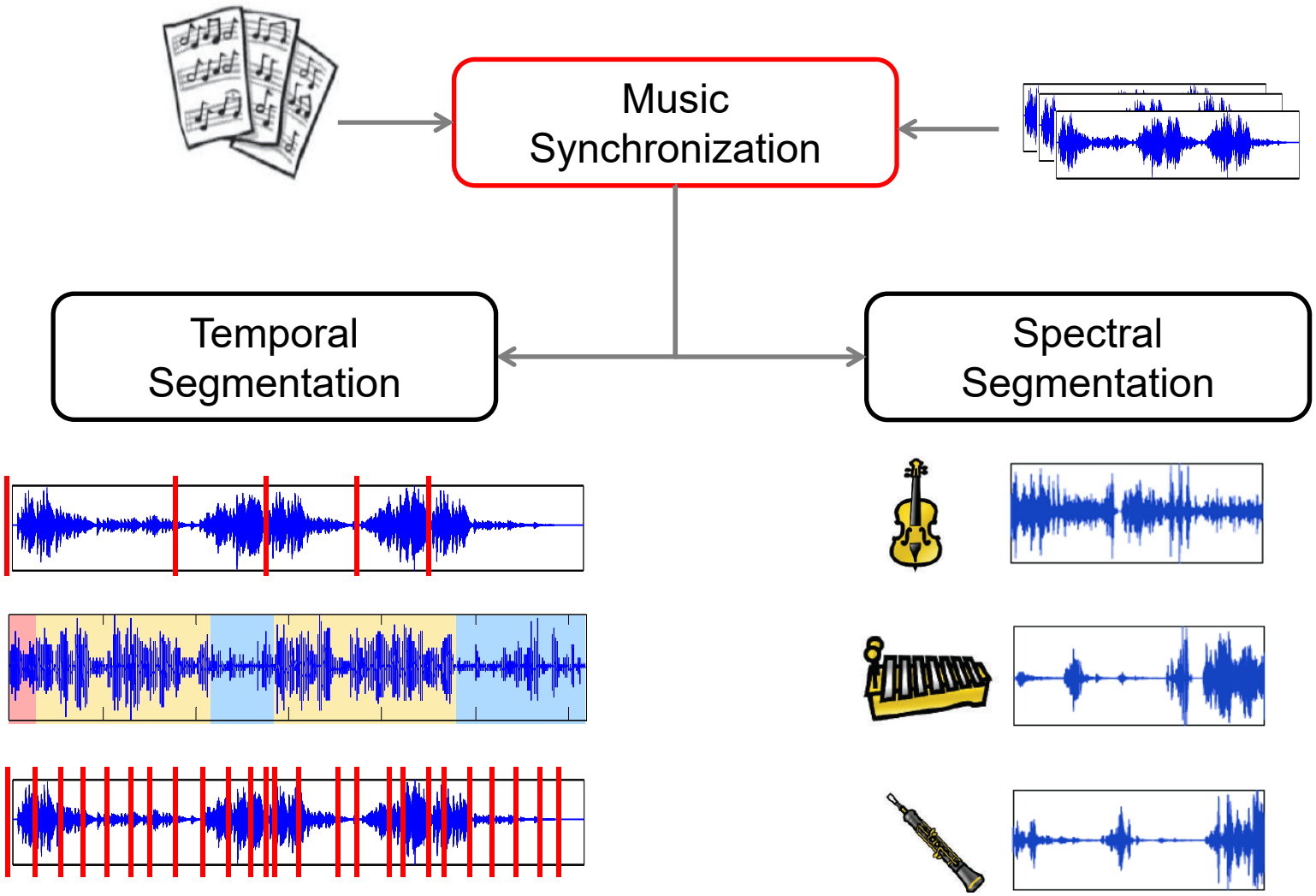
- 23 mostly complete recordings
- 10 abridged/short versions
- Recorded between 1933 and 2001

Example: Song (No. 4) from “Der Freischütz”

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

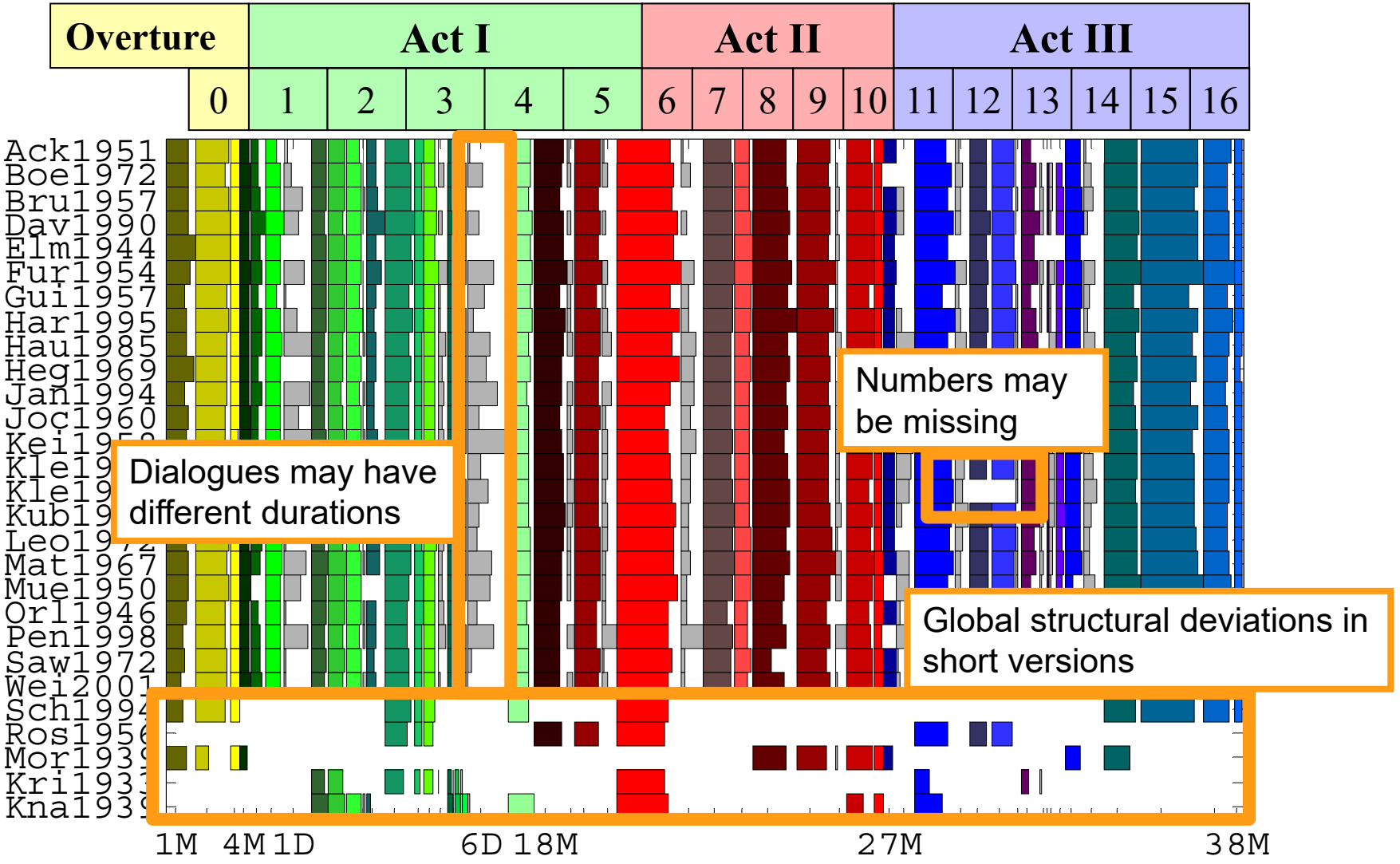
Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL



Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL



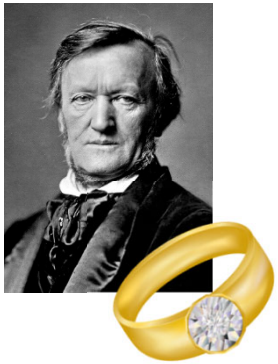
Scenario: Freischütz Digital

FREISCHÜTZ DIGITAL

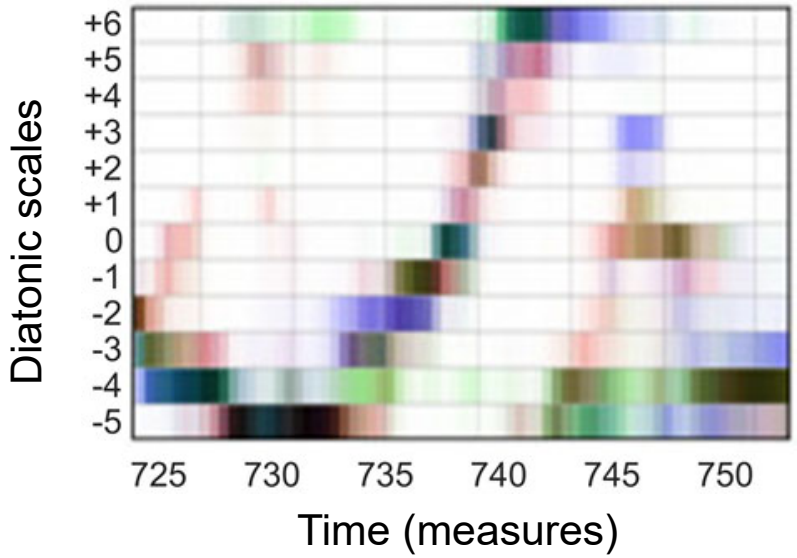
- Global inconsistencies and deviations
- Annotation process raises research questions
  - Structure analysis
  - Partial alignment
  - Language detection
  - Key detection
  - …
- Annotation process becomes the subject of research

Daniel Röwenstrunk, Thomas Prätzlich, Thomas Betzwieser, Meinard Müller, Gerd Szwillus, Joachim Veit: **Das Gesamtkunstwerk Oper aus Datensicht — Aspekte des Umgangs mit einer heterogenen Datenlage im BMBF-Projekt Freischütz Digital'‘.** Datenbank-Spektrum, 15(1): 65–72, 2015.

