

## Music Information Retrieval

When Music Meets Computer Science

**Meinard Müller**

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meinard.mueller@audiolabs-erlangen.de

Berlin MIR Meetup  
20.03.2017

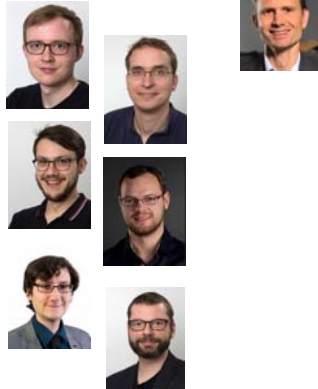
## Meinard Müller



- 2001 PhD, Bonn University
- 2002/2003 Postdoc, Keio University, Japan
- 2007 Habilitation, Bonn University  
"Information Retrieval for Music and Motion"
- 2007-2012 Senior Researcher  
Max-Planck Institut für Informatik, Saarland
- 2012: Professor  
Semantic Audio Processing  
Universität Erlangen-Nürnberg

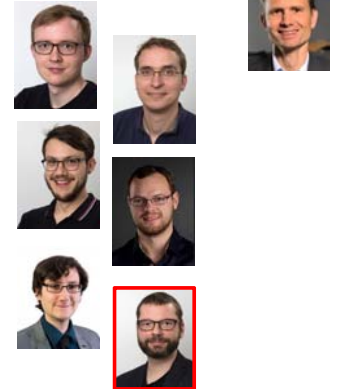
## Group Members

- Stefan Balke
- Christian Dittmar
- Patricio López-Serrano
- Christof Weiß
- Frank Zalkow
- Thomas Prätzlich

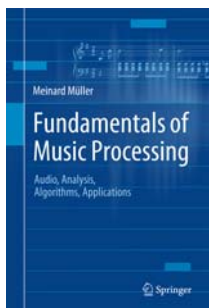


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## Book: Fundamentals of Music Processing



Meinard Müller  
Fundamentals of Music Processing  
Audio, Analysis, Algorithms, Applications  
483 p., 249 illus., 30 illus. in color, hardcover  
ISBN: 978-3-319-21944-8  
Springer, 2015

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

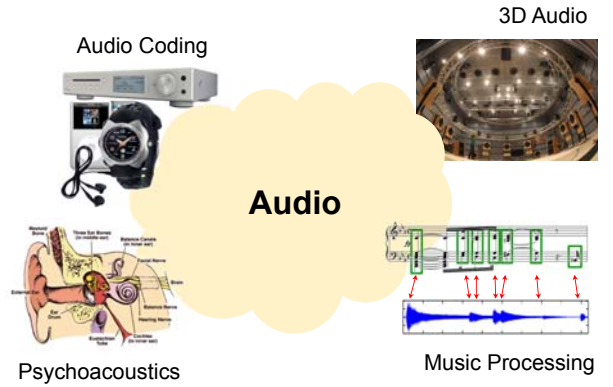
## International Audio Laboratories Erlangen



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Audio

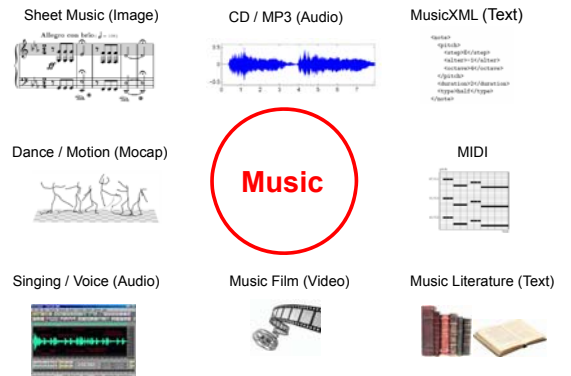
## International Audio Laboratories Erlangen



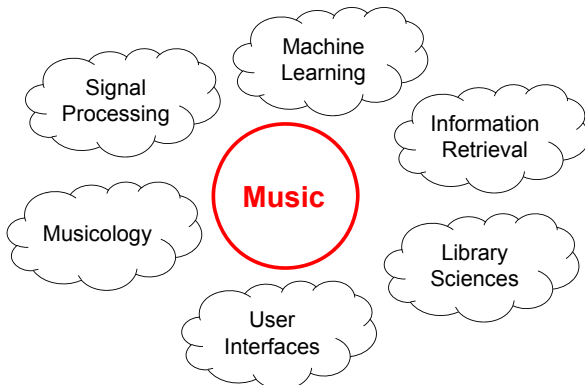
Music



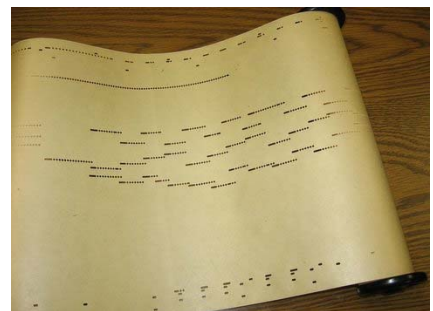
## Music Information Retrieval



## Music Information Retrieval



## Piano Roll Representation



## Player Piano (1900)



## Piano Roll Representation (MIDI)

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

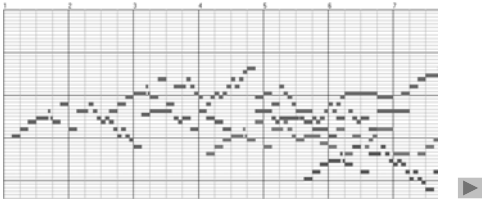


## Piano Roll Representation (MIDI)

Query:



