Music Information Retrieval

When Music Meets Computer Science

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Berlin MIR Meetup
20.03.2017

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Fraunhofer IIS

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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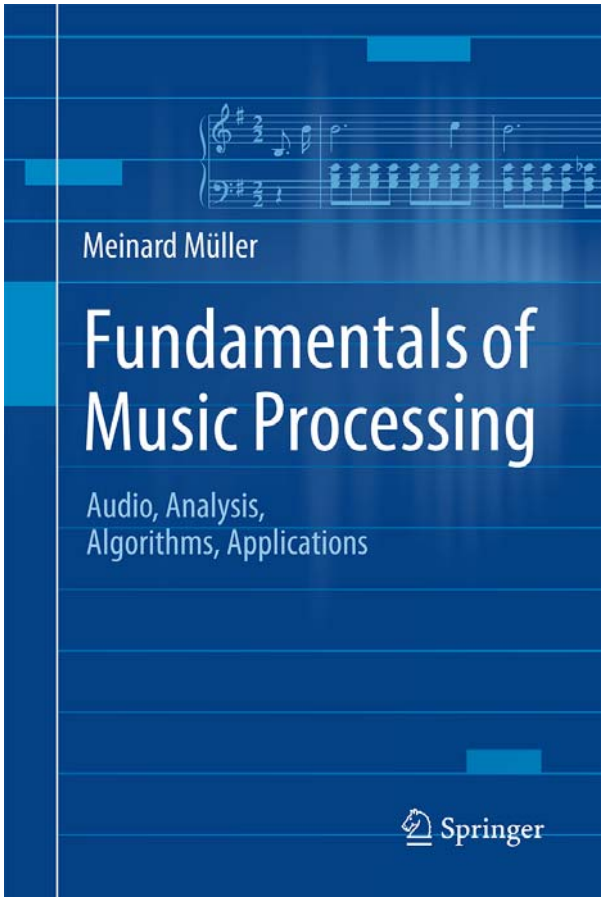
Book: Fundamentals of Music Processing



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

International Audio Laboratories Erlangen

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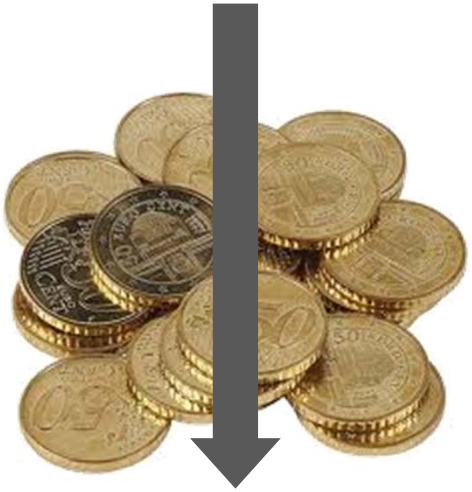
mp3



FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

AUDIO LABS

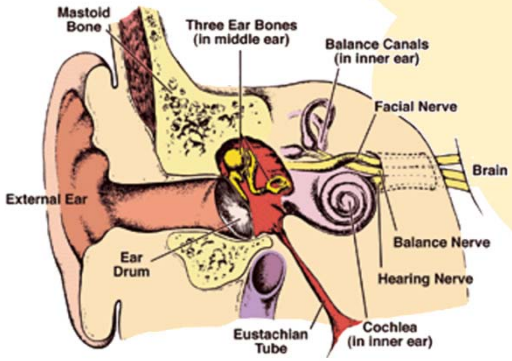
International Audio Laboratories Erlangen

International Audio Laboratories Erlangen

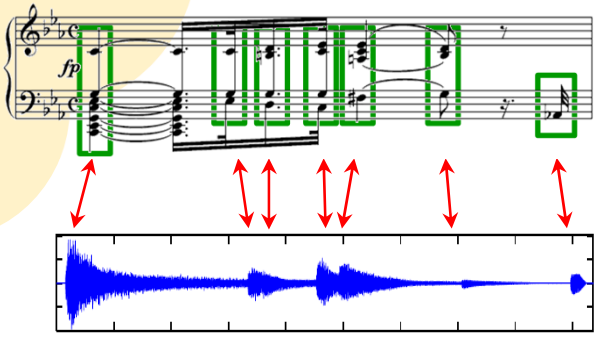
Audio Coding

3D Audio

Audio



Psychoacoustics

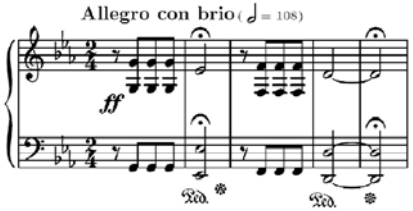


Music Processing

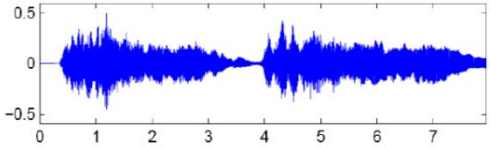
Music

Music Information Retrieval

Sheet Music (Image)



CD / MP3 (Audio)



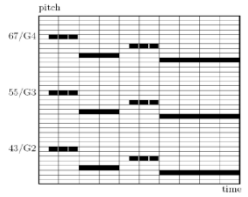
MusicXML (Text)

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

Dance / Motion (Mocap)

Music

MIDI

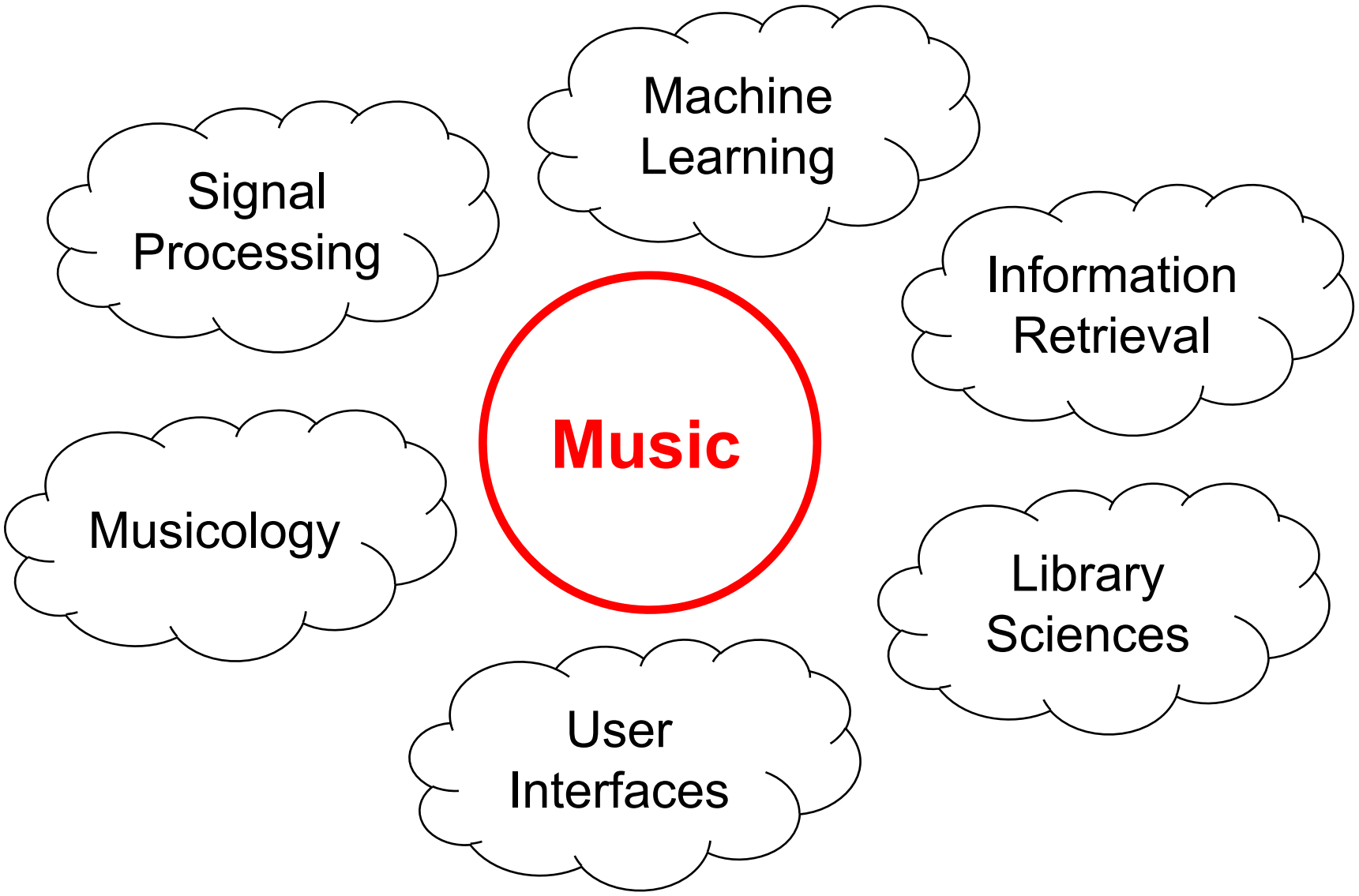


Singing / Voice (Audio)

