

Automatische Erschließung von Musikdaten

Meinard Müller

International Audio Laboratories Erlangen
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Symposium
Künstliche Intelligenz: Maschinelles Lernen und Mustererkennung
BAW, 22. Juli 2022



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

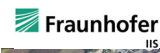


Meinard Müller: Research Group

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



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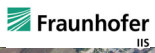


- Fraunhofer Institute for Integrated Circuits IIS
- Largest Fraunhofer institute with ≈ 1000 members
- Applied research for sensor, audio, and media technology



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

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- Largest Fraunhofer institute with ≈ 1000 members
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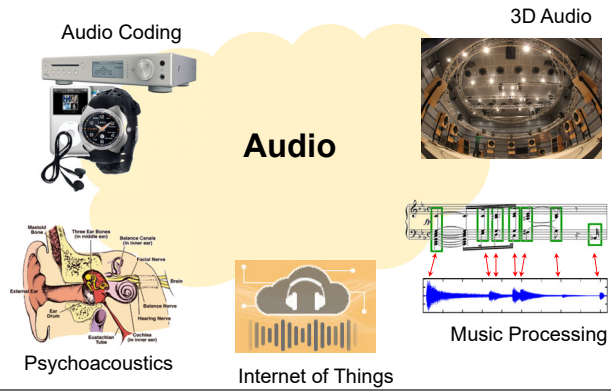


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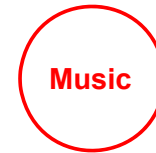
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Automatische Erschließung von Musikdaten

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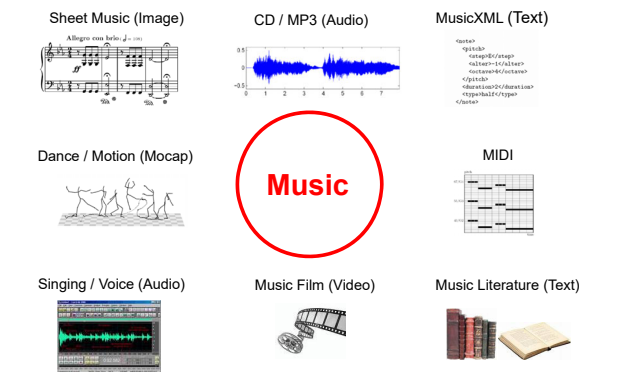
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Music Information Retrieval (MIR)



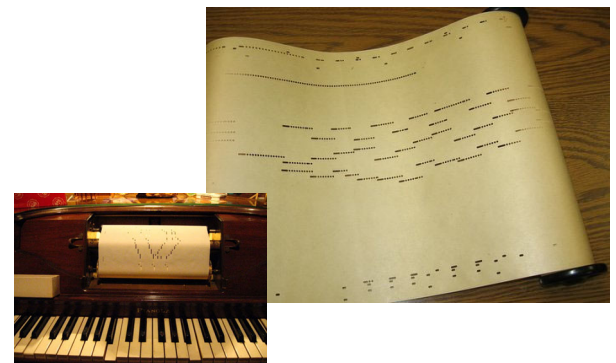
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Piano Roll Representation (1900)



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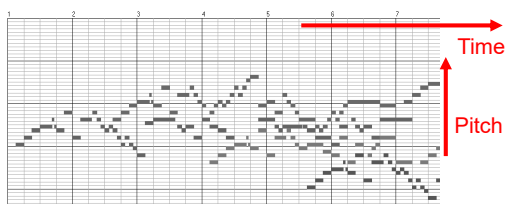
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Piano Roll Representation

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



Automatische Erschließung von Musikdaten

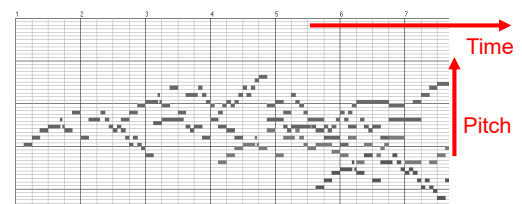
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Piano Roll Representation