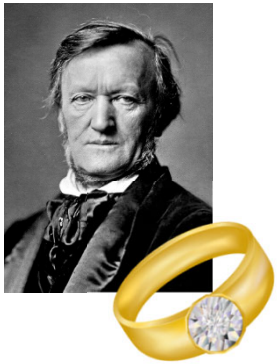
Scenario: Wagner's Ring



- DFG (2014 – 2023)
- Saarbrücken
  (Prof. Kleinertz, Musicology)
- Erlangen
  (Prof. Müller, Computer Science)
- Objectives
  - Harmony-based structural analysis
  - Visualization techniques
  - Exploration of interdisciplinary research



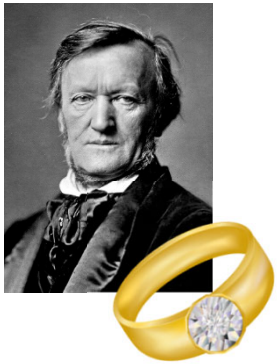
Scenario: Wagner's Ring



No.	Conductor	Recording	hh:mm:ss
1	Barenboim	1991–92	14:54:55
2	Boulez	1980–81	13:44:38
3	Böhm	1967–71	13:39:28
4	Furtwängler	1953	15:04:22
5	Haitink	1988–91	14:27:10
6	Janowski	1980–83	14:08:34
7	Karajan	1967–70	14:58:08
8	Keilberth/Furtwängler	1952–54	14:19:56
9	Krauss	1953	14:12:27
10	Levine	1987–89	15:21:52
11	Neuhold	1993–95	14:04:35
12	Sawallisch	1989	14:06:50
13	Solti	1958–65	14:36:58
14	Swarowsky	1968	14:56:34
15	Thielemann	2011	14:31:13
16	Weigle	2010–12	14:48:46

- Large-scale work
- Four operas
  - ca.15 hours
  - 21941 measures
- 16 performances

Scenario: Wagner's Ring



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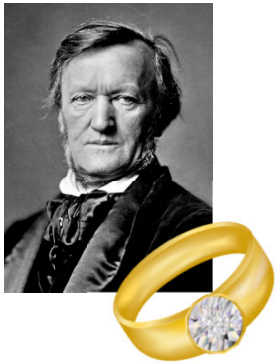
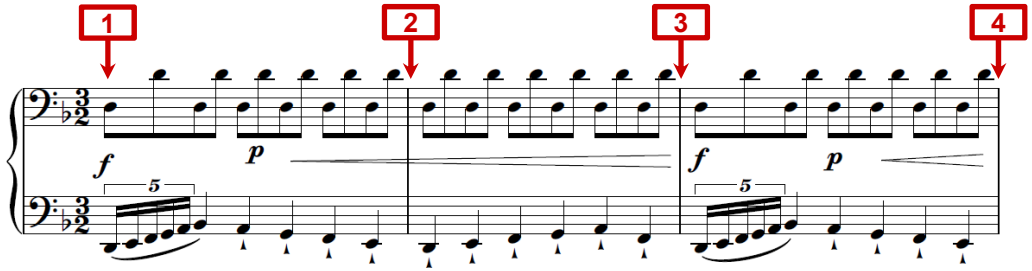
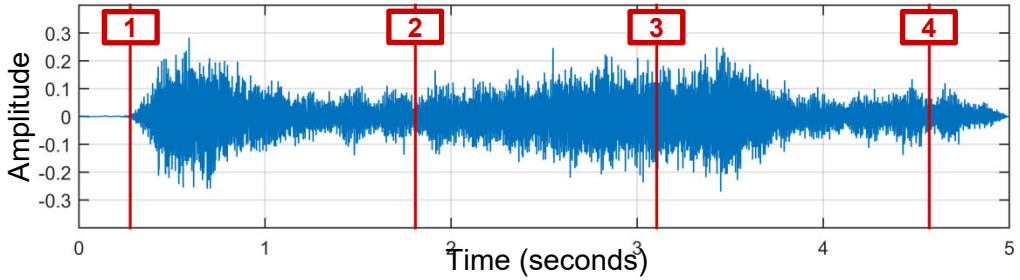
16	Weigle	2010–12	14:48:46

- Large-scale work
- Four operas
  - ca.15 hours
  - 21941 measures
- 16 performances
- Manual measure annotations

