

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



Lecture

Music Processing

Introduction

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Music

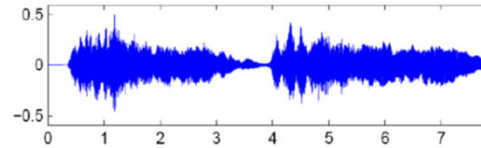


Music Information Retrieval (MIR)

Sheet Music (Image)



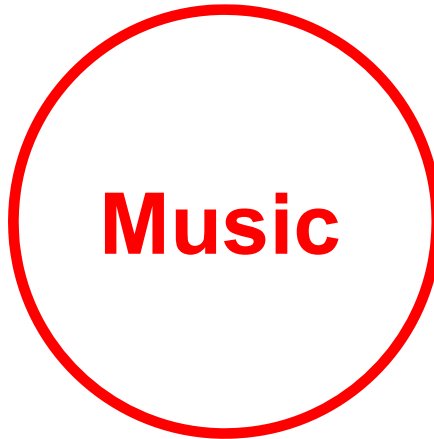
CD / MP3 (Audio)



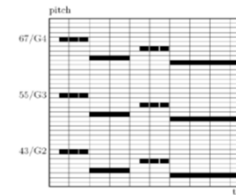
MusicXML (Text)

```
<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)



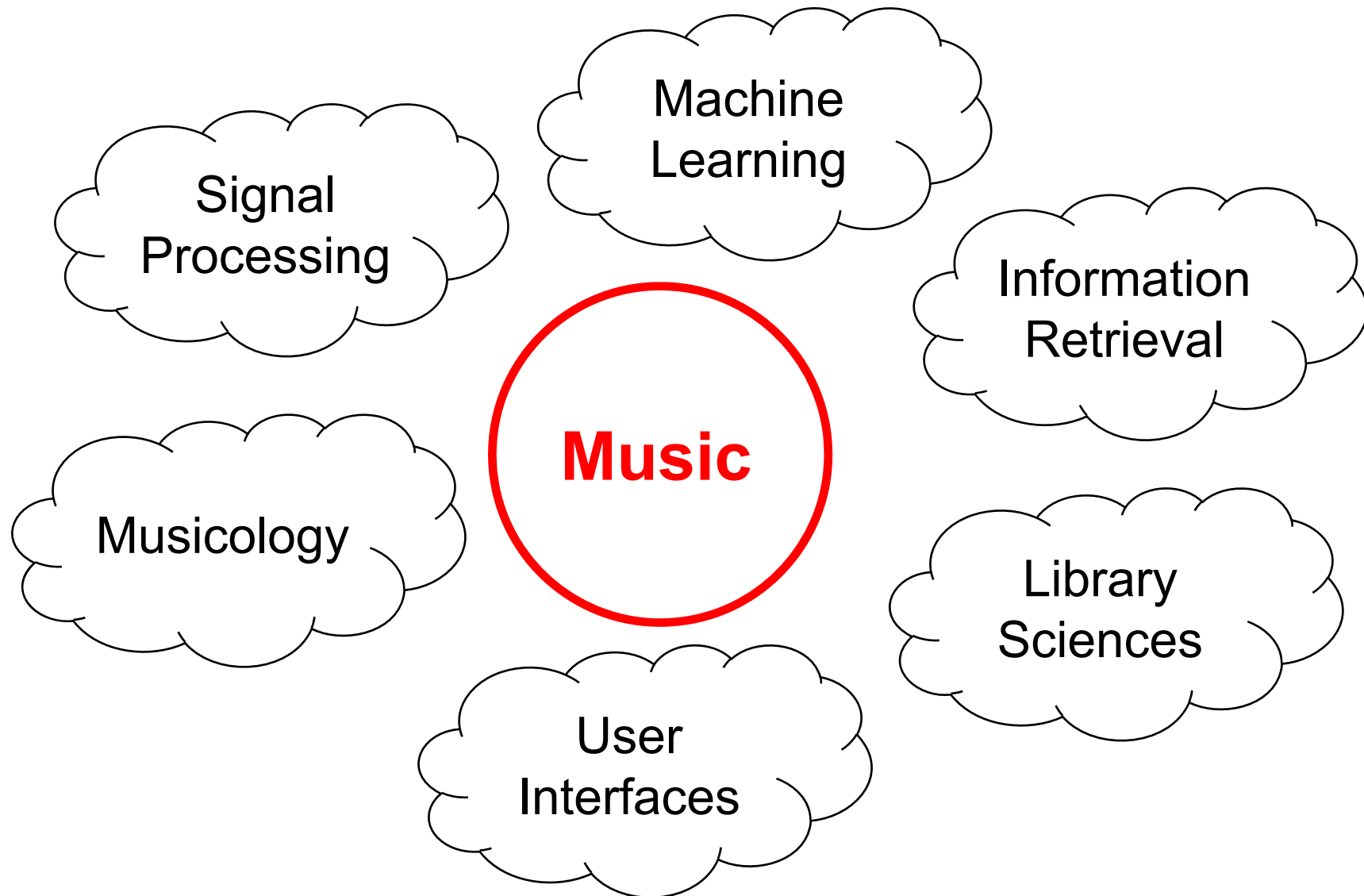
Music Film (Video)



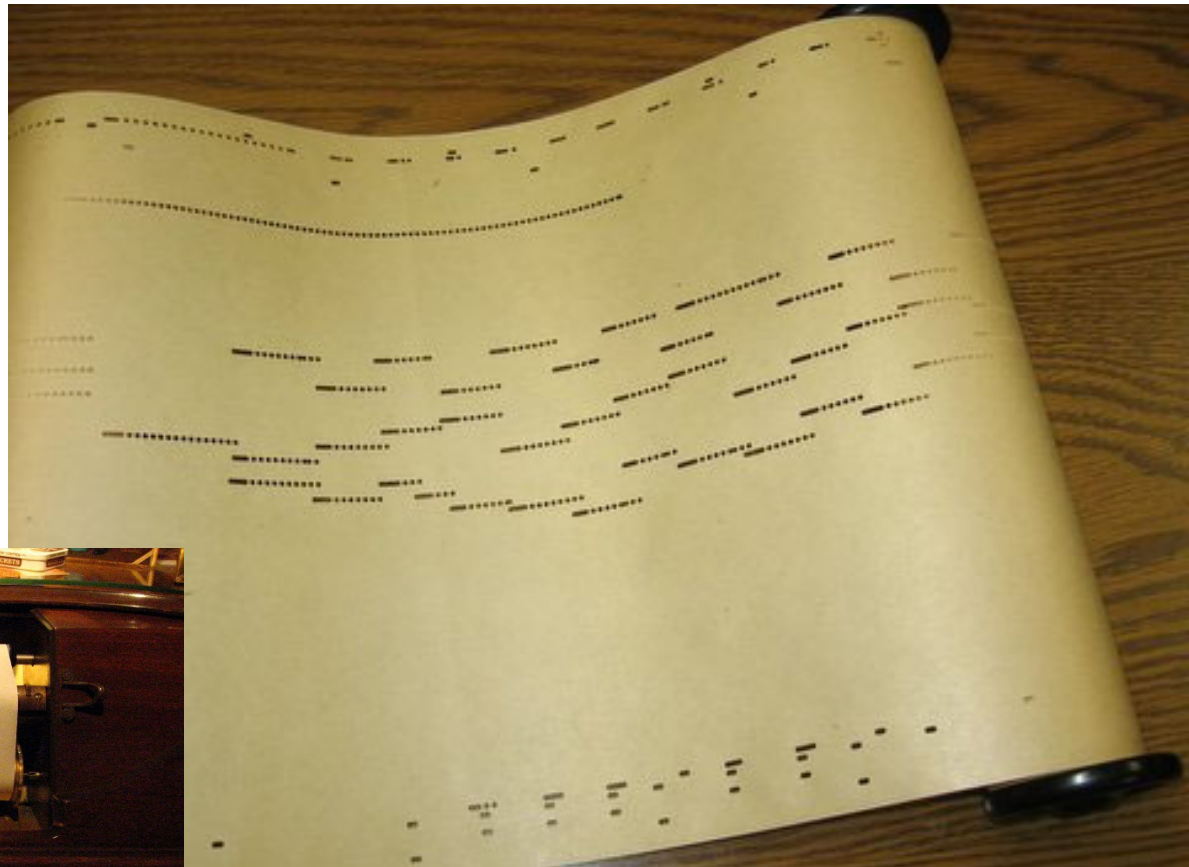
Music Literature (Text)



Music Information Retrieval (MIR)

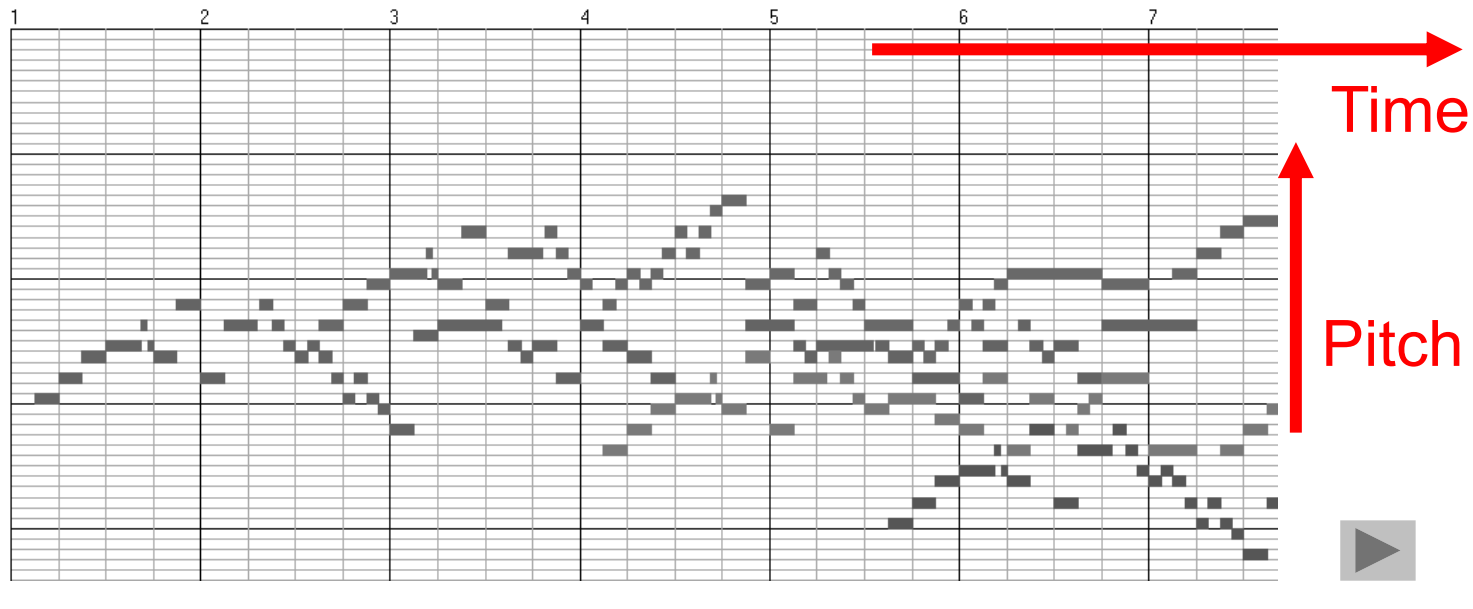
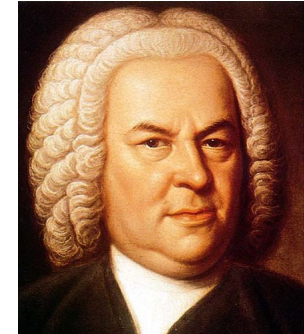


Piano Roll Representation (1900)



Piano Roll Representation

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

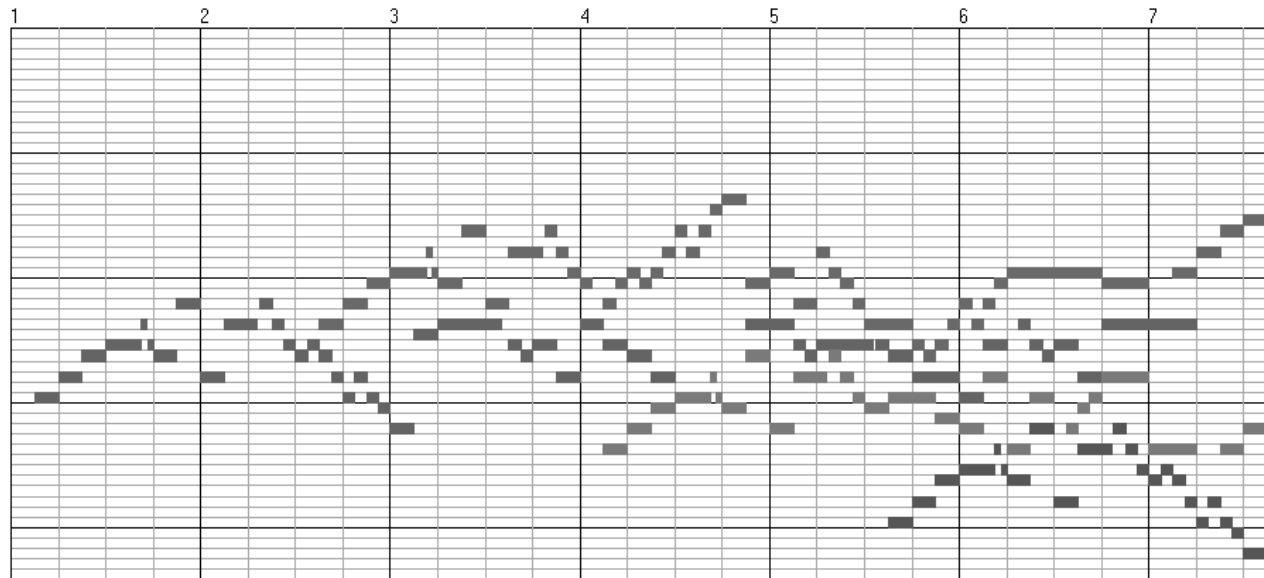
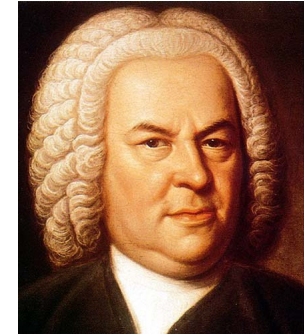


Piano Roll Representation

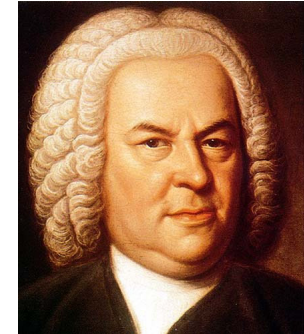
Query:



Goal: Find all occurrences of the query



Piano Roll Representation

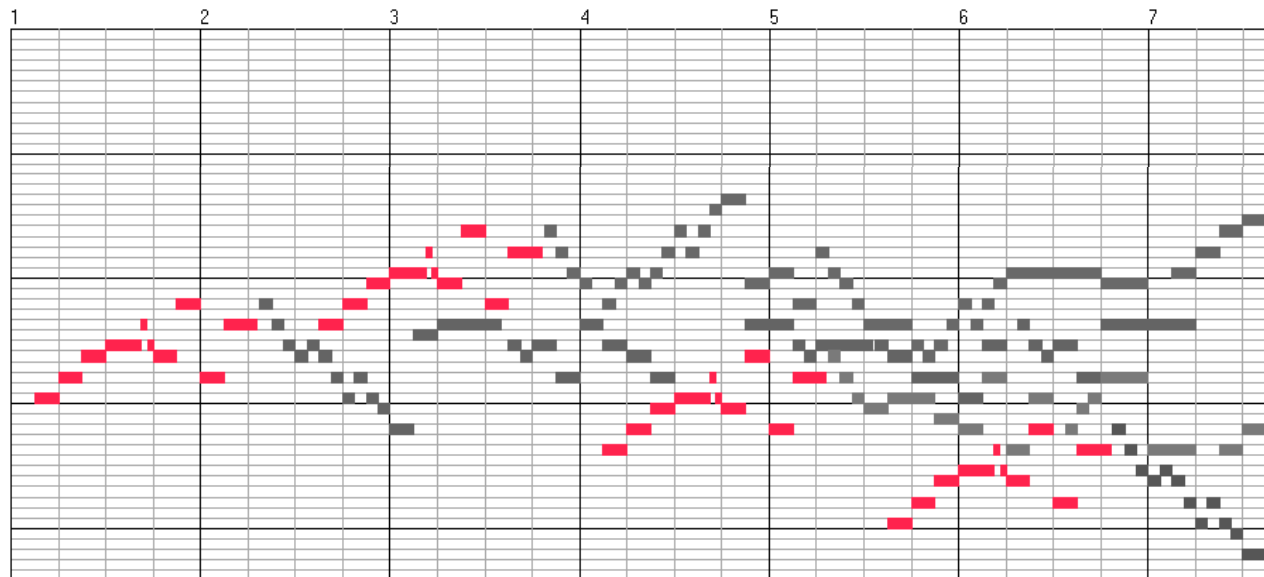


Query:

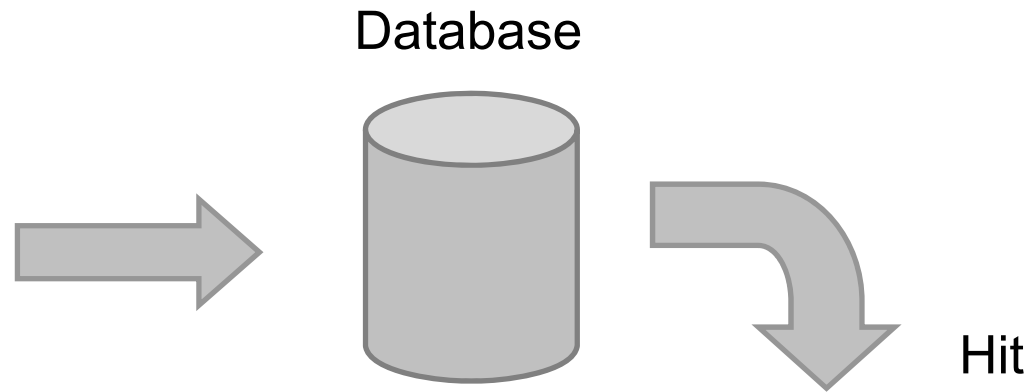


Goal: Find all occurrences of the query

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: Audio-Audio

Beethoven's Fifth