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



Automatische Erschließung von Musikdaten

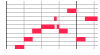
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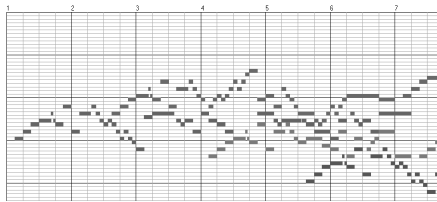


Piano Roll Representation

Query:



Goal: Find all occurrences of the query

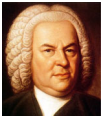


Piano Roll Representation

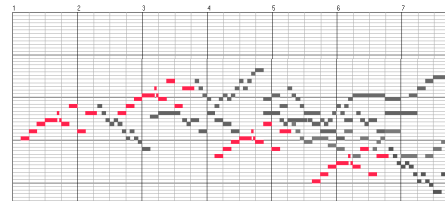
Query:



Goal: Find all occurrences of the query

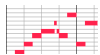


Matches:



Piano Roll Representation

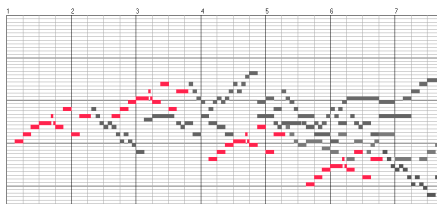
Query:



Goal: Find all occurrences of the query



Matches:



Music Retrieval

Query



Music Retrieval

Query

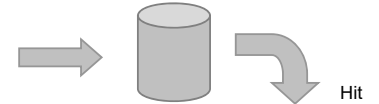


Music Retrieval

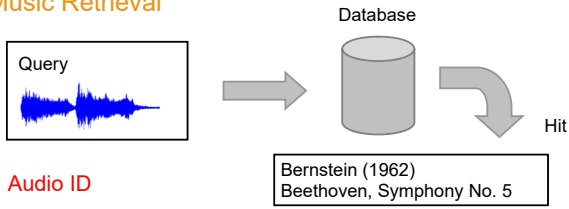
Query



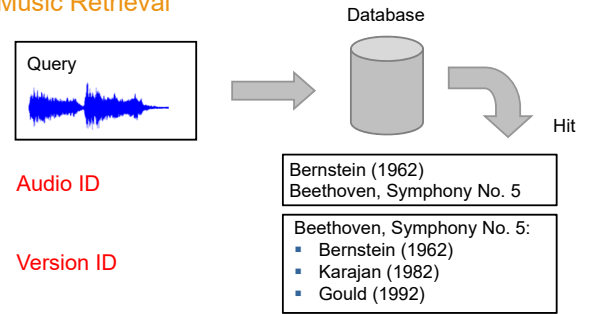
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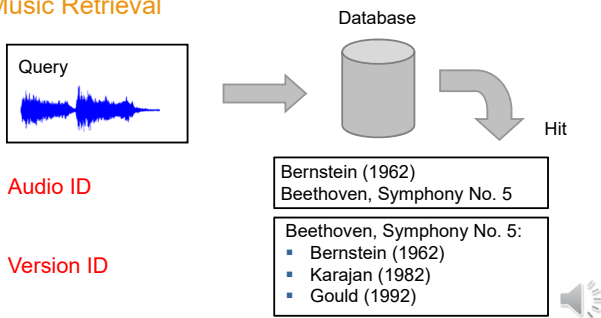
Music Retrieval