Goal: Find all occurrences of the query



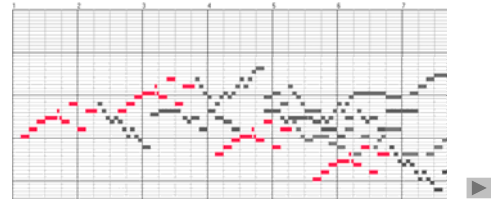
## Piano Roll Representation (MIDI)

Query:

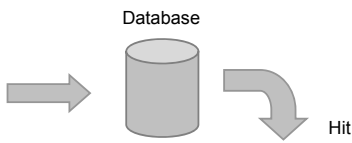


Goal: Find all occurrences of the query

Matches:



## Music Retrieval



Audio-ID

Version-ID

Category-ID

Bernstein (1962)  
Beethoven, Symphony No. 5

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

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

## Music Synchronization: Audio-Audio

Beethoven's Fifth

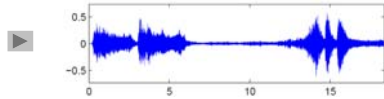


## Music Synchronization: Audio-Audio

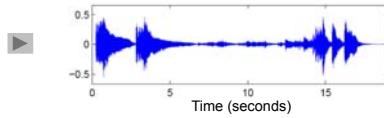
Beethoven's Fifth



Orchester (Karajan)



Piano (Scherbakov)



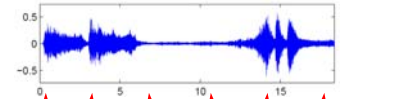
Time (seconds)

## Music Synchronization: Audio-Audio

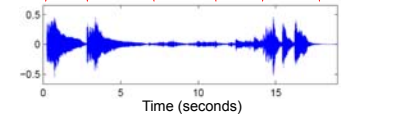
Beethoven's Fifth



Orchester (Karajan)



Piano (Scherbakov)

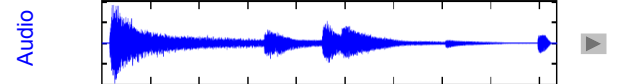


Time (seconds)

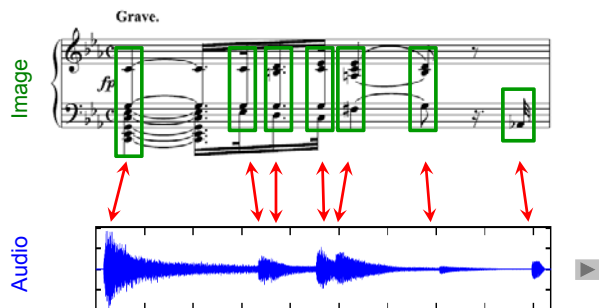
## Application: Interpretation Switcher



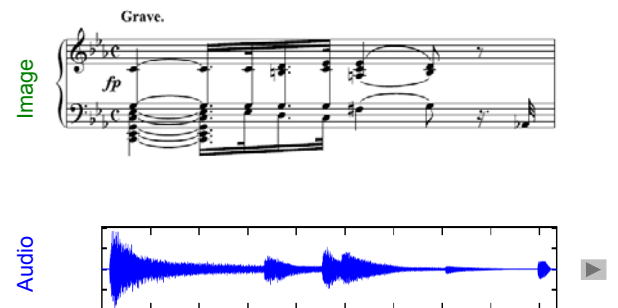
## Music Synchronization: Image-Audio



## Music Synchronization: Image-Audio

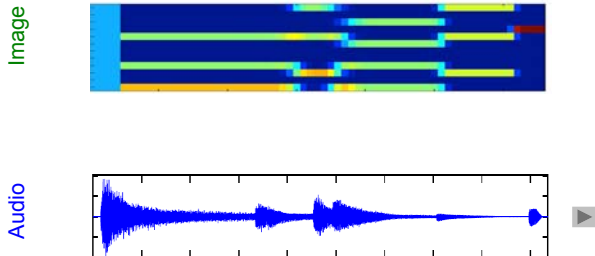


## How to make the data comparable?



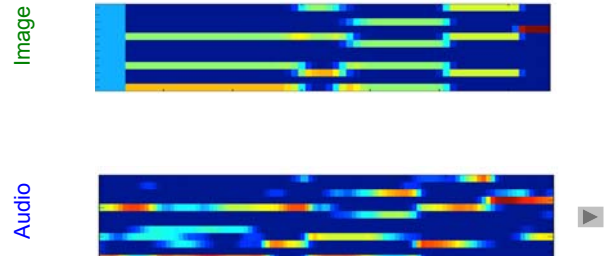
How to make the data comparable?

Image Processing: Optical Music Recognition



How to make the data comparable?

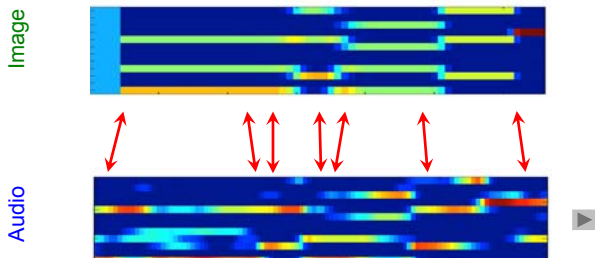
Image Processing: Optical Music Recognition



Audio Processing: Fourier Analysis

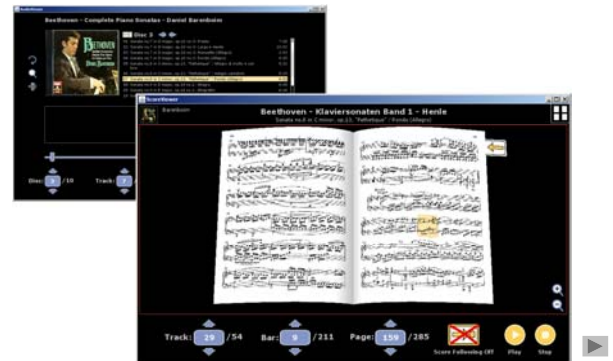
How to make the data comparable?