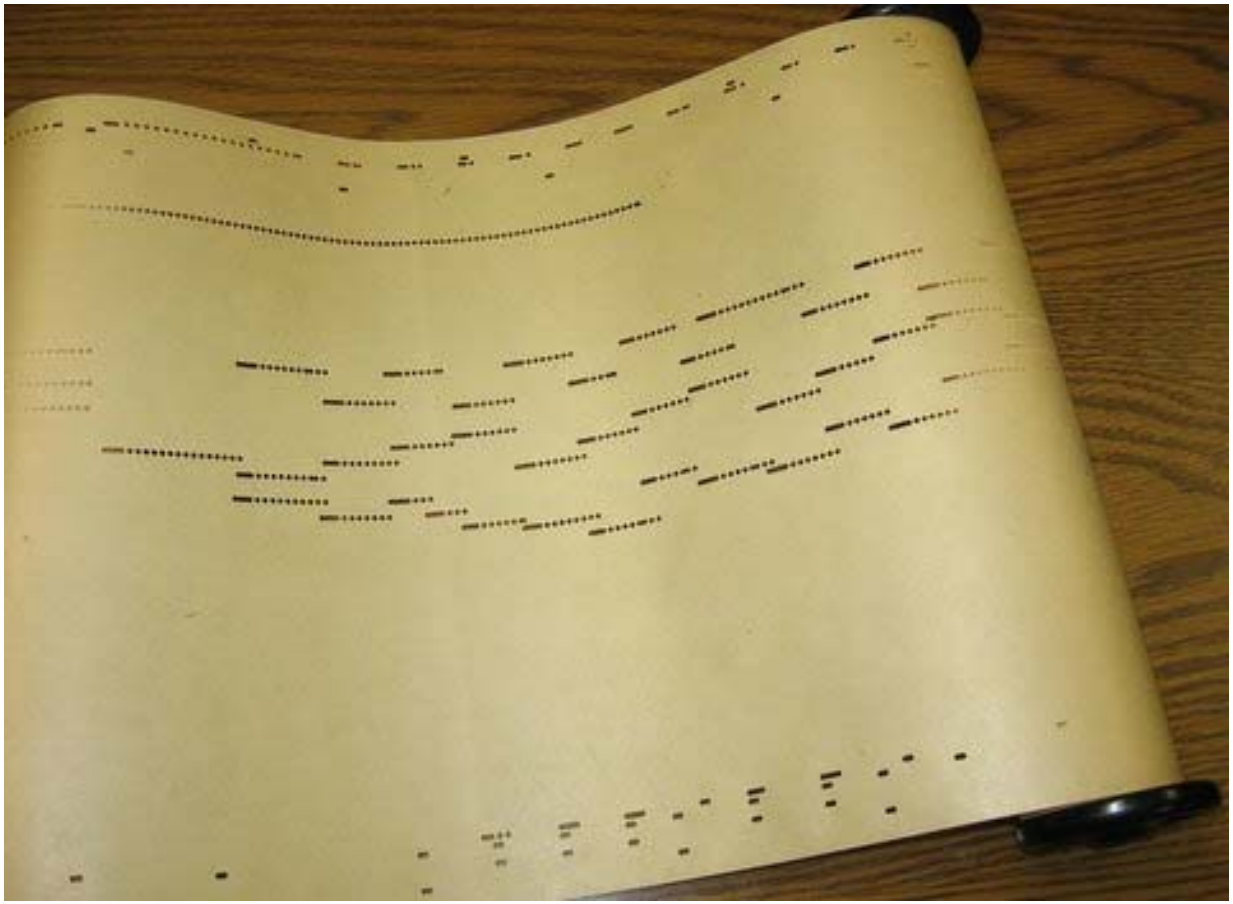
Music Film (Video)

Music Literature (Text)

Music Information Retrieval

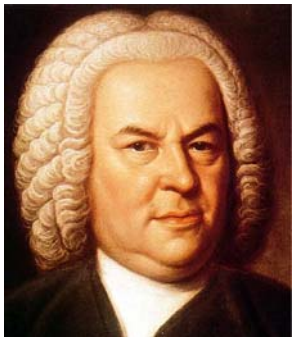


Piano Roll Representation



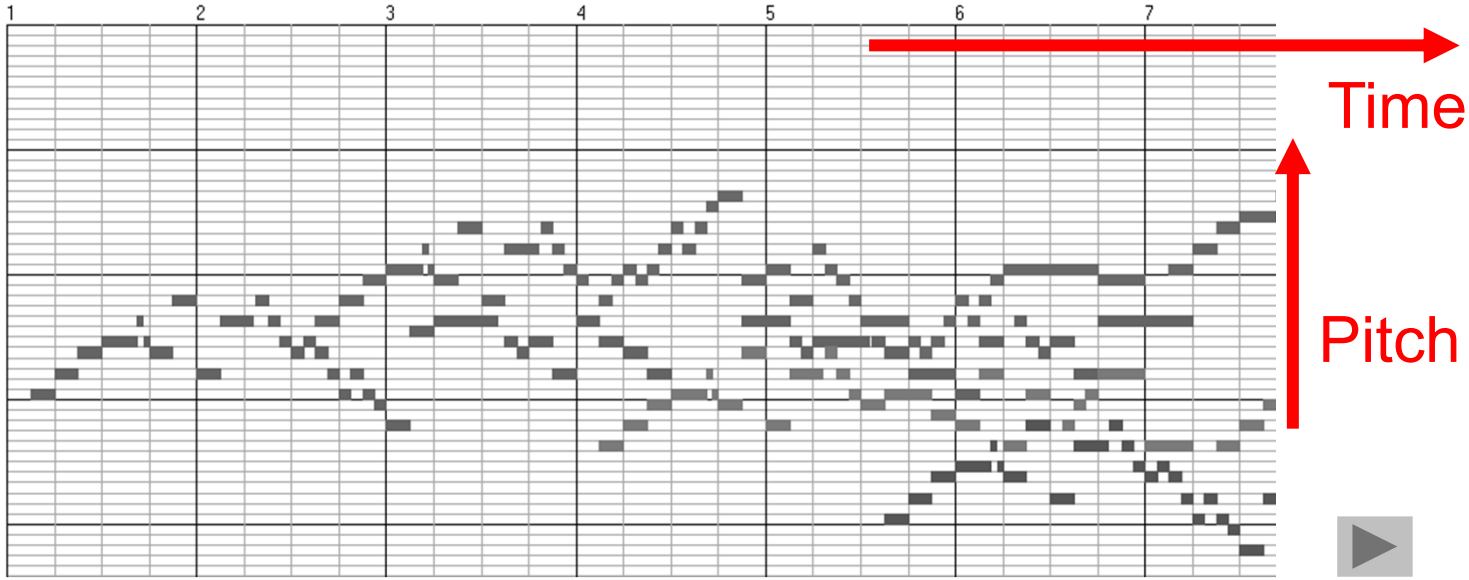
Player Piano (1900)

Piano Roll Representation (MIDI)

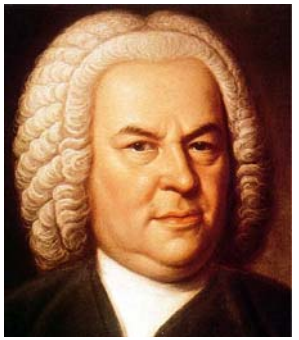


J.S. Bach, C-Major Fuge

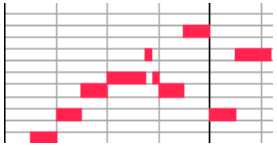
(Well Tempered Piano, BWV 846)