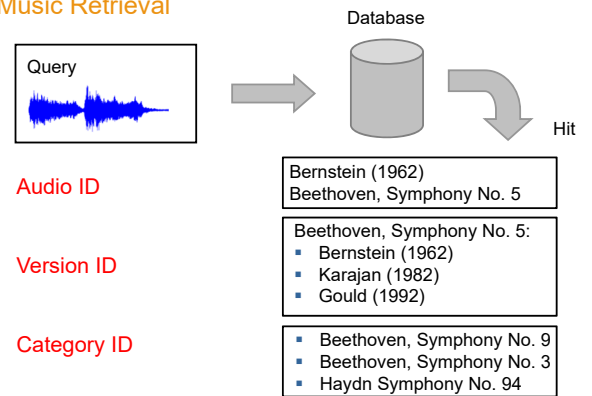
Music Retrieval



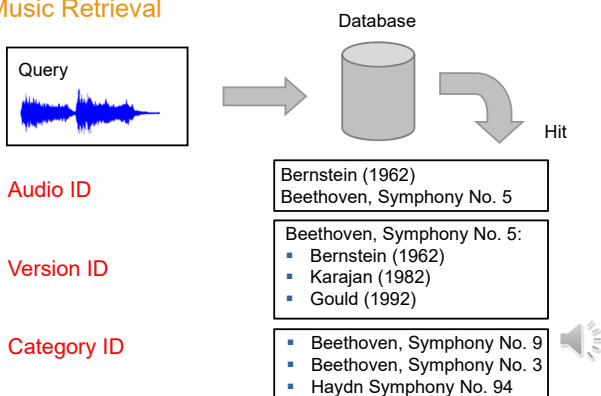
Music Retrieval



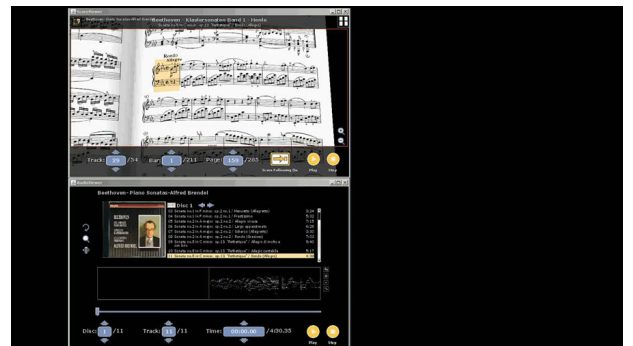
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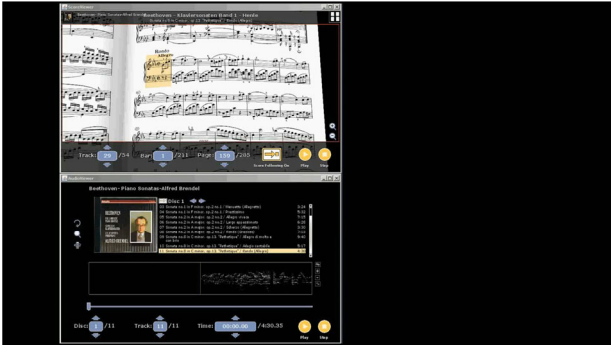
Music Retrieval



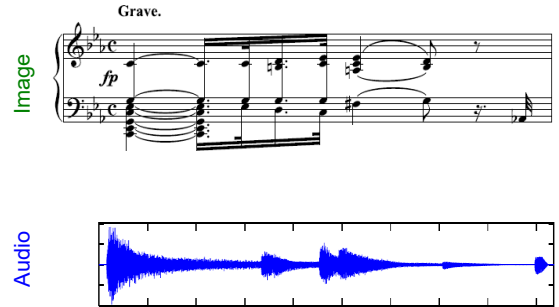
Music Synchronization



Music Synchronization

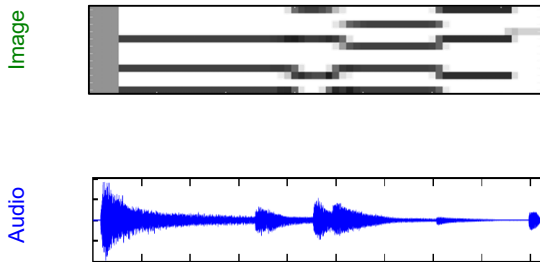


Music Synchronization: Image-Audio



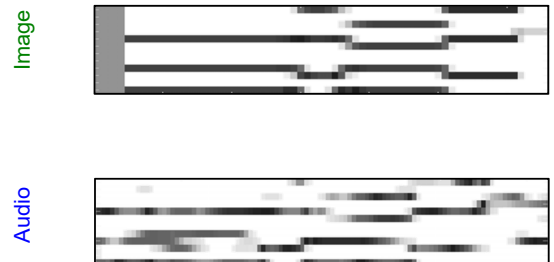
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition



