

Automatische Erschließung von Musikdaten

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INVisionDay 2023

Fakultät Informatik, Technischen Hochschule Nürnberg

26. April 2023



Friedrich-Alexander-Universität
Erlangen-Nürnberg



IIS

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 (ISMIR)
- IEEE Fellow for contributions to Music Signal Processing



Meinard Müller: Research Group

- Michael Krause
- Yigitcan Özer
- Simon Schwär
- Johannes Zeitler
- Peter Meier (external)
- Christof Weiß
- Sebastian Rosenzweig
- Frank Zalkow
- 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 $\approx 40,000$ students
- Strong Technical Faculty

International Audio Laboratories Erlangen



Audio

International Audio Laboratories Erlangen

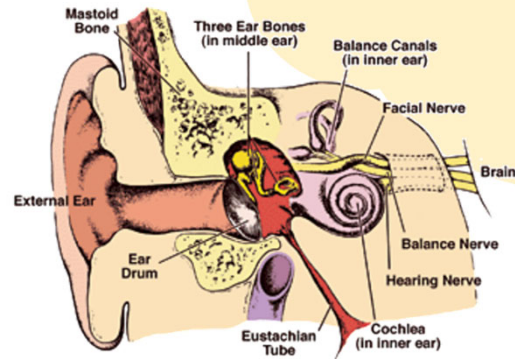
Audio Coding



3D Audio



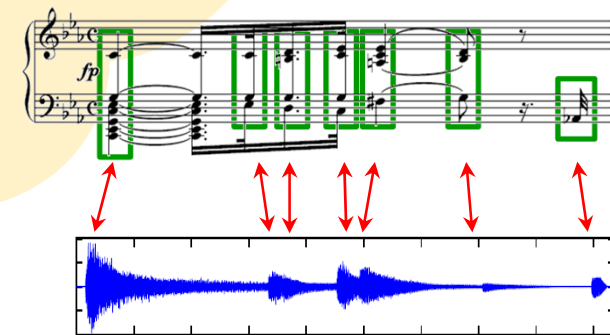
Audio



Psychoacoustics



Internet of Things



Music Processing



Music

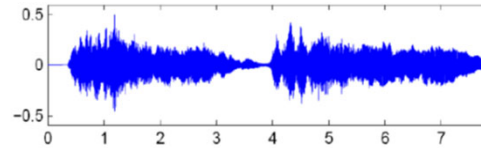


Music Information Retrieval (MIR)

Sheet Music (Image)



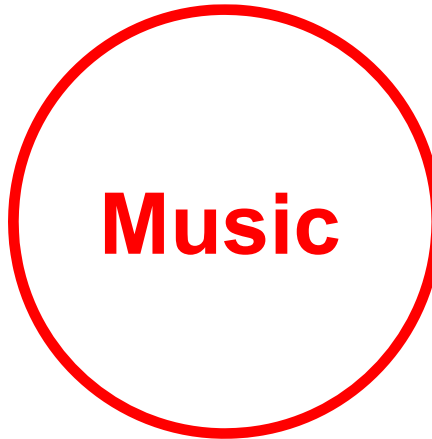
CD / MP3 (Audio)



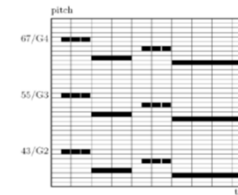
MusicXML (Text)

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

Dance / Motion (Mocap)



MIDI



Singing / Voice (Audio)



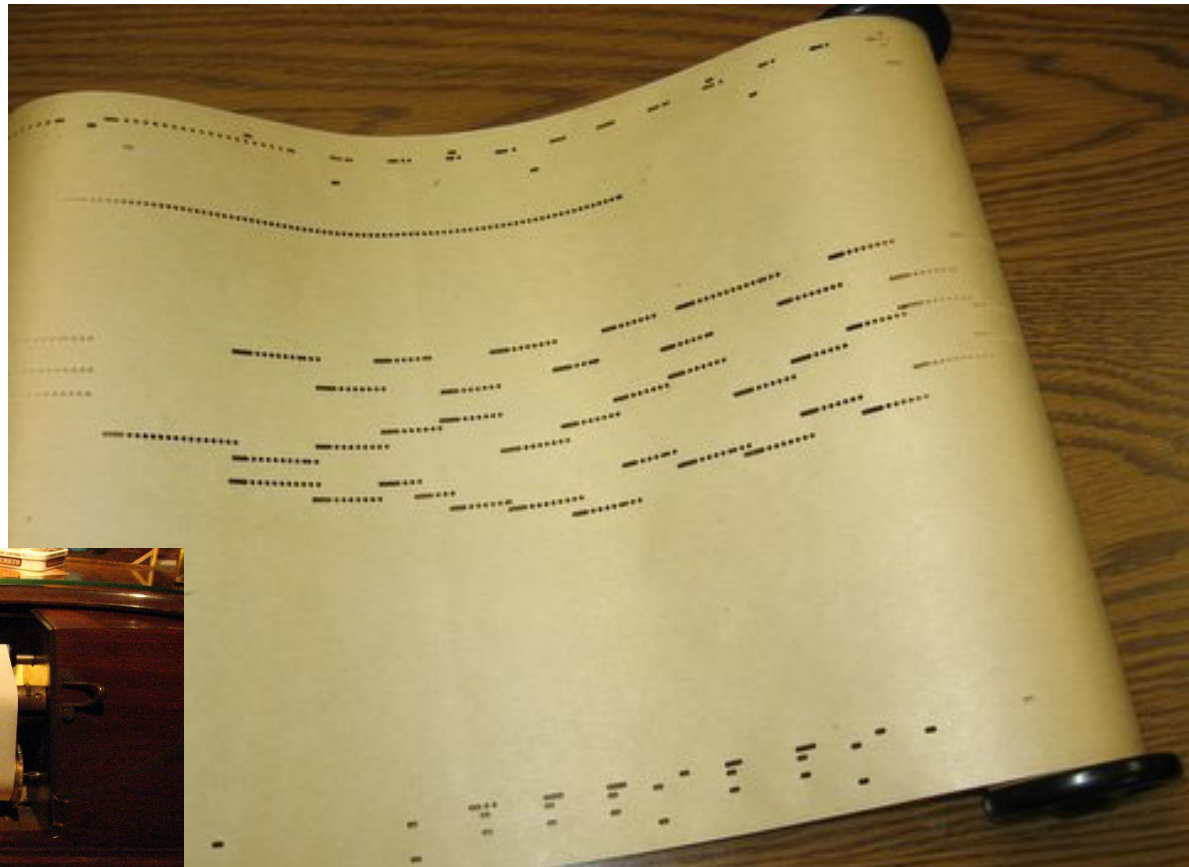
Music Film (Video)



Music Literature (Text)



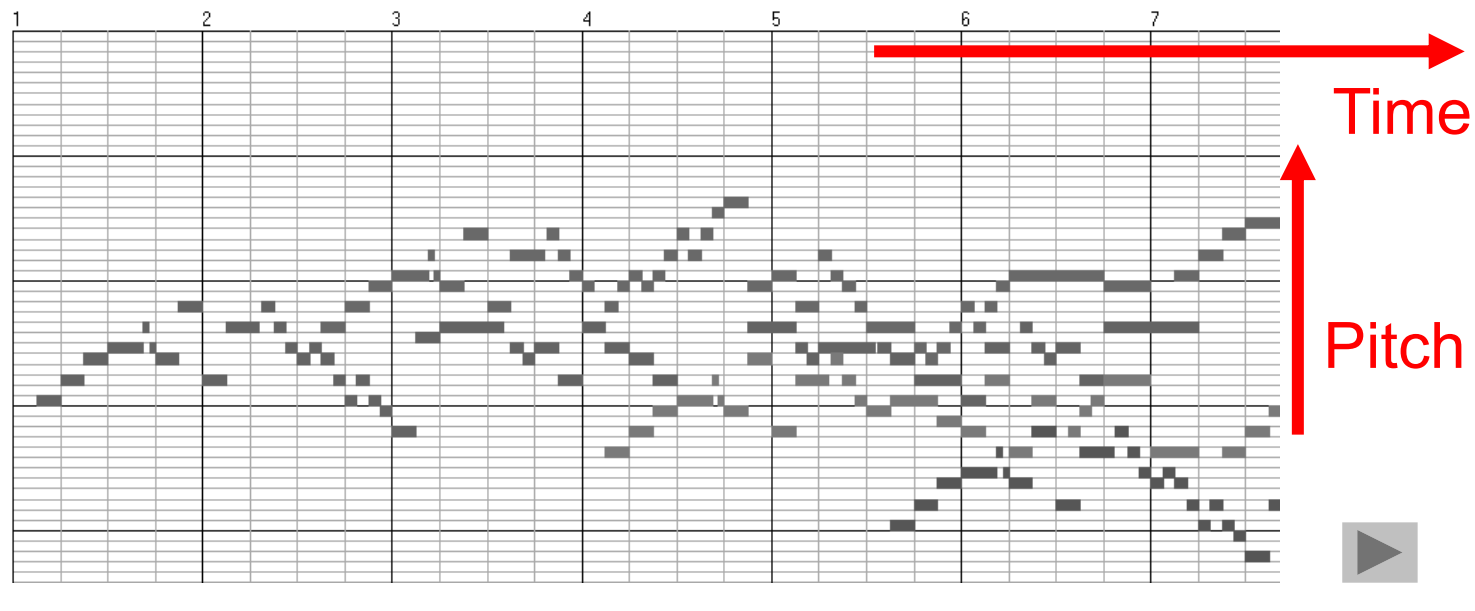
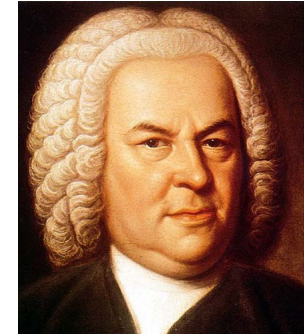
Piano Roll Representation (1900)



Piano Roll Representation

J.S. Bach, C-Major Fuge

(Well Tempered Piano, BWV 846)