Image Processing: Optical Music Recognition



Audio Processing: Fourier Analysis

Application: Score Viewer



Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?

Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?

## Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?
Identify despite of differences	Identify the differences

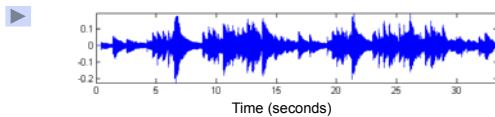
## Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
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Identify despite of differences	Identify the differences
Example tasks: <b>Audio Matching</b> <b>Cover Song Identification</b>	Example tasks: <b>Tempo Estimation</b> <b>Performance Analysis</b>

## Performance Analysis

Schumann: Träumerei

Performance:



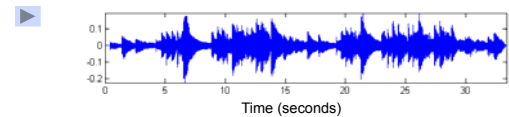
## Performance Analysis

Schumann: Träumerei

Score (reference):



Performance:



## Performance Analysis

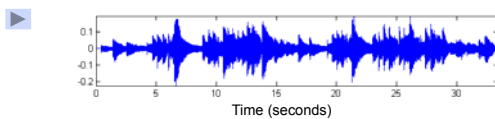
Schumann: Träumerei

Score (reference):



**Strategy: Compute score-audio synchronization and derive tempo curve**

Performance:



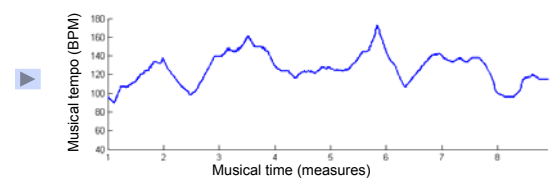
## Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curve:



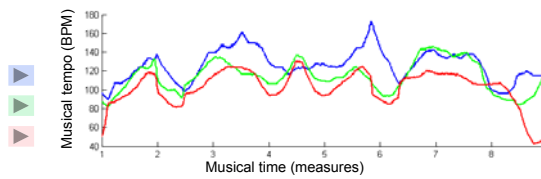
## Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:



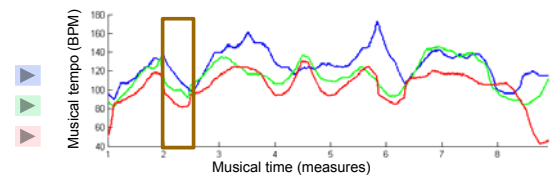
## Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:



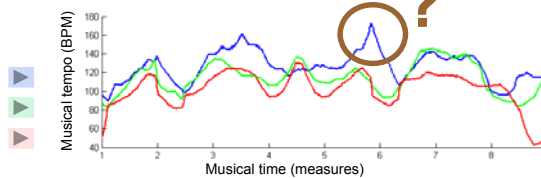
## Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:

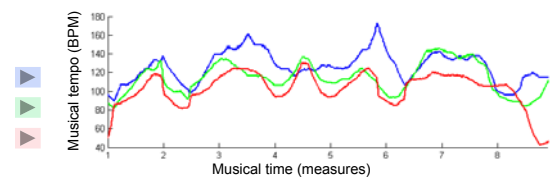


## Performance Analysis

Schumann: Träumerei

**What can be done if no reference is available?**

Tempo Curves:



## Music Processing

Relative	Absolute
Given: Several versions	Given: One version

## Music Processing

Relative	Absolute
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Comparison of extracted parameters	Direct interpretation of extracted parameters

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Extraction errors have often no consequence on final result	Extraction errors immediately become evident

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Relative	Absolute
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Comparison of extracted parameters	Direct interpretation of extracted parameters
Extraction errors have often no consequence on final result	Extraction errors immediately become evident
Example tasks: <b>Music Synchronization</b> <b>Genre Classification</b>	Example tasks: <b>Music Transcription</b> <b>Tempo Estimation</b>

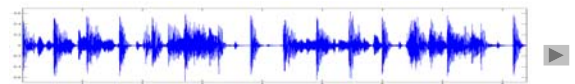
## Tempo Estimation and Beat Tracking

Basic task: "Tapping the foot when listening to music"

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Example: Queen – Another One Bites The Dust

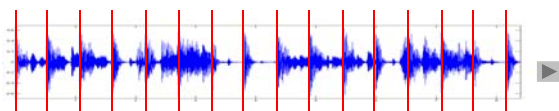


Time (seconds)

## Tempo Estimation and Beat Tracking

Basic task: "Tapping the foot when listening to music"

Example: Queen – Another One Bites The Dust



Time (seconds)



## Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

Pulse level: **Measure**

Musical notation for 'Happy Birthday to you' in 3/4 time. The top staff shows the melody with lyrics: 'Hap - py Birth - day to you, Hap - py Birth - day to you, Hap - py'. The bottom staff shows the bass line with lyrics: 'Birth - day dear \_\_\_\_\_, Hap - py Birth - day to you!'. Red arrows point to the first note of each measure in the melody.



## Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

Pulse level: **Tactus (beat)**



## Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

Pulse level: **Tatum (temporal atom)**



## Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: ???