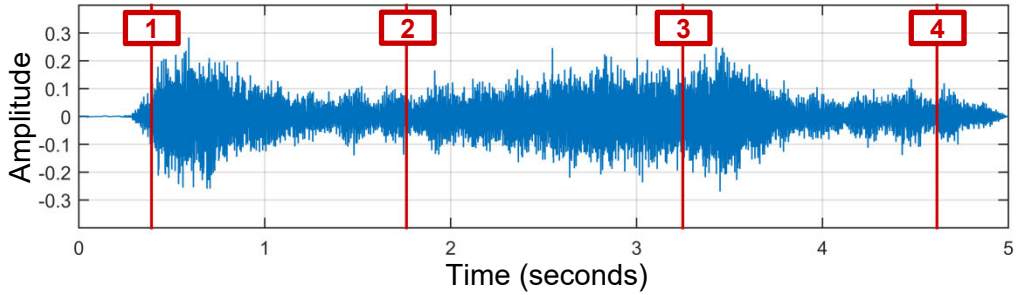
Scenario: Wagner's Ring



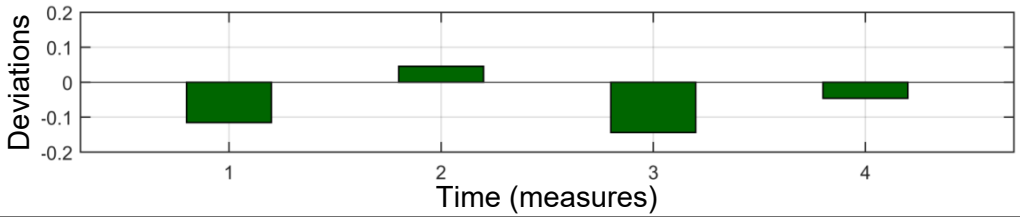




Annotator 1

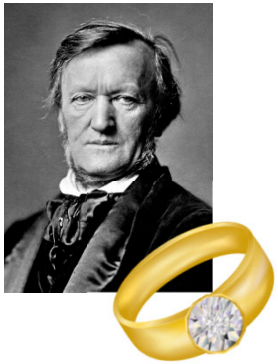


Annotator 2

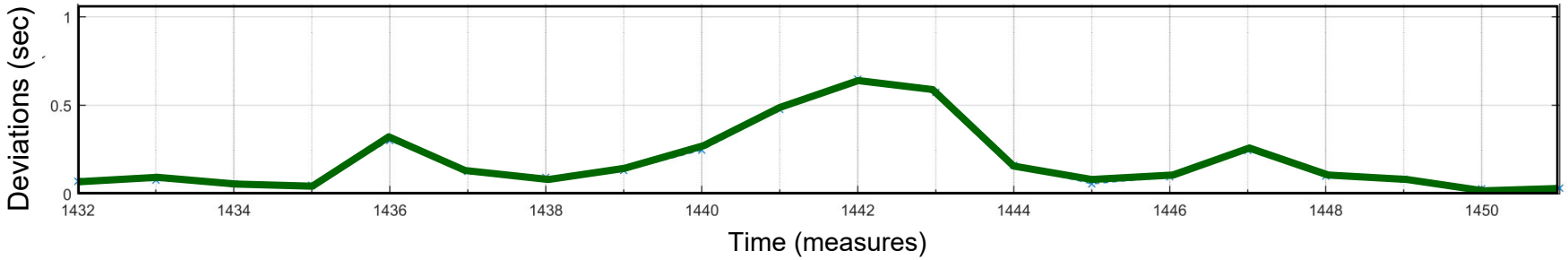


Deviations

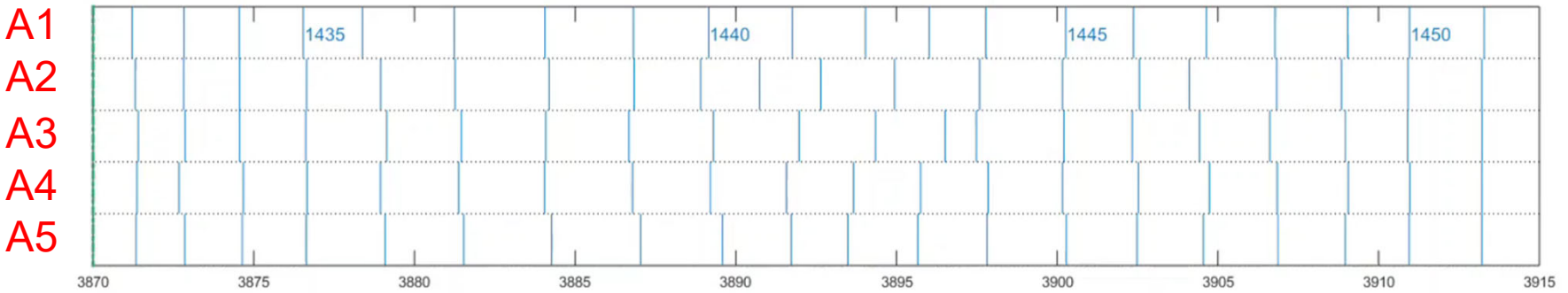
Scenario: Wagner's Ring



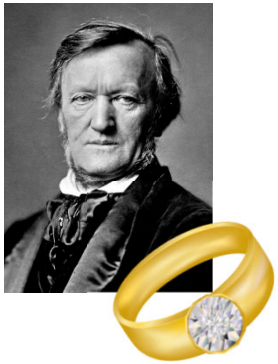
Standard deviations among **annotators**



Tenor	Trumpets	Violins	Tenor



Scenario: Wagner's Ring

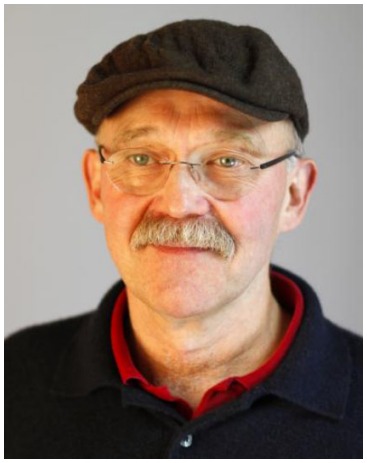


- Measure position ambiguities
  - Rhythm or beat unclear
  - Vague note onset positions
  - Non-synchronous parts (e.g., singers and orchestra)
  - …
- Introduce confidence measures
  - Cross-annotator agreement
  - Cost function based on novelty and homogeneity
  - …

Christof Weiß, Vlora Arifi-Müller, Thomas Prätzlich, Rainer Kleinertz, Meinard Müller:
Analyzing Measure Annotations for Western Classical Music Recordings.
In Proceedings of the International Society for Music Information Retrieval Conference (ISMIR): 517–523, 2016.

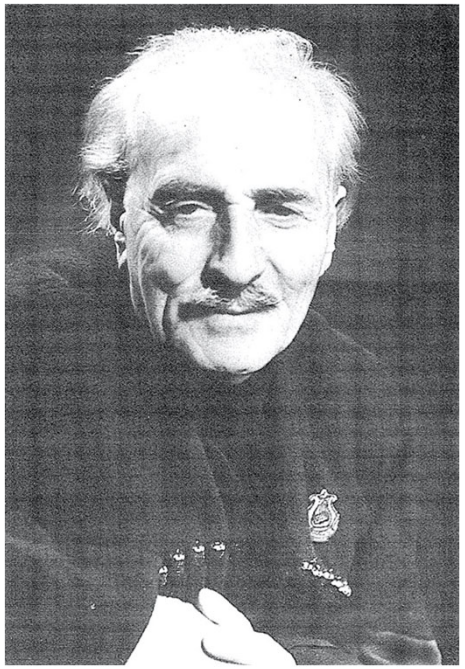
Scenario: Georgian Music

- DFG (2018 – 2022)
- Potsdam
  (Prof. Scherbaum, Ethnomusicology)
- Erlangen
  (Prof. Müller, Computer Science)
- Objectives
  - Harmonic and melodic singing analysis
  - New sensors (larynx microphones)
  - Digital humanities



Scenario: Georgian Music
Erkomaishvili Dataset

- Collection of traditional three-voice Georgian songs

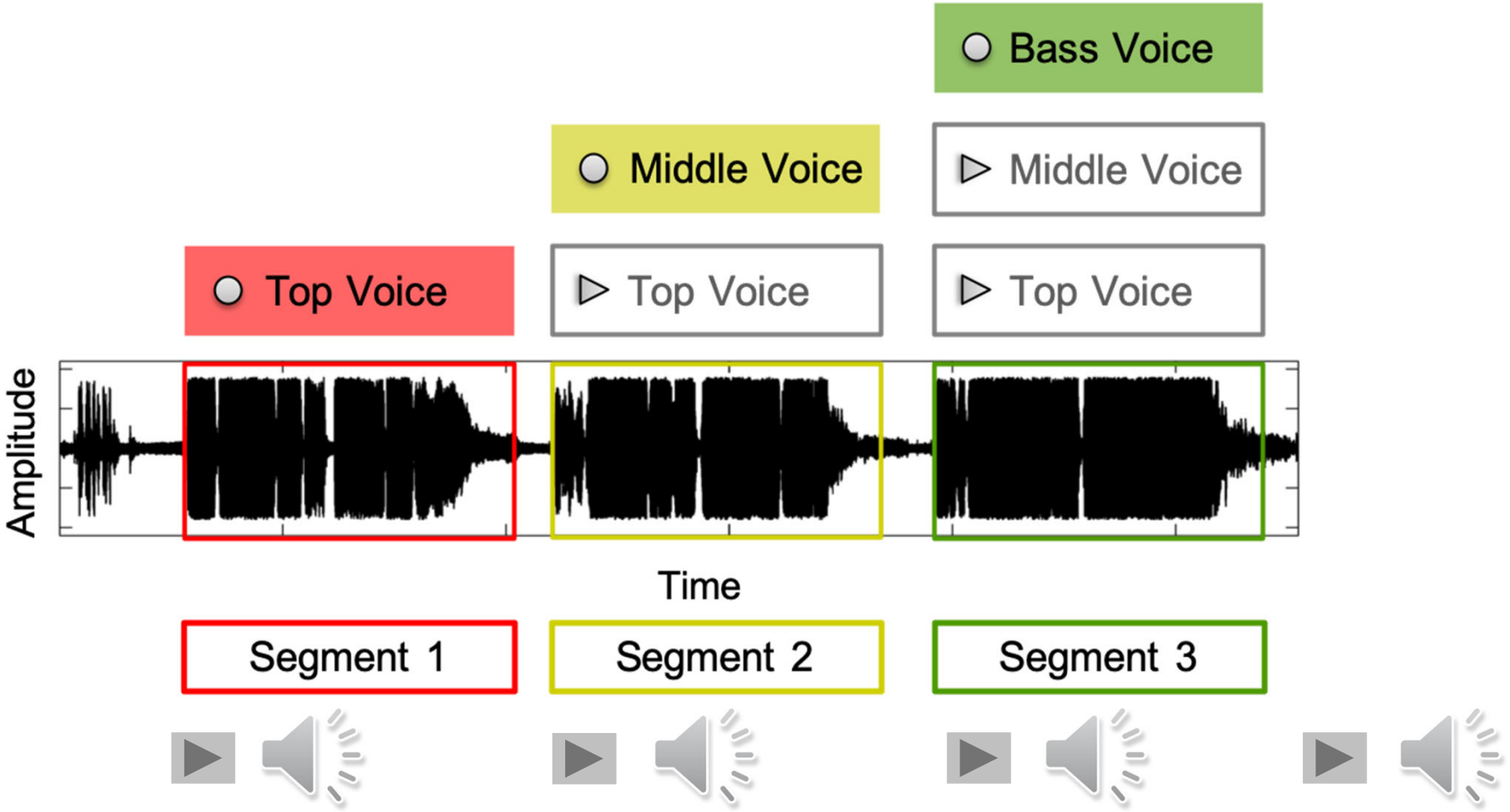


- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)