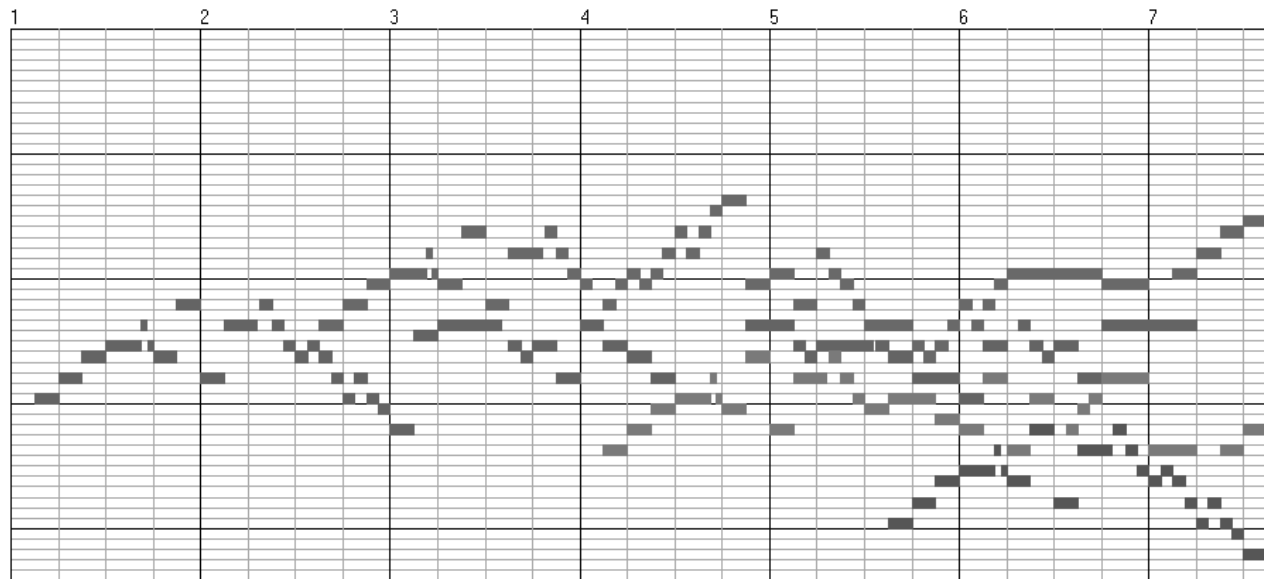
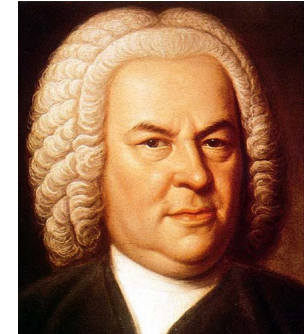


Piano Roll Representation

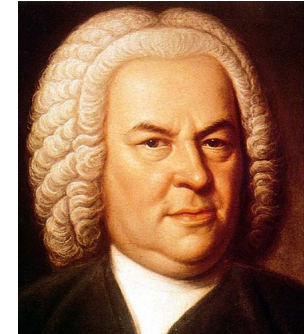
Query:



Goal: Find all occurrences of the query



Piano Roll Representation

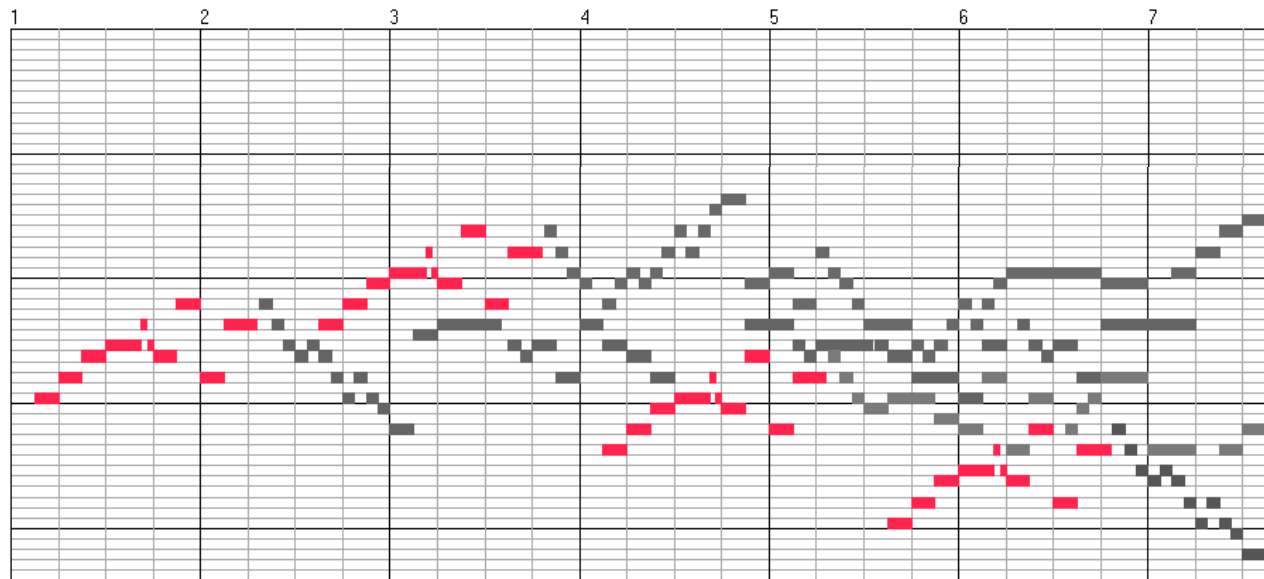


Query:

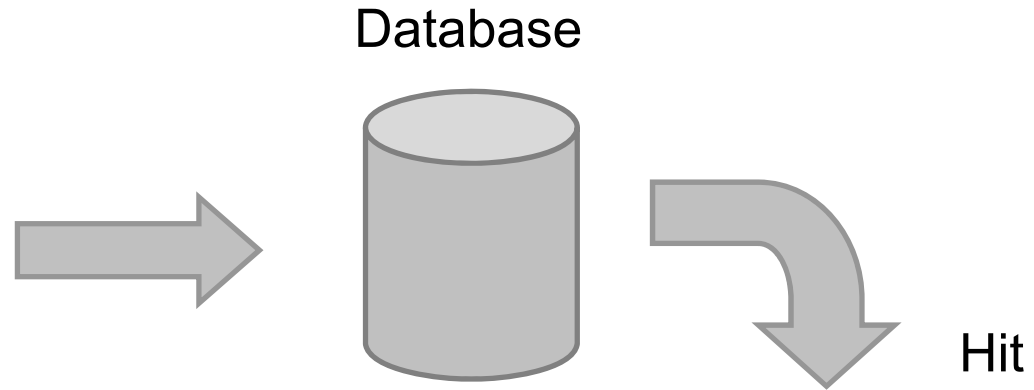


Goal: Find all occurrences of the query

Matches:



Music Retrieval



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



Music Synchronization

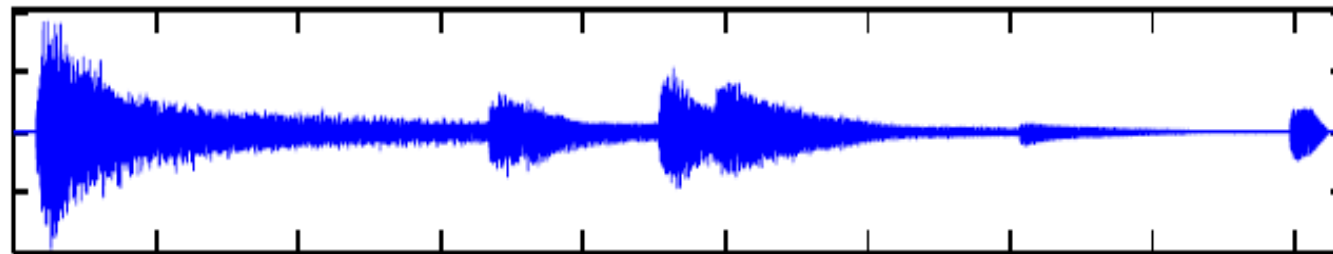
The screenshot displays two windows from a music synchronization application. The top window, titled "ScoreViewer", shows a musical score for "Beethoven - Klaviersonaten Band 1 - Henle". The score is for "Sonata no.8 in C minor, op.13 'Pathétique' / Rondo (Allegro)". The score is currently on track 29 of 54, bar 1 of 211, and page 159 of 285. The bottom window, titled "AudioViewer", shows a tracklist for "Beethoven - Piano Sonatas-Alfred Brendel". The tracklist includes 11 tracks, with track 11, "Sonata no.8 in C minor, op.13 'Pathétique' / Rondo (Allegro)", selected. The audio player shows the current time as 00:00.00 out of 4:30.35. The interface includes navigation buttons for Play and Stop, and a "Score Following On" indicator.

Music Synchronization: Image-Audio

Image



Audio



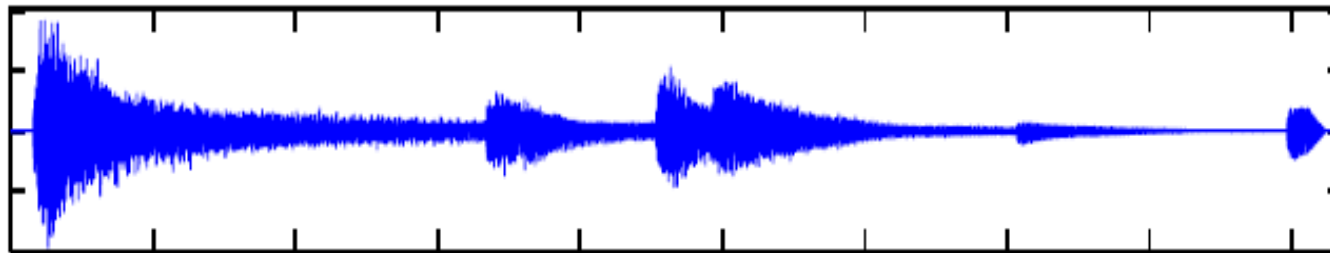
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image



Audio



Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image



Audio



Audio Processing: Fourier Analysis

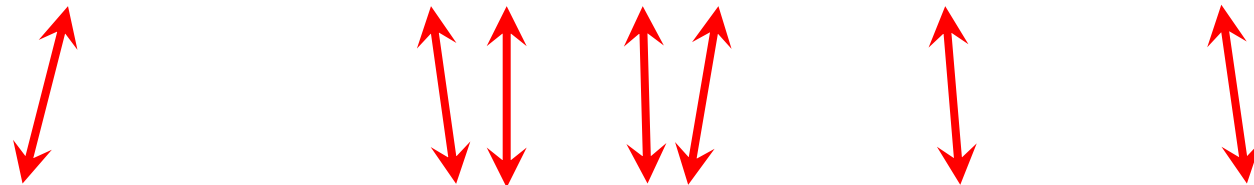
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image