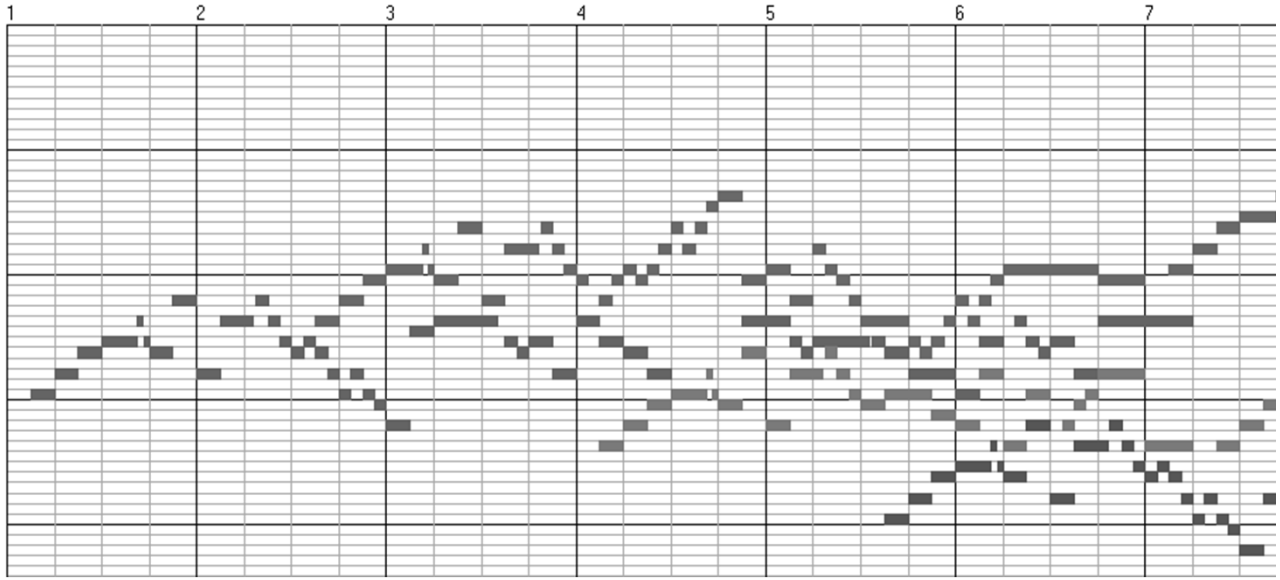
Piano Roll Representation (MIDI)



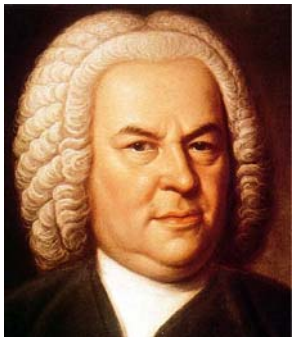
Query:



Goal: Find all occurrences of the query



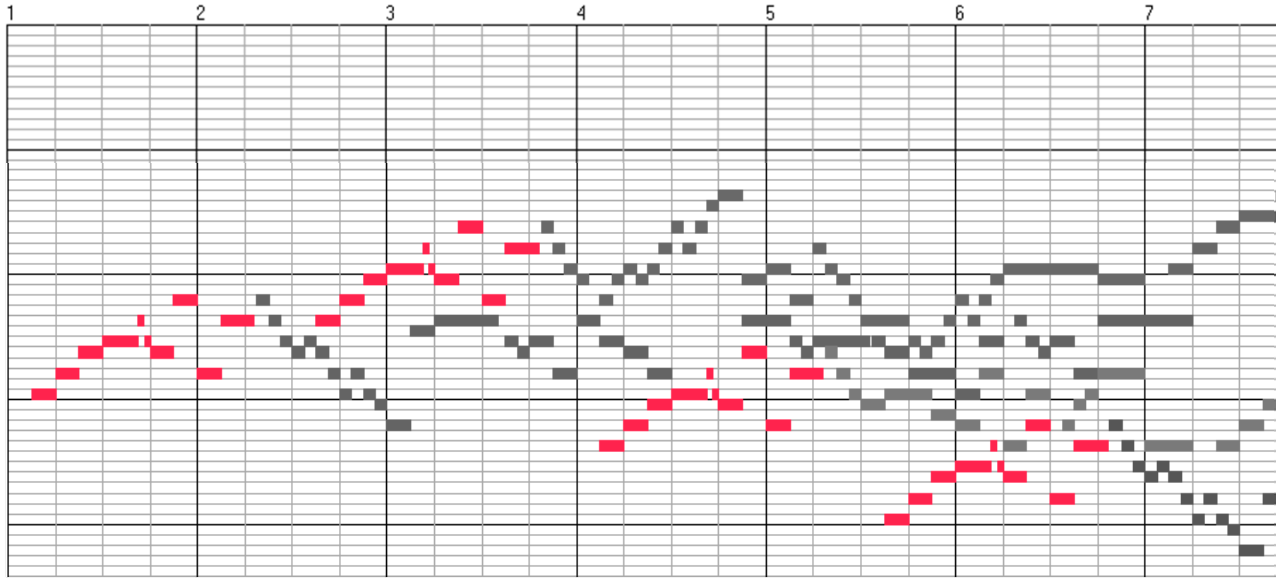
Piano Roll Representation (MIDI)



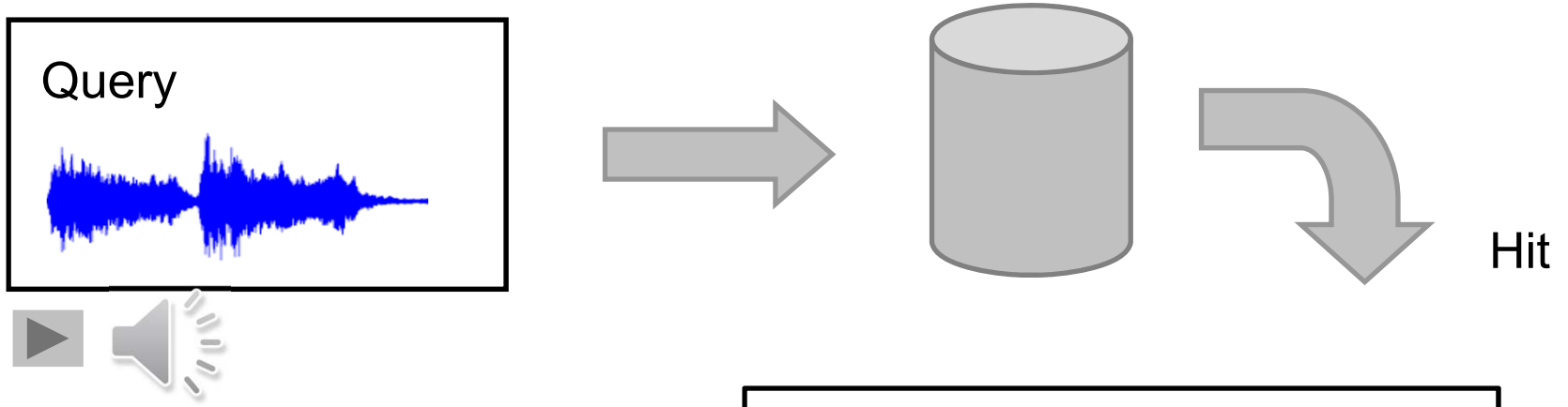
Query:

Goal: Find all occurrences of the query

Matches:



Music Retrieval



Audio-ID

Bernstein (1962)
Beethoven, Symphony No. 5

Version-ID

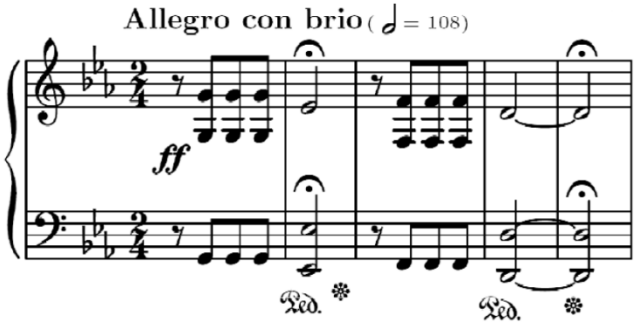
Beethoven, Symphony No. 5:
- Bernstein (1962)
- Karajan (1982)
- Gould (1992)