Music Synchronization: Image-Audio

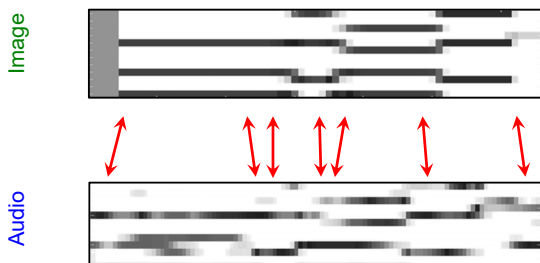
Image Processing: Optical Music Recognition



Audio Processing: Fourier Analysis

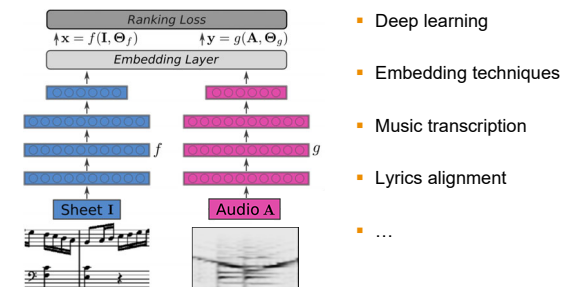
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition



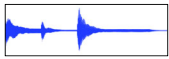
Audio Processing: Fourier Analysis

Music Synchronization: Image-Audio

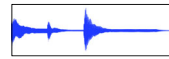
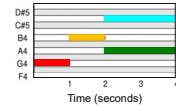


- Deep learning
- Embedding techniques
- Music transcription
- Lyrics alignment
- ...

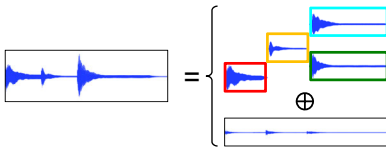
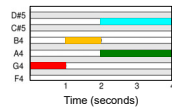
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

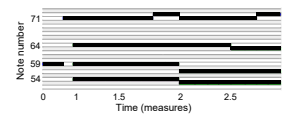


Score-Informed Audio Decomposition

Sheet music



Piano roll

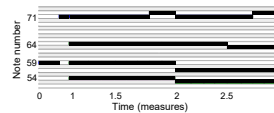


Score-Informed Audio Decomposition

Sheet music



Piano roll



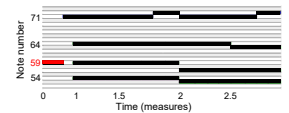
Score-Informed Audio Decomposition

Sheet music

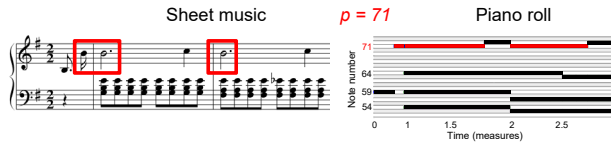


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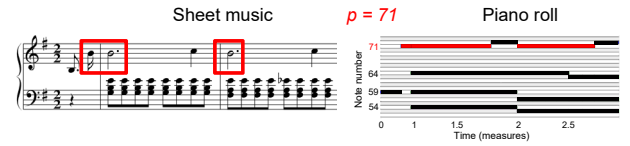
Piano roll



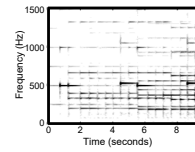
Score-Informed Audio Decomposition



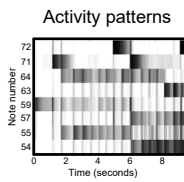
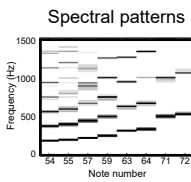
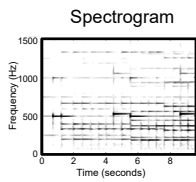
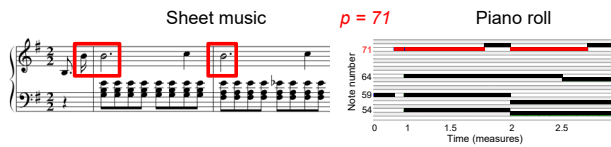
Score-Informed Audio Decomposition