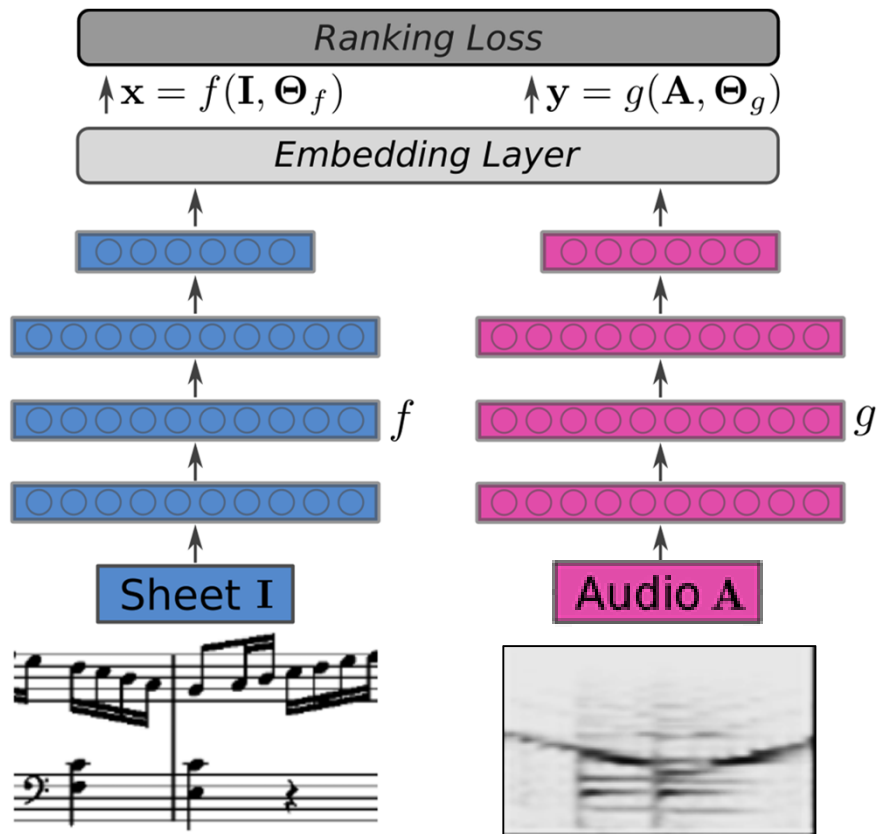


Audio



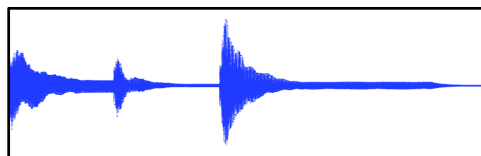
Audio Processing: Fourier Analysis

Music Synchronization: Image-Audio

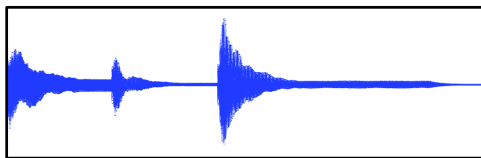
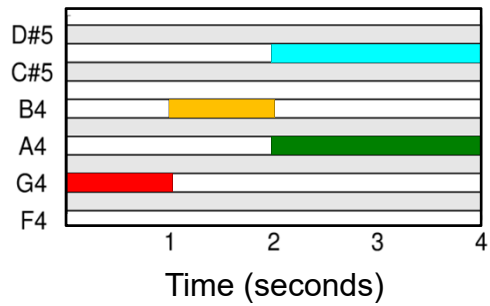
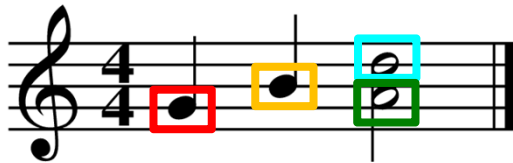


- Deep learning
- Embedding techniques
- Music transcription
- Lyrics alignment
- ...

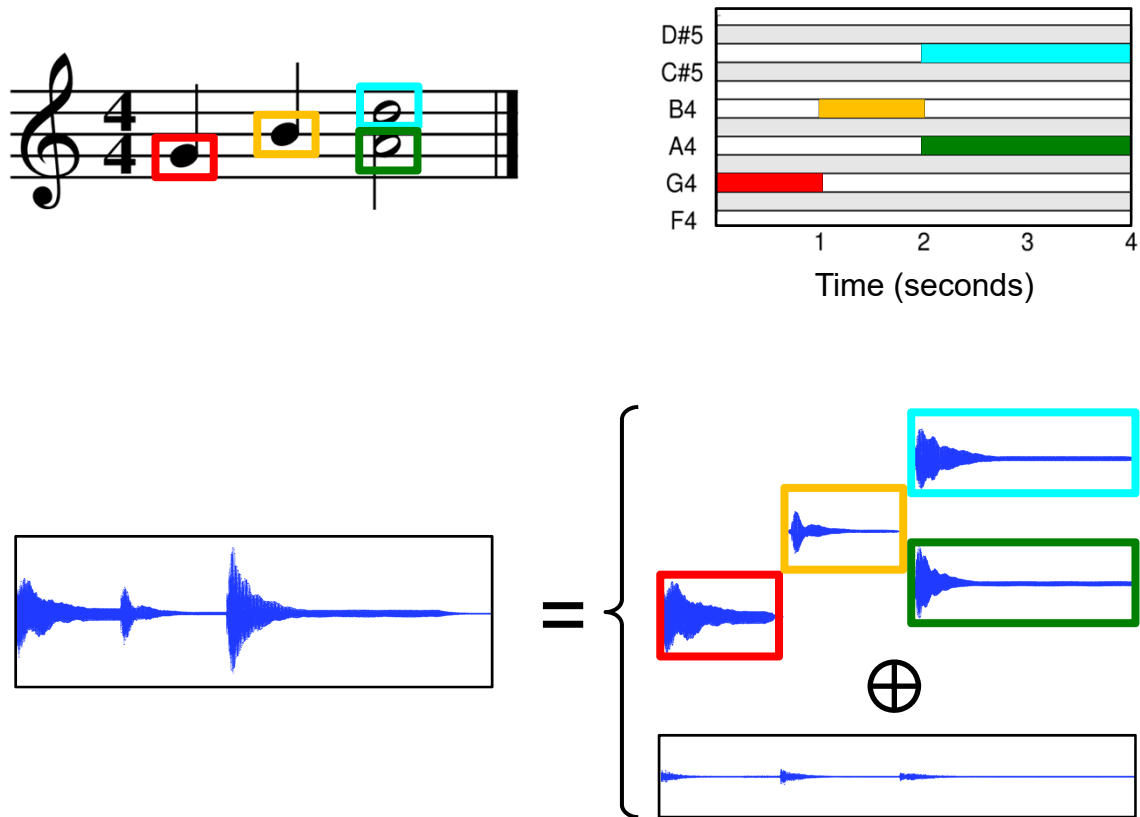
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