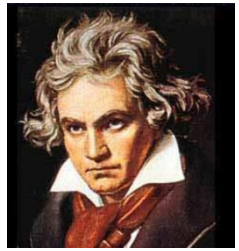
Category-ID

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

Music Synchronization: Audio-Audio

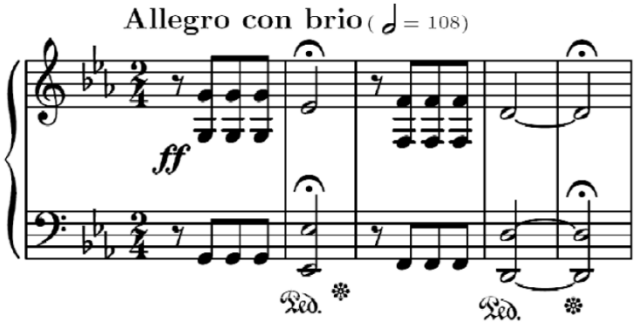
Beethoven's Fifth

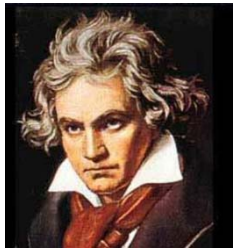




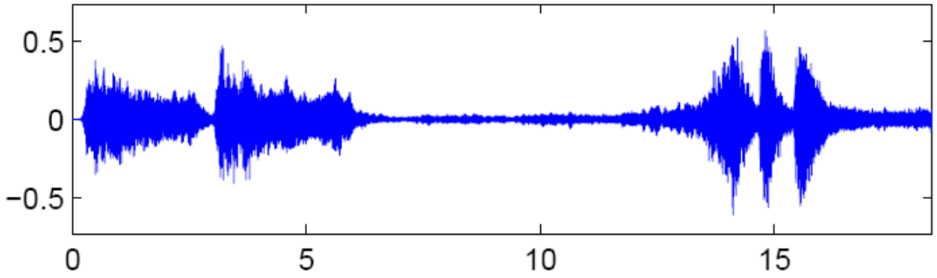
Music Synchronization: Audio-Audio

Beethoven's Fifth

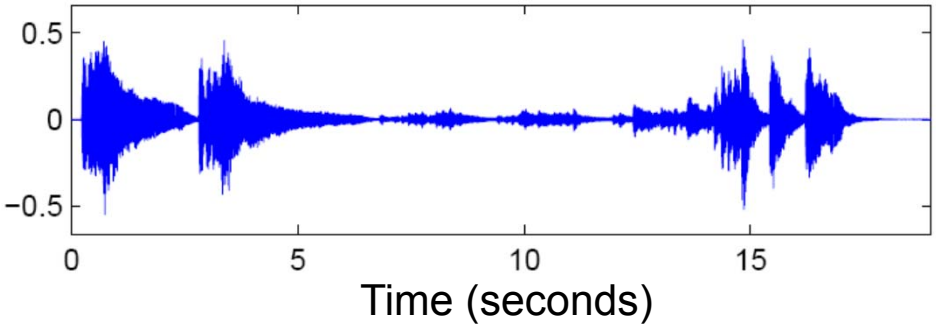




Orchester (Karajan)

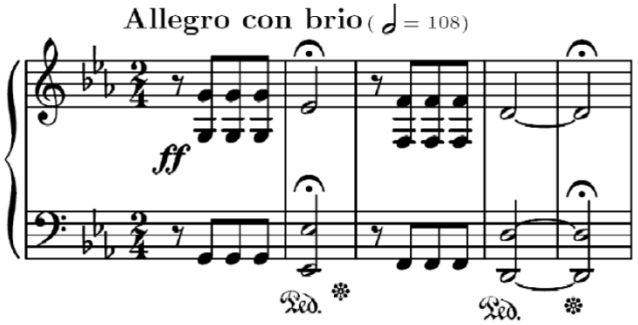


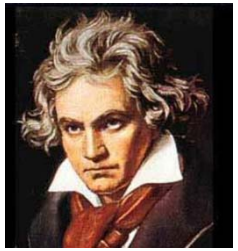
Piano (Scherbakov)



Music Synchronization: Audio-Audio

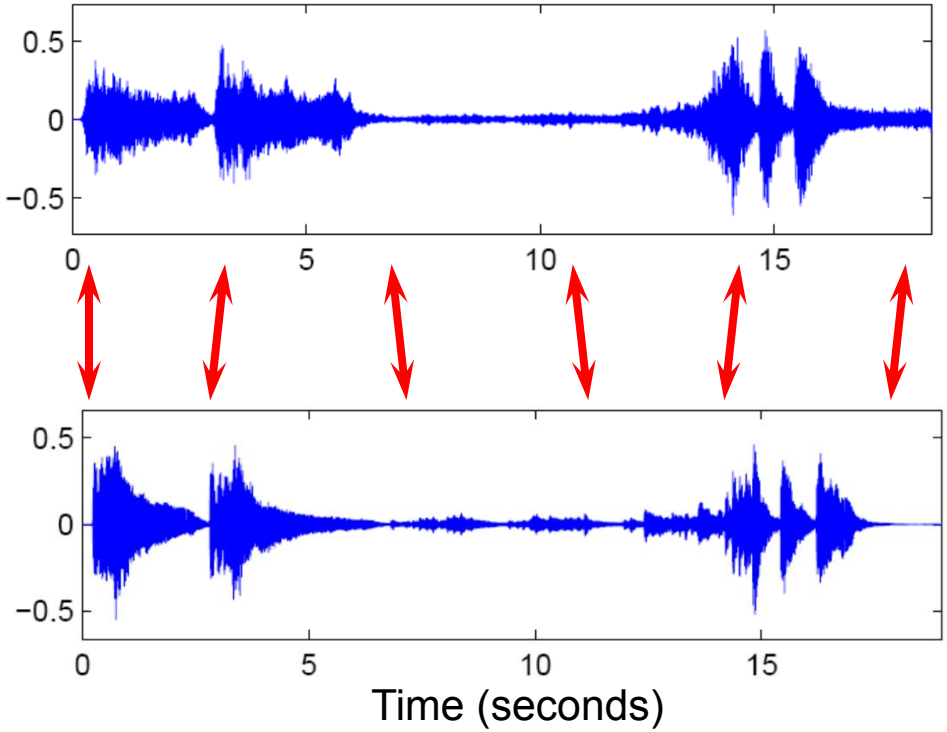
Beethoven's Fifth



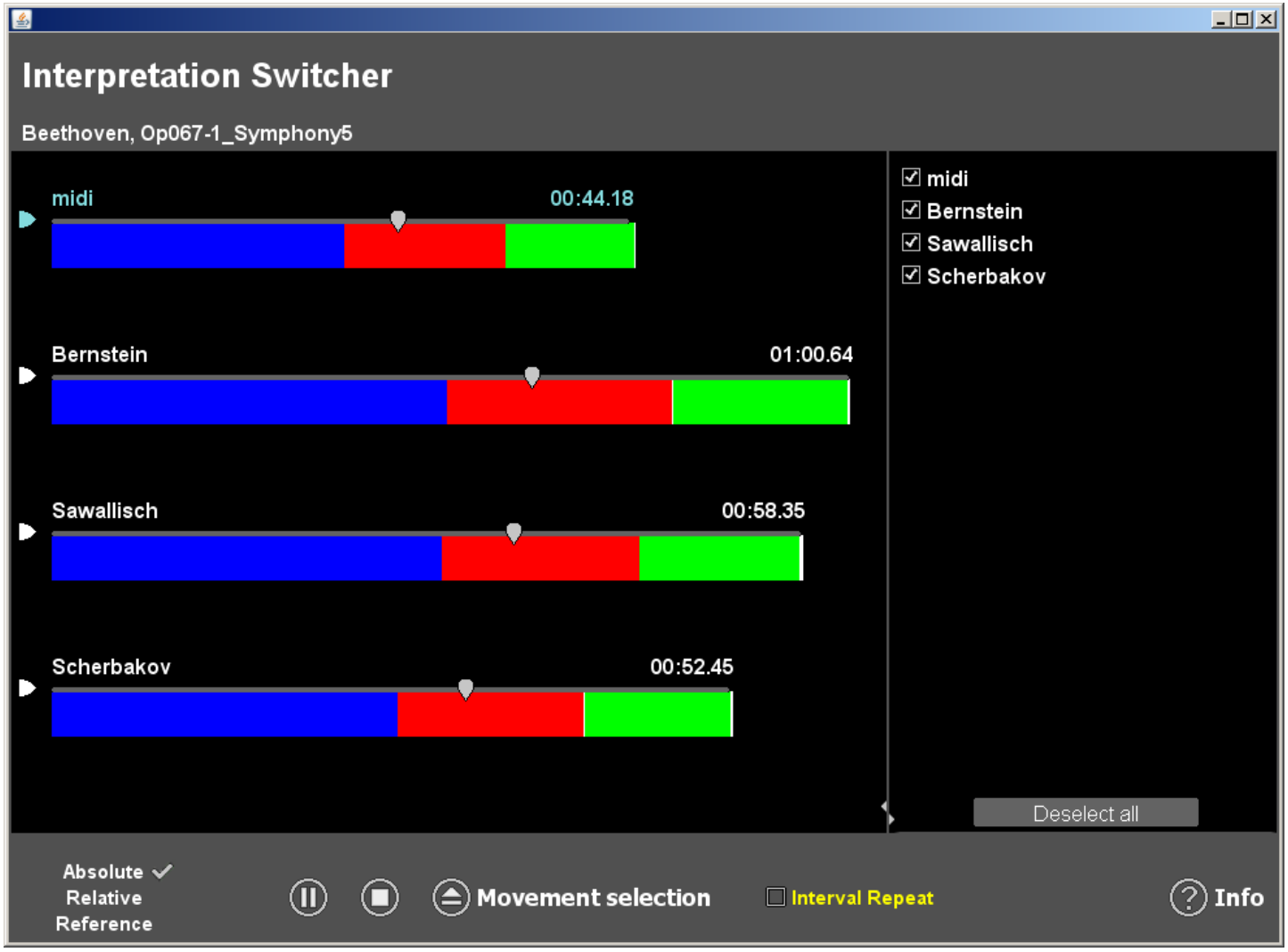


Orchester (Karajan)

Piano (Scherbakov)