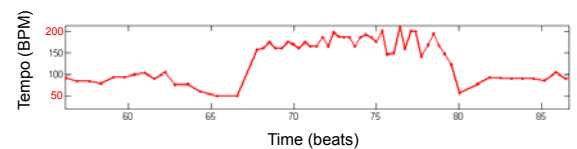
## Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: **50-200 BPM**

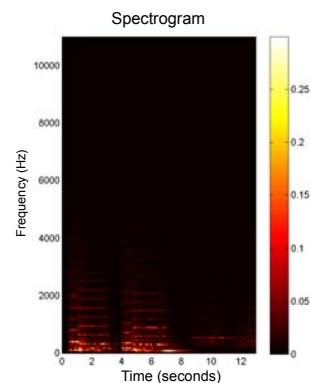
Tempo curve



## Tempo Estimation and Beat Tracking

- Which temporal level?
- Local tempo deviations
- Sparse information (e.g., only note onsets available)
- Vague information (e.g., extracted note onsets corrupt)

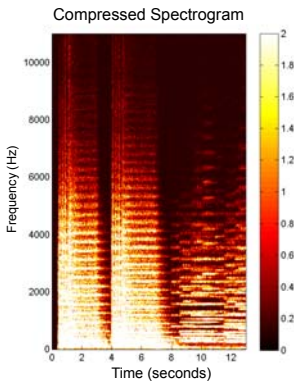
## Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram

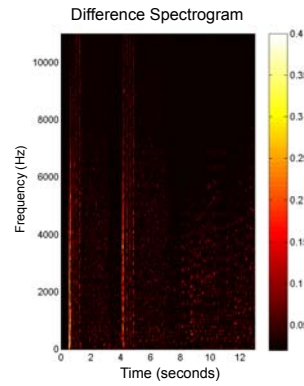
## Tempo Estimation and Beat Tracking



**Steps:**

1. Spectrogram
2. Log Compression

## Tempo Estimation and Beat Tracking



**Steps:**

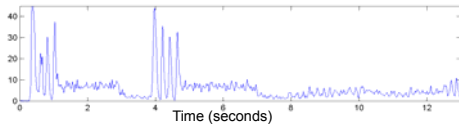
1. Spectrogram
2. Log Compression
3. Differentiation