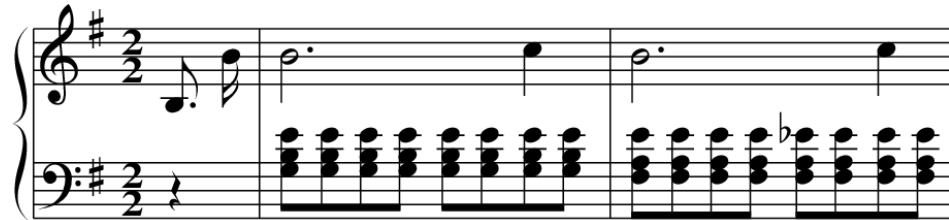


Score-Informed Audio Decomposition

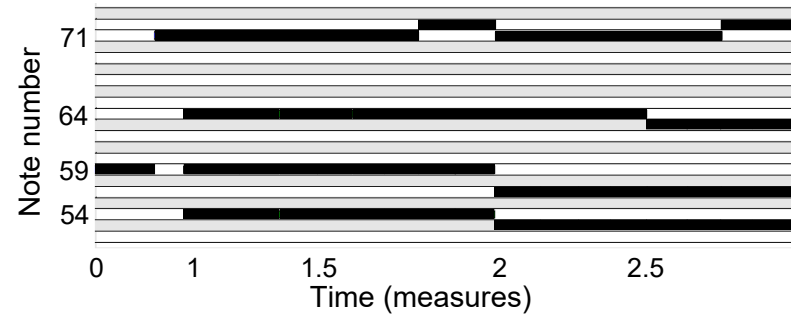


Score-Informed Audio Decomposition

Sheet music

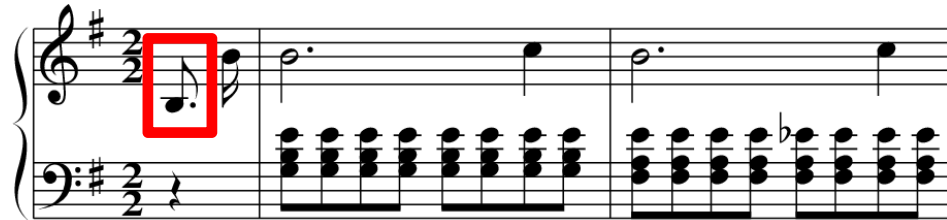


Piano roll



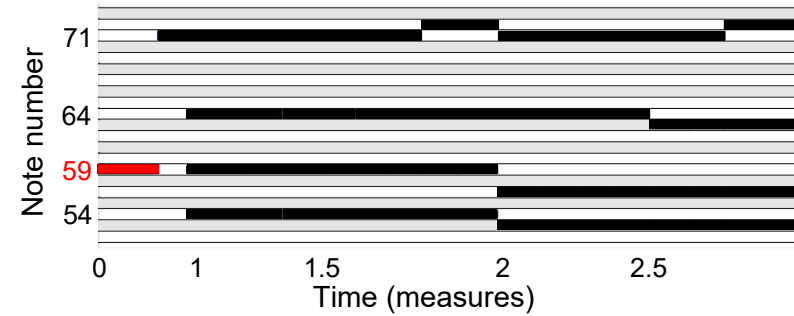
Score-Informed Audio Decomposition

Sheet music



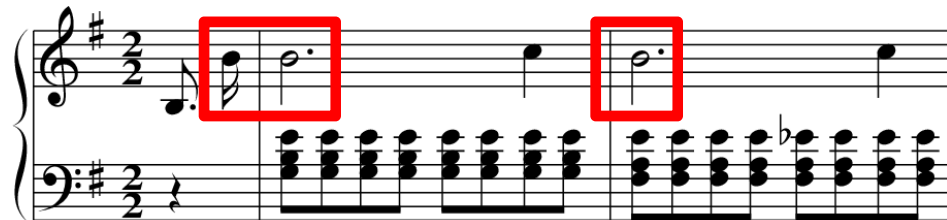
$p = 59$

Piano roll



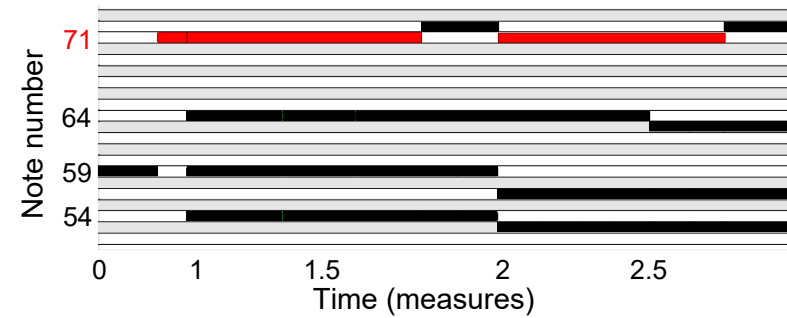
Score-Informed Audio Decomposition

Sheet music



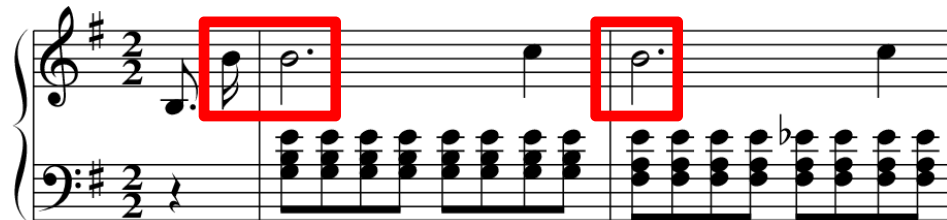
$p = 71$

Piano roll



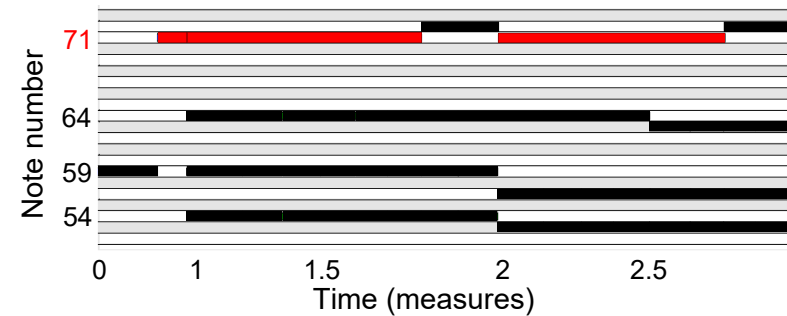
Score-Informed Audio Decomposition

Sheet music

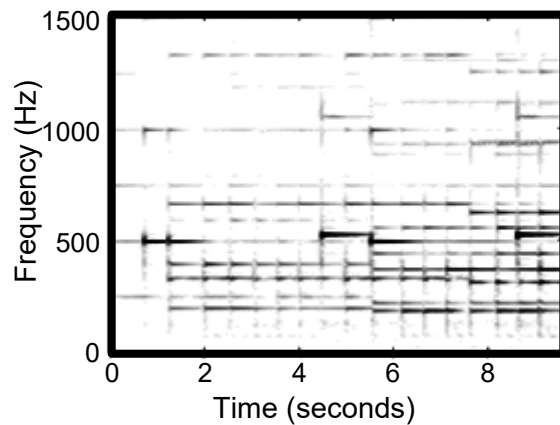


$p = 71$

Piano roll

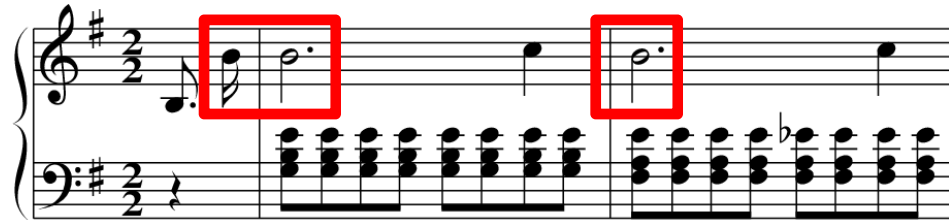


Spectrogram



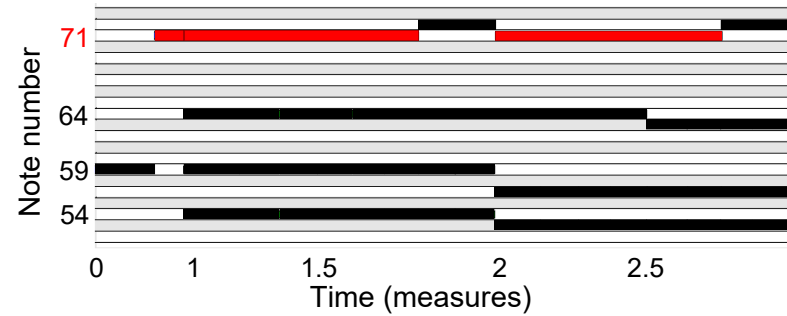
Score-Informed Audio Decomposition

Sheet music

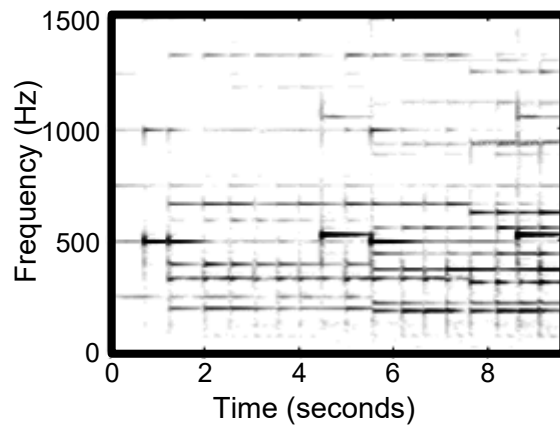


$p = 71$

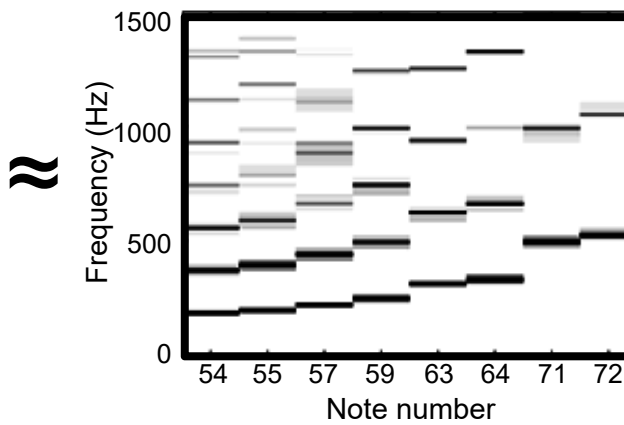
Piano roll



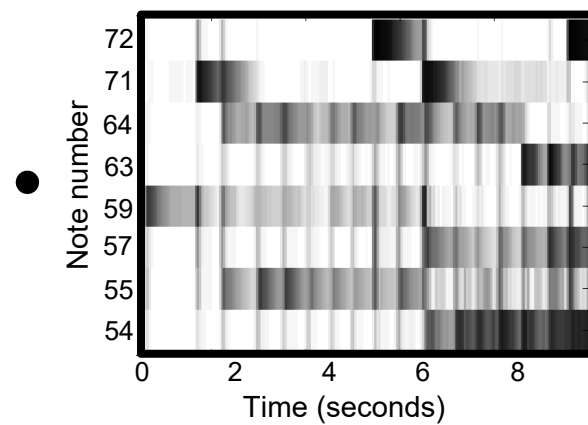
Spectrogram



Spectral patterns

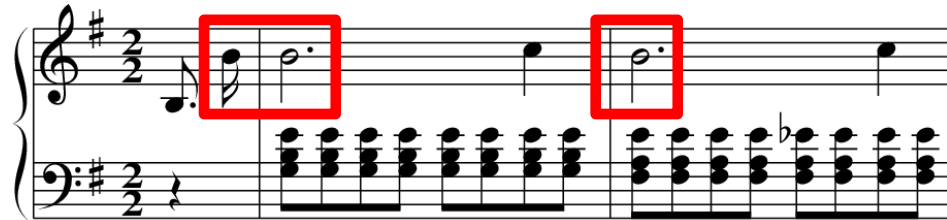


Activity patterns



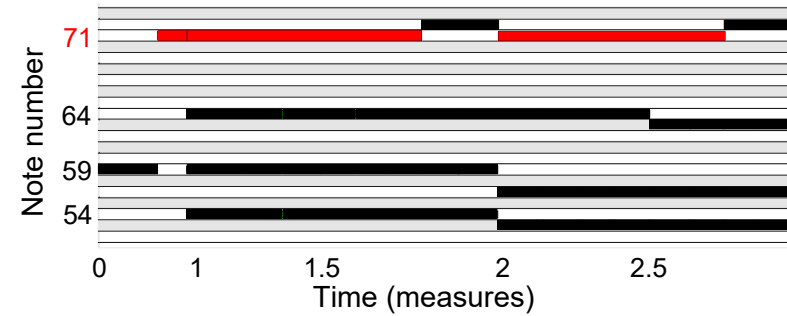
Score-Informed Audio Decomposition

Sheet music