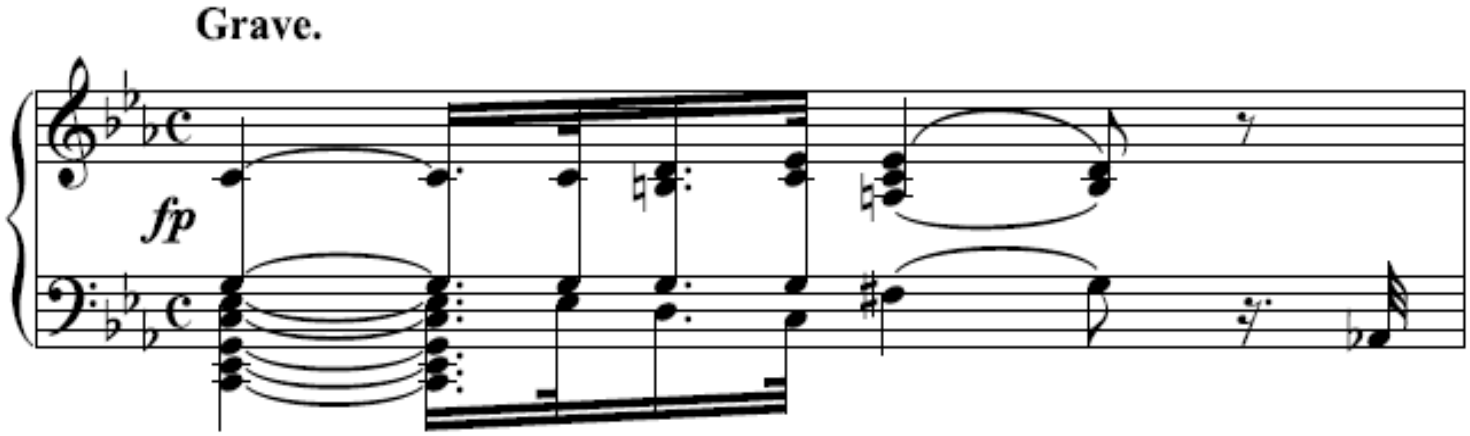


Application: Interpretation Switcher

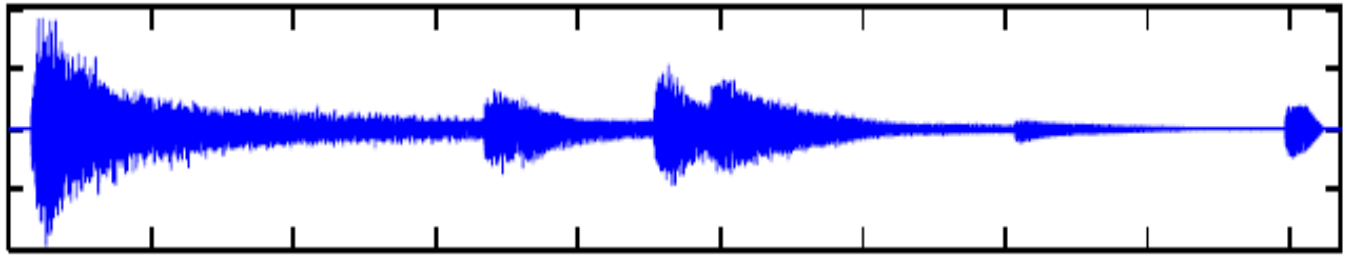


Music Synchronization: Image-Audio

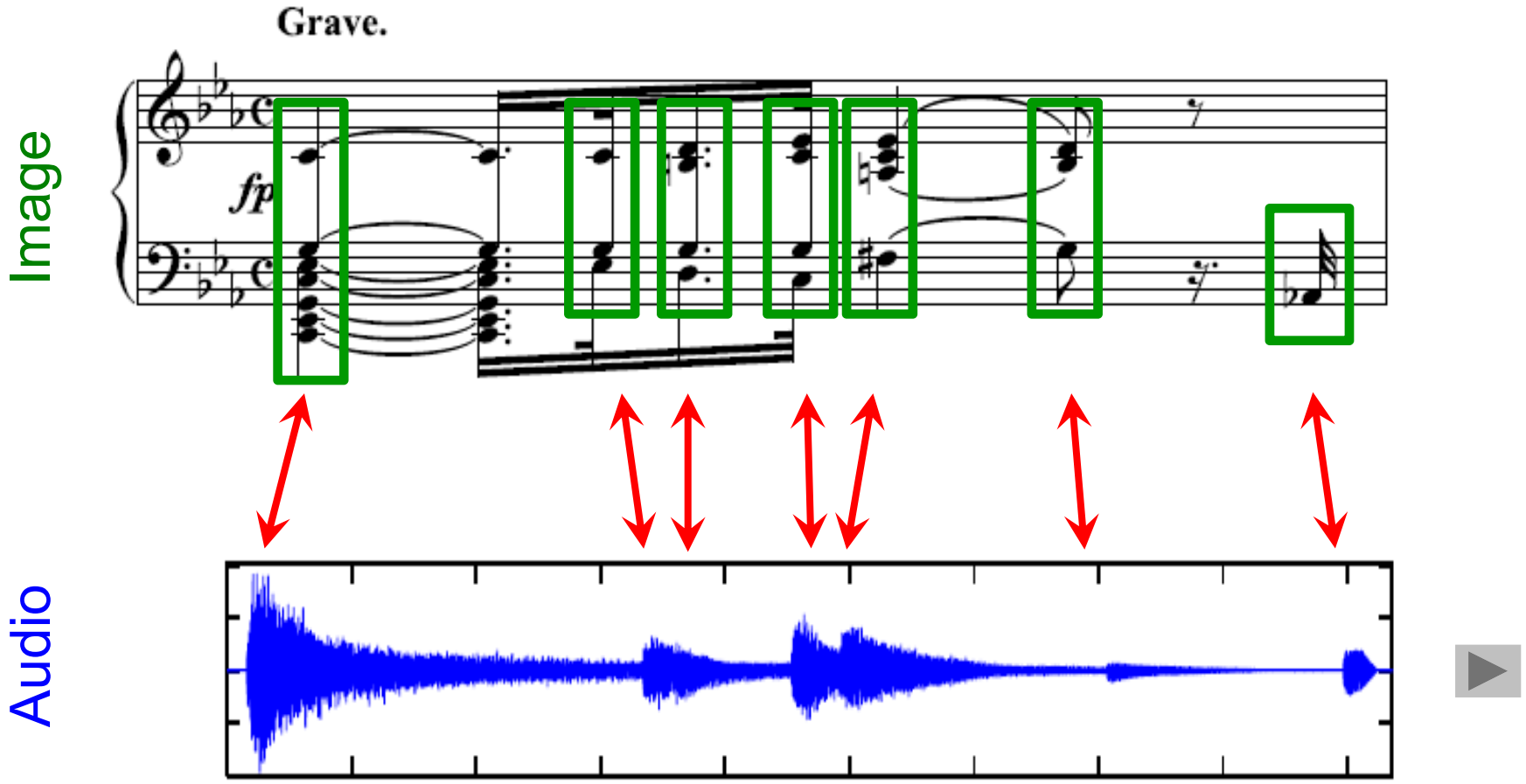
Image



Audio

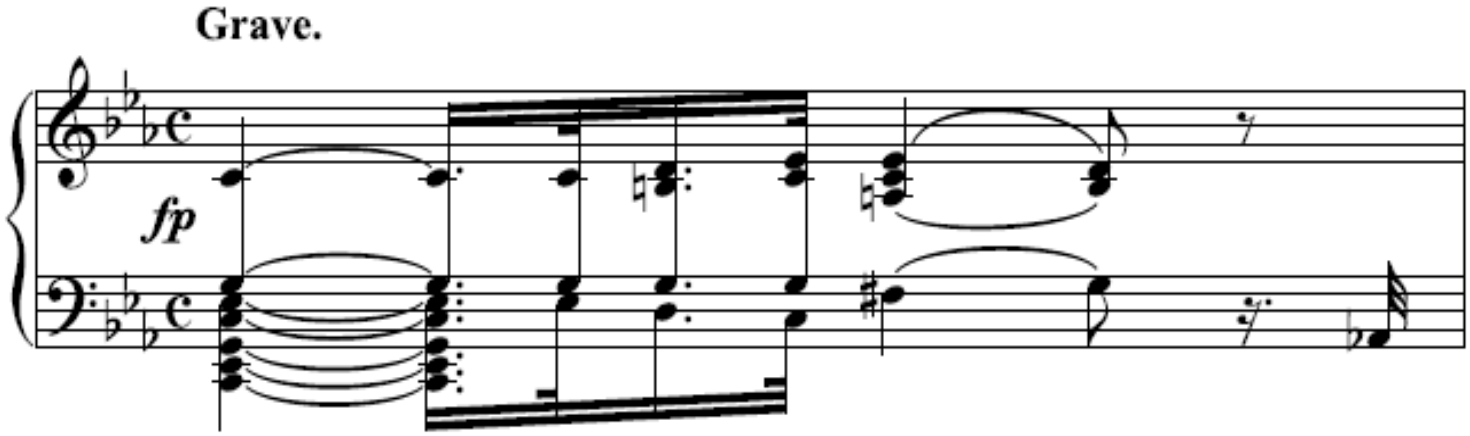


Music Synchronization: Image-Audio

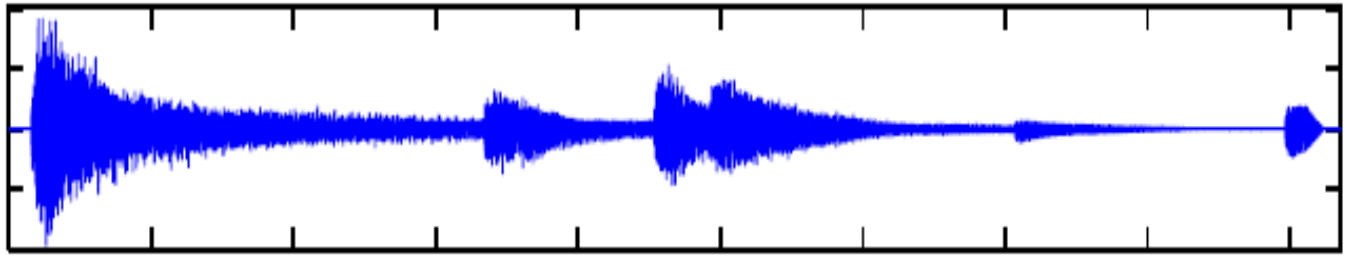


How to make the data comparable?

Image



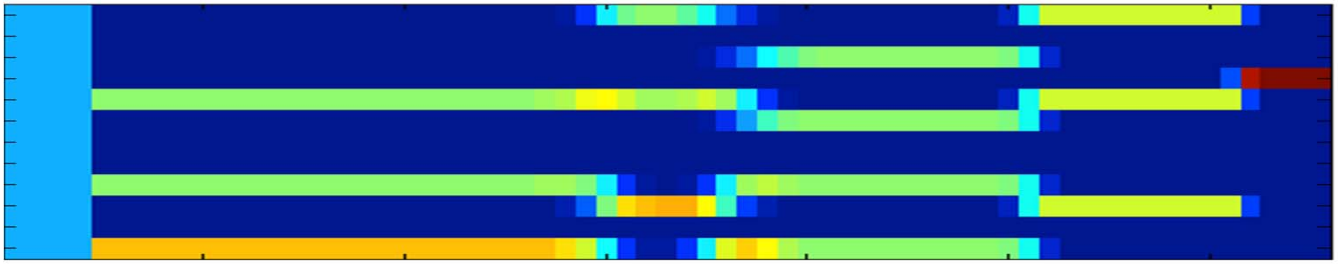
Audio