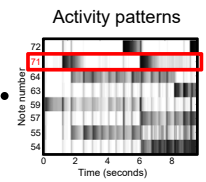
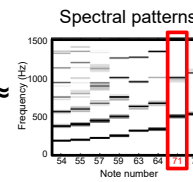
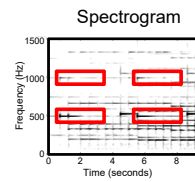
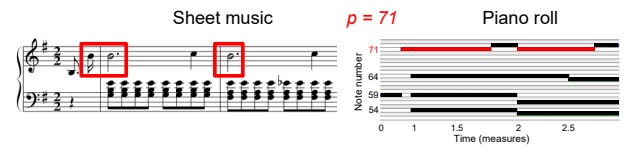
Spectrogram



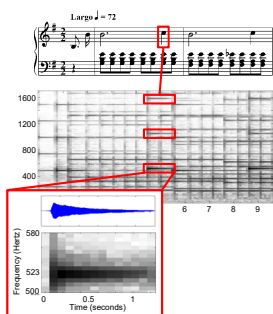
Score-Informed Audio Decomposition



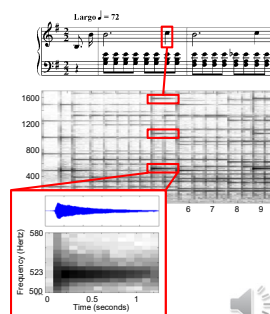
Score-Informed Audio Decomposition



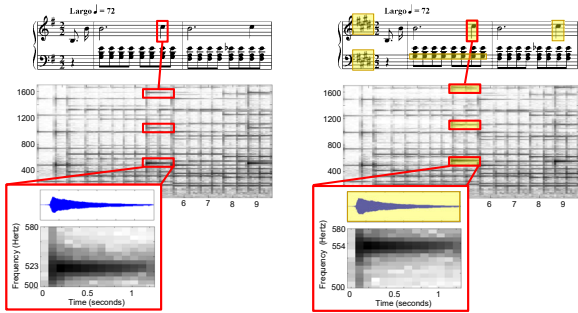
Score-Informed Audio Decomposition



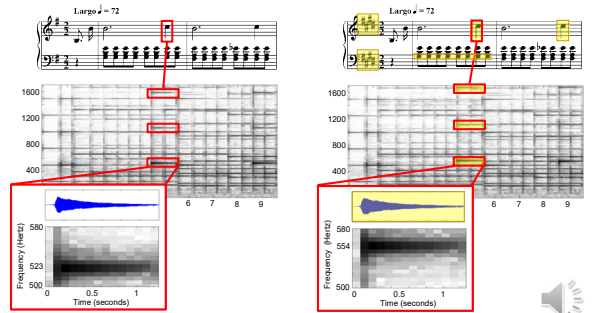
Score-Informed Audio Decomposition



Score-Informed Audio Decomposition



Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles—Let it be



Source signal: Bees



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles—Let it be



Source signal: Bees



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles—Let it be



Source signal: Bees



Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles—Let it be



Source signal: Bees



Mosaic signal: Let it Bee

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*

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3



Mazurka.

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

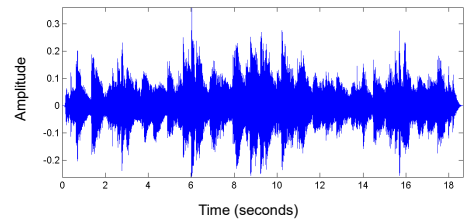
Allegretto.

41. *p*

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

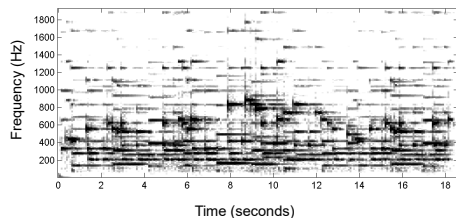
- Waveform



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

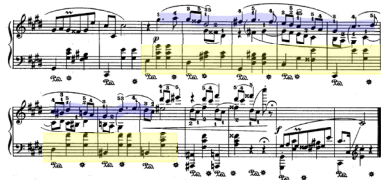
- Tempo
- Dynamics
- Note deviations
- Sustain pedal

- Polyphony

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram
- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal
- Polyphony