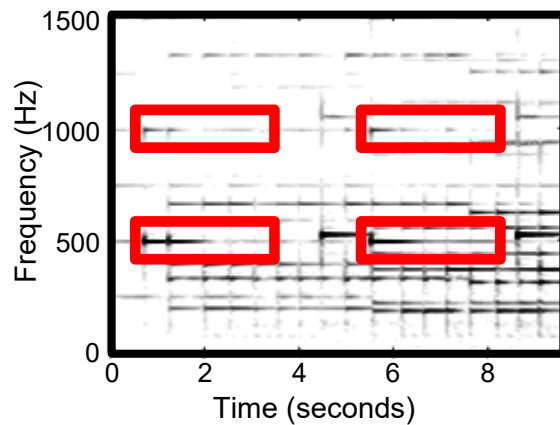


$p = 71$

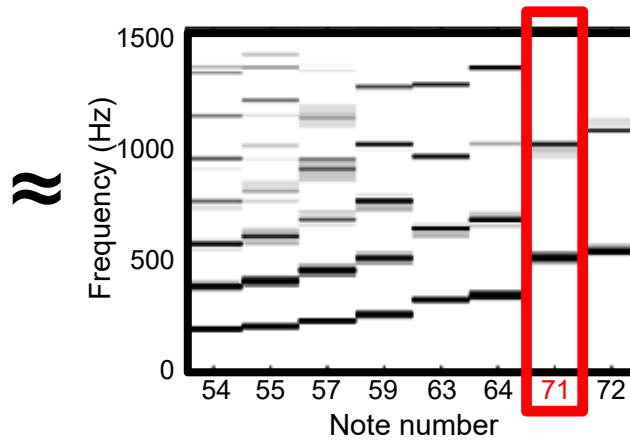
Piano roll



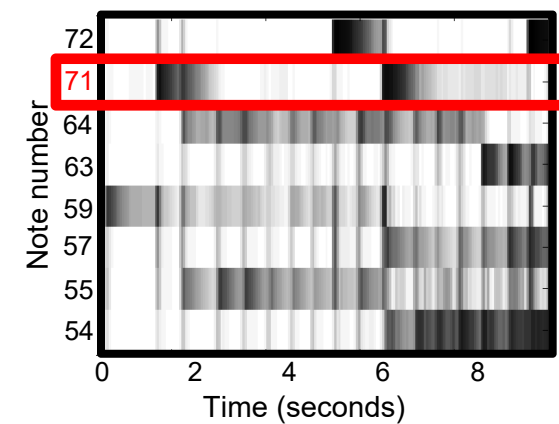
Spectrogram



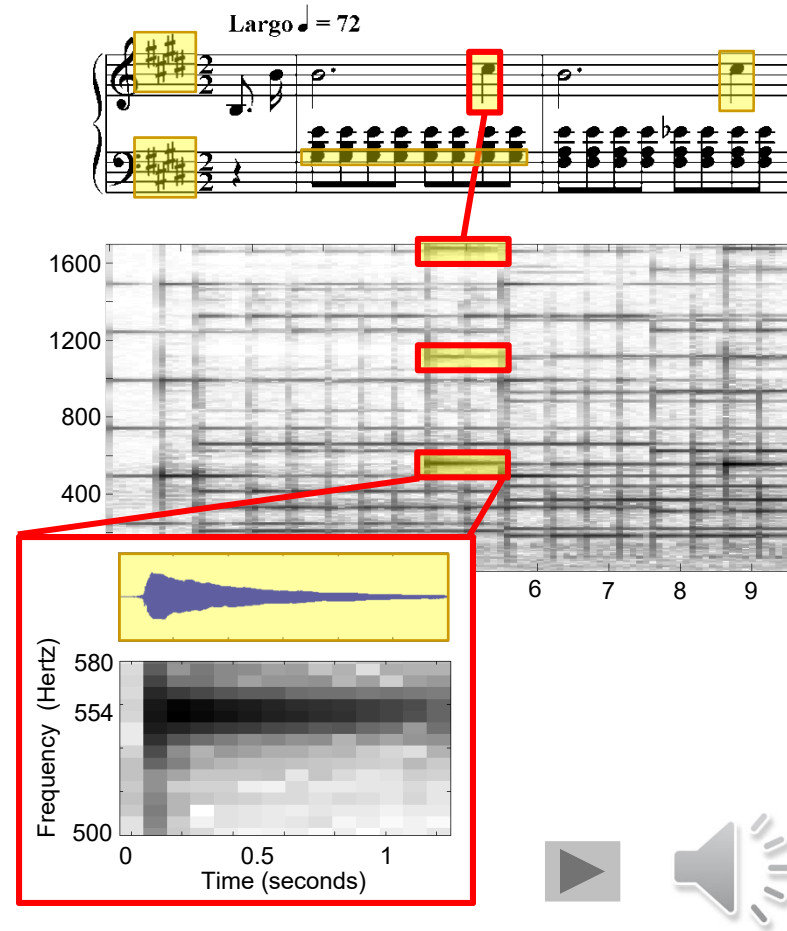
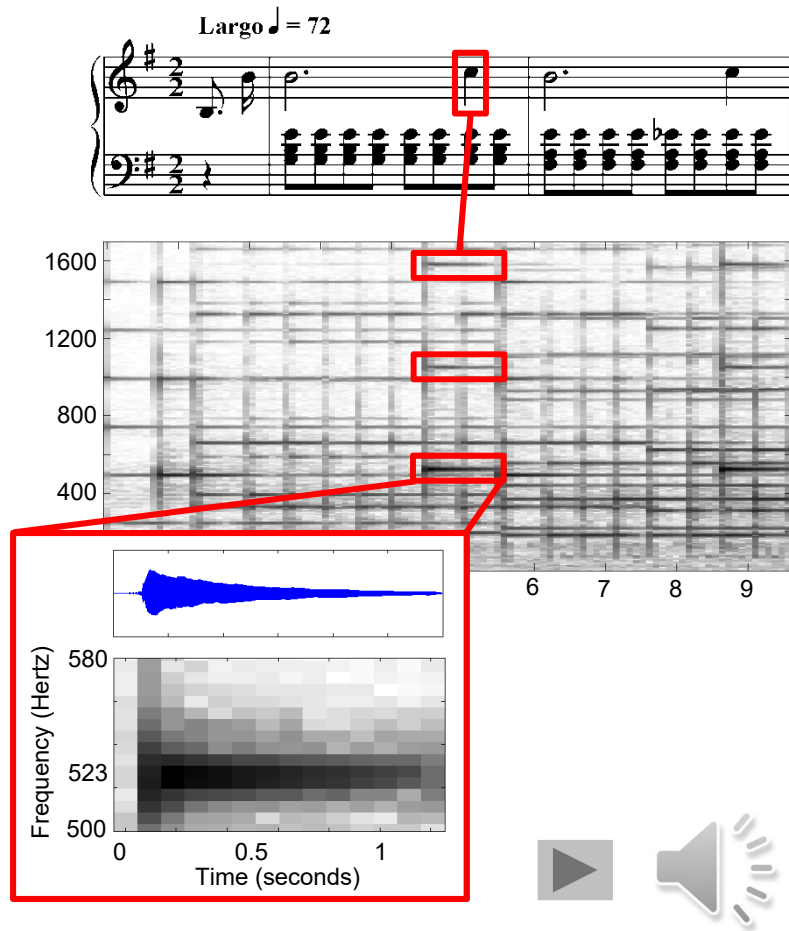
Spectral patterns



Activity patterns

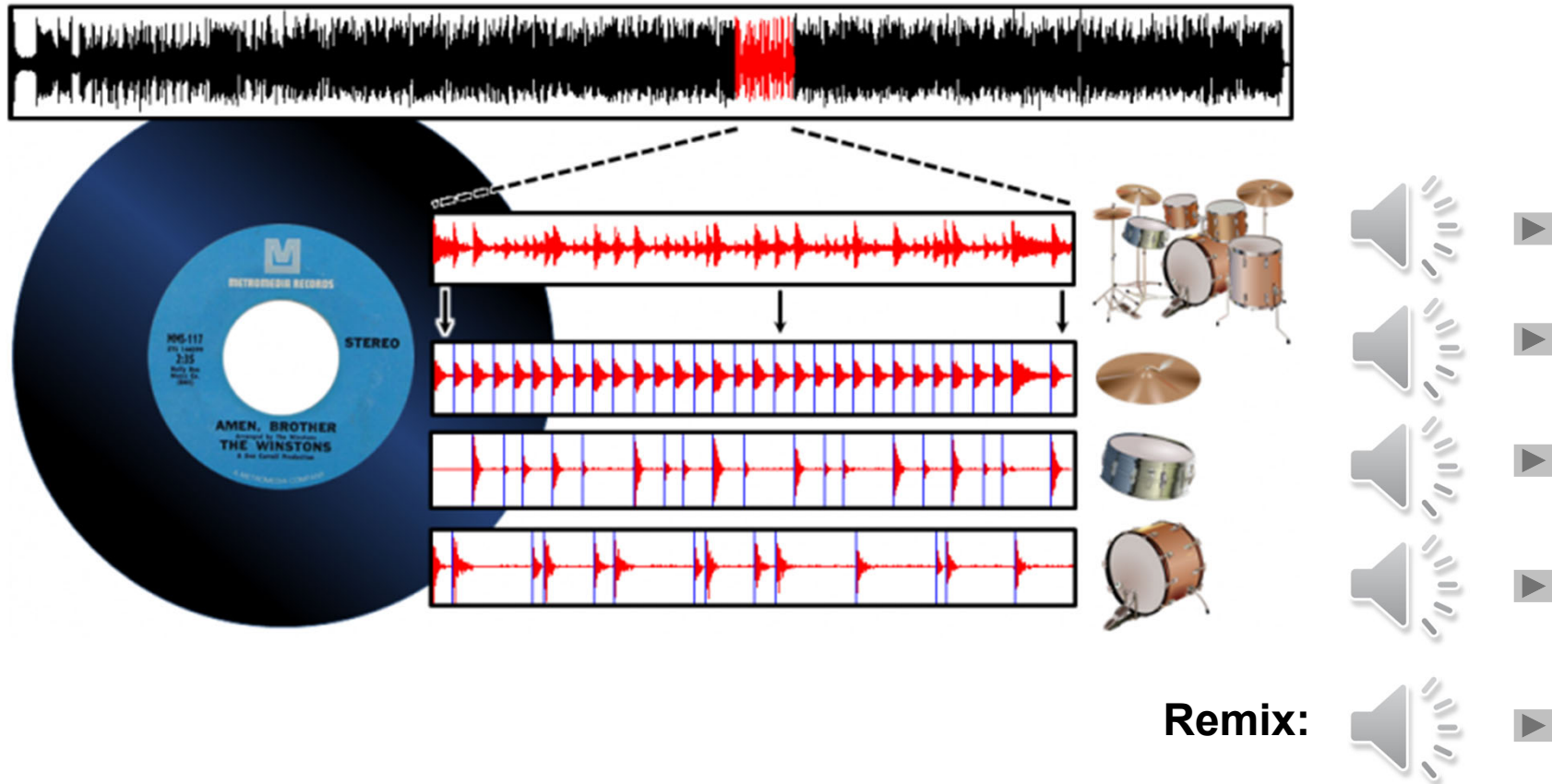


Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

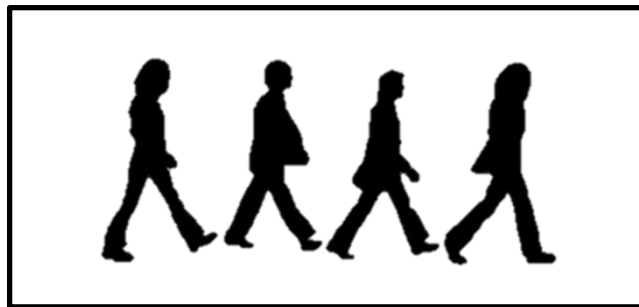
Informed Drum-Sound Decomposition



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles–Let it be



Source signal: Bees



Mosaic signal: **Let it Bee**

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3



Mazurka.

F. CHOPIN. Op. 63, No. 3.

Allegretto.

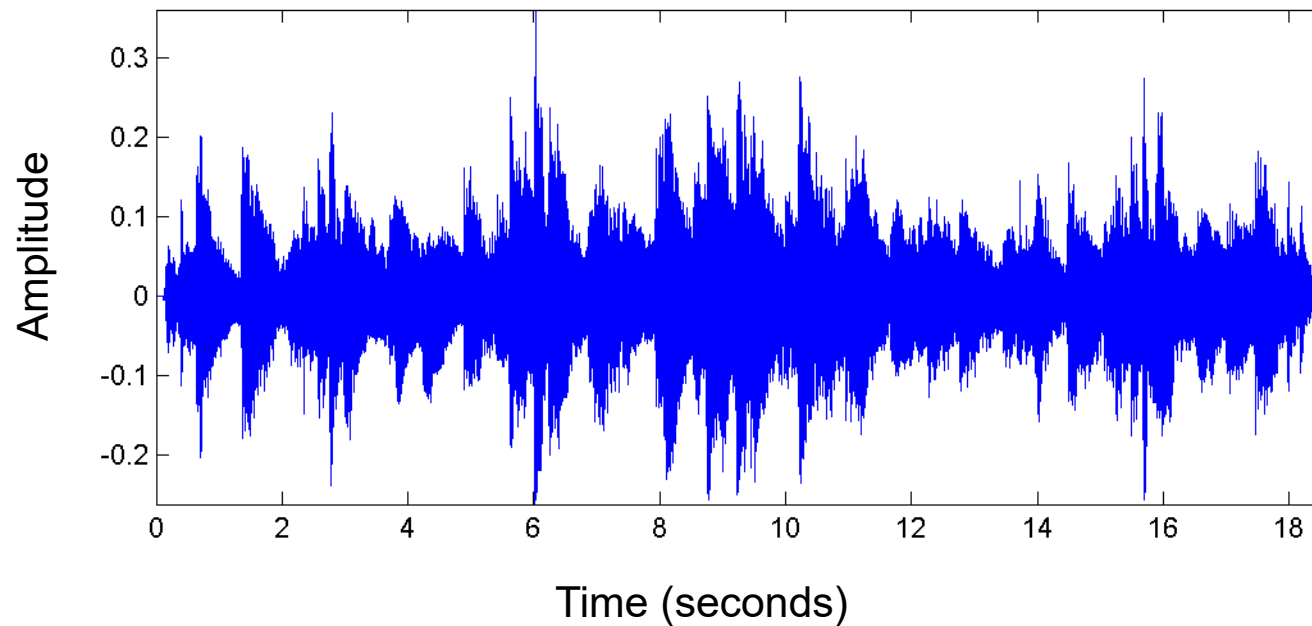
41. *p*

The image shows a musical score for Chopin's Mazurka Op. 63 No. 3, measures 41-50. The score is in 3/4 time, key of D major, and marked 'Allegretto'. It features a treble and bass clef. The right hand (treble clef) has a melody with triplets and slurs. The left hand (bass clef) has a bass line with triplets and slurs. The score is marked with 'p' (piano) and includes dynamic markings like 'Ped.' and asterisks. The number '41.' is written on the left side of the first system.