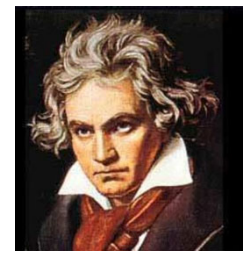
Music Synchronization: Audio-Audio

Beethoven's Fifth

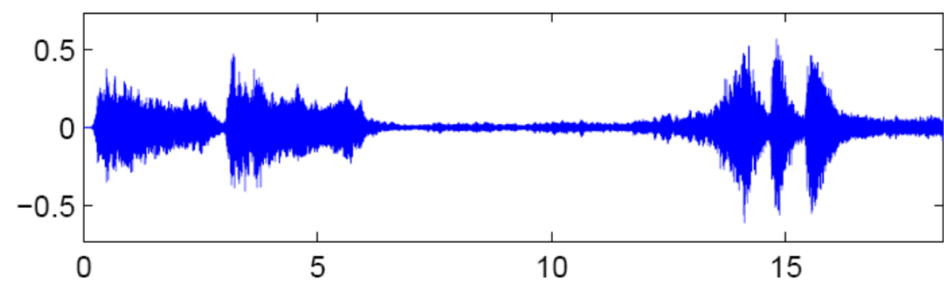
Allegro con brio ($\text{♩} = 108$)

ff

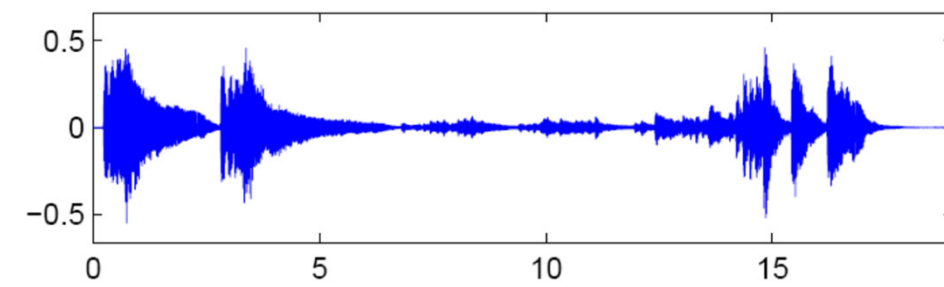
rit. * *rit.* *



Orchester
(Karajan)



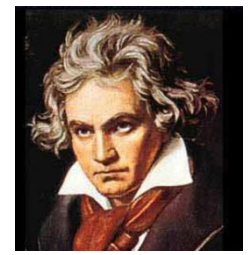
Piano
(Scherbakov)



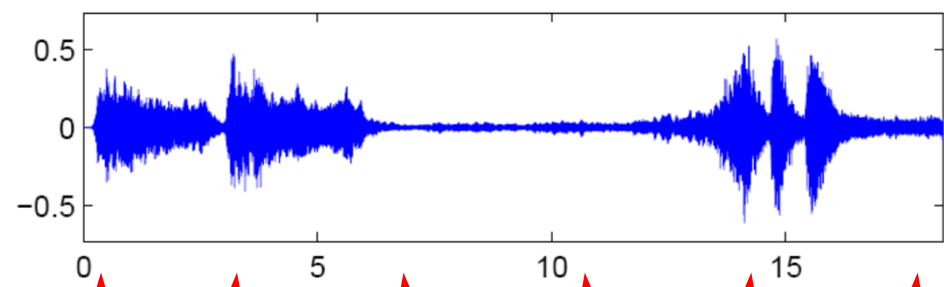
Time (seconds)

Music Synchronization: Audio-Audio

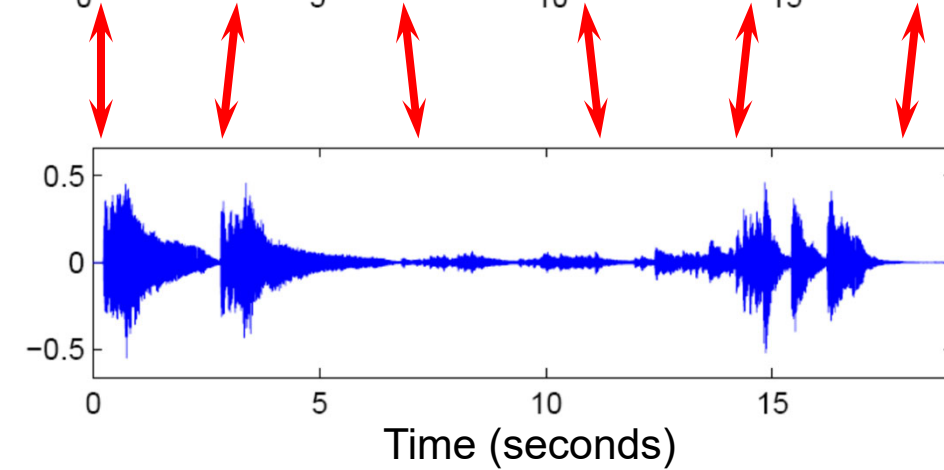
Beethoven's Fifth



Orchester
(Karajan)



Piano
(Scherbakov)



Application: Interpretation Switcher

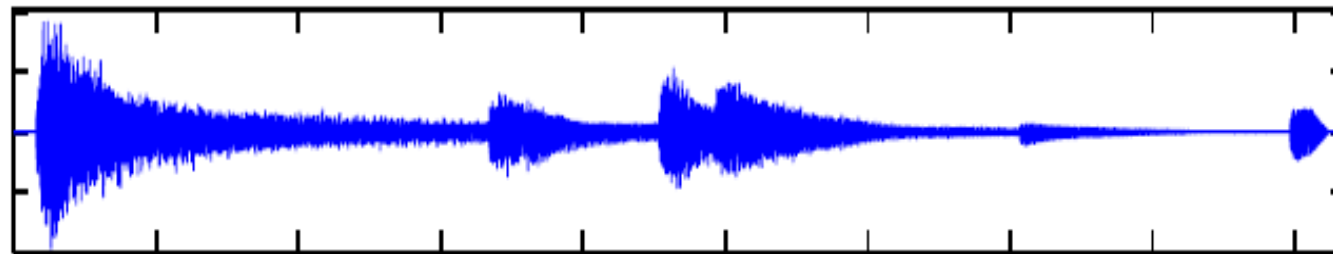


Music Synchronization: Image-Audio

Image



Audio



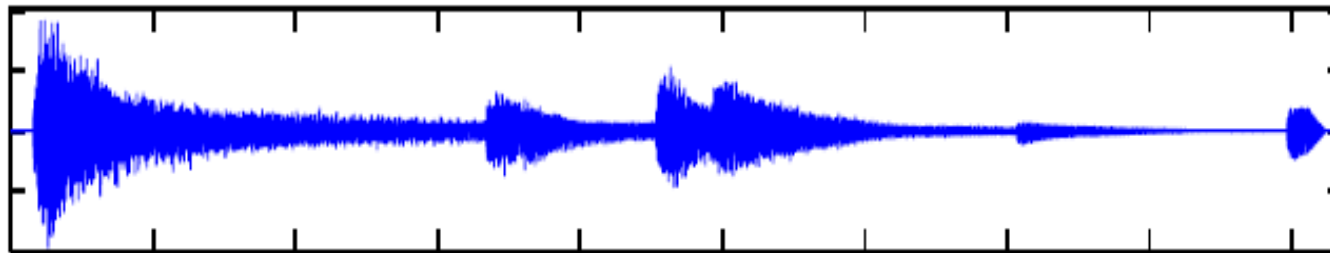
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image



Audio



Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image



Audio



Audio Processing: Fourier Analysis

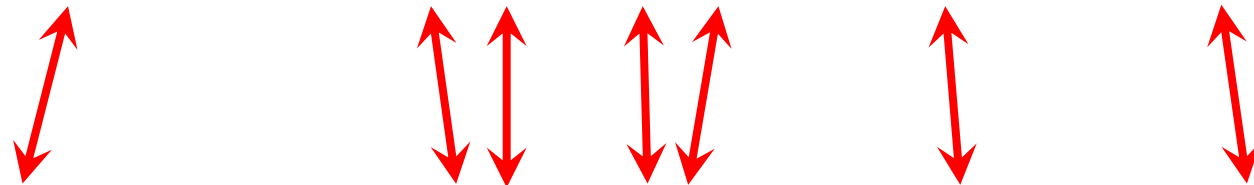
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition

Image

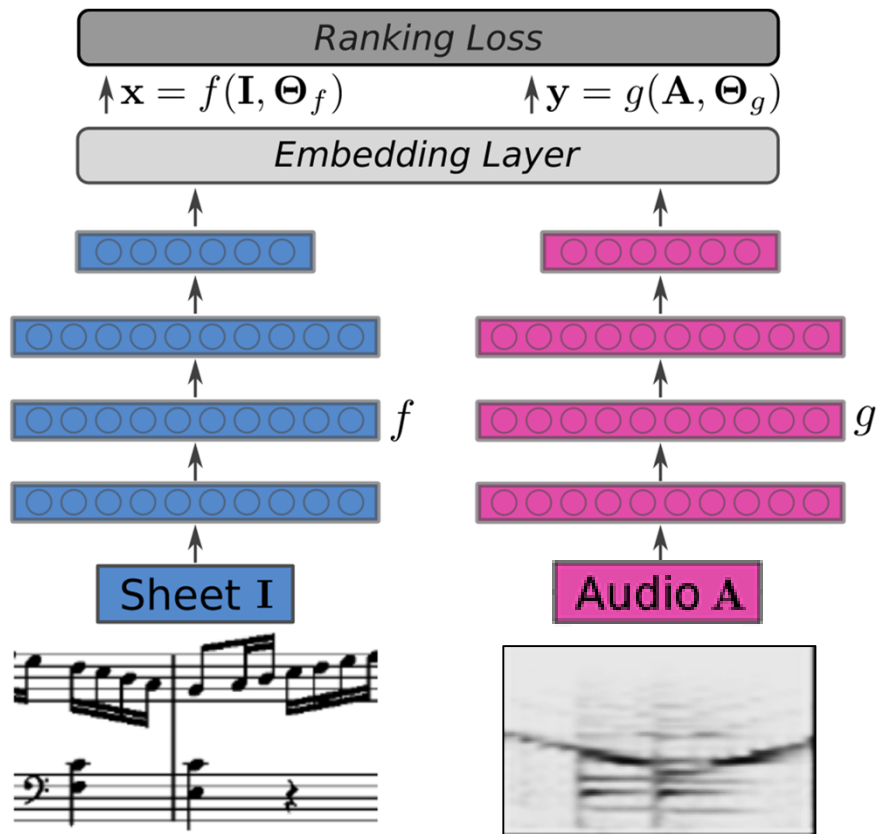


Audio



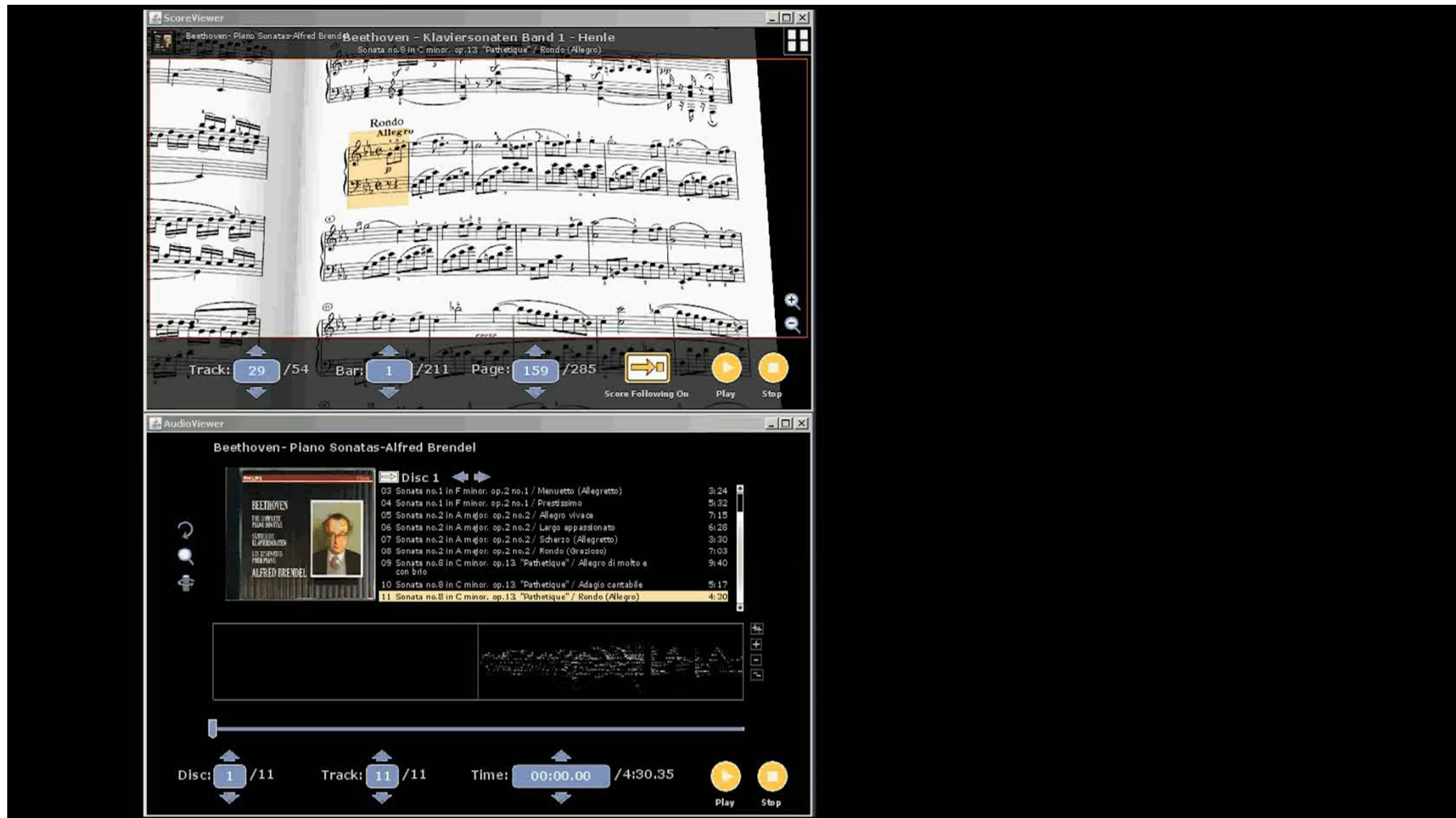
Audio Processing: Fourier Analysis

Music Synchronization: Image-Audio



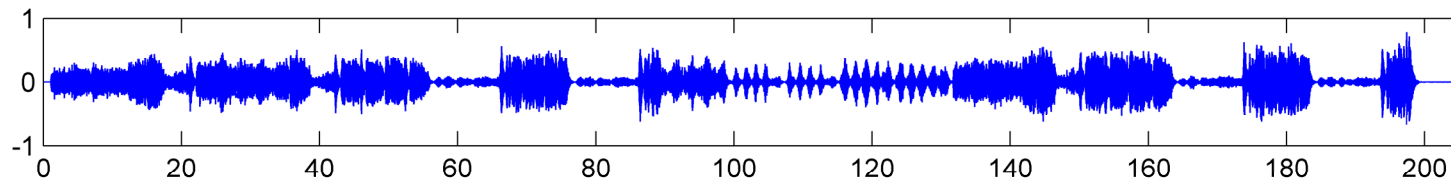
- Deep learning
- Embedding techniques
- Triplet loss
- ...