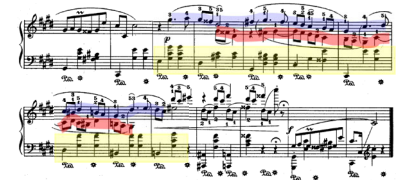


■ Main Melody
■ Accompaniment

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram
- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal
- Polyphony



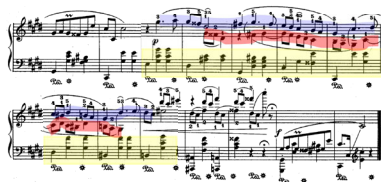
■ Main Melody
■ Additional melody line
■ Accompaniment

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3



- Waveform / Spectrogram
- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal
- Polyphony



■ 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"

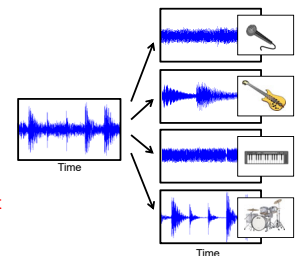


Source Separation

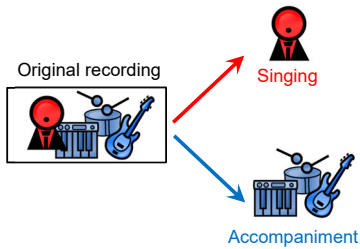
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- "Cocktail party effect"
- Several input signals
- Sources are assumed to be statistically independent

Source Separation (Music)

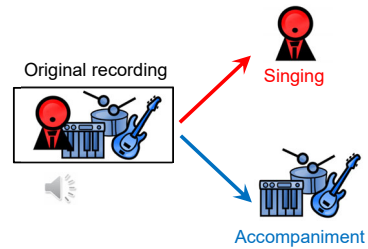
- Main melody, accompaniment, drum track
- Instrumental voices
- Individual note events
- Only mono or stereo
- Sources are often highly dependent



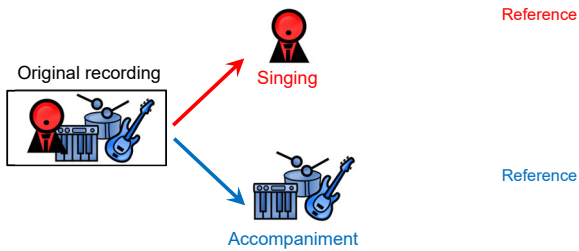
AI-Based Source Separation



AI-Based Source Separation

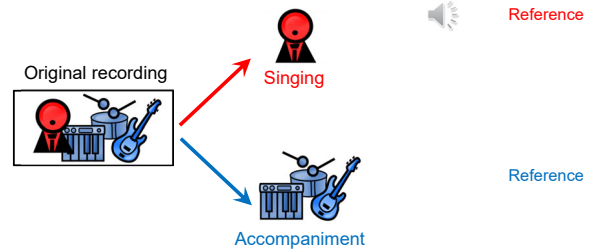


AI-Based Source Separation



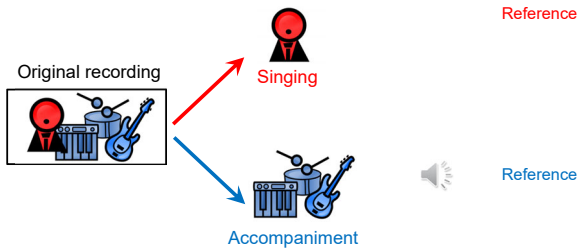
- Reference: Best possible result

AI-Based Source Separation



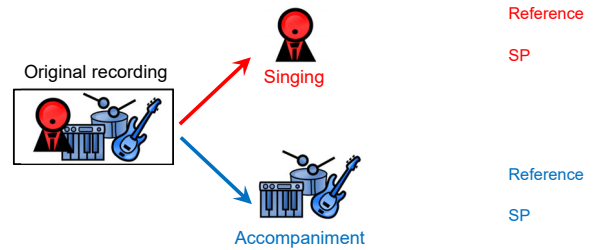
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AI-Based Source Separation