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

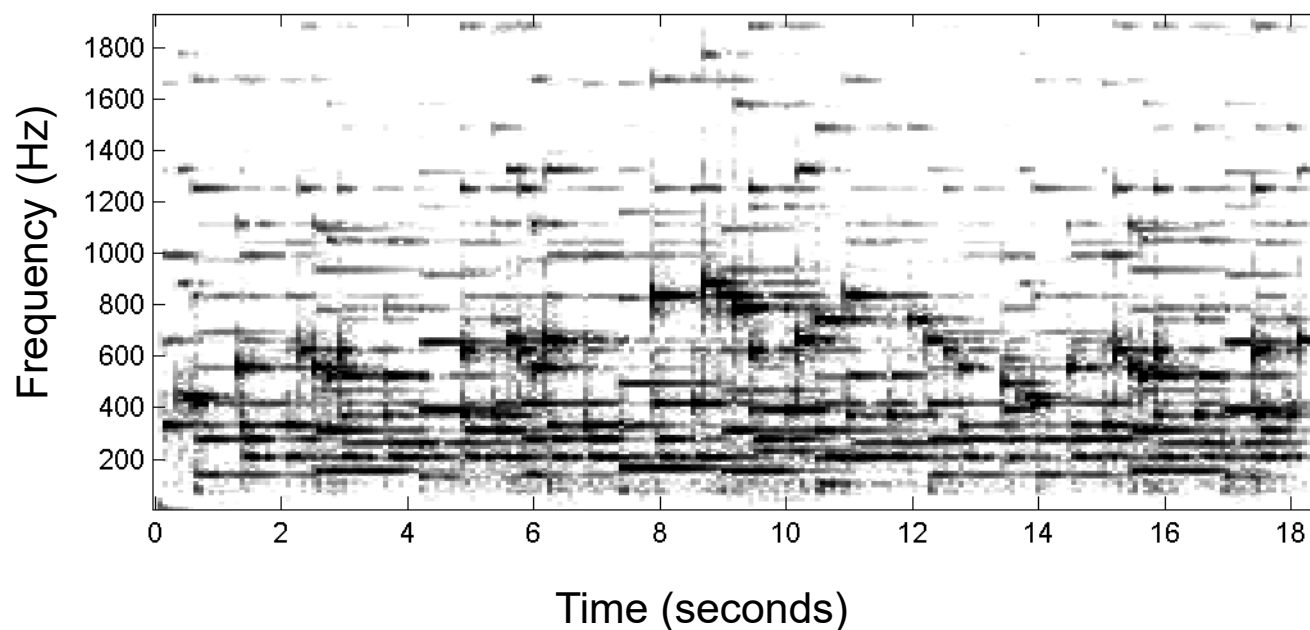
- Waveform



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

A musical score for Chopin's Mazurka Op. 63 No. 3, showing two systems of piano music. The score is annotated with performance information: blue highlights on the upper staff indicate the main melody, red highlights on the lower staff indicate an additional melody line, and yellow highlights on the lower staff indicate the accompaniment. Fingerings and dynamics like 'p' and 'f' are also visible.

 **Main Melody**
 **Additional melody line**
 **Accompaniment**

Source Separation

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

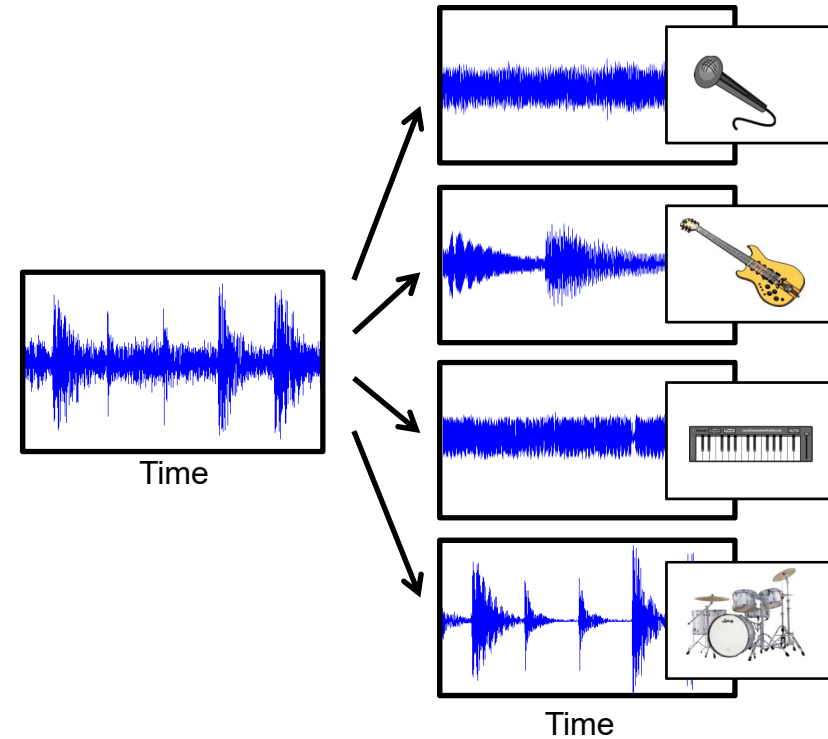


Source Separation

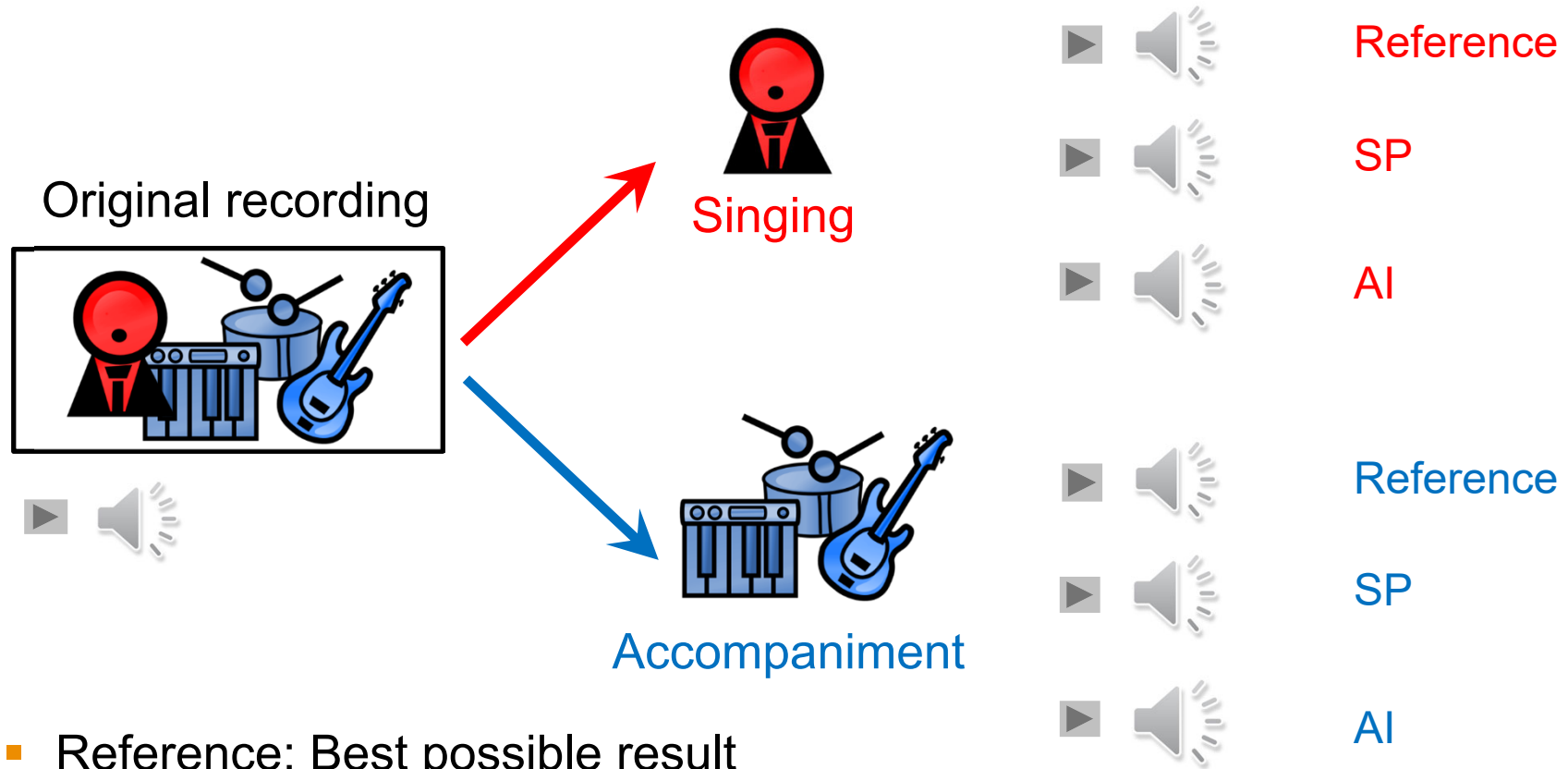
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”
- Several input signals
- Sources are assumed to be statistically independent

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



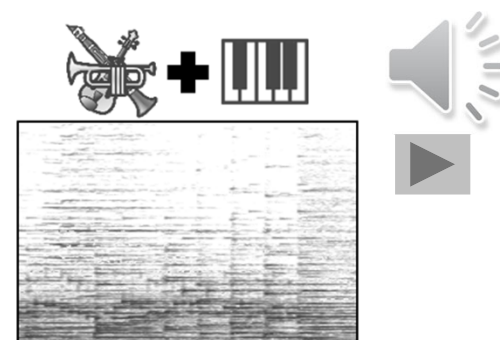
Only Piano!