## Tempo Estimation and Beat Tracking

**Steps:**

1. Spectrogram
2. Log Compression
3. Differentiation
4. Accumulation

**Novelty Curve**

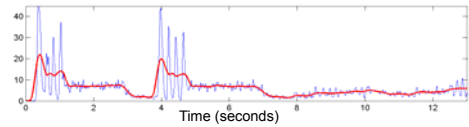


## Tempo Estimation and Beat Tracking

**Steps:**

1. Spectrogram
2. Log Compression
3. Differentiation
4. Accumulation

**Novelty Curve  
Local Average**

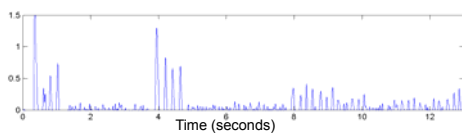


## Tempo Estimation and Beat Tracking

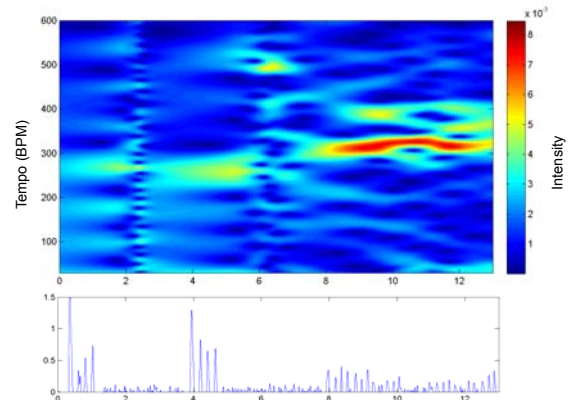
**Steps:**

1. Spectrogram
2. Log Compression
3. Differentiation
4. Accumulation
5. Normalization

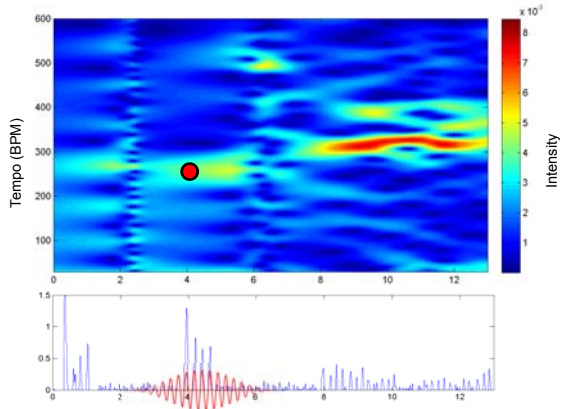
**Novelty Curve**



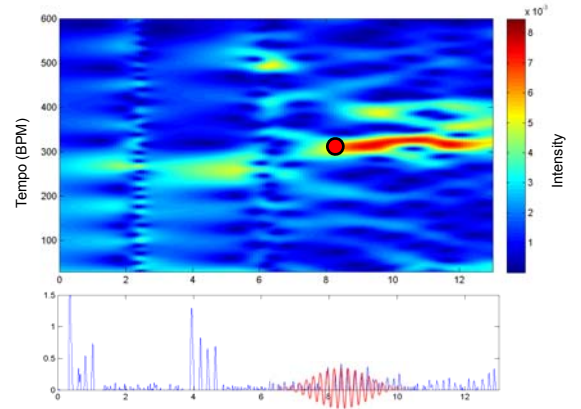
## Tempo Estimation and Beat Tracking



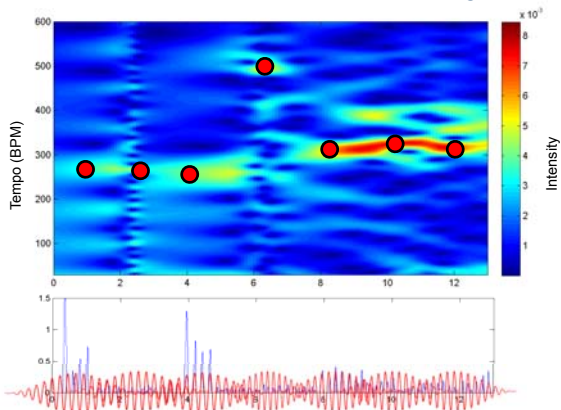
### Tempo Estimation and Beat Tracking



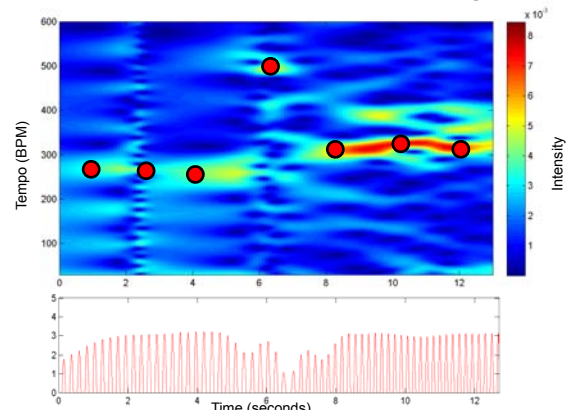
### Tempo Estimation and Beat Tracking



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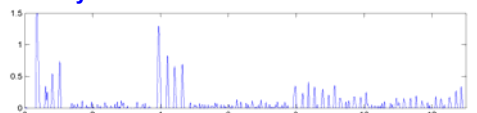
### Tempo Estimation and Beat Tracking



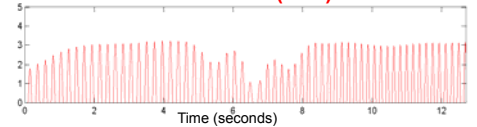
### Tempo Estimation and Beat Tracking



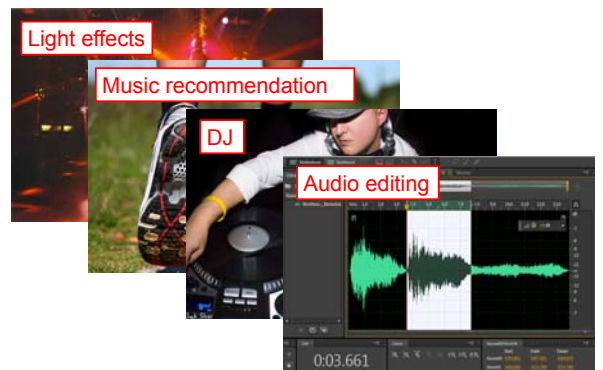
#### Novelty Curve





#### Predominant Local Pulse (PLP)



### 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.

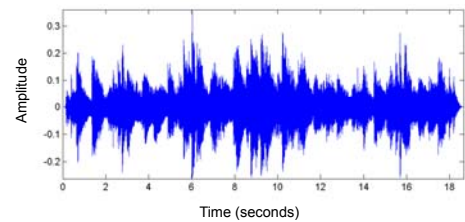
41. *p*



## Why is Music Processing Challenging?

**Example:** Chopin, Mazurka Op. 63 No. 3

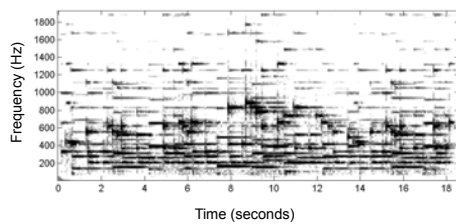
- Waveform



## 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

## 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”

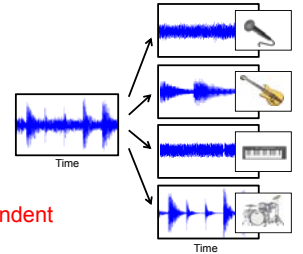


## Source Separation

- 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)

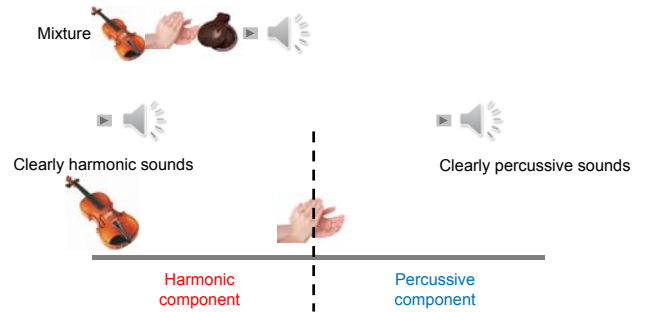
- Main melody, accompaniment, drum track
- Instrumental voices
- Individual note events
- Only mono or stereo
- Sources are often highly dependent