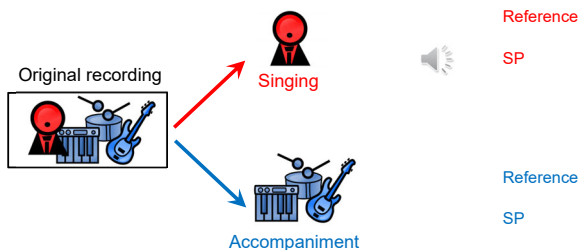
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AI-Based Source Separation



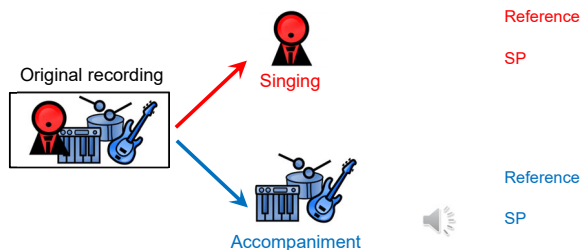
- Reference: Best possible result
- SP: Using traditional signal processing

AI-Based Source Separation



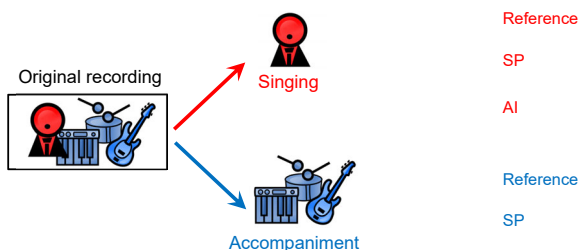
- Reference: Best possible result
- SP: Using traditional signal processing

AI-Based Source Separation



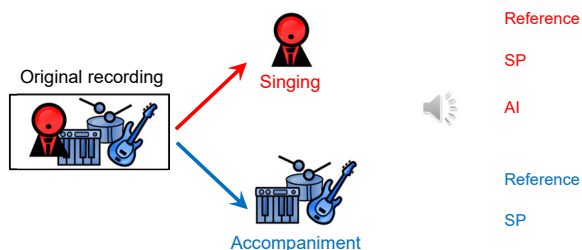
- Reference: Best possible result
- SP: Using traditional signal processing

AI-Based Source Separation



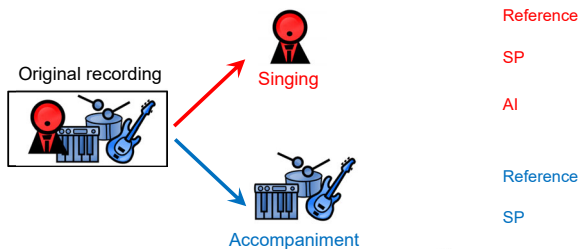
- Reference: Best possible result
- SP: Using traditional signal processing
- AI: Using data-driven approach

AI-Based Source Separation



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

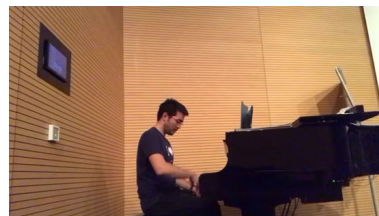
AI-Based Source Separation



- 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



Automatische Erschließung von Musikdaten

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AI-Based Source Separation

- Yigitcan Özer
- PhD student in engineering
- Pianist



Only Piano!



Where is the orchestra?



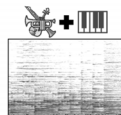
Automatische Erschließung von Musikdaten

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AI-Based Source Separation



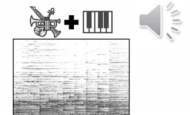
Automatische Erschließung von Musikdaten

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AI-Based Source Separation



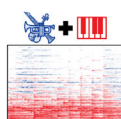
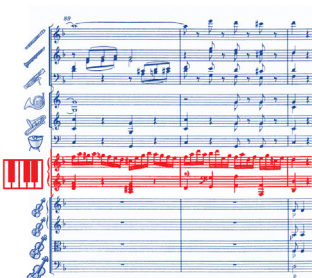
Automatische Erschließung von Musikdaten