- Recorded using tape recorders in 1966

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

Scenario: Georgian Music
Erkomaishvili Dataset



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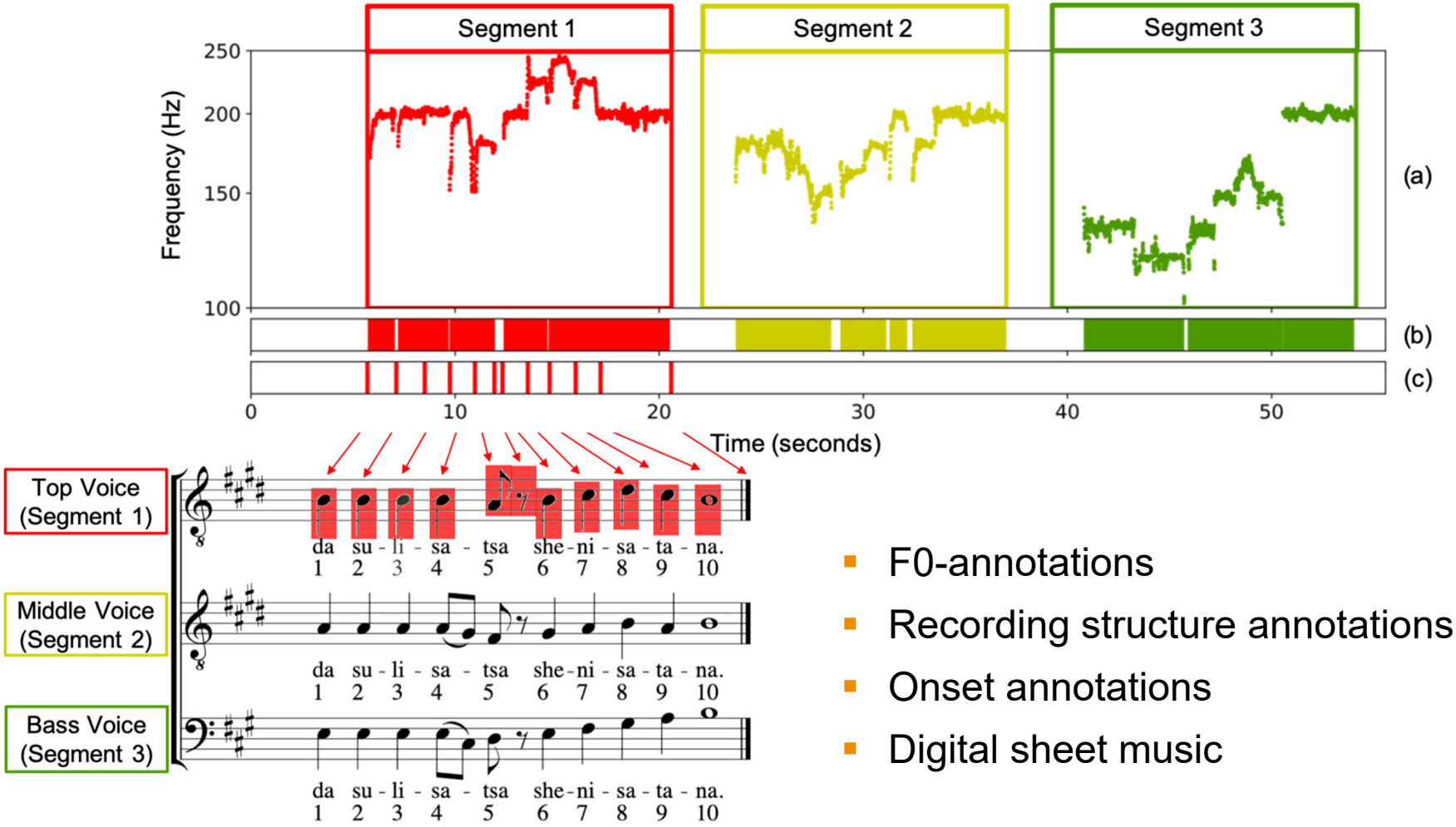
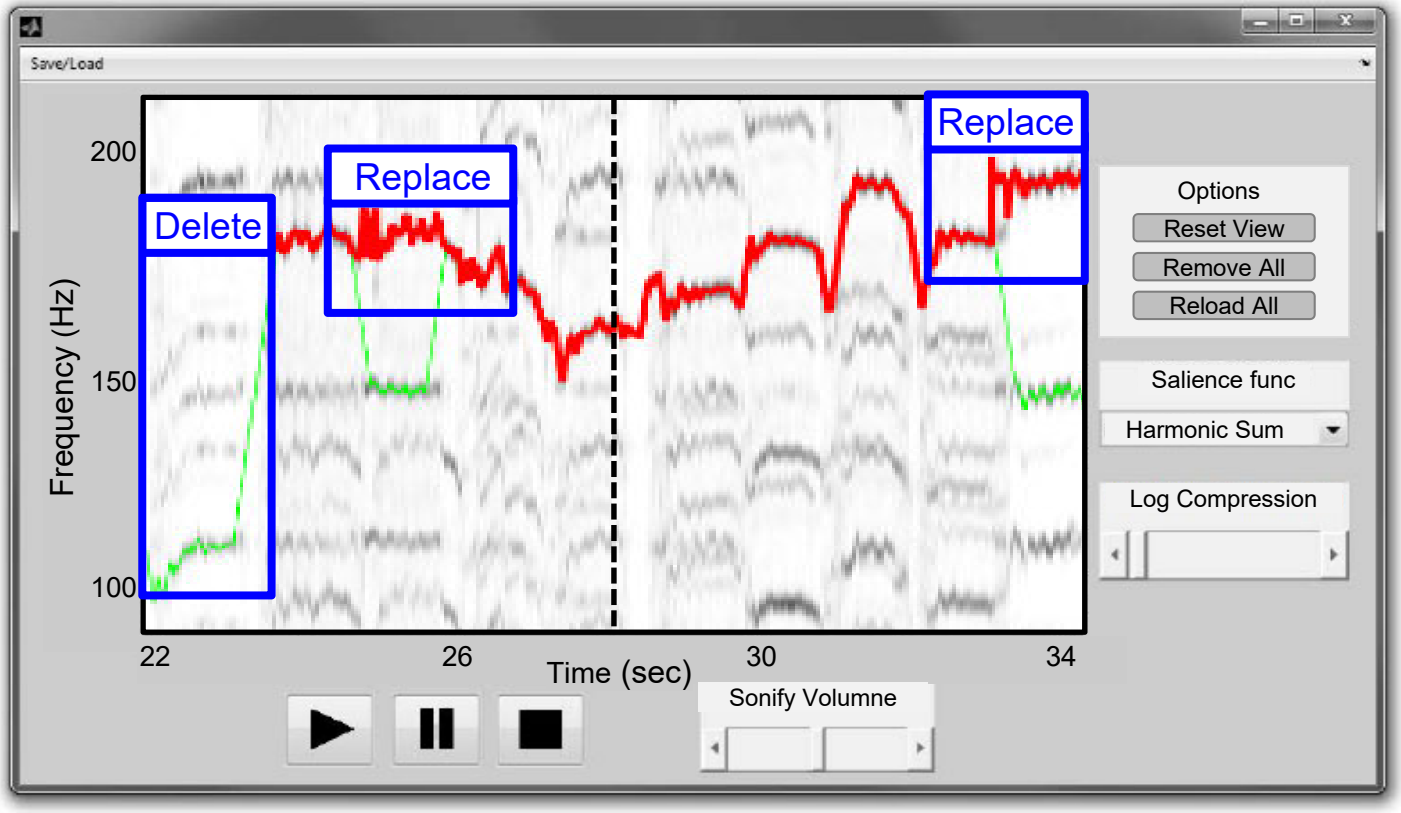
Scenario: Georgian Music
Erkomaishvili Dataset



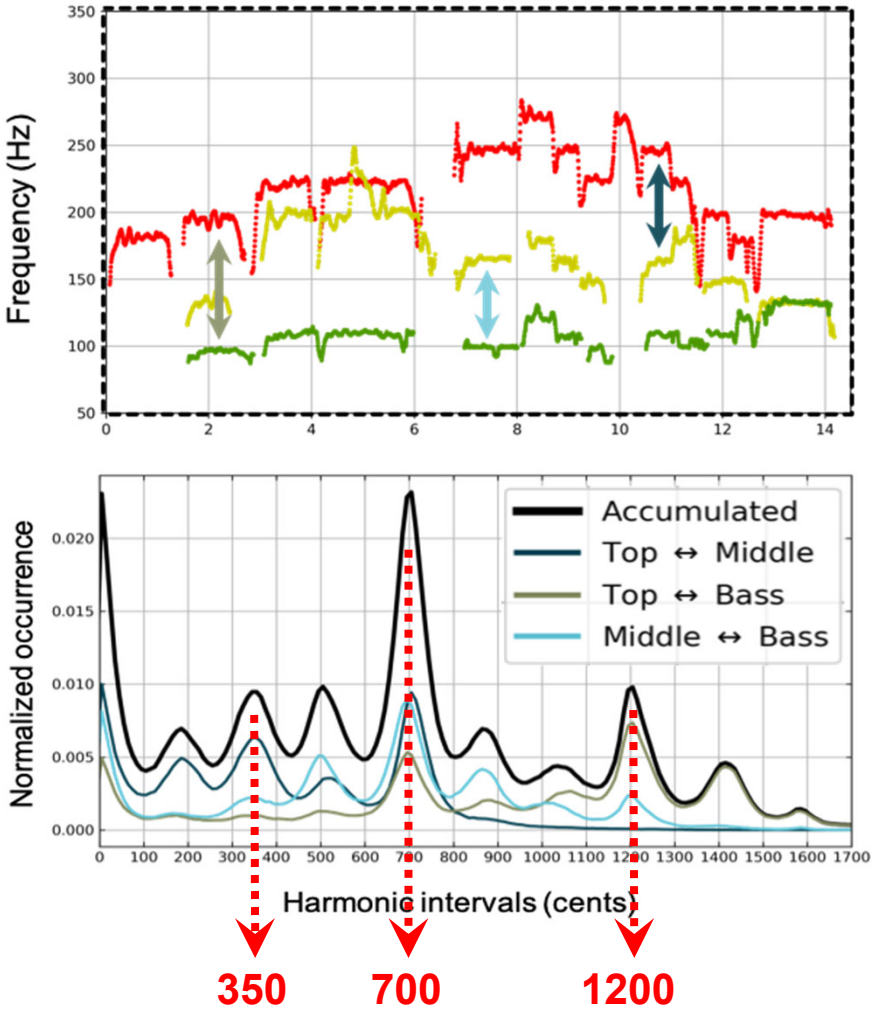
- F0-annotations
- Recording structure annotations
- Onset annotations
- Digital sheet music