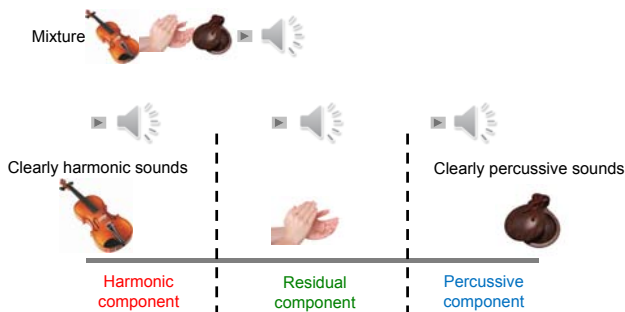
## Harmonic-Percussive Decomposition



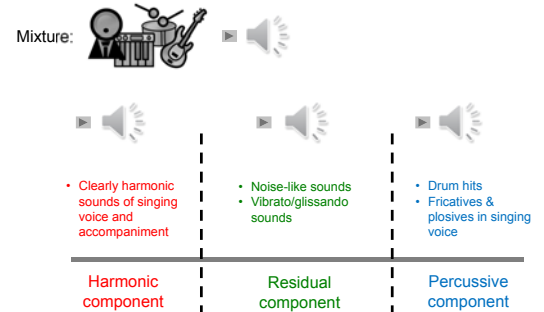
## Harmonic-Percussive Decomposition



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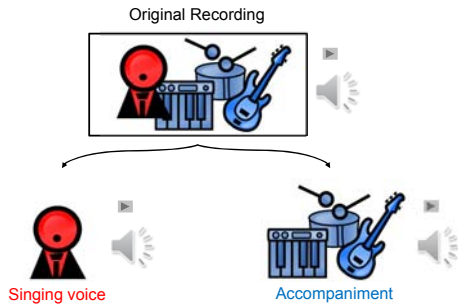


## Harmonic-Percussive Decomposition

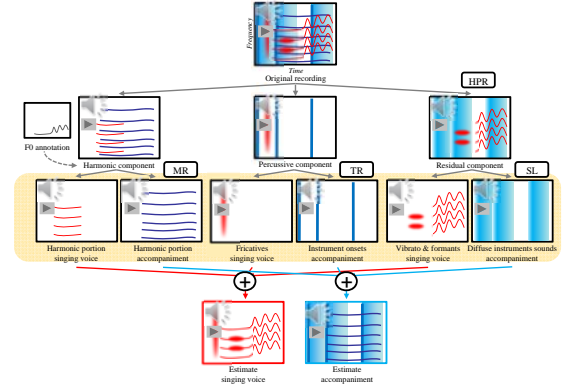


Literature: [Driedger/Müller/Disch, ISMIR 2014]  
Demo: <https://www.audiolabs-erlangen.de/resources/2014-ISMIR-ExtHPSep/>

## Singing Voice Extraction

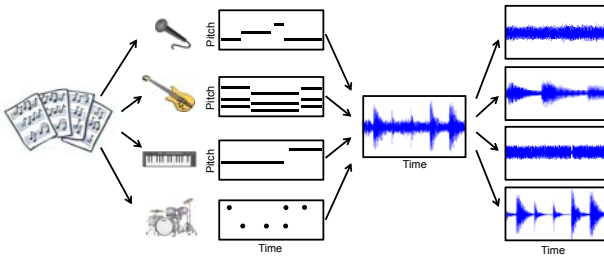


## Singing Voice Extraction



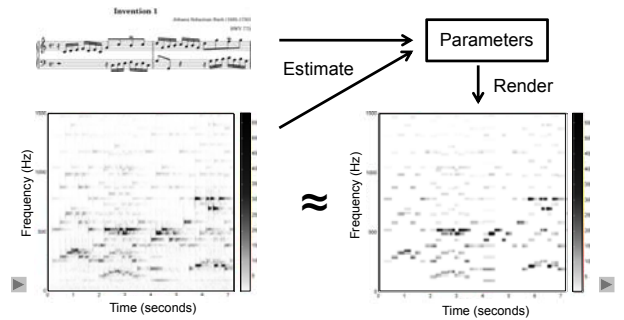
## Score-Informed Source Separation

Exploit musical score to support separation process

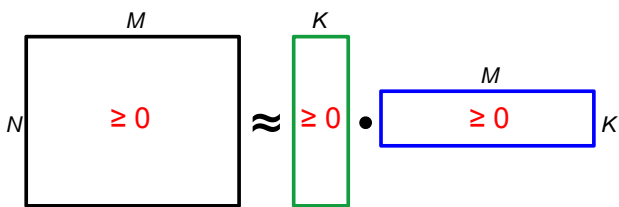


## Parametric Model Approach

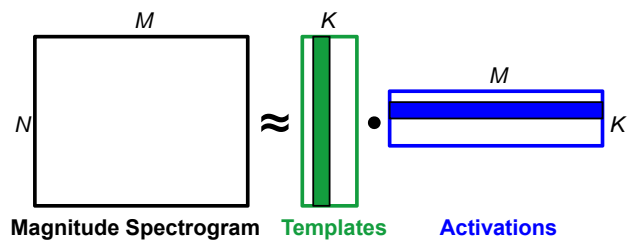
Rebuild spectrogram information



## NMF (Nonnegative Matrix Factorization)



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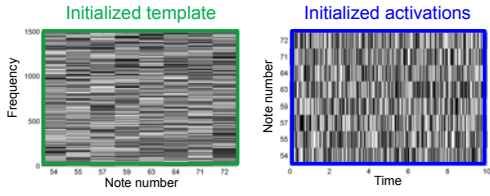
Templates: Pitch + Timbre

Activations: Onset time + Duration

“How does it sound”

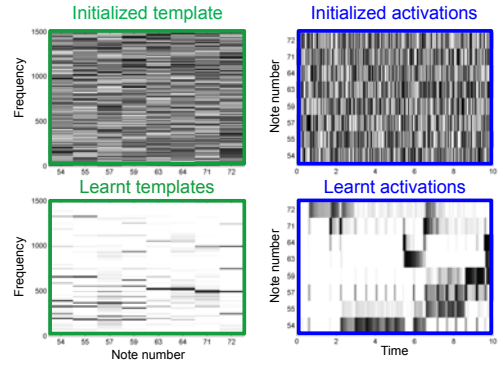
“When does it sound”