76

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AI-Based Source Separation



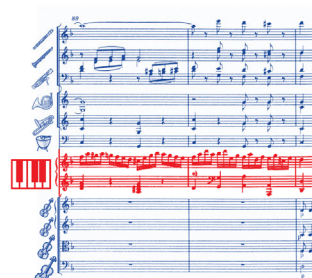
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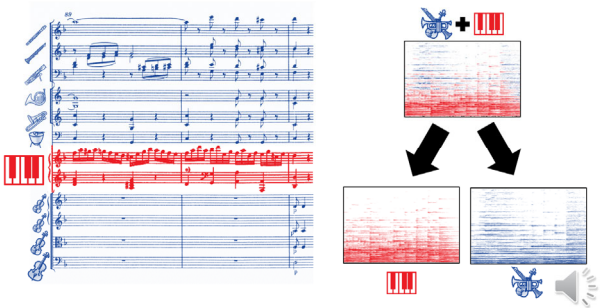
Automatische Erschließung von Musikdaten

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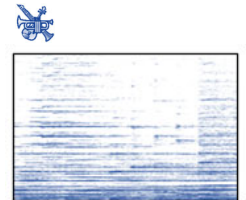
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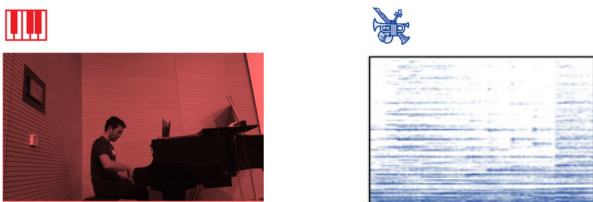
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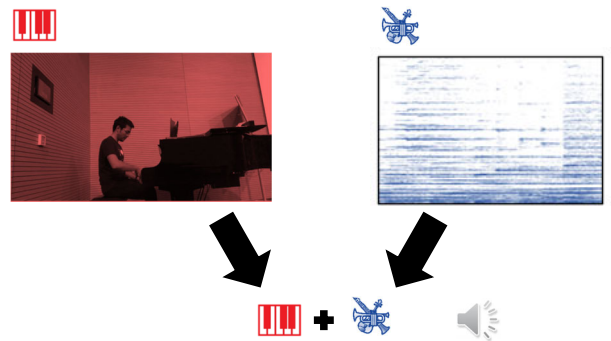
AI-Based Source Separation



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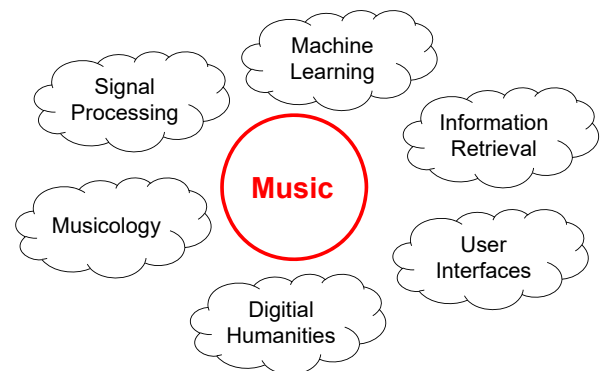
AI-Based Source Separation



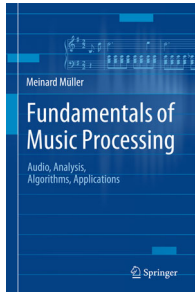
AI-Based Source Separation

- 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)



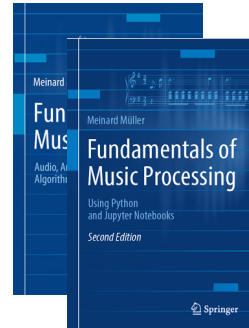
Fundamentals of Music Processing (FMP)



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

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)



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

Fundamentals of Music Processing (FMP)

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

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Fundamentals of Music Processing
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Springer, 2021

FMP Notebooks: Education & Research

FMP Notebooks
Python Notebooks for Fundamentals of Music Processing

The FMP notebooks offer a collection of educational material closely following the textbook *Fundamentals of Music Processing (FMP)*. 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.
<https://www.springer.com/gp/book/9783030698072>
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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>
- 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.
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- Meinard Müller, Brian McFee, and Katherine Kinnaid: 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>