Application: Score Viewer



Music Structure Analysis

Example: Brahms Hungarian Dance No. 5 (Ormandy)

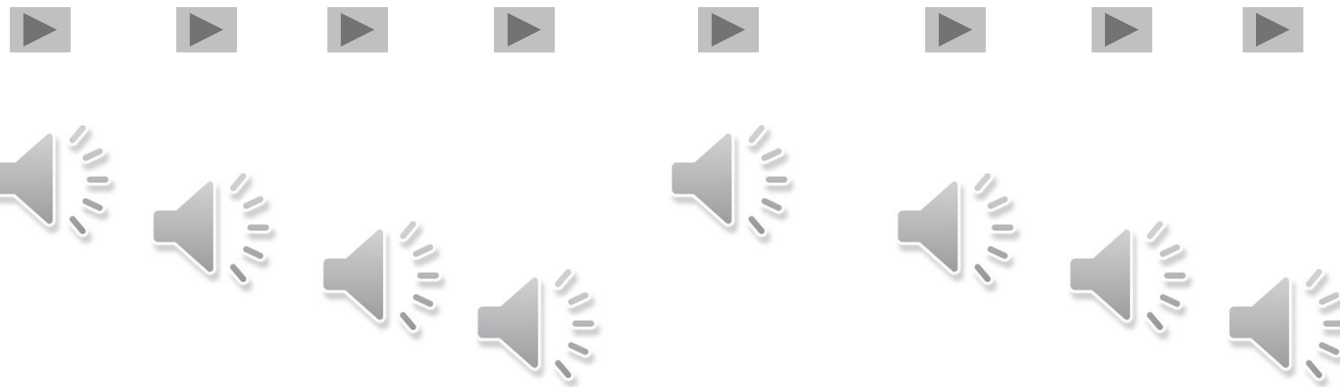
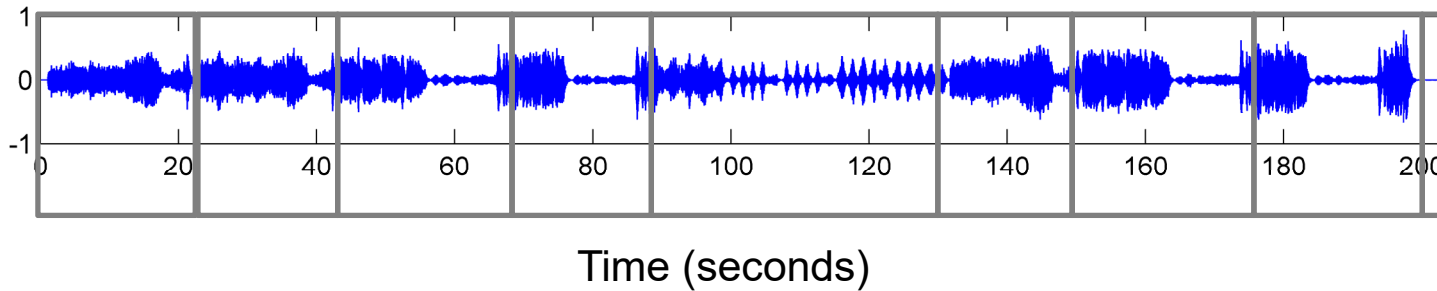


Time (seconds)



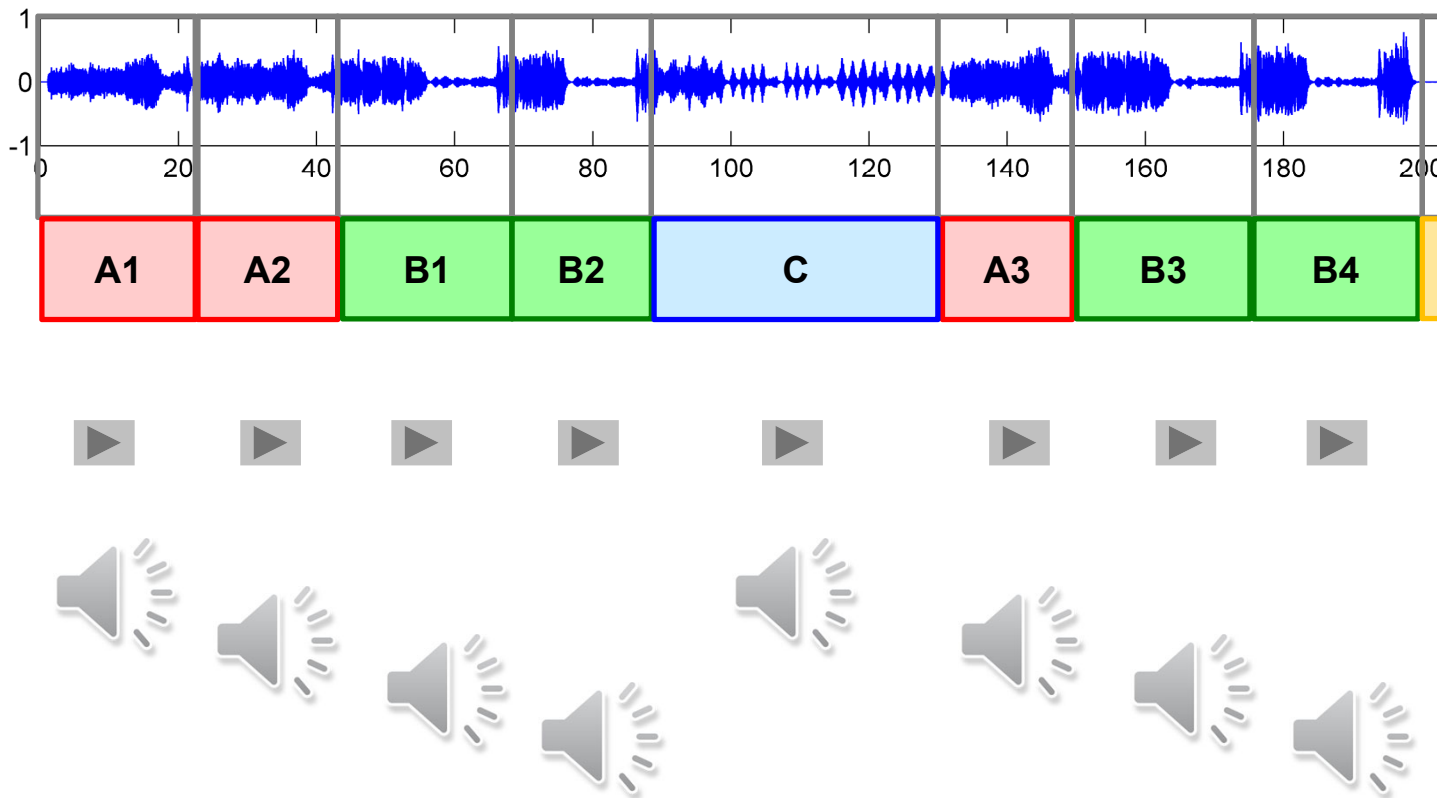
Music Structure Analysis

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Music Structure Analysis

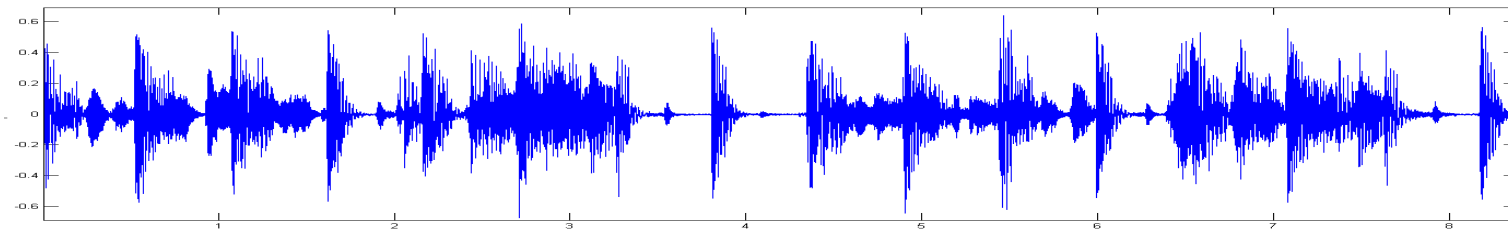
Example: Brahms Hungarian Dance No. 5 (Ormandy)



Tempo Estimation and Beat Tracking

Basic task: “Tapping the foot when listening to music”

Example: Queen – Another One Bites The Dust

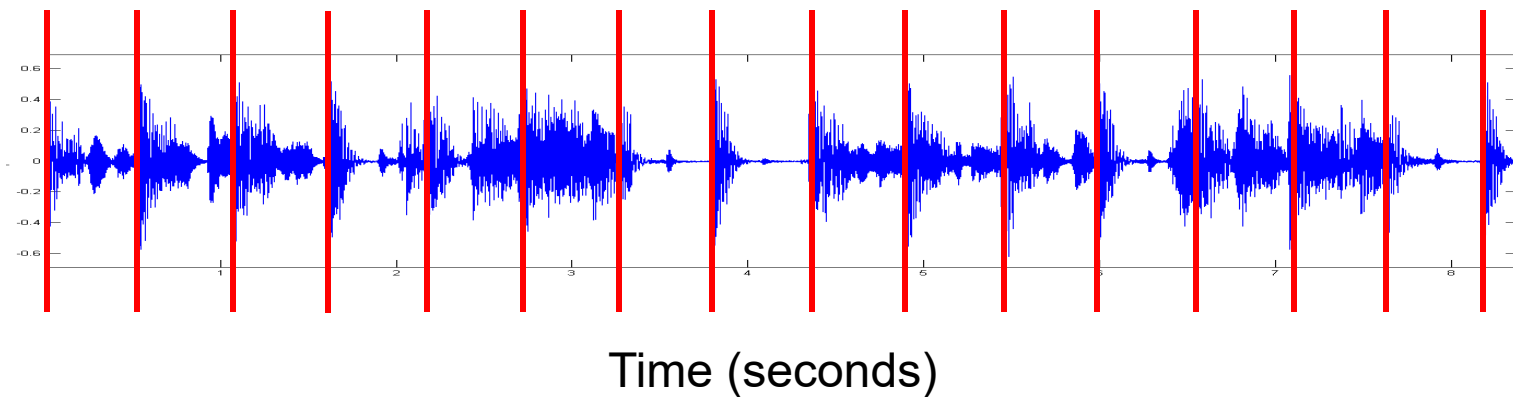


Time (seconds)

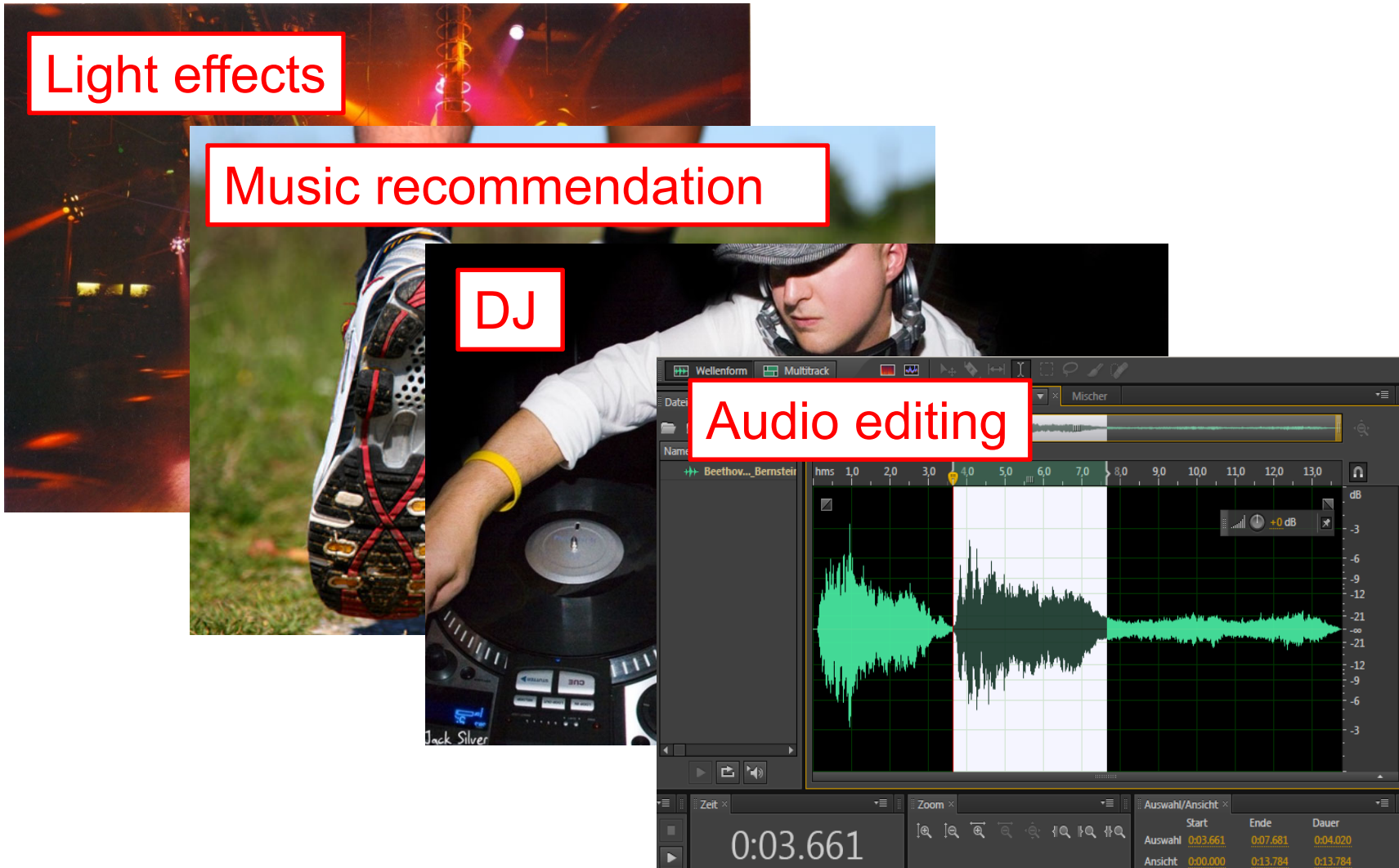
Tempo Estimation and Beat Tracking

Basic task: “Tapping the foot when listening to music”

Example: Queen – Another One Bites The Dust



Tempo Estimation and Beat Tracking



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3



Mazurka.