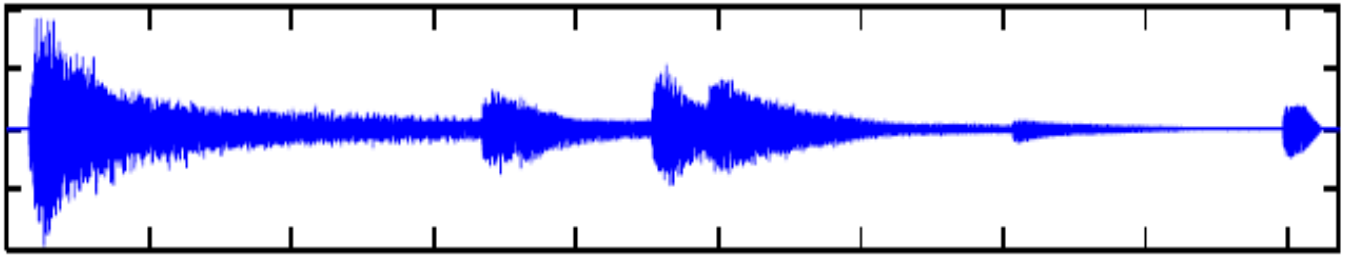
How to make the data comparable?

Image Processing: Optical Music Recognition

Image



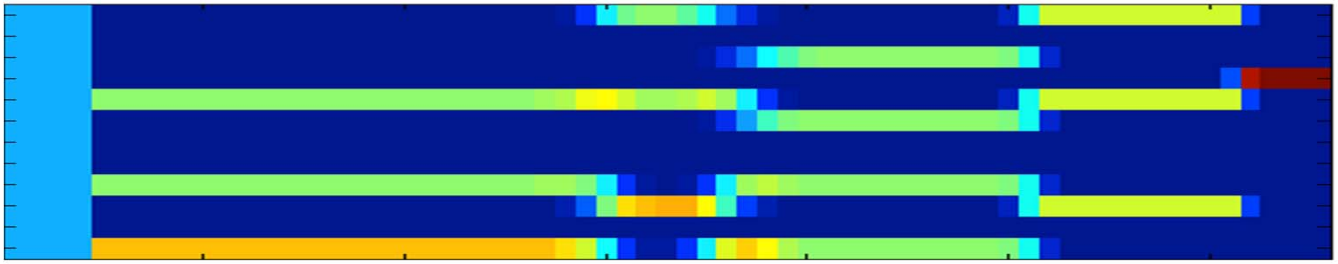
Audio



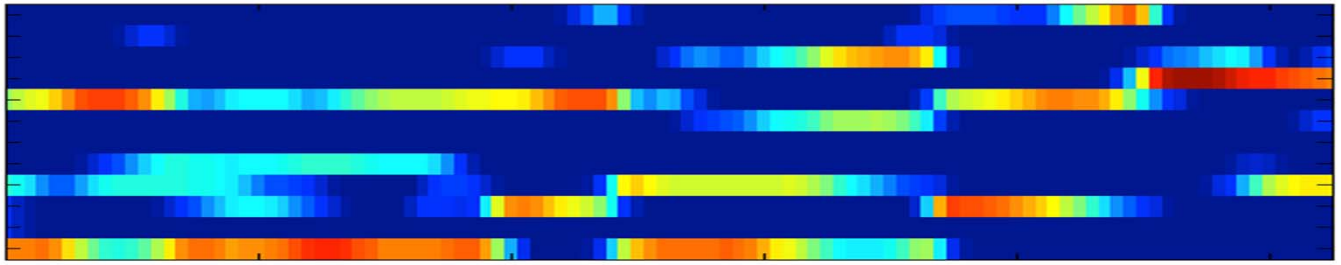
How to make the data comparable?

Image Processing: Optical Music Recognition

Image



Audio

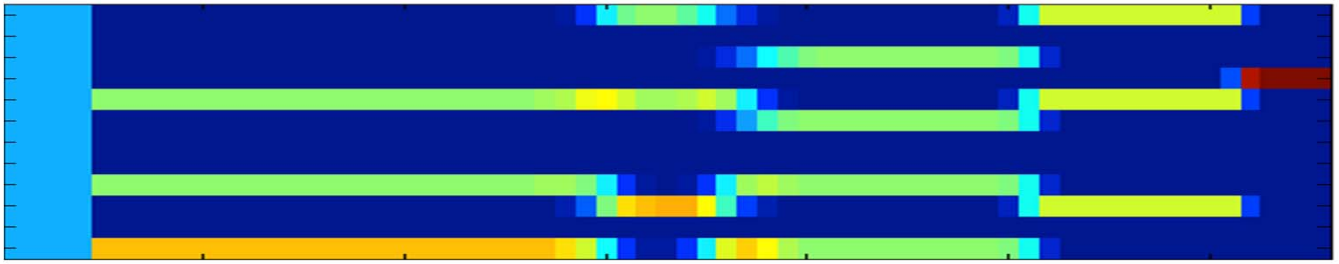


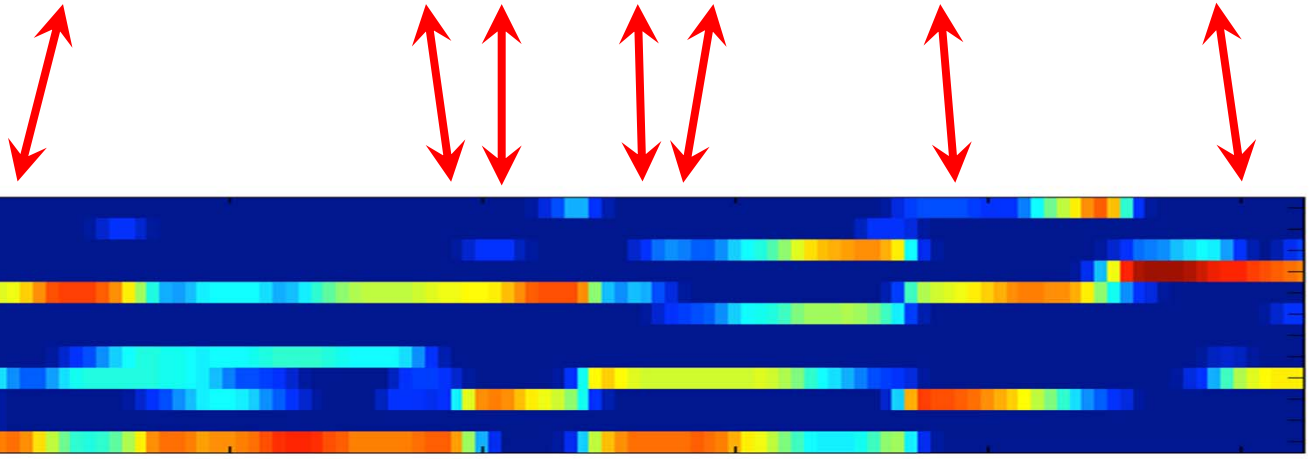
Audio Processing: Fourier Analysis

How to make the data comparable?