Scenario: Georgian Music
Interactive F0 Annotation Tool



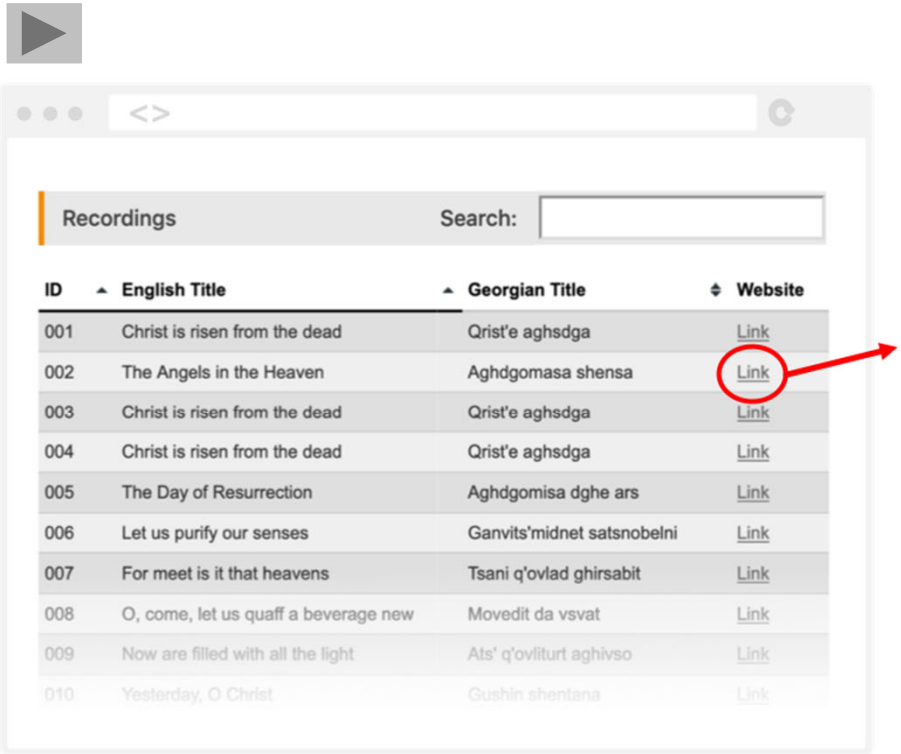
Meinard Müller, Sebastian Rosenzweig, Jonathan Driedger, and Frank Scherbaum:
Interactive Fundamental Frequency Estimation with Applications to Ethnomusicological Research.
In Proceedings of the AES Conference on Semantic Audio, 2017.

Scenario: Georgian Music
Erkomaishvili Dataset



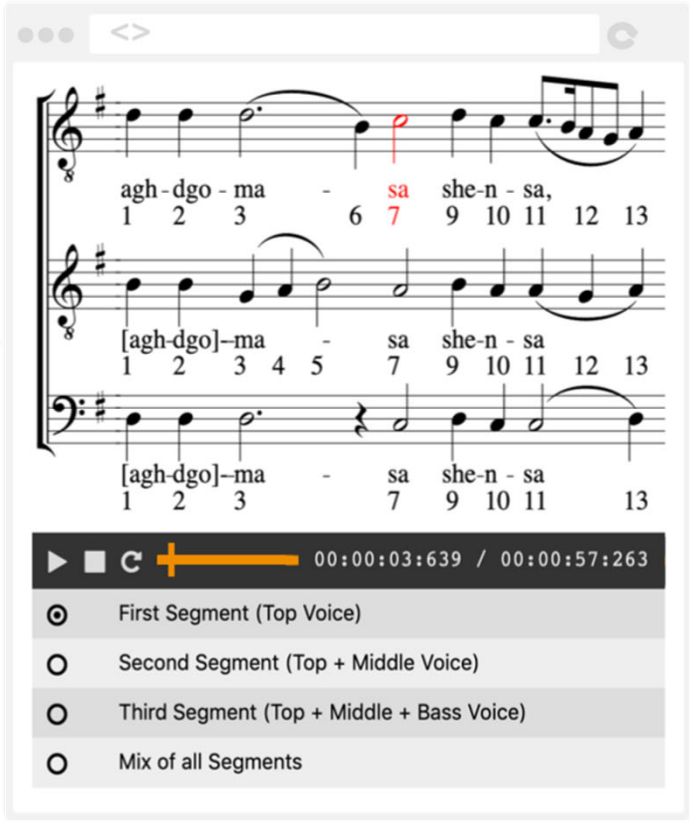
- Superimposed F0-trajectories
- Measuring harmonic intervals
- Peak at 350 cents (between minor and major third)
- **Non-western temperament**

Scenario: Georgian Music
Erkomaishvili Dataset



Recordings Search:

ID	English Title	Georgian Title	Website
001	Christ is risen from the dead	Qrist'e aghsdga	Link
002	The Angels in the Heaven	Aghdgomasa shensa	Link
003	Christ is risen from the dead	Qrist'e aghsdga	Link
004	Christ is risen from the dead	Qrist'e aghsdga	Link
005	The Day of Resurrection	Aghdgomisa dghe ars	Link
006	Let us purify our senses	Ganvits'midnet satsnobelni	Link
007	For meet is it that heavens	Tsani q'ovlad ghirsabit	Link
008	O, come, let us quaff a beverage new	Movedit da vsvat	Link
009	Now are filled with all the light	Ats' q'ovliturt aghivso	Link
010	Yesterday, O Christ	Gushin shentana	Link



https://www.audiolabs-erlangen.de/resources/MIR/2019-GeorgianMusic-Erkomaishvili

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Scenario: Georgian Music
Erkomaishvili Dataset

- Temporal organization
  - No notion of meter
  - Continuous note transitions (glissando)
  - Voices not synchronous
- Tonal organization
  - Non-western temperament
  - Harmonic vs. melodic intonation
  - Transcription problematic
- Poor recording conditions

Sebastian Rosenzweig, Frank Scherbaum, David Shugliashvili, Vlora Arifi-Müller, and Meinard Müller:
Erkomaishvili Dataset: A Curated Corpus of Traditional Georgian Vocal Music for Computational Musicology.
Transactions of the International Society for Music Information Retrieval (TISMIR), 3(1): 31–41, 2020.

Scenario: Schubert Winterreise

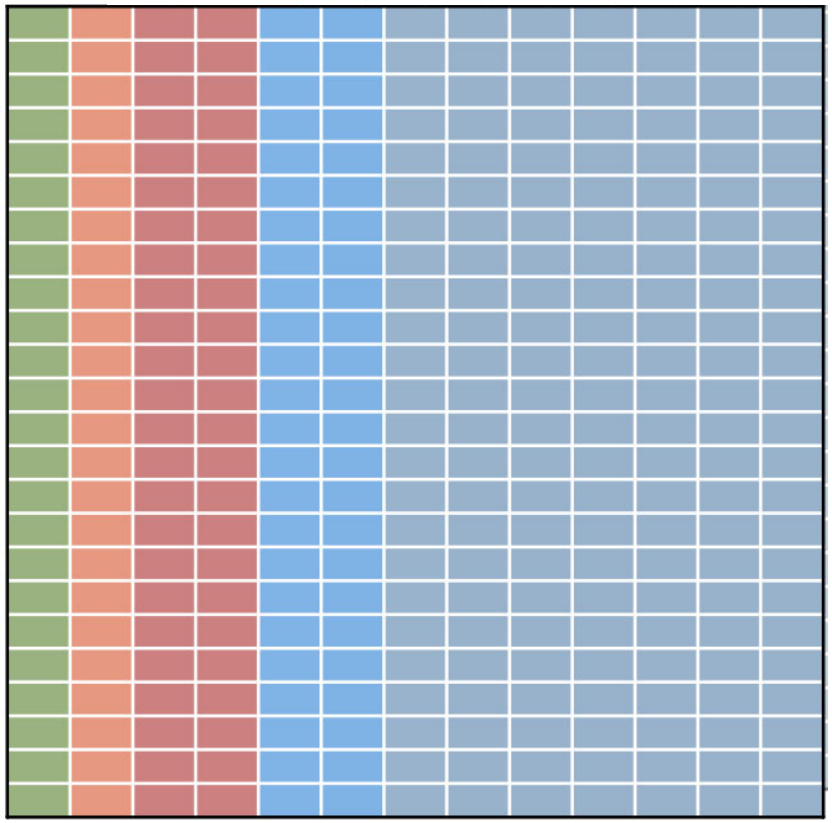
- Winterreise
  - Song cycle for voice and piano
  - Music: Franz Schubert (1828)
  - Poems: Wilhelm Müller

- MIR Objectives
  - Music synchronization
  - Stucture analysis
  - Harmonic analysis
  - Activity detection (singing, lyrics, …)
  - …