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

Allegretto.

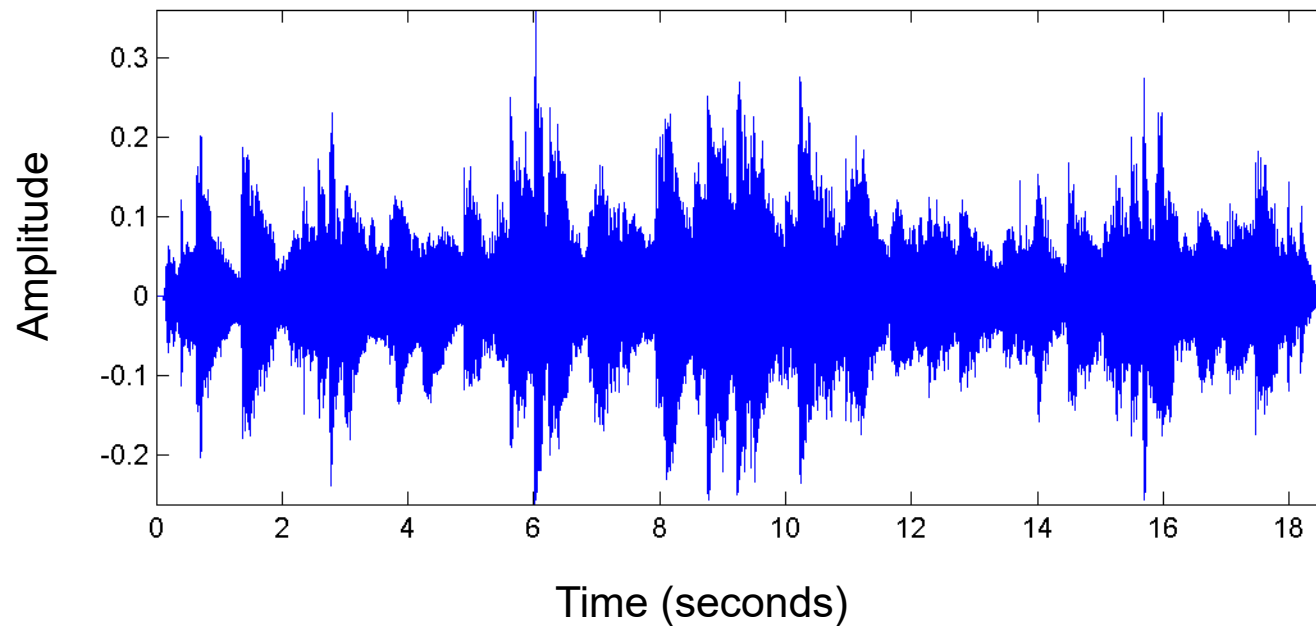
41. *p*

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 melody in the treble clef includes triplets and a fourth note. The bass clef has a piano (*p*) dynamic and a repeating bass line marked with 'Ped.' and asterisks. The score is numbered '41.' at the beginning.

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

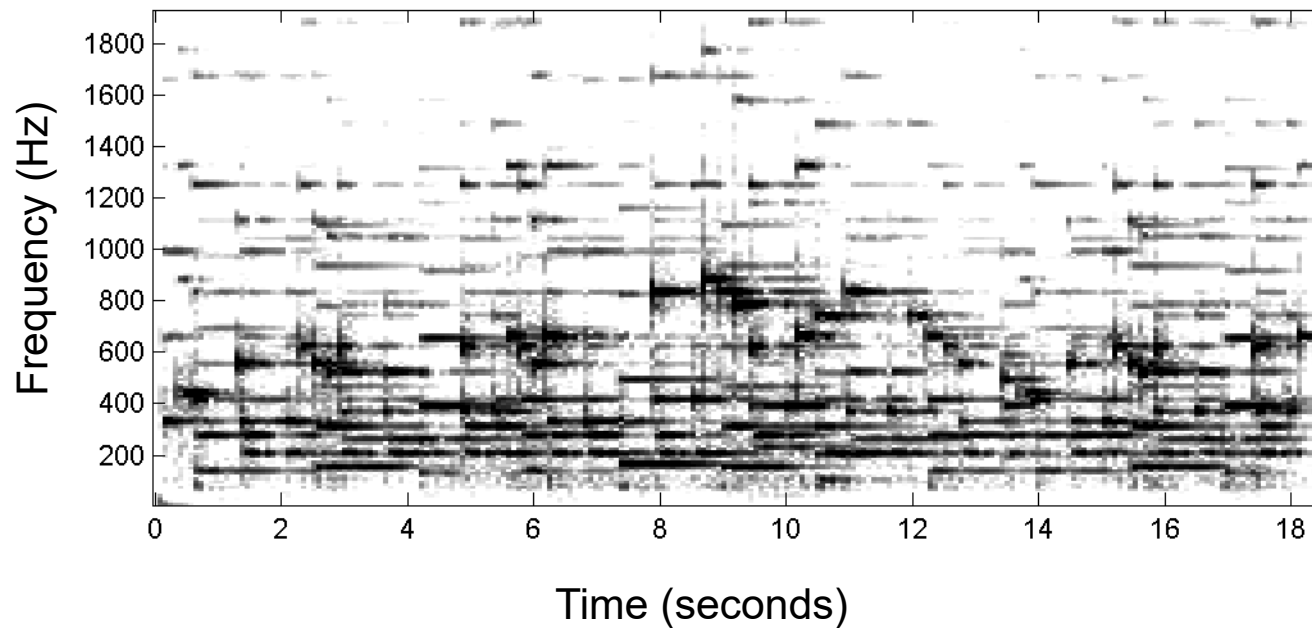
- Waveform



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”

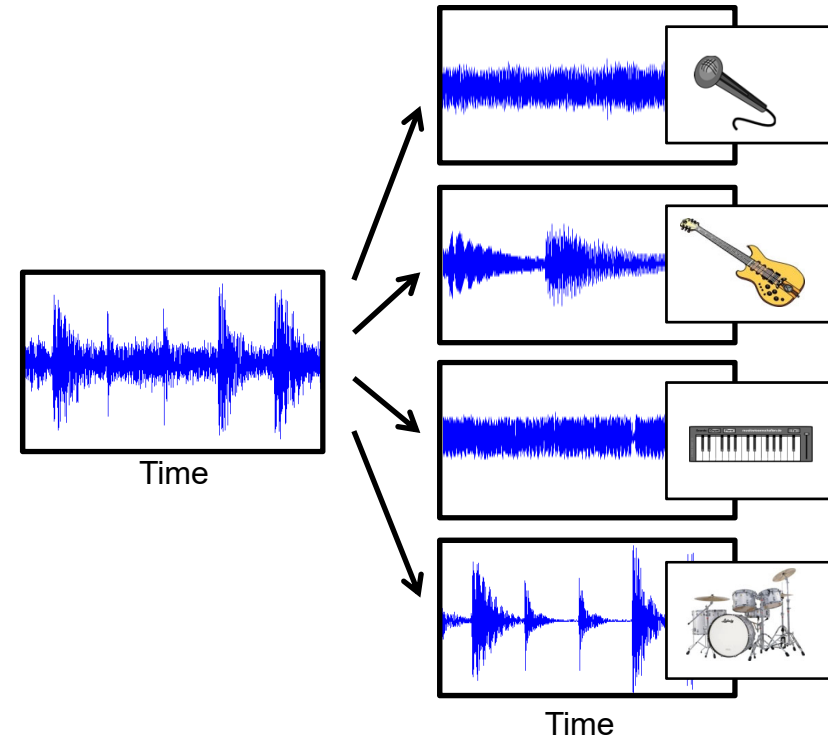


Source Separation

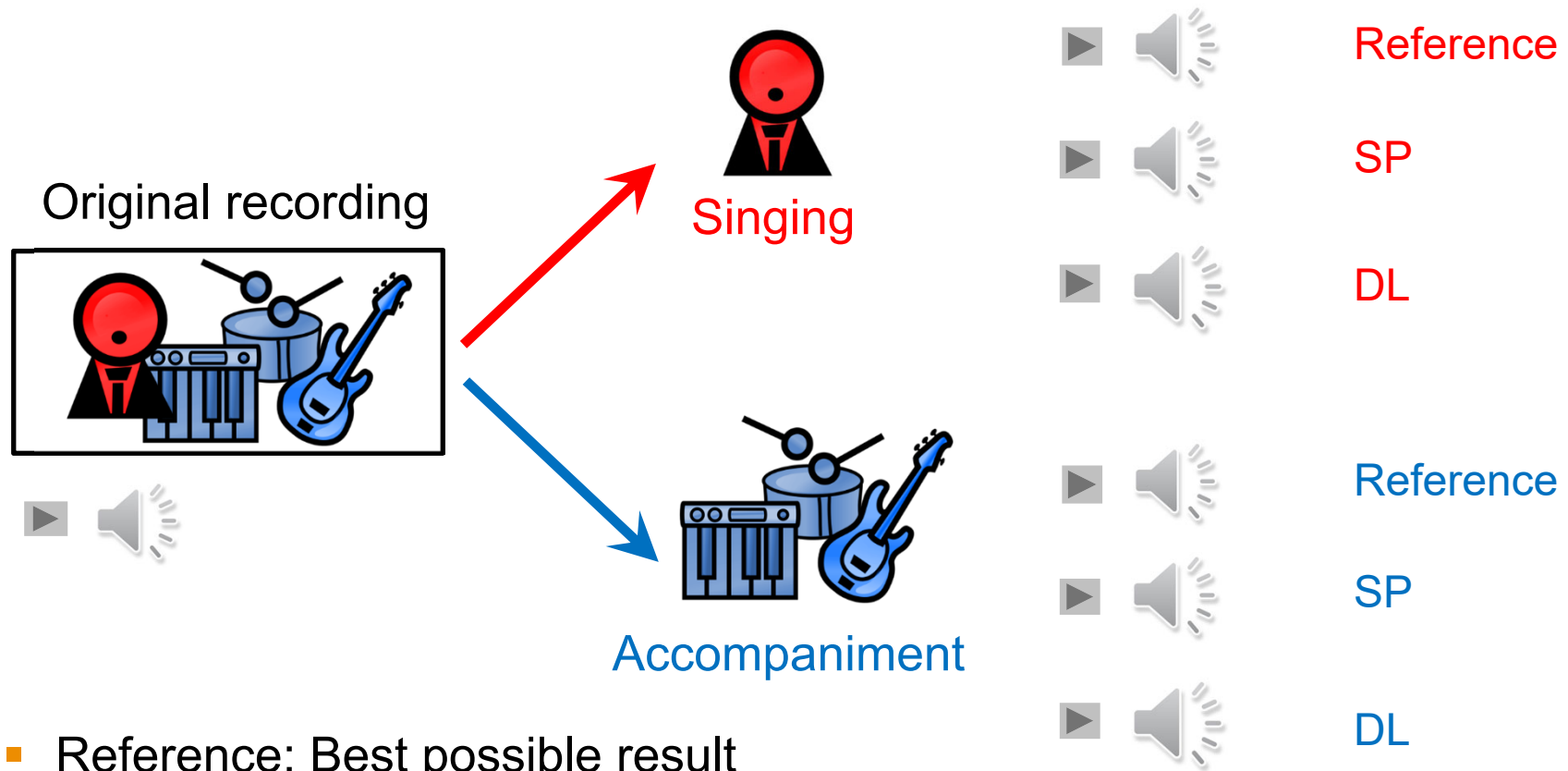
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”
- Several input signals
- Sources are assumed to be statistically independent

Source Separation (Music)

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



Source Separation (Music)



- Reference: Best possible result
- SP: Using traditional signal processing
- DL: Using data-driven approach based on deep learning

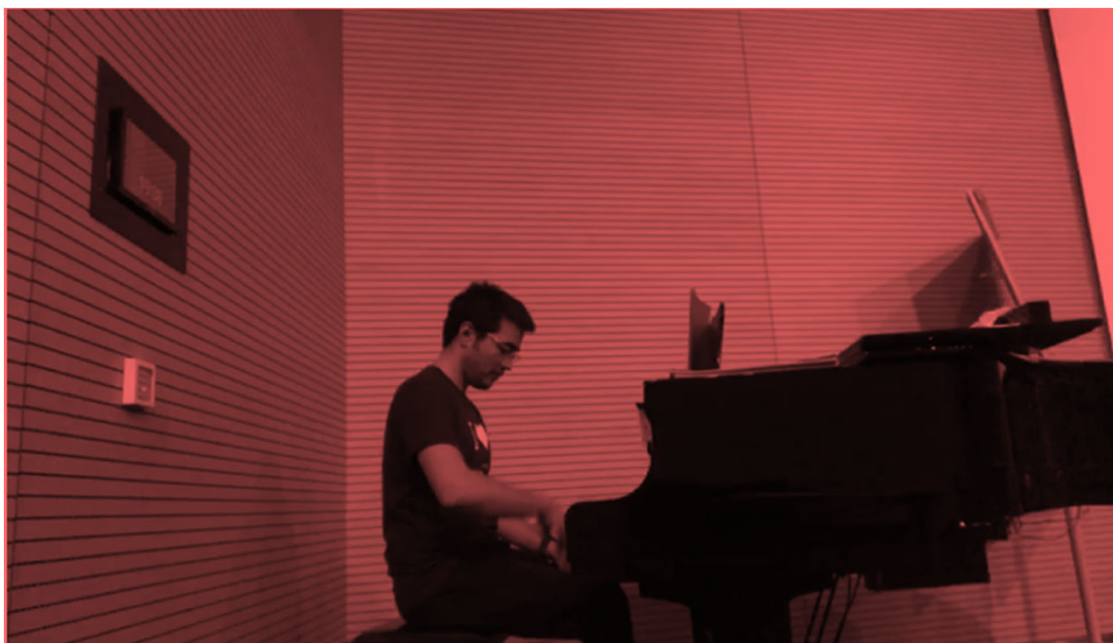
Source Separation (Music)

- Yigitcan Özer
- PhD student in engineering
- Pianist



Source Separation (Music)

- Yigitcan Özer
- PhD student in engineering
- Pianist



Only Piano!