Image Processing: Optical Music Recognition

Image

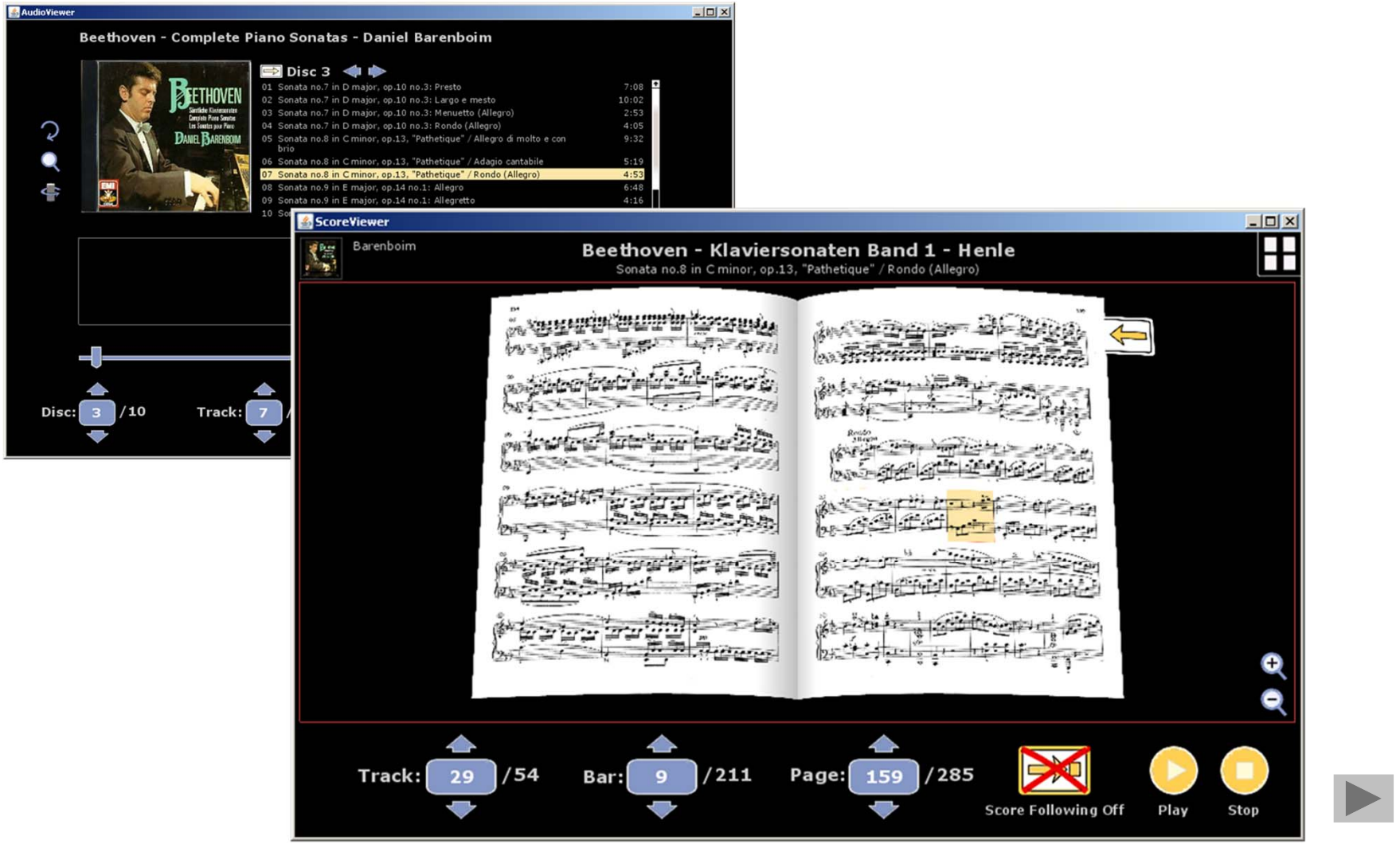




Audio

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

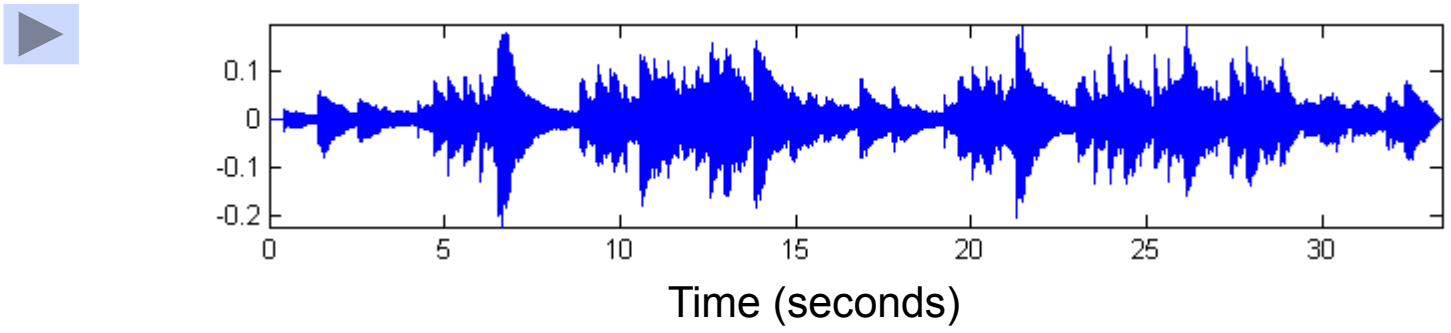
Music Processing

Coarse Level	**Fine Level**
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?
Identify despite of differences	Identify the differences
Example tasks: **Audio Matching** **Cover Song Identification**	Example tasks: **Tempo Estimation** **Performance Analysis**

Performance Analysis

Schumann: Träumerei

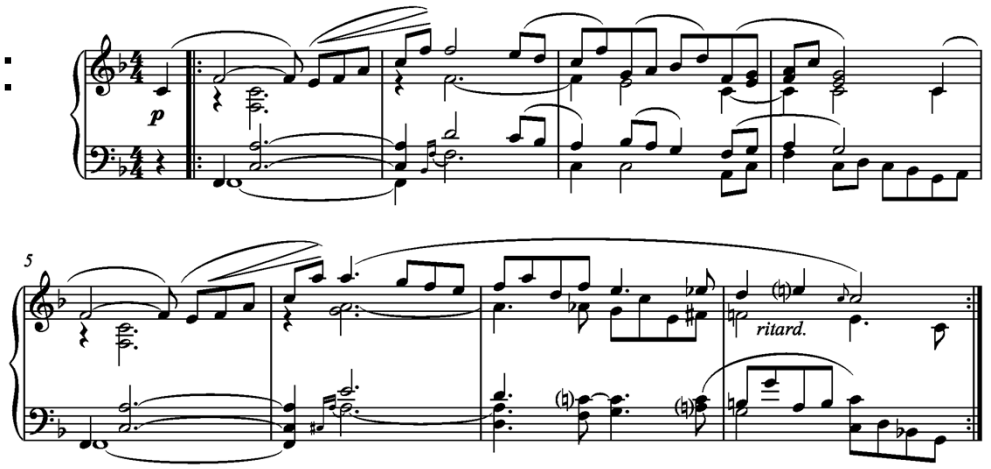
Performance:



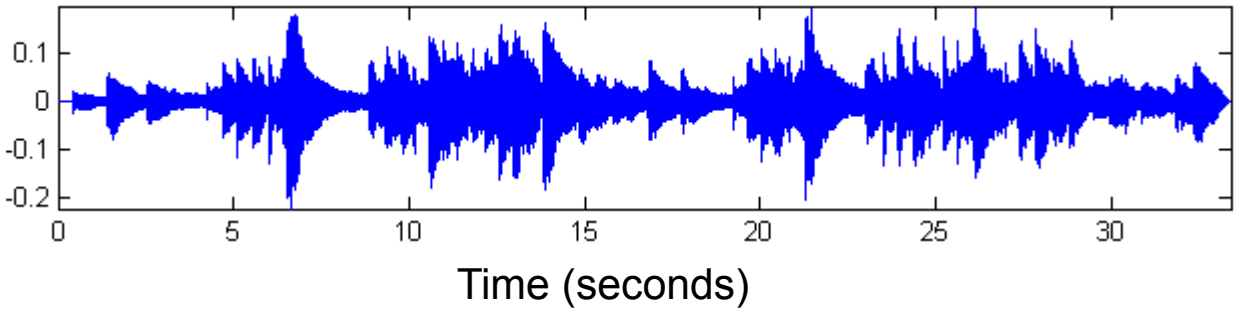
Performance Analysis

Schumann: Träumerei

Score (reference):