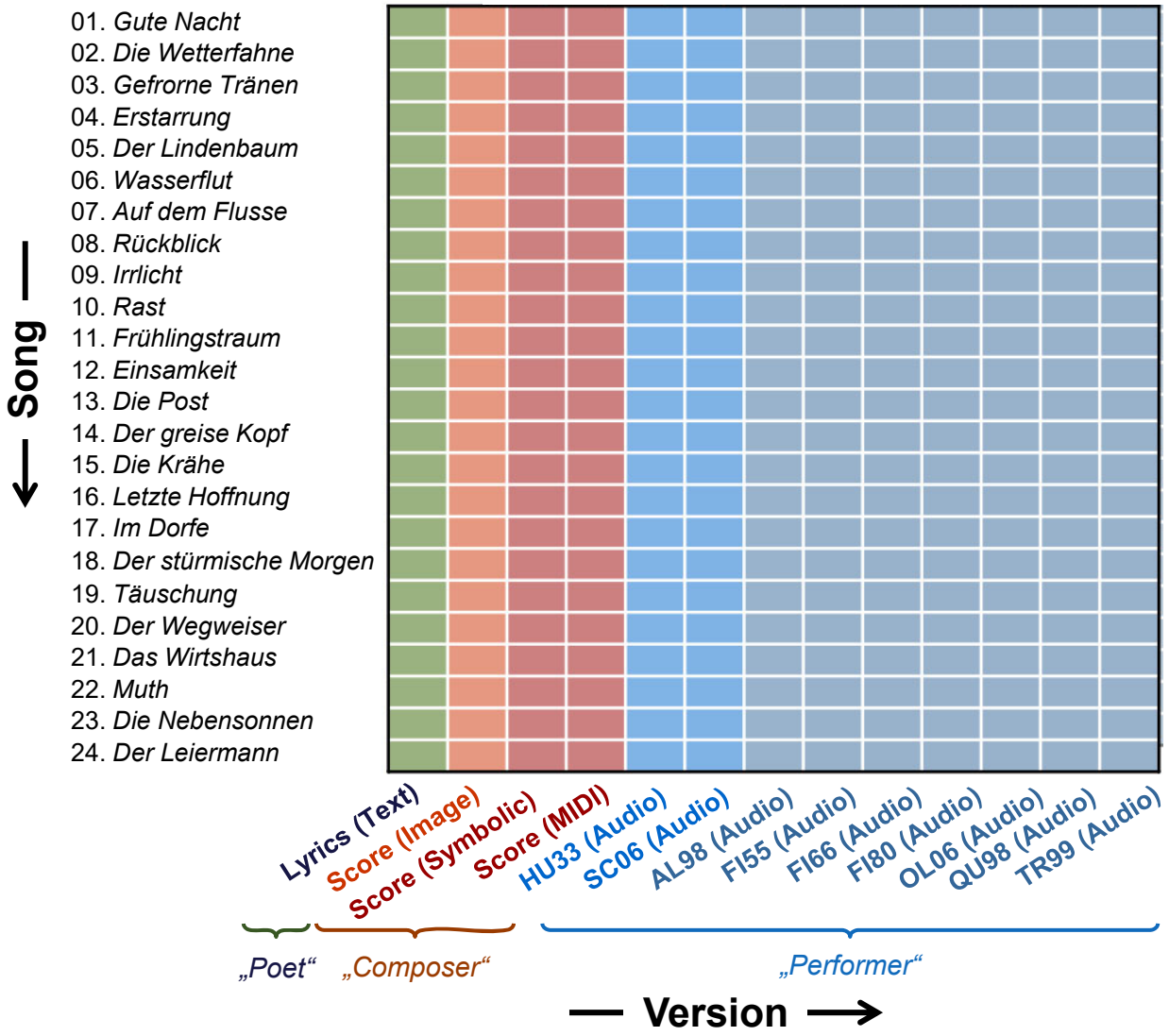
Scenario: Schubert Winterreise

Song →

01. *Gute Nacht*
02. *Die Wetterfahne*
03. *Gefrorne Tränen*
04. *Erstarrung*
05. *Der Lindenbaum*
06. *Wasserflut*
07. *Auf dem Flusse*
08. *Rückblick*
09. *Irrlicht*
10. *Rast*
11. *Frühlingstraum*
12. *Einsamkeit*
13. *Die Post*
14. *Der greise Kopf*
15. *Die Krähe*
16. *Letzte Hoffnung*
17. *Im Dorfe*
18. *Der stürmische Morgen*
19. *Täuschung*
20. *Der Wegweiser*
21. *Das Wirtshaus*
22. *Muth*
23. *Die Nebensonnen*
24. *Der Leiermann*



Scenario: Schubert Winterreise



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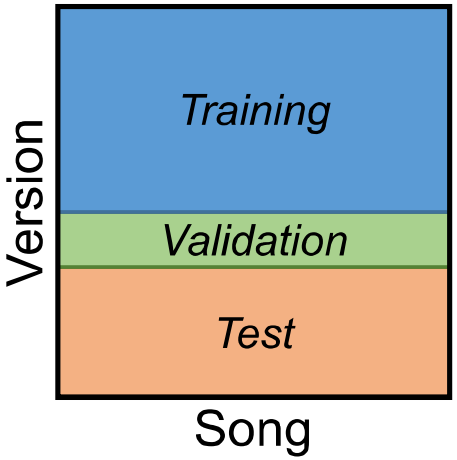
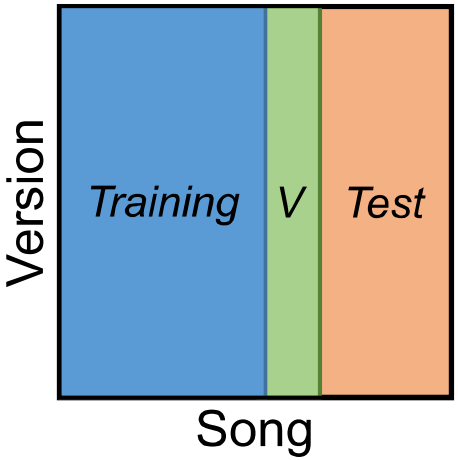
Scenario: Schubert Winterreise