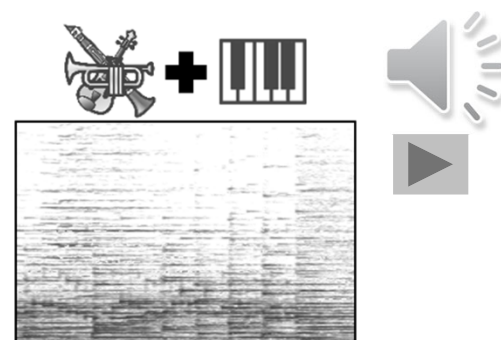
**Where is the
orchestra?**



Source Separation (Music)




A musical score for a piece starting at measure 89. The score is arranged in a grand staff with multiple staves. On the left side, there are vertical columns of instrument icons: woodwinds (flute, clarinet, saxophone), brass (trumpet, trombone, horn), strings (violin, viola, cello, double bass), and a keyboard instrument (piano). The notation includes various notes, rests, and dynamic markings like 'p' (piano).

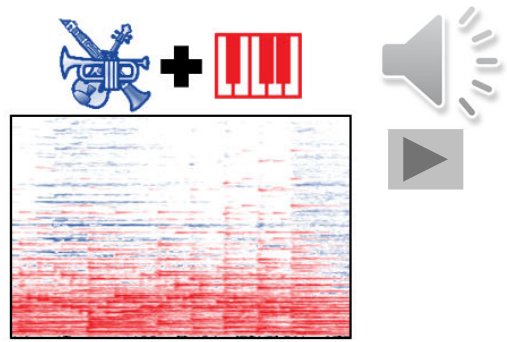


A diagram illustrating the source separation process. It shows a plus sign between a trumpet icon and a piano keyboard icon. Below this is a spectrogram representing the combined audio signal. To the right of the spectrogram are a speaker icon and a play button icon, indicating the output of the process.

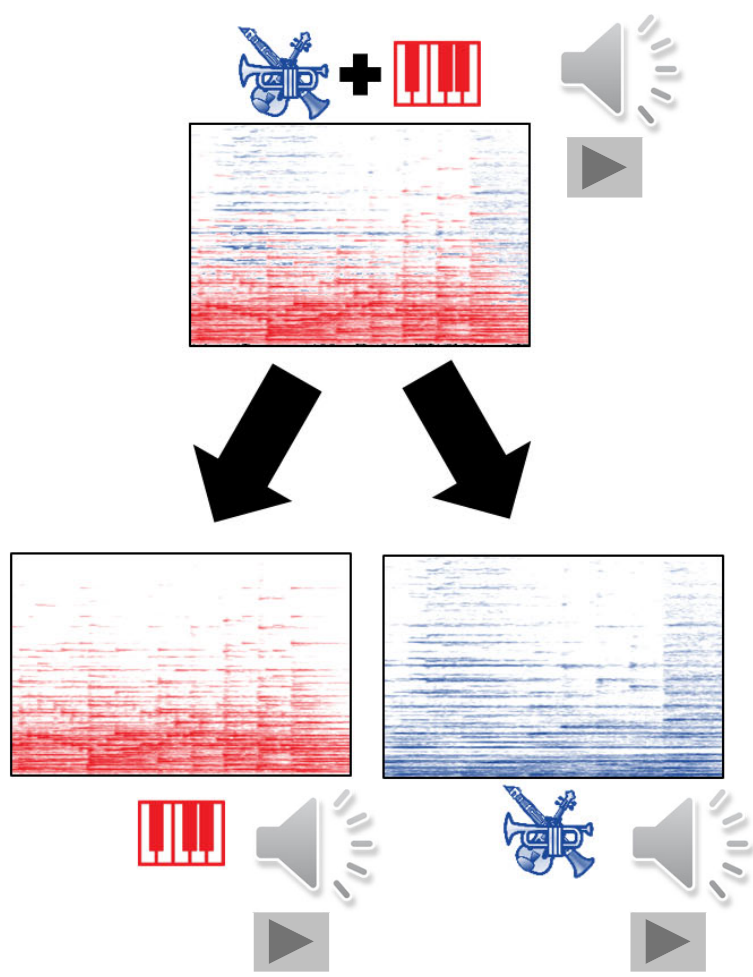
Source Separation (Music)



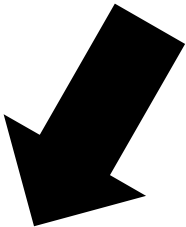
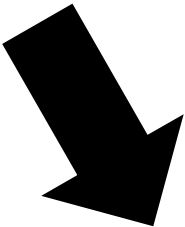
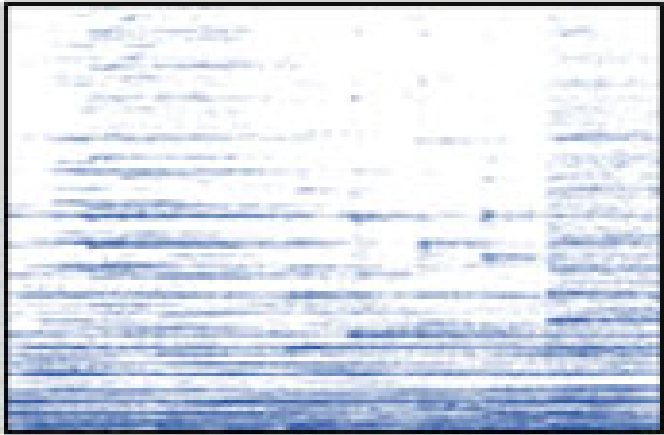
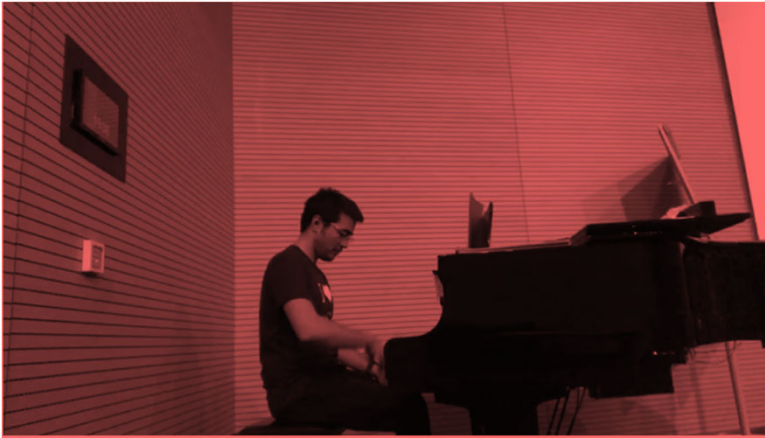
A musical score with multiple staves. The top staves are in blue, and the bottom staves are in red. A red piano keyboard icon is positioned to the left of the red staves. The score is marked with the number 89 at the beginning.



Source Separation (Music)



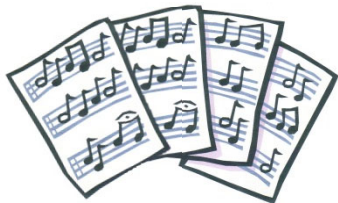
Source Separation (Music)



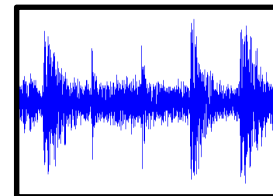
Score-Informed Source Separation

Exploit musical score to support decomposition process

Musical
Information



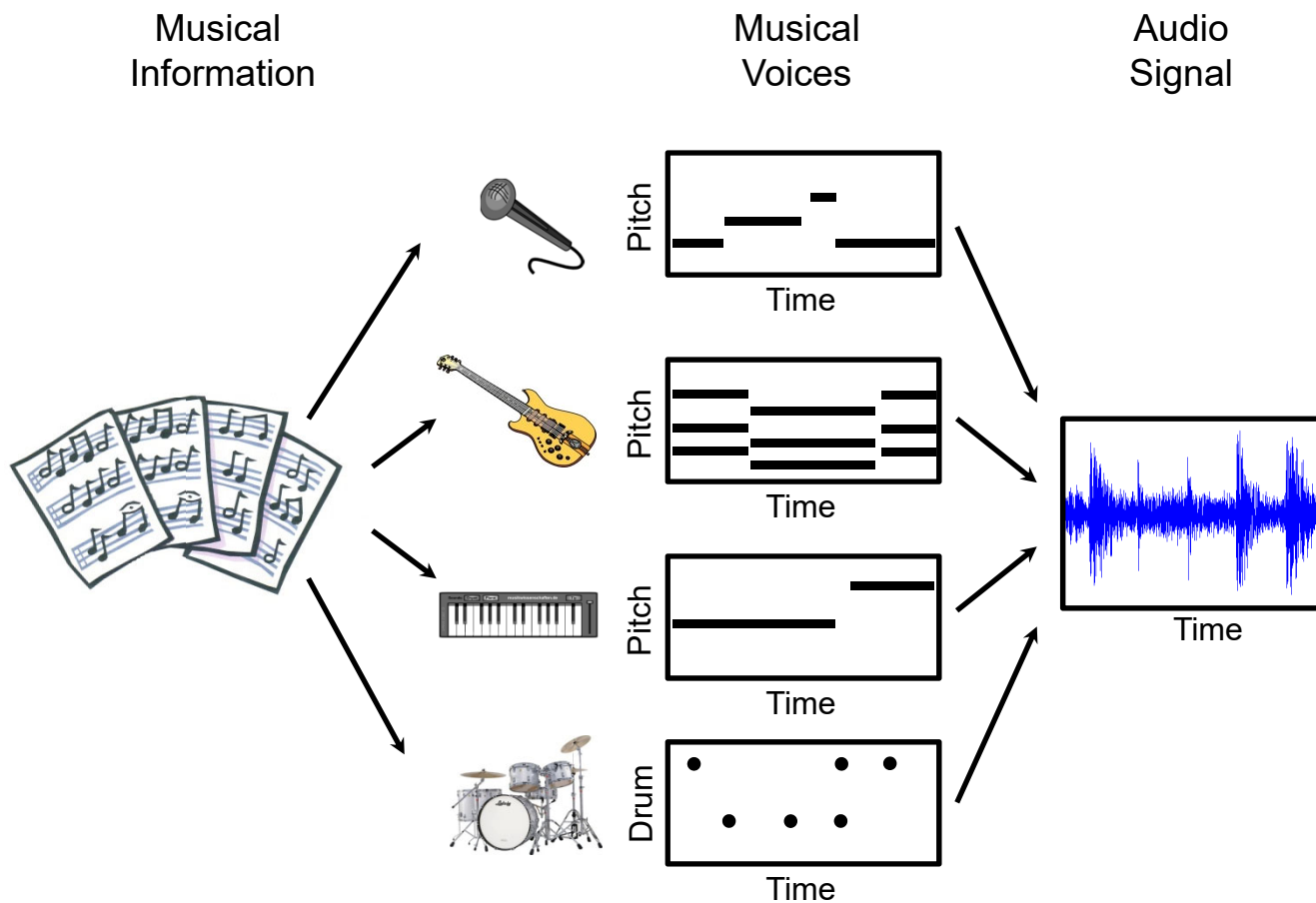
Audio
Signal



Time

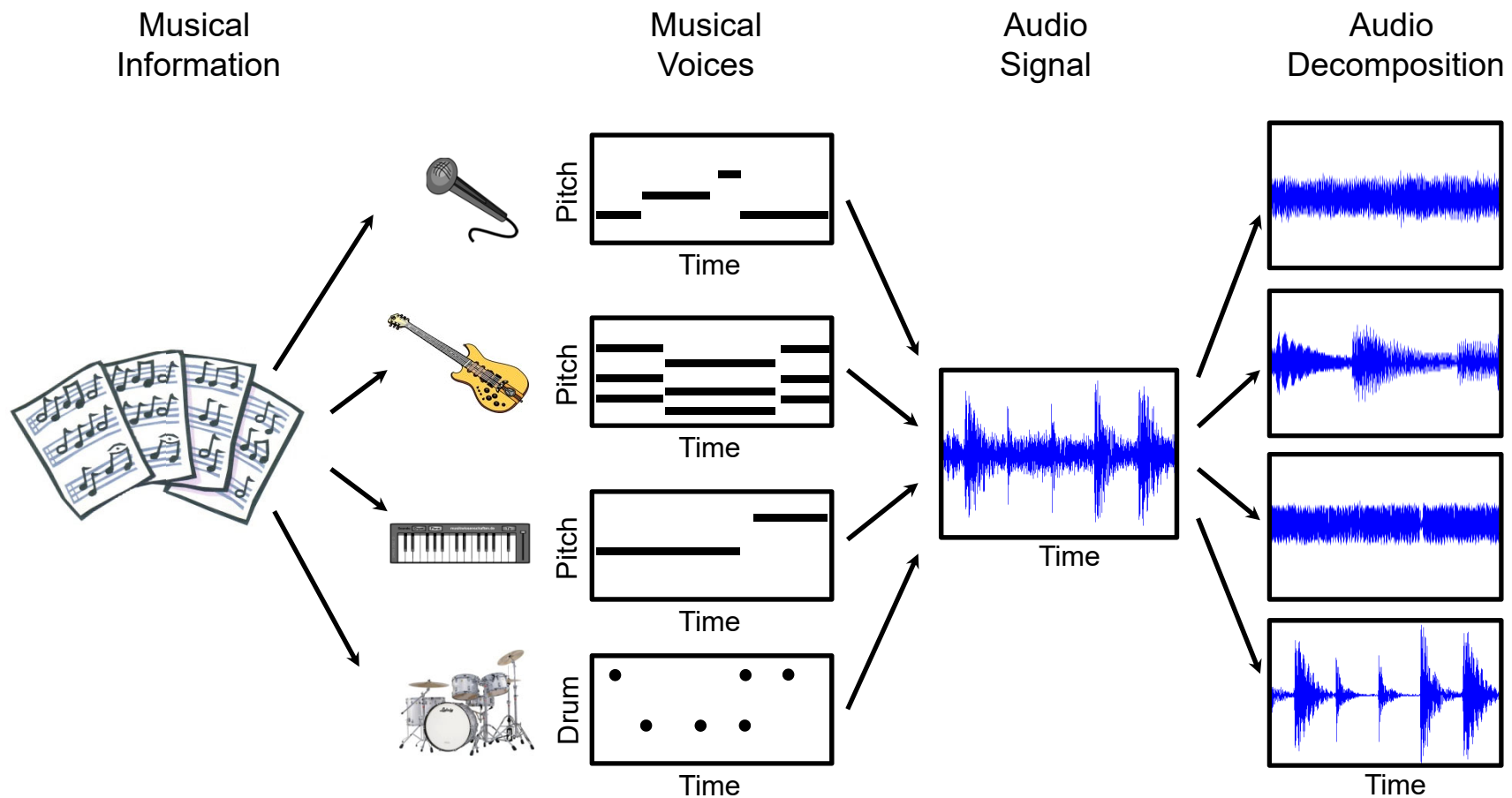
Score-Informed Source Separation

Exploit musical score to support decomposition process