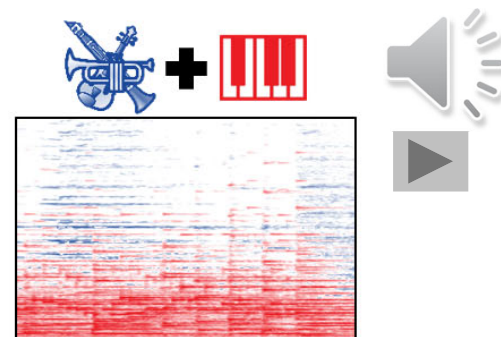
**Where is the
orchestra?**



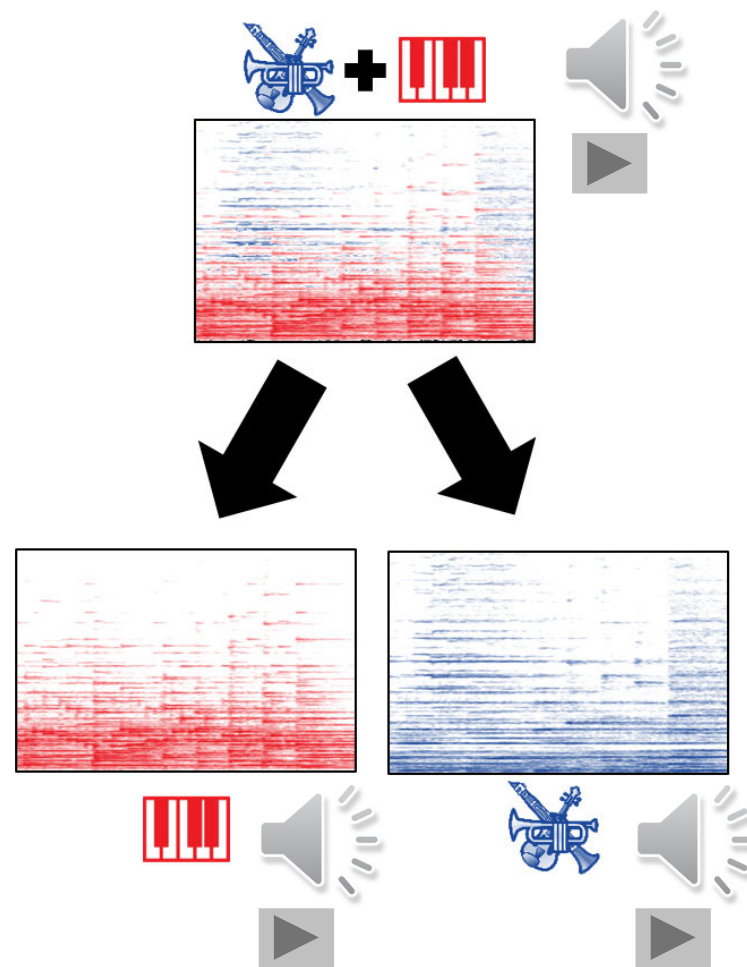
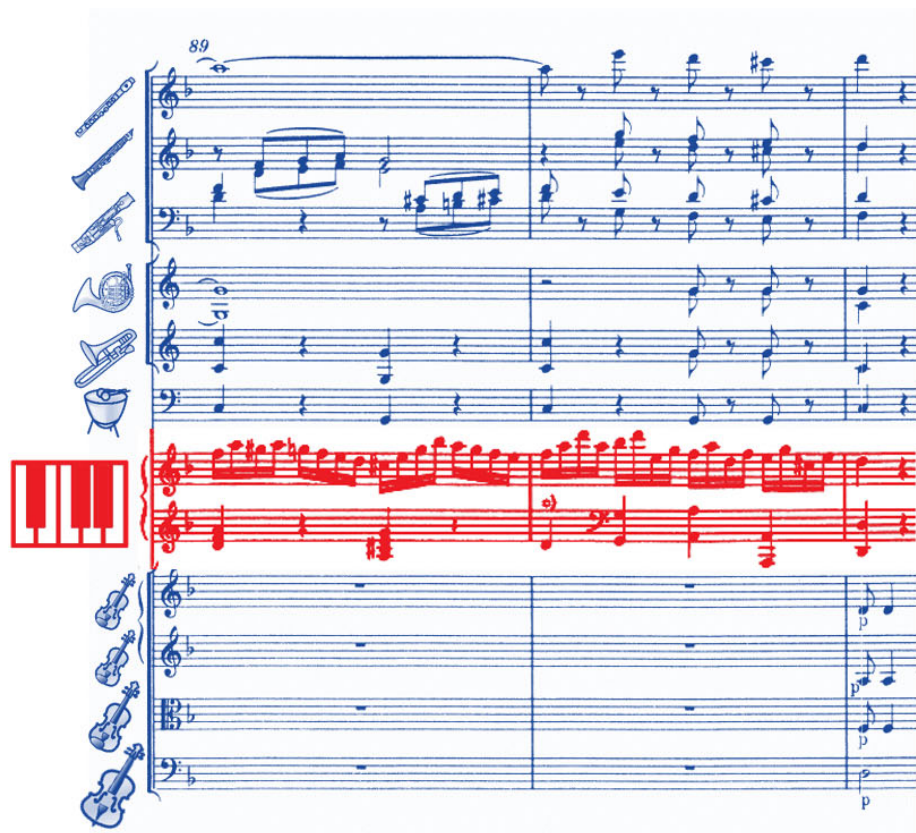
AI-Based Source Separation



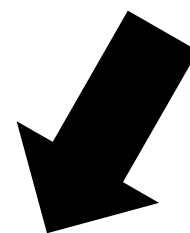
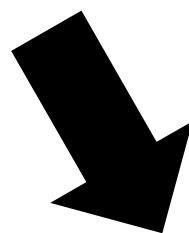
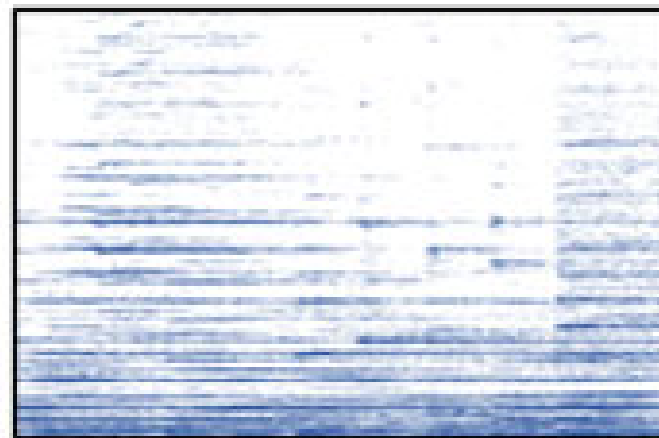
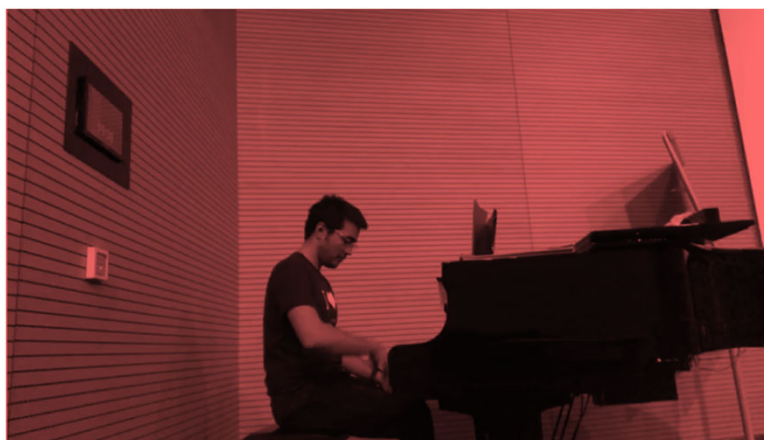
AI-Based Source Separation