Cross-Version Evaluation

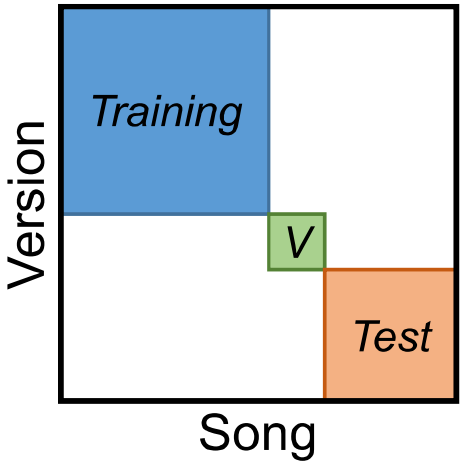
Version split



Song split

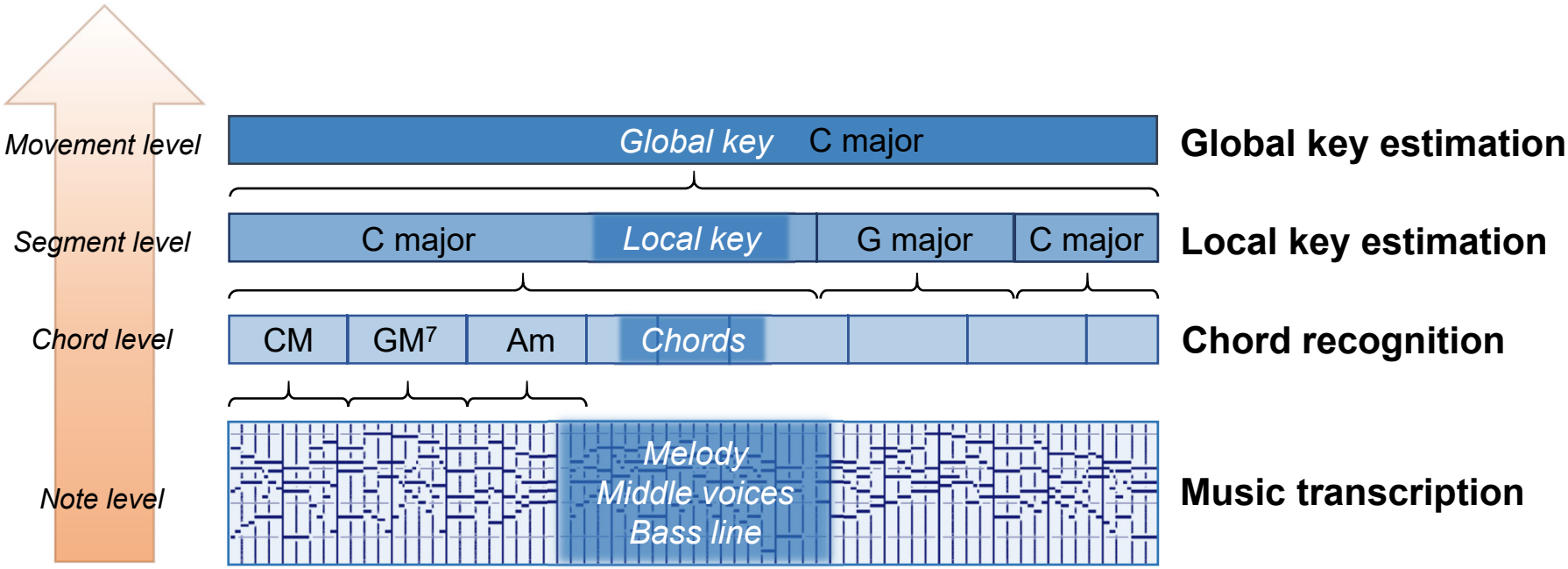


Neither split



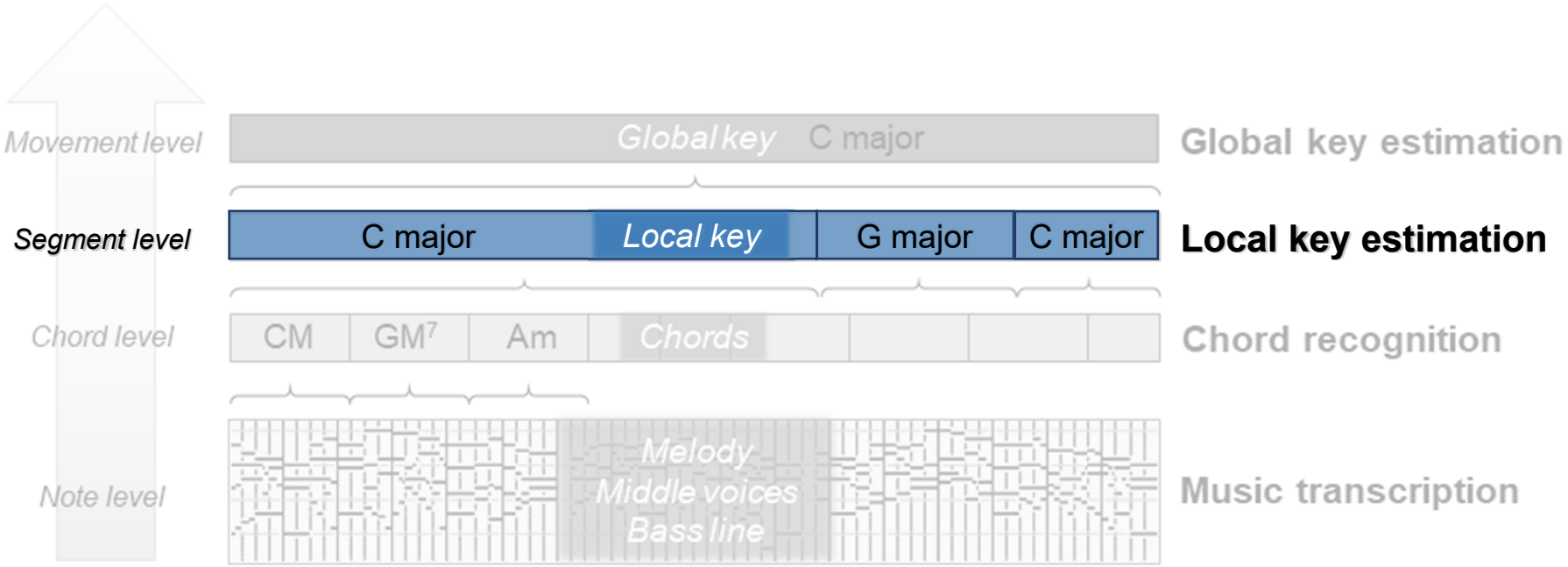
Scenario: Schubert Winterreise

Harmony Analysis



Scenario: Schubert Winterreise

Harmony Analysis



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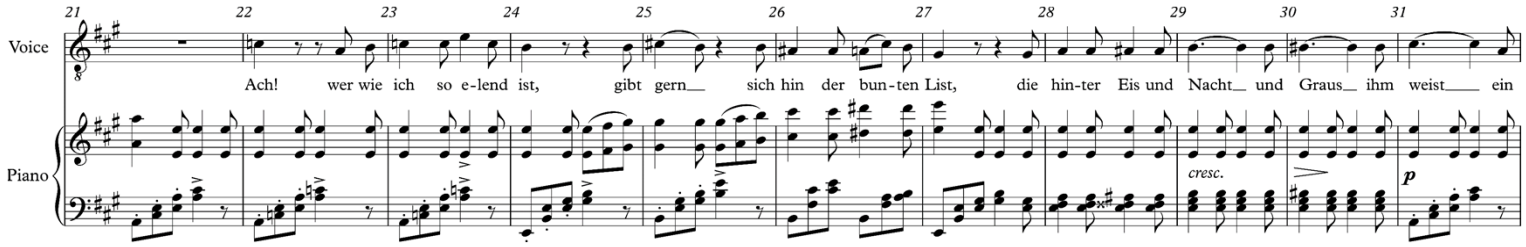
Scenario: Schubert Winterreise

Harmony Analysis

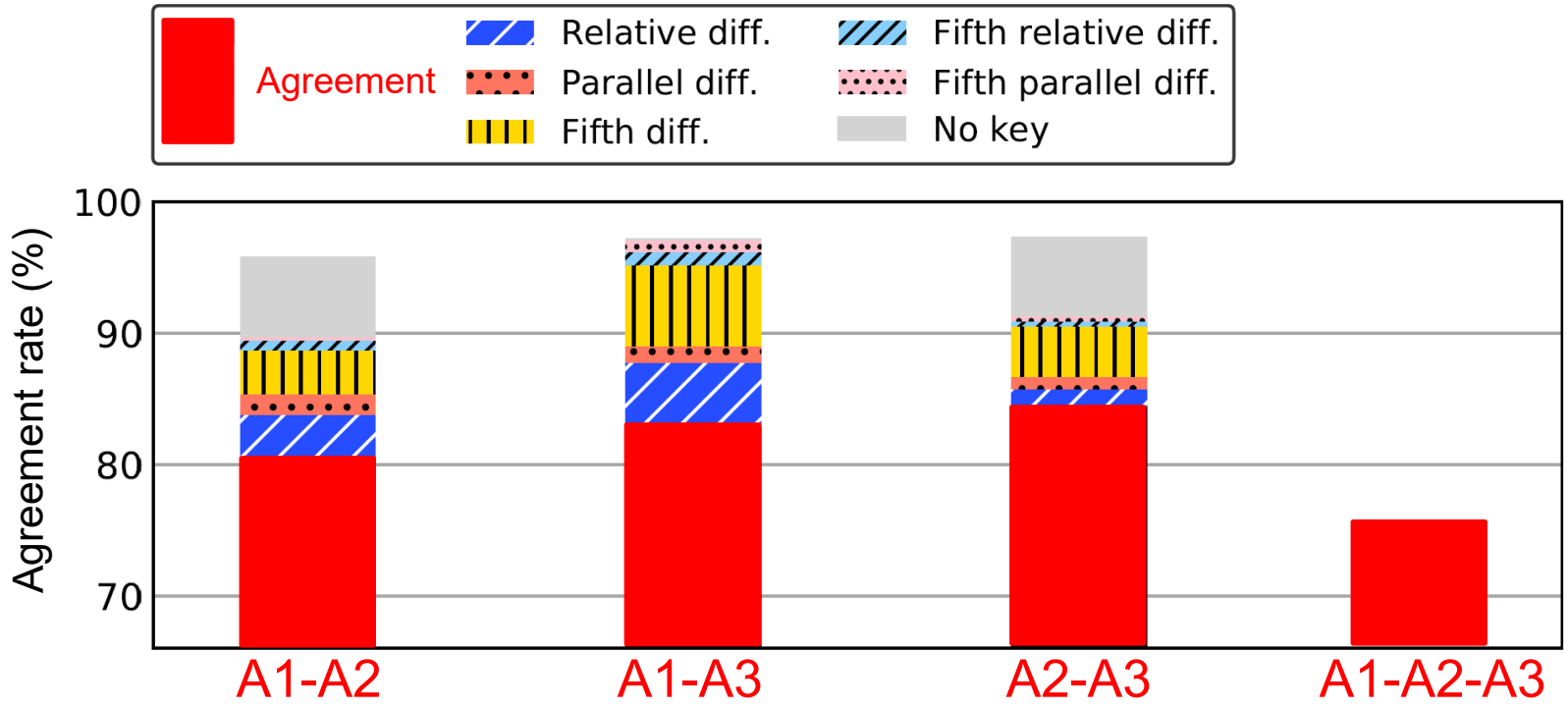


Annotations

A1	A major	A minor	E major	A major
A2	A major			
A3	A major	A minor		A major

Scenario: Schubert Winterreise
Harmony Analysis

Annotator agreements and differences



Scenario: Schubert Winterreise
Harmony Analysis

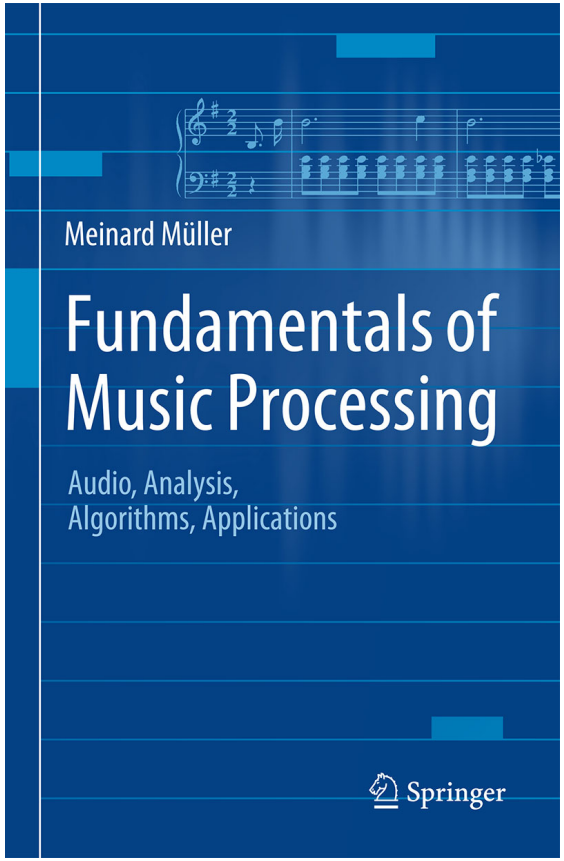
- Harmony-related annotations
  - Hierarchical nature of musical structures
  - High degree of subjectivity
  - Dependence on user needs and applications
- …