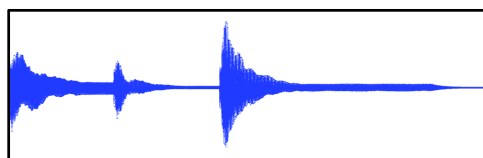


Score-Informed Source Separation

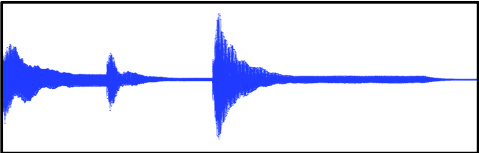
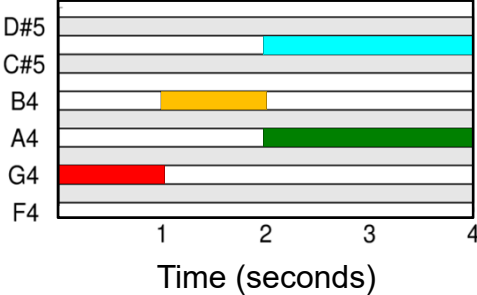
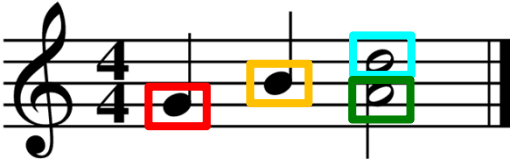
Exploit musical score to support decomposition process



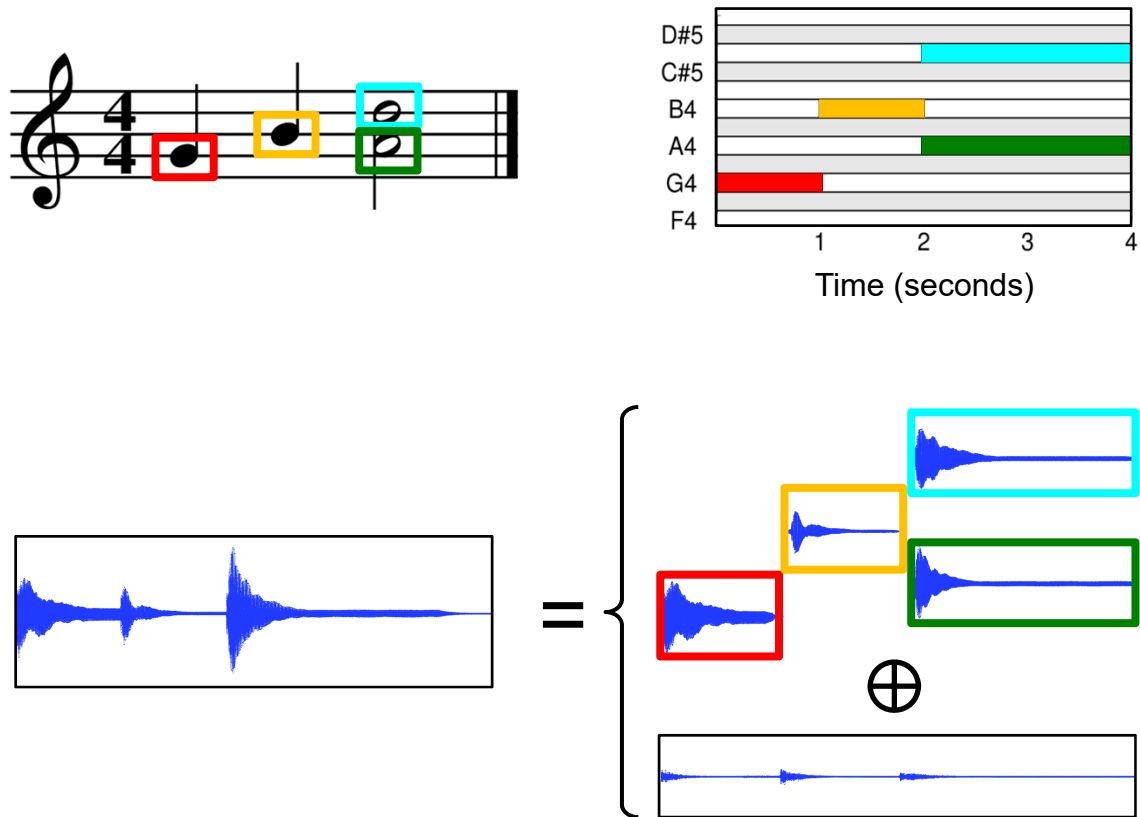
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

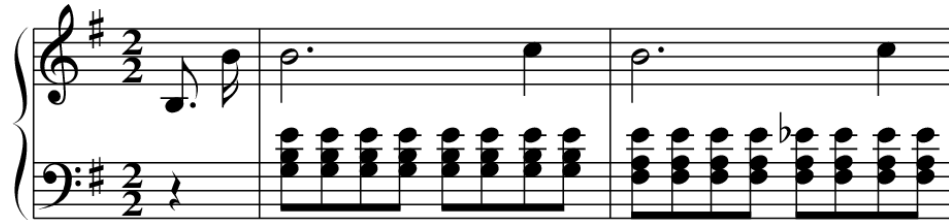


Score-Informed Audio Decomposition

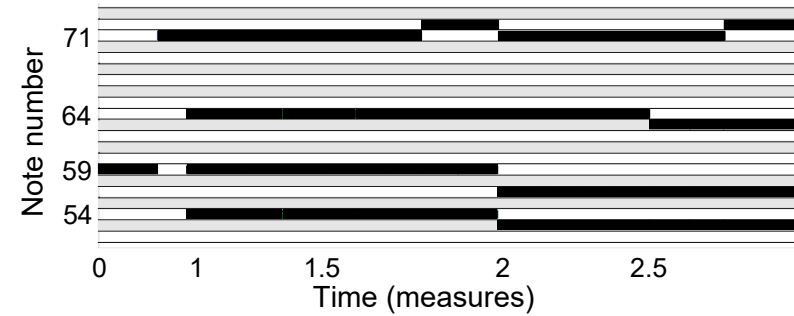


Score-Informed Audio Decomposition

Sheet music

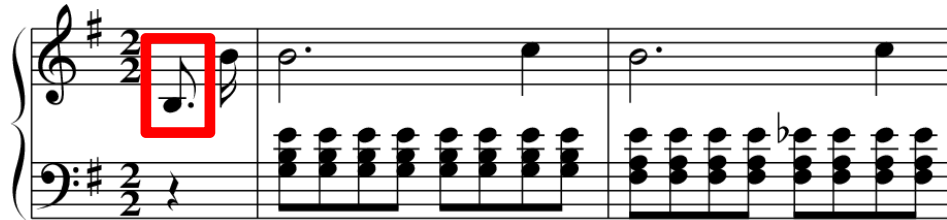


Piano roll



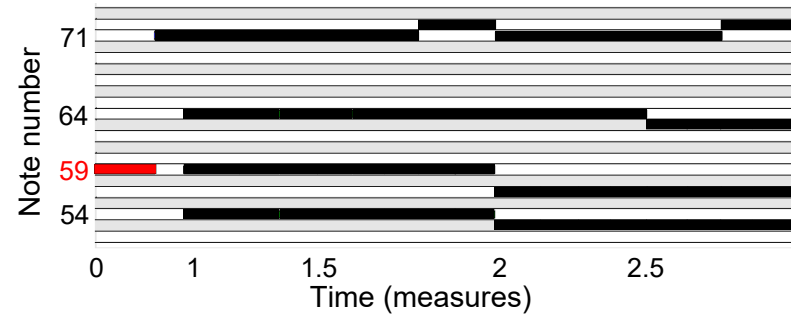
Score-Informed Audio Decomposition

Sheet music



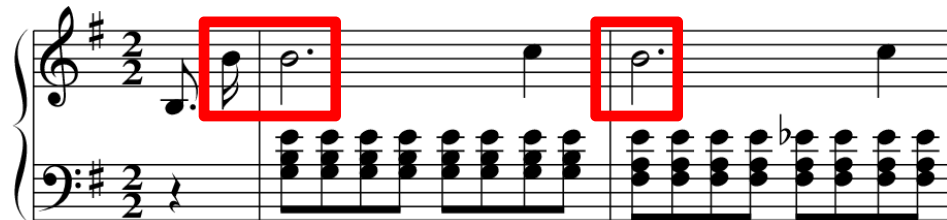
$p = 59$

Piano roll



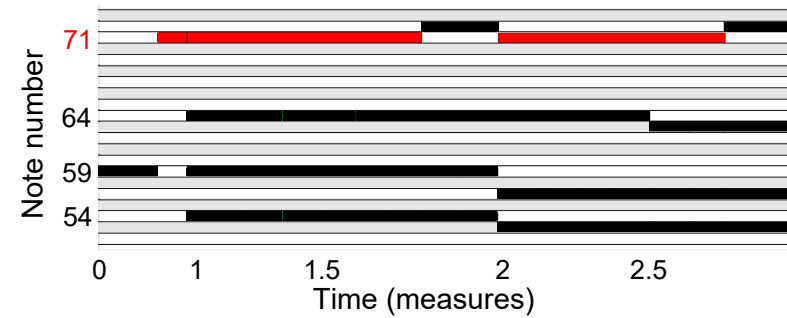
Score-Informed Audio Decomposition

Sheet music



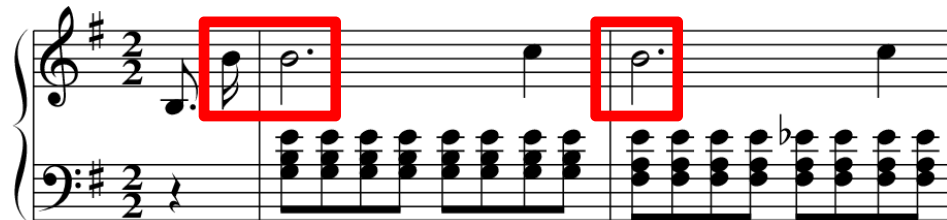
$p = 71$

Piano roll



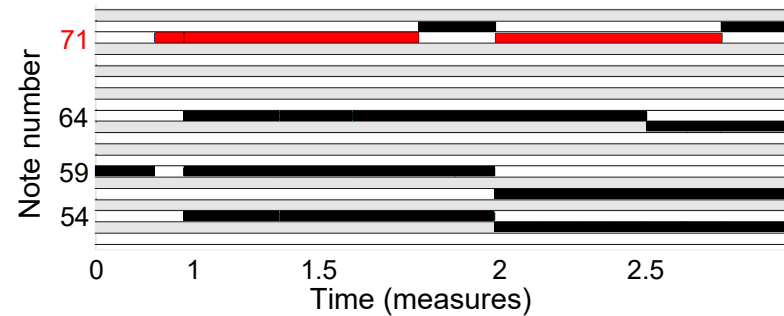
Score-Informed Audio Decomposition

Sheet music

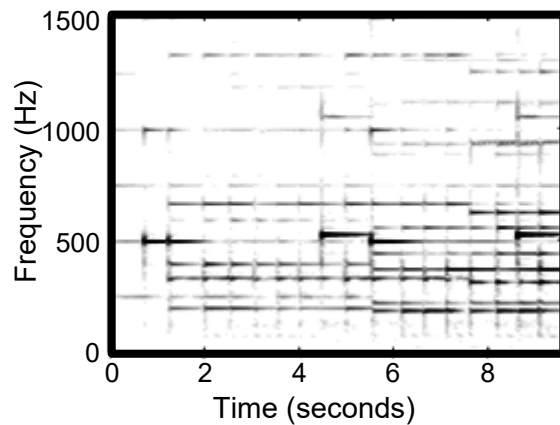


$p = 71$

Piano roll

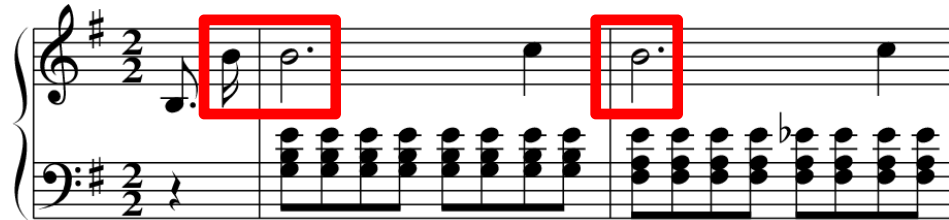


Spectrogram



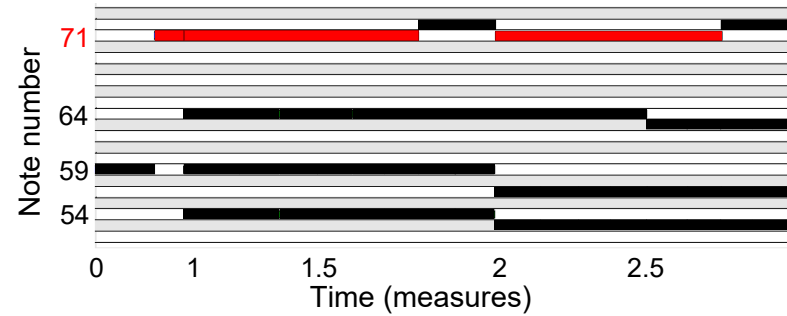
Score-Informed Audio Decomposition

Sheet music

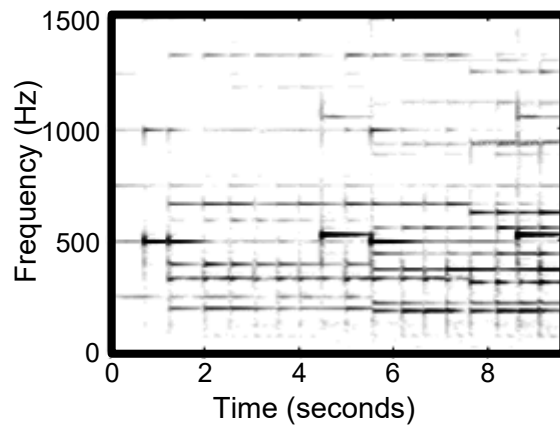


$p = 71$

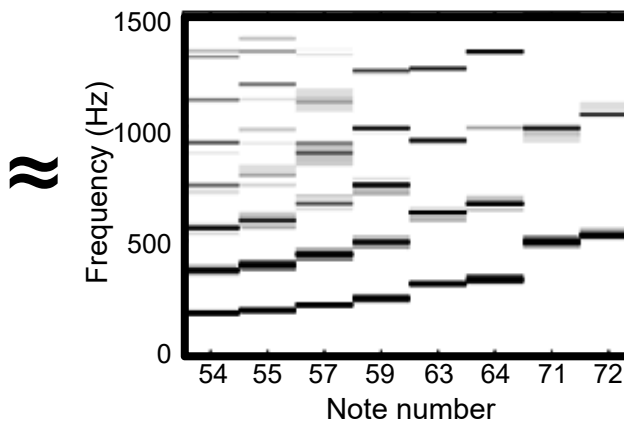
Piano roll



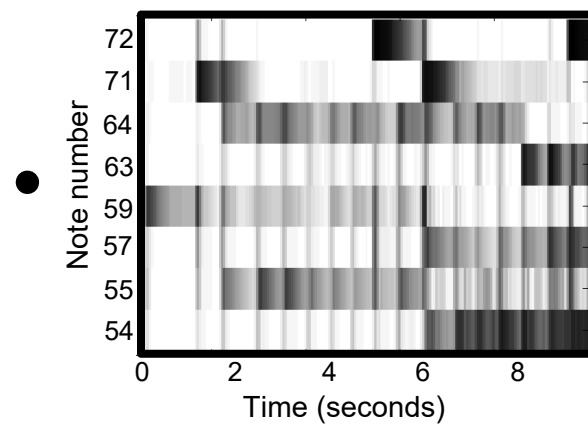
Spectrogram



Spectral patterns

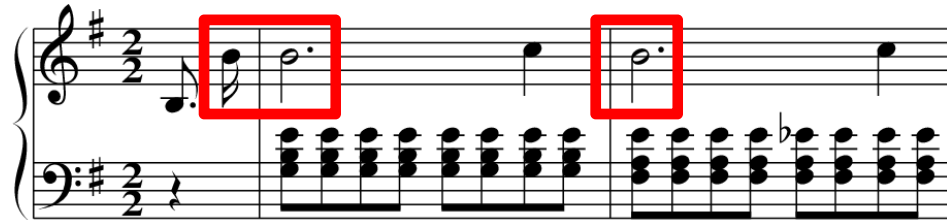


Activity patterns



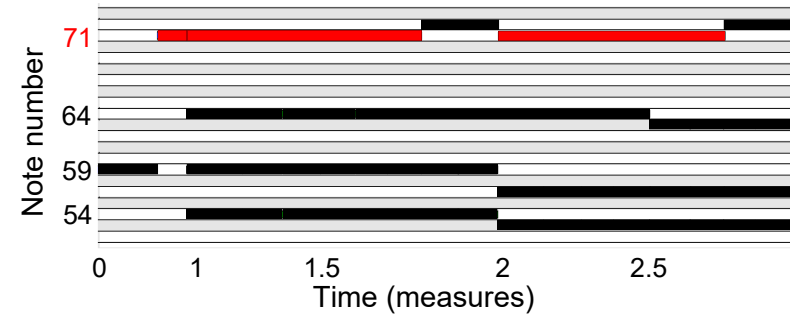
Score-Informed Audio Decomposition

Sheet music

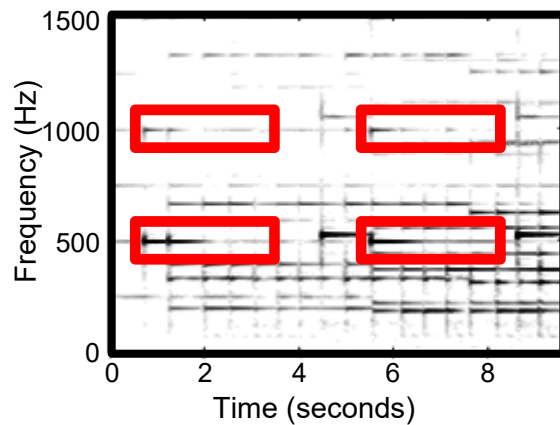


$p = 71$

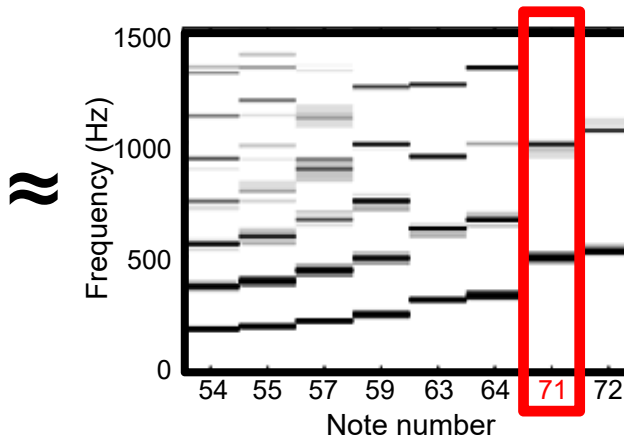
Piano roll



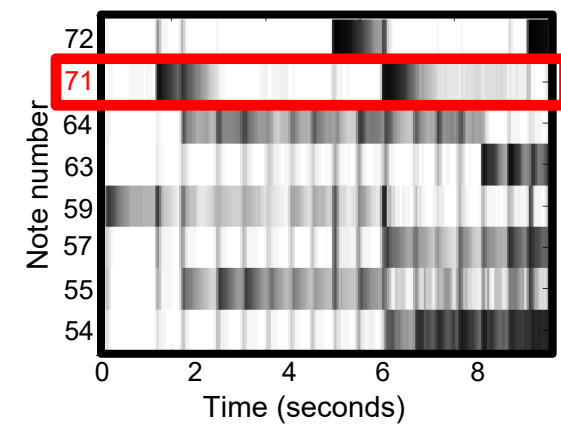
Spectrogram



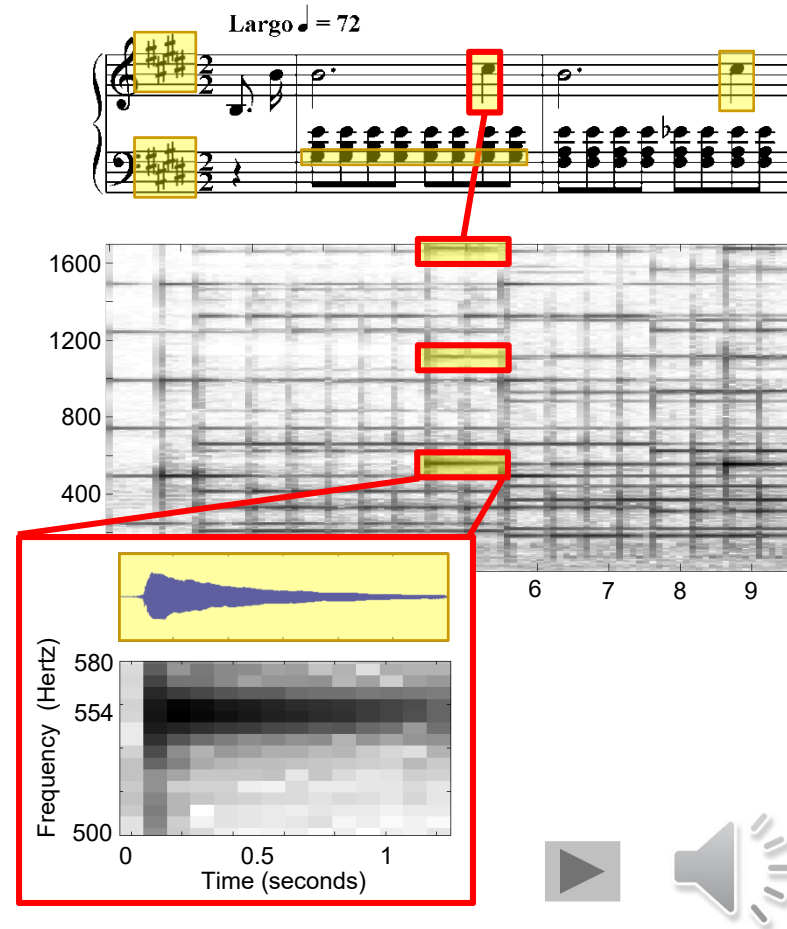