AI-Based Source Separation



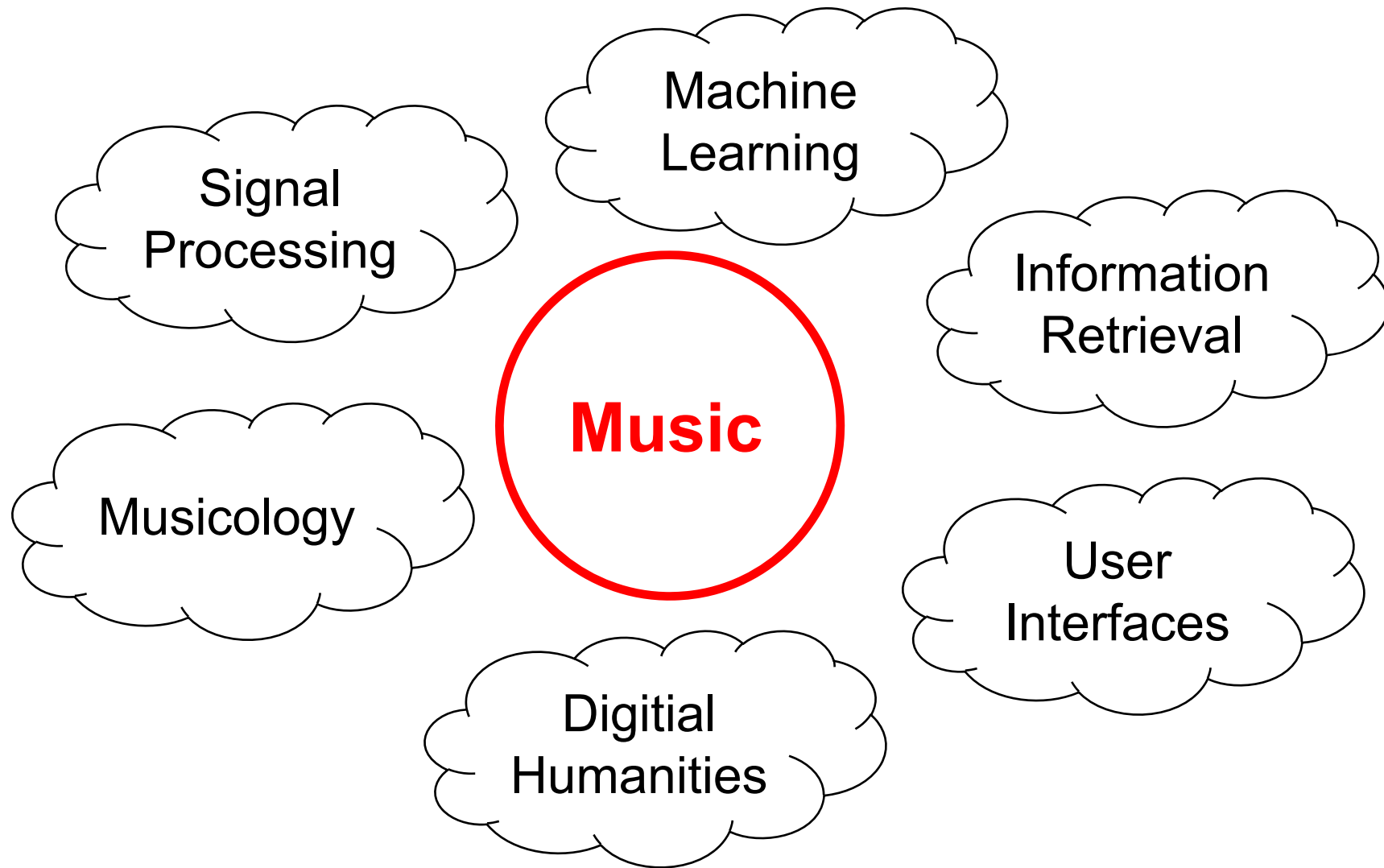
AI-Based Source Separation



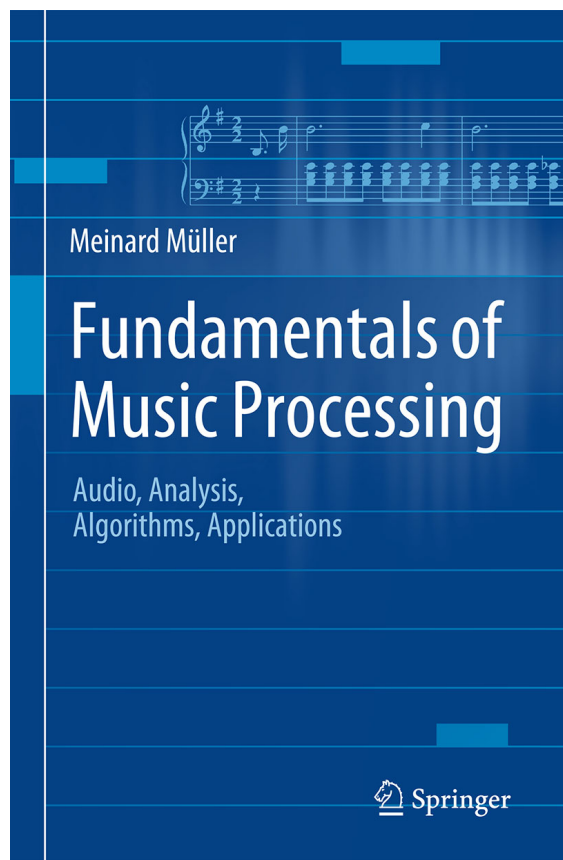
AI-Based Source Separation

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

Music Information Retrieval (MIR)



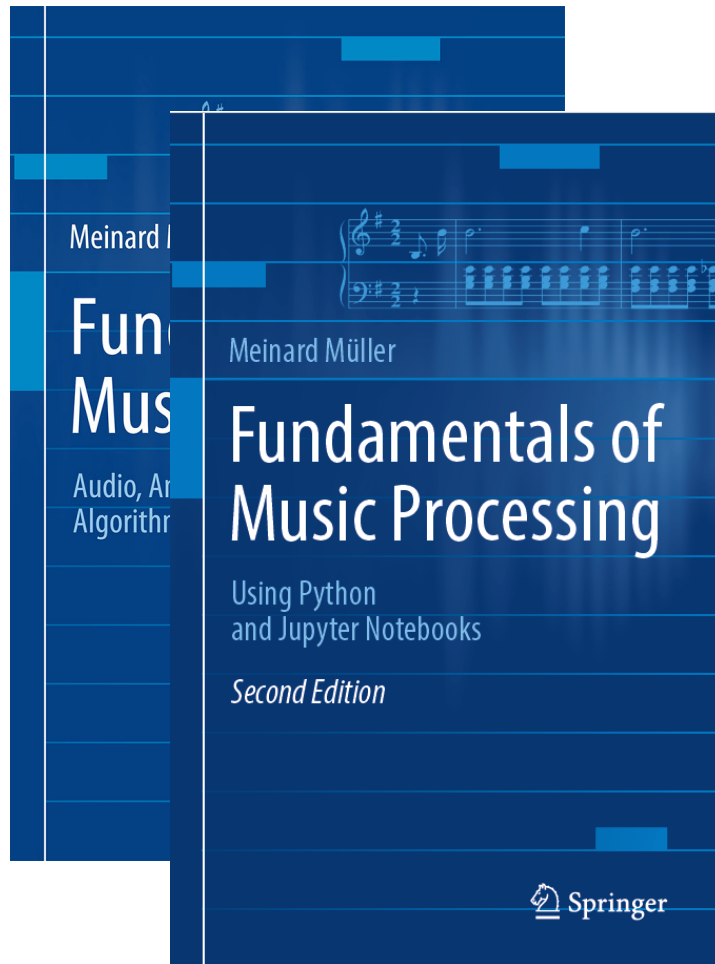
Fundamentals of Music Processing (FMP)



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

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)

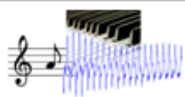

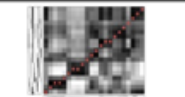
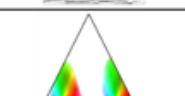

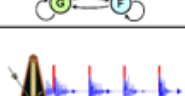




Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
Springer, 2015

Accompanying website:
www.music-processing.de

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

Fundamentals of Music Processing (FMP)

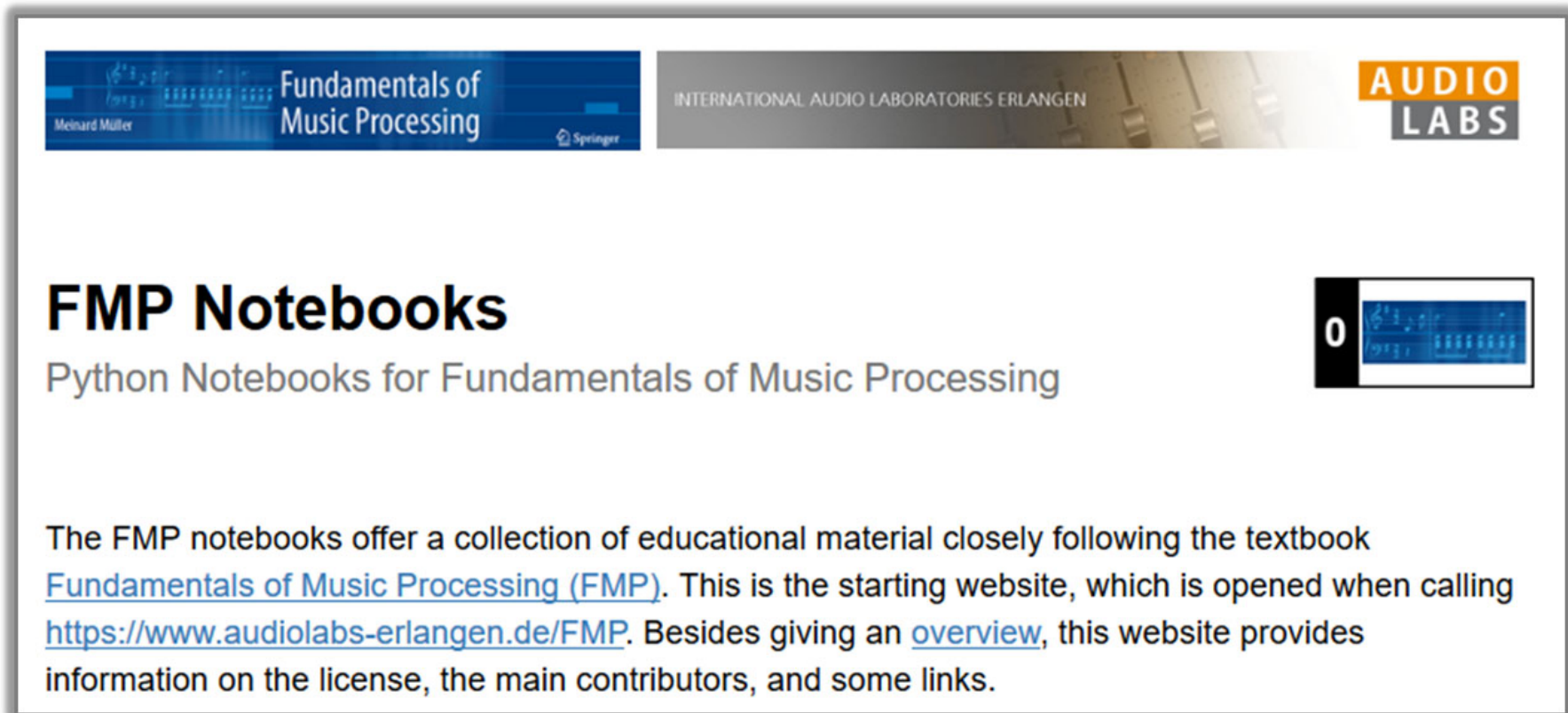
Chapter		Music Processing Scenario
1		Music Representations
2		Fourier Analysis of Signals
3		Music Synchronization
4		Music Structure Analysis
5		Chord Recognition
6		Tempo and Beat Tracking
7		Content-Based Audio Retrieval
8		Musically Informed Audio Decomposition

Meinard Müller
Fundamentals of Music Processing
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Springer, 2015

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

FMP Notebooks: Education & Research

The screenshot shows the top section of the FMP Notebooks website. It features a blue header with the title 'Fundamentals of Music Processing' and the author 'Meinard Müller' on the left, and the 'AUDIO LABS' logo on the right. Below the header, the main heading 'FMP Notebooks' is displayed in a large, bold, black font. Underneath it, the subtitle 'Python Notebooks for Fundamentals of Music Processing' is written in a smaller, grey font. To the right of the subtitle is a small icon of a notebook with a blue cover and a white page. Below the subtitle, a paragraph of text describes the notebooks as educational material following the textbook 'Fundamentals of Music Processing (FMP)'. It provides the starting website URL 'https://www.audiolabs-erlangen.de/FMP' and mentions that the site offers an overview, license information, and contributor details.

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 \(FMP\)](#). 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.
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<https://joss.theoj.org/papers/10.21105/joss.03326>
- Meinard Müller: An Educational Guide Through the FMP Notebooks for Teaching and Learning Fundamentals of Music Processing. Signals, 2(2): 245–285, 2021.
<https://www.mdpi.com/2624-6120/2/2/18>
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<https://zenodo.org/record/3527872#.YOhEQOgzaUk>
- Meinard Müller, Brian McFee, and Katherine Kinnaird: Interactive Learning of Signal Processing Through Music: Making Fourier Analysis Concrete for Students. IEEE Signal Processing Magazine, 38(3): 73–84, 2021.
<https://ieeexplore.ieee.org/document/9418542>

Resources (Group Meinard Müller)

- FMP Notebooks:

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

- libfmp:

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

- synctoolbox:

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

- libtsm:

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

- Preparation Course Python (PCP) Notebooks:

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

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