## NMF-Decomposition



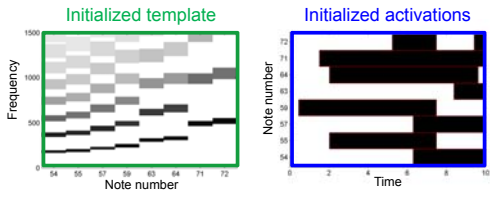
Random initialization

## NMF-Decomposition



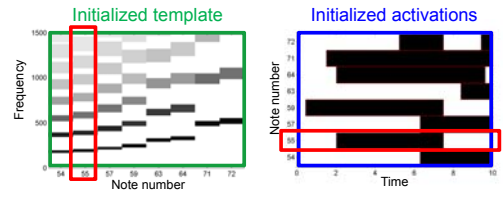
Random initialization → No semantic meaning

## NMF-Decomposition



Constrained initialization

## NMF-Decomposition

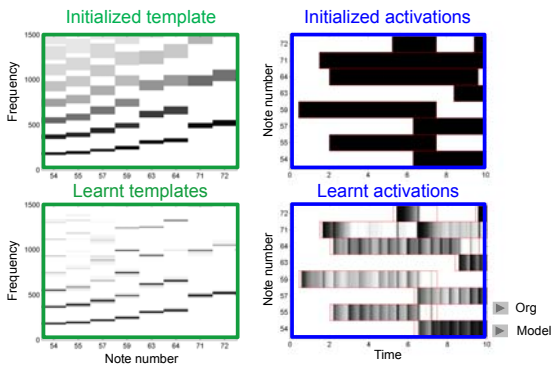


Template constraint for  $p=55$

Activation constraints for  $p=55$

Constrained initialization

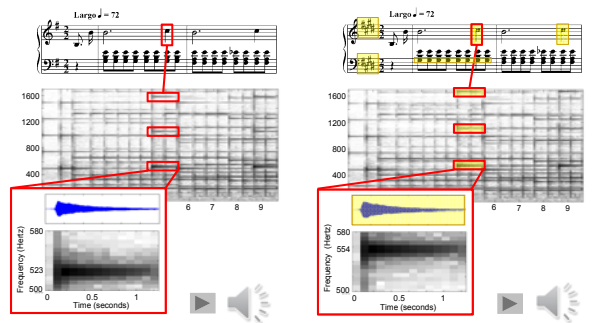
## NMF-Decomposition



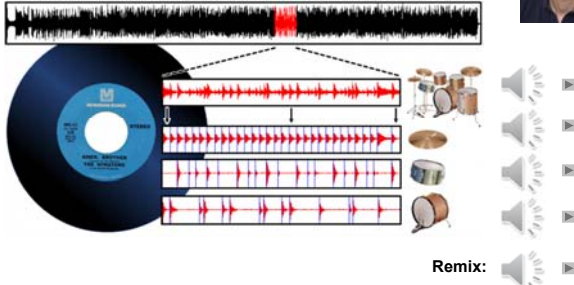
Constrained initialization → NMF as refinement

## Score-Informed Audio Decomposition

Application: Audio editing

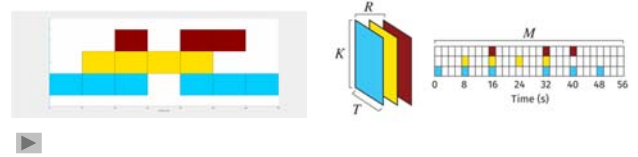


## Informed Drum-Sound Decomposition



Literature: [Dittmar/Müller, IEEE/ACM-TASLP 2016]  
 Demo: <https://www.audiolabs-erlangen.de/resources/MIR/2016-IEEE-TASLP-DrumSeparation>

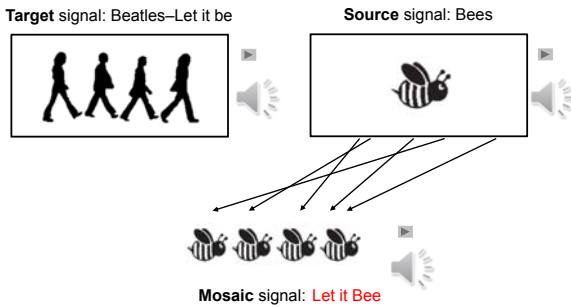
## Loop Decomposition of EDM



Decomposition      Patterns      Activations

Literature: [López-Serrano/Dittmar/Müller, ISMIR 2016]  
 Demo: <https://www.audiolabs-erlangen.de/resources/MIR/2016-ISMIR-EMLoop>

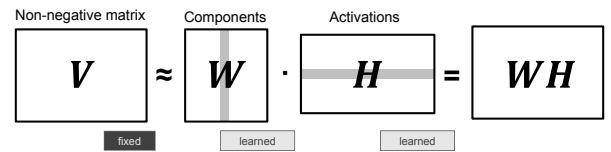
## Audio Mosaicing



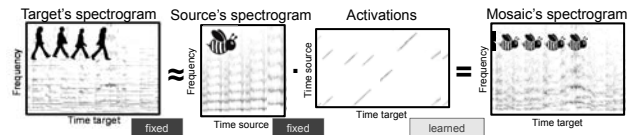
Literature: [Driedger/Müller, ISMIR 2015]  
 Demo: <https://www.audiolabs-erlangen.de/resources/MIR/2015-ISMIR-LetttBee>