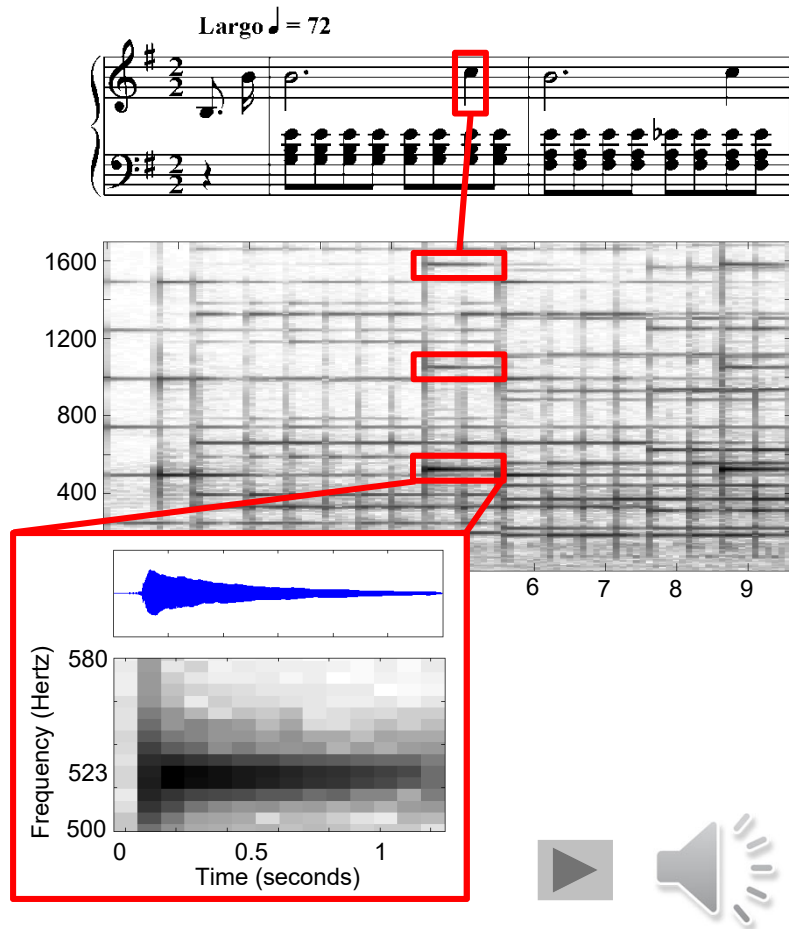
Spectral patterns



Activity patterns

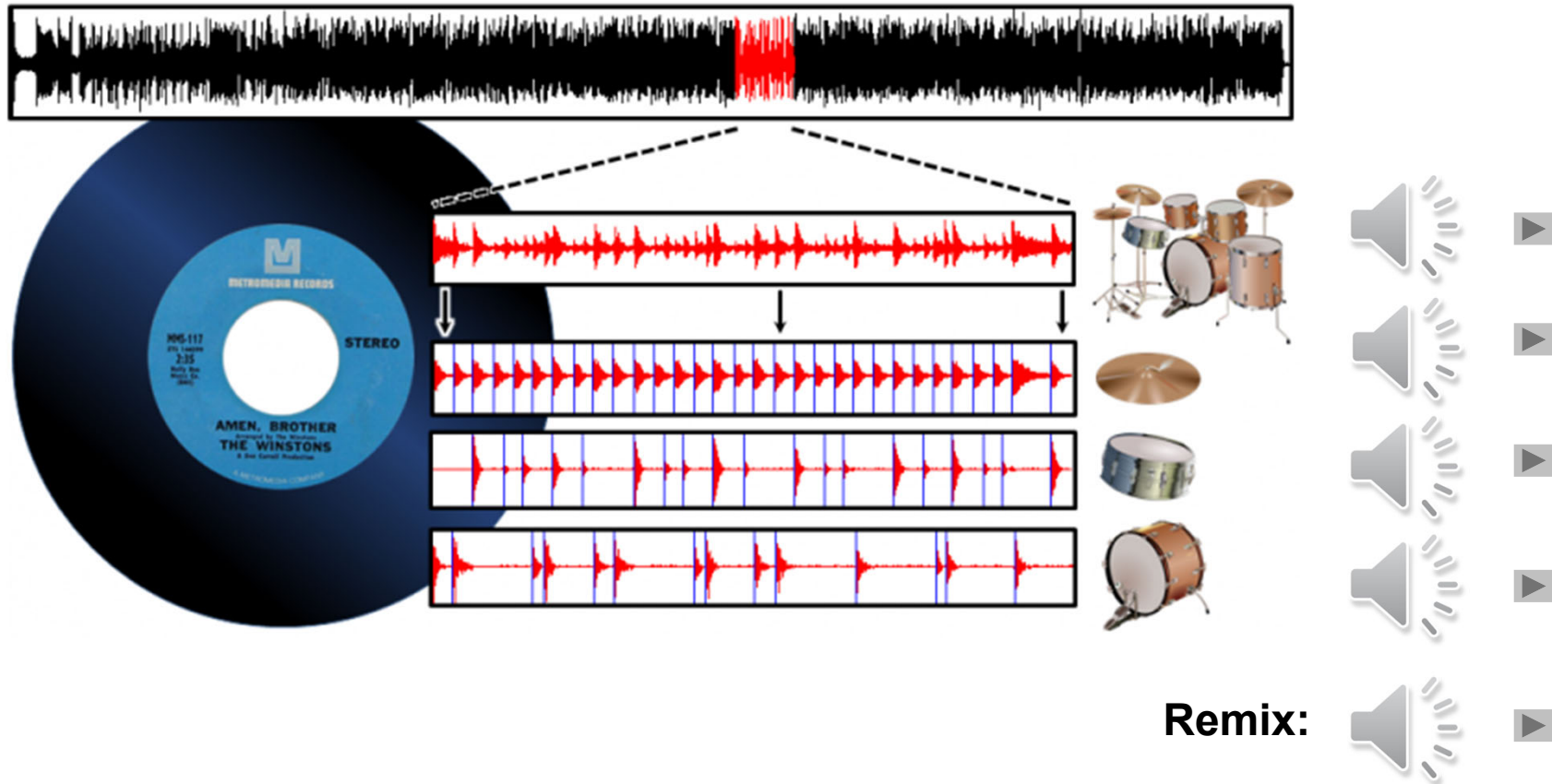


Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

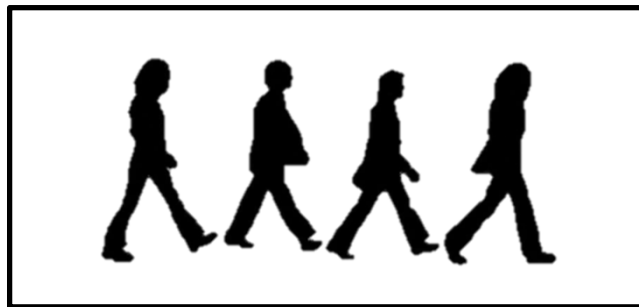
Informed Drum-Sound Decomposition



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles–Let it be



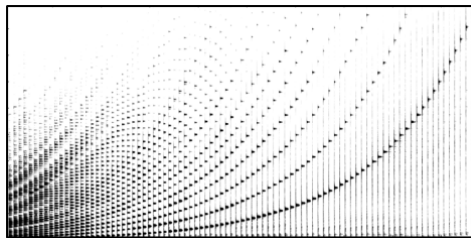
Source signal: Bees



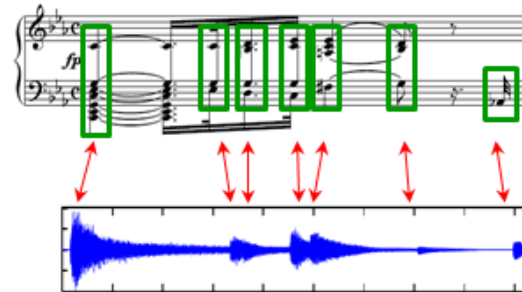
Mosaic signal: **Let it Bee**

Music Processing

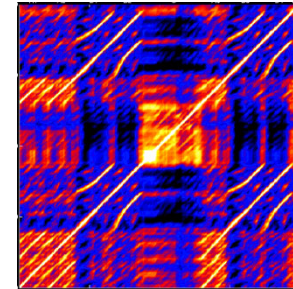
Fourier Transform Audio Features



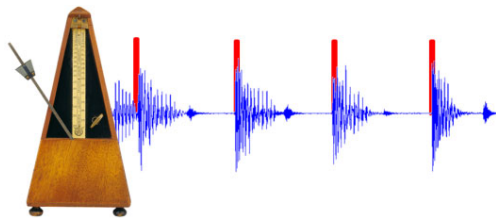
Music Synchronization



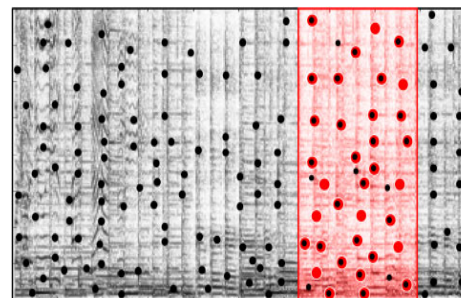
Structure Analysis



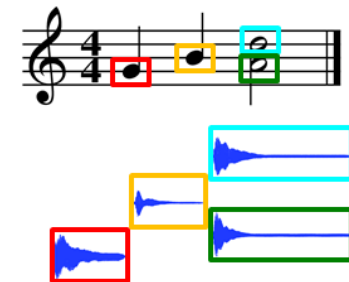
Tempo and Beat Tracking



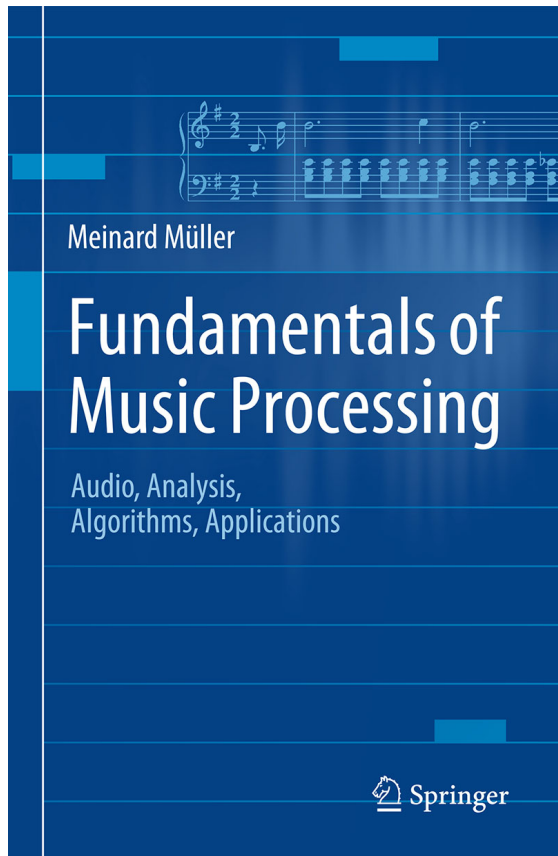
Audio Identification



Audio Decomposition



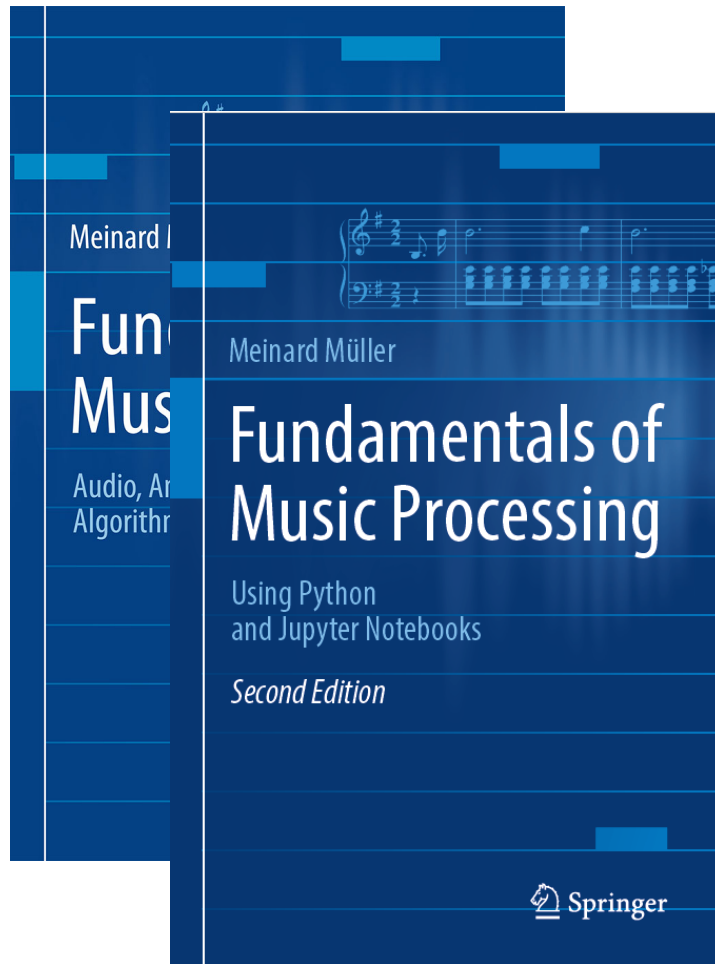
Fundamentals of Music Processing (FMP)



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

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)

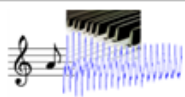

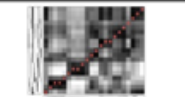
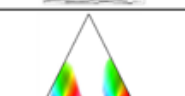

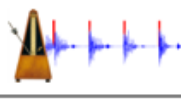




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2nd edition
Meinard Müller
Fundamentals of Music Processing
Using Python and Jupyter Notebooks
Springer, 2021

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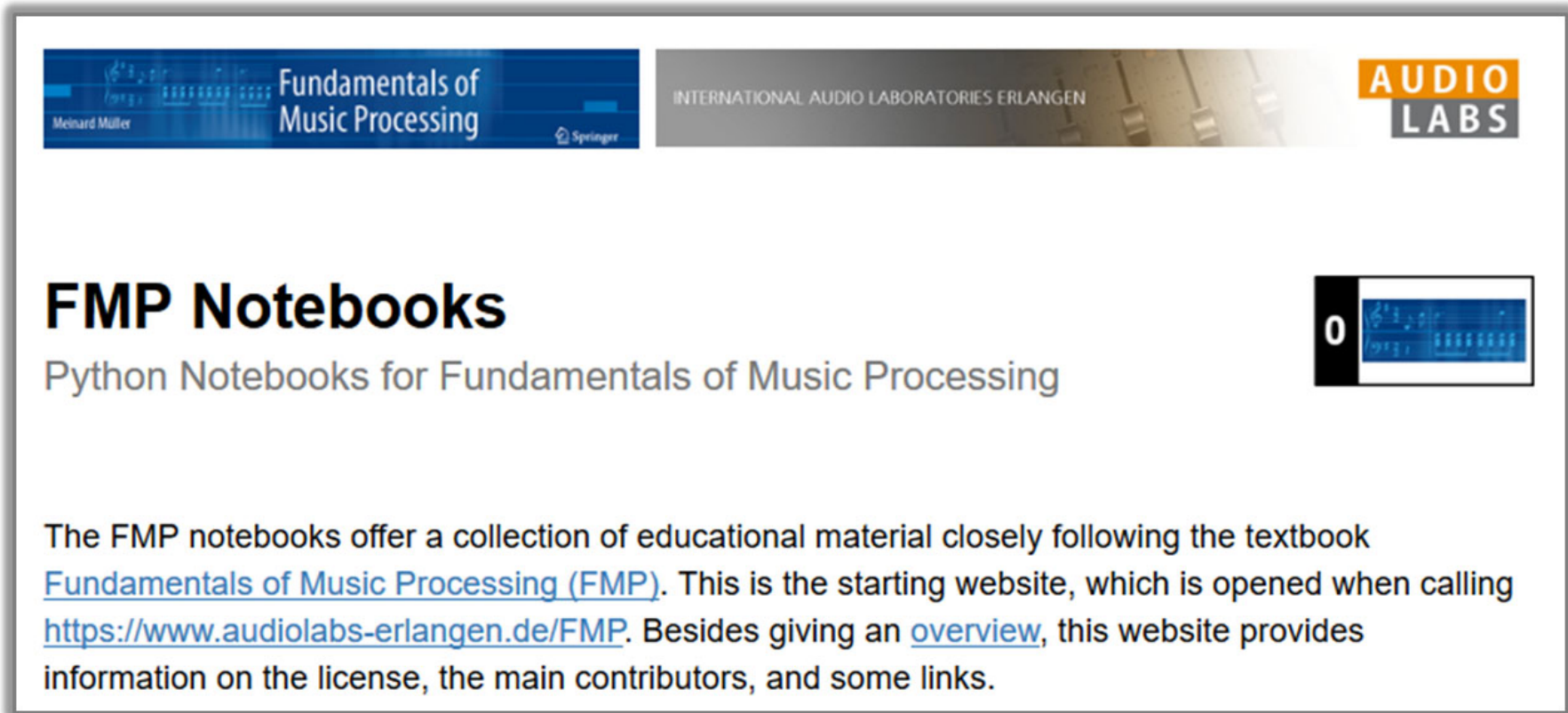
Chapter	Music Processing Scenario
1	 Music Representations
2	 Fourier Analysis of Signals
3	 Music Synchronization
4	 Music Structure Analysis
5	 Chord Recognition
6	 Tempo and Beat Tracking
7	 Content-Based Audio Retrieval
8	 Musically Informed Audio Decomposition

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Springer, 2021