Christof Weiß, Frank Zalkow, Vlora Arifi-Müller, Meinard Müller, Hendrik Vincent Koops, Anja Volk, Harald Grohganz:
Schubert Winterreise Dataset: A Multimodal Scenario for Music Analysis.
ACM Journal on Computing and Cultural Heritage (JOCCH), 15(2): 1–18, 2021.

Conclusions

- Annotating music data is a challenge
  - Data inconsistencies
  - Underlying model assumptions often violated
  - High degree of subjectivity
  - Dependency on user needs and applications
  - Never trust your annotations!
- Annotations and analyses cannot be separated
  - Needs to be an interactive process
  - Requires a dialogue between domain experts and computer scientists
  - Requires an understanding and adaption of tools
- Opportunities
  - Annotation process becomes subject of research
  - Increasing appreciation of datasets
  - Great potential for interdisciplinary research

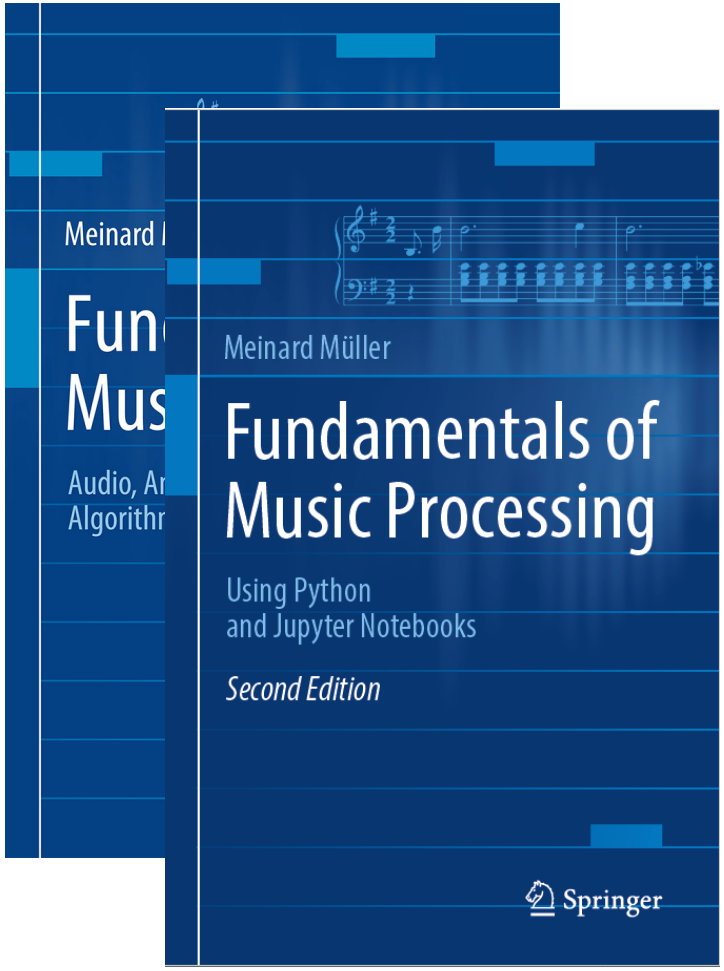
Fundamentals of Music Processing (FMP)



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
Fundamentals of Music Processing
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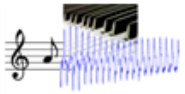
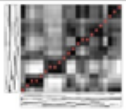
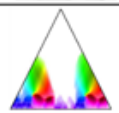
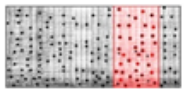
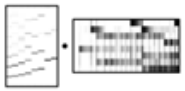
www.music-processing.de

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 Represenations
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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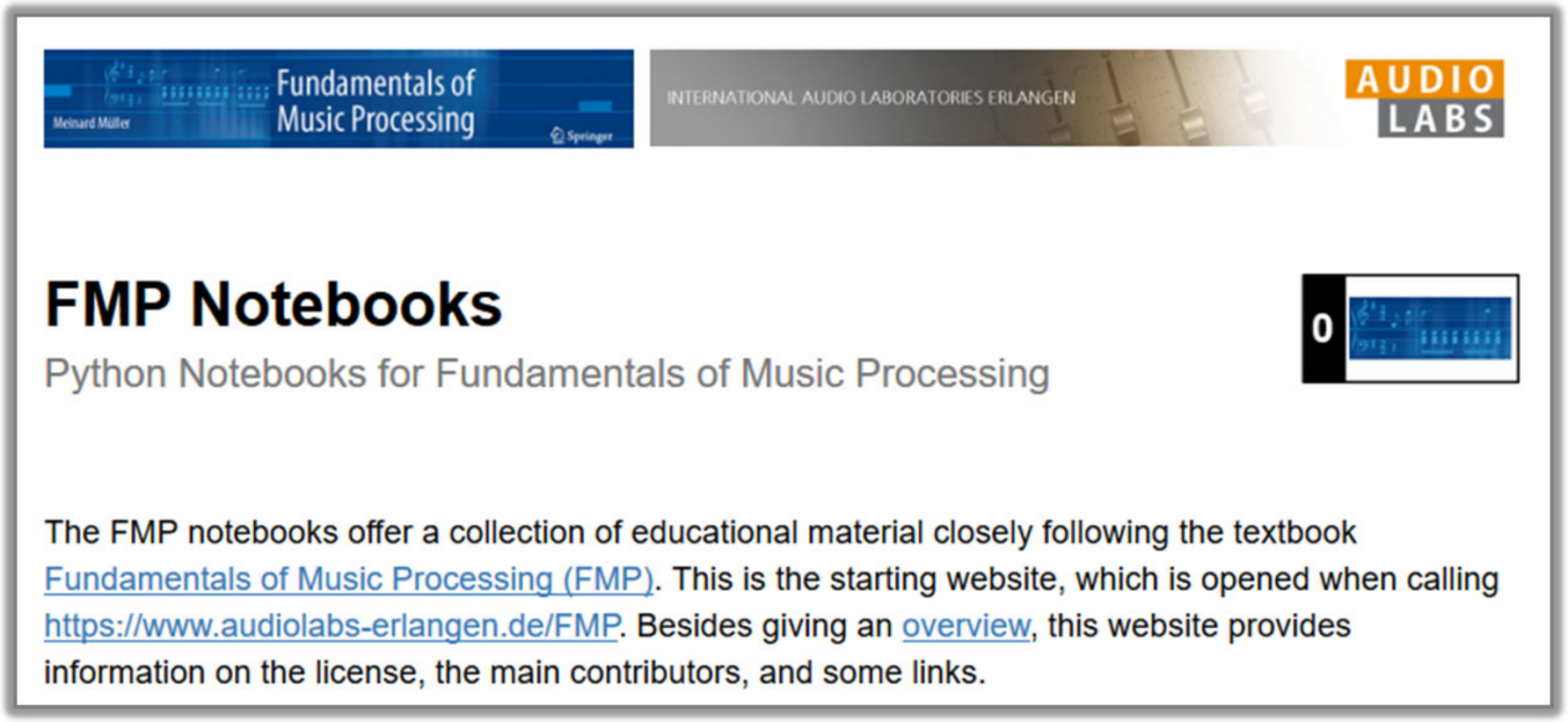
Springer, 2021

FMP Notebooks: Education & Research



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

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

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- Christof Weiß, Vlora Arifi-Müller, Thomas Prätzlich, Rainer Kleinertz, Meinard Müller: **Analyzing Measure Annotations for Western Classical Music Recordings.** In Proceedings of the International Society for Music Information Retrieval Conference (ISMIR): 517–523, 2016.
- Sebastian Rosenzweig, Frank Scherbaum, David Shugliashvili, Vlora Arifi-Müller, and Meinard Müller: **Erkomaishvili Dataset: A Curated Corpus of Traditional Georgian Vocal Music for Computational Musicology.** Transactions of the International Society for Music Information Retrieval (TISMIR), 3(1): 31–41, 2020.
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- Christof Weiß, Hendrik Schreiber, Meinard Müller: **Local Key Estimation in Music Recordings: A Case Study Across Songs, Versions, and Annotators.** IEEE/ACM Transactions on Audio, Speech, and Language Processing, 28: 2919–2932, 2020.