## NMF-Inspired Audio Mosaicing

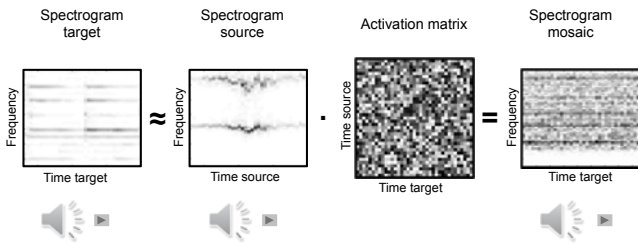
### Non-negative matrix factorization (NMF)



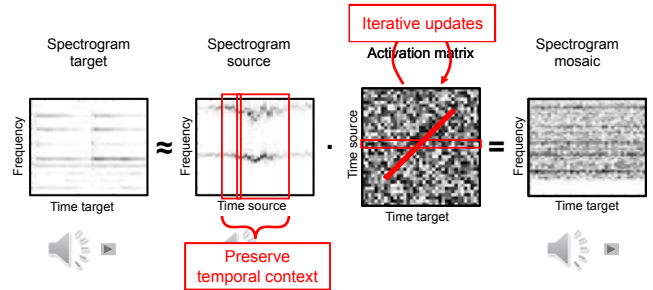
### Proposed audio mosaicing approach



## NMF-Inspired Audio Mosaicing



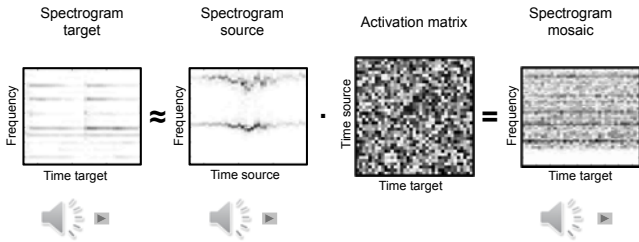
## NMF-Inspired Audio Mosaicing



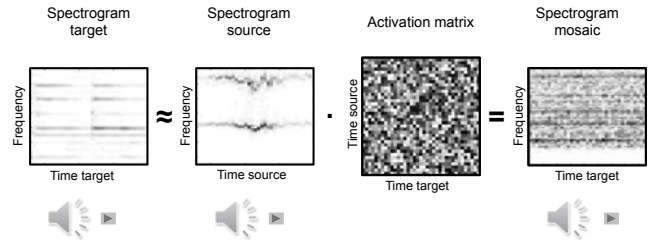
Core idea: support the development of sparse diagonal activation structures



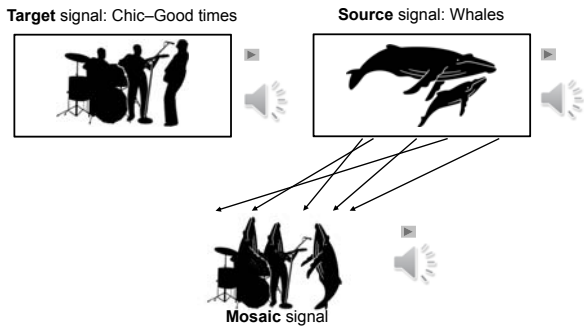
## NMF-Inspired Audio Mosaicing



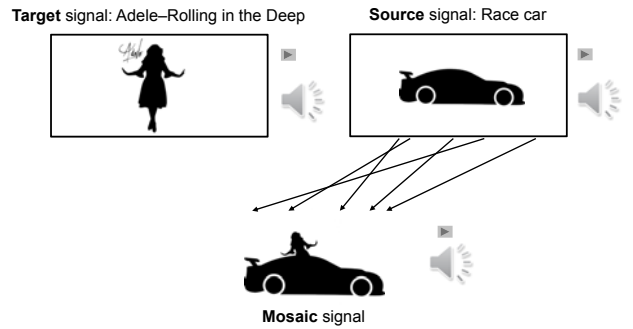
## NMF-Inspired Audio Mosaicing



## Audio Mosaicing



## Audio Mosaicing



## Motivic Similarity

Var. 4: Vivace

The image shows a musical score for 'Var. 4: Vivace' in bass clef, 2/4 time. It consists of four staves of music. A play button is located at the bottom left.

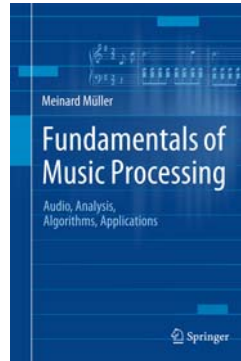
## Motivic Similarity

The image shows a musical score for 'Motivic Similarity' in treble clef, 4/4 time. It features a vocal line with lyrics: 'auf - ge - raff, und nie - mand ach - tet drauf'. A red box highlights a specific melodic motif in the vocal line. A play button is located at the bottom right.

## Summary

- Music information retrieval
- Audio decomposition techniques
- Machine learning
- Music applications & musicology
- Multimedia scenarios
- Web-based interfaces
- Teaching
- Academic training of students
- Fundamental research

## Book: Fundamentals of Music Processing



Meinard Müller  
Fundamentals of Music Processing  
Audio, Analysis, Algorithms, Applications  
483 p., 249 illus., hardcover  
ISBN: 978-3-319-21944-8  
Springer, 2015

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

## Book: Fundamentals of Music Processing

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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## MIR-Related Events in Germany

AES Conference on  
Semantic Audio  
22 – 24 June 2017  
Erlangen



GI Jahrestagung  
25 – 29 September 2017  
Chemnitz



- Workshop: Musik trifft Informatik  
26 September 2017
- Tutorial: Musikverarbeitung  
25 September 2017