FMP Notebooks: Education & Research



The screenshot shows the top banner of the FMP Notebooks website. On the left is the cover of the book 'Fundamentals of Music Processing' by Meinard Müller, published by Springer. In the center, it says 'INTERNATIONAL AUDIO LABORATORIES ERLANGEN'. On the right is the 'AUDIO LABS' logo. Below the banner, the title 'FMP Notebooks' is displayed in a large, bold font, followed by the subtitle 'Python Notebooks for Fundamentals of Music Processing'. To the right of the subtitle is a small icon of a notebook with a '0' on it. Below this, 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 also provides an overview, license information, and contributor details.

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

References (FMP Notebooks)

- Meinard Müller: Fundamentals of Music Processing – Using Python and Jupyter Notebooks. 2nd Edition, Springer, 2021.
<https://www.springer.com/gp/book/9783030698072>
- Meinard Müller and Frank Zalkow: libfmp: A Python Package for Fundamentals of Music Processing. Journal of Open Source Software (JOSS), 6(63): 1–5, 2021.
<https://joss.theoj.org/papers/10.21105/joss.03326>
- Meinard Müller: An Educational Guide Through the FMP Notebooks for Teaching and Learning Fundamentals of Music Processing. Signals, 2(2): 245–285, 2021.
<https://www.mdpi.com/2624-6120/2/2/18>
- Meinard Müller and Frank Zalkow: FMP Notebooks: Educational Material for Teaching and Learning Fundamentals of Music Processing. Proc. International Society for Music Information Retrieval Conference (ISMIR): 573–580, 2019.
<https://zenodo.org/record/3527872#.YOhEQOgzaUk>
- Meinard Müller, Brian McFee, and Katherine 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>