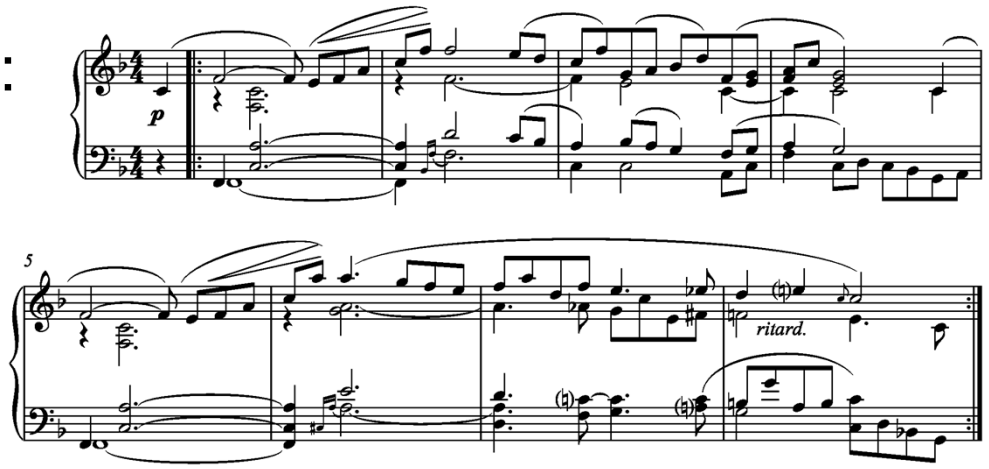
Performance:



Performance Analysis

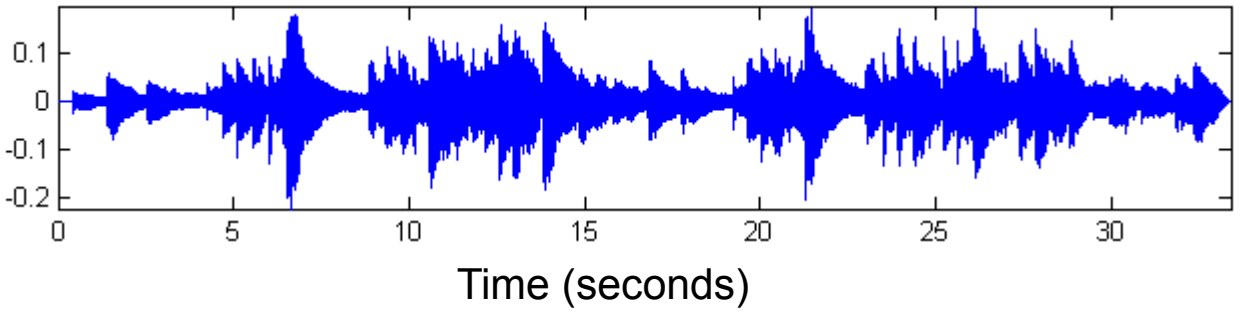
Schumann: Träumerei

Score (reference):



Strategy: Compute score-audio synchronization and derive tempo curve

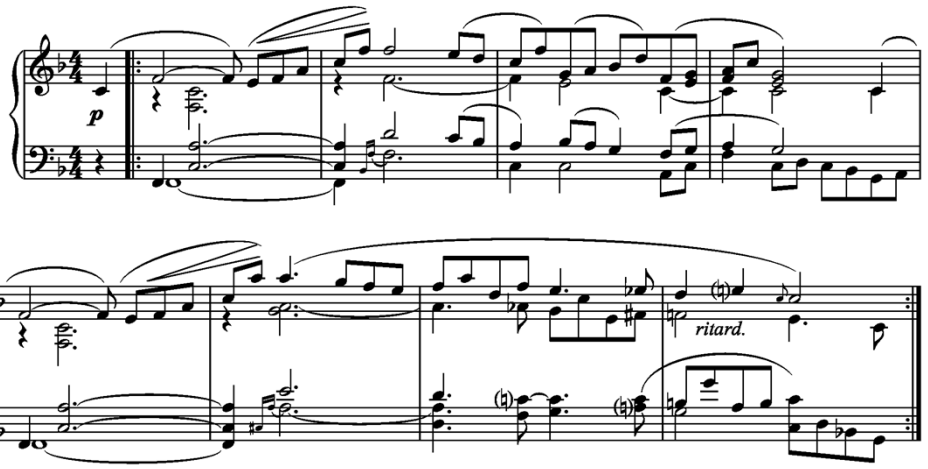
Performance:



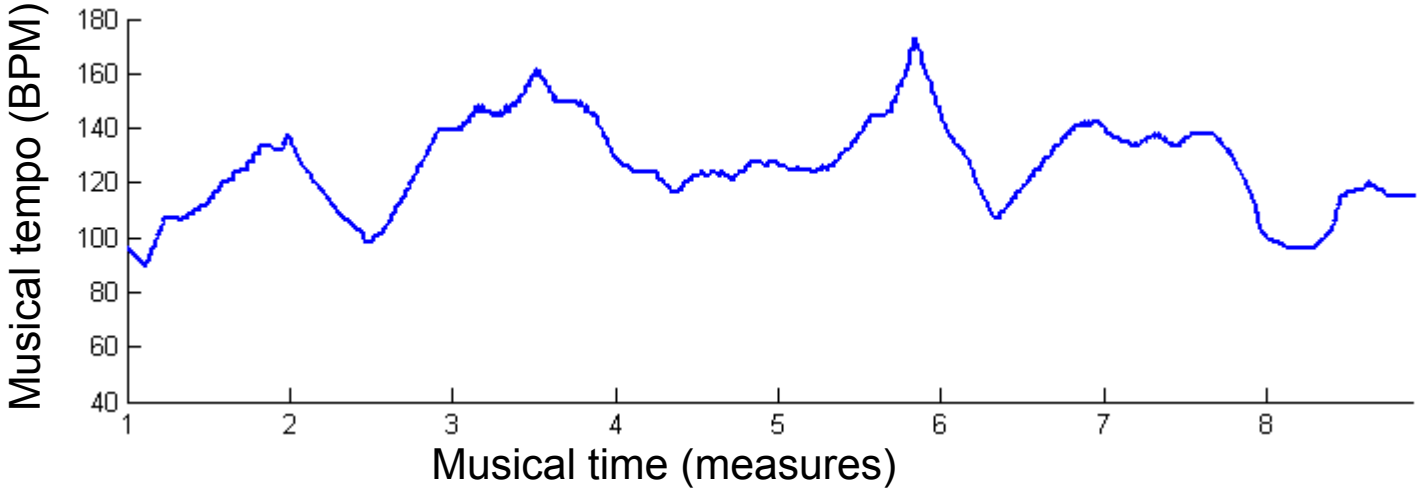
Performance Analysis

Schumann: Träumerei

Score (reference):



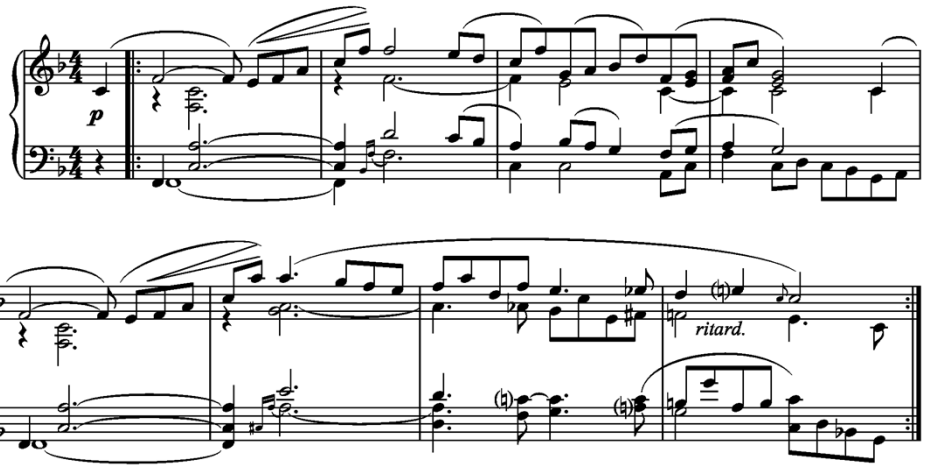
Tempo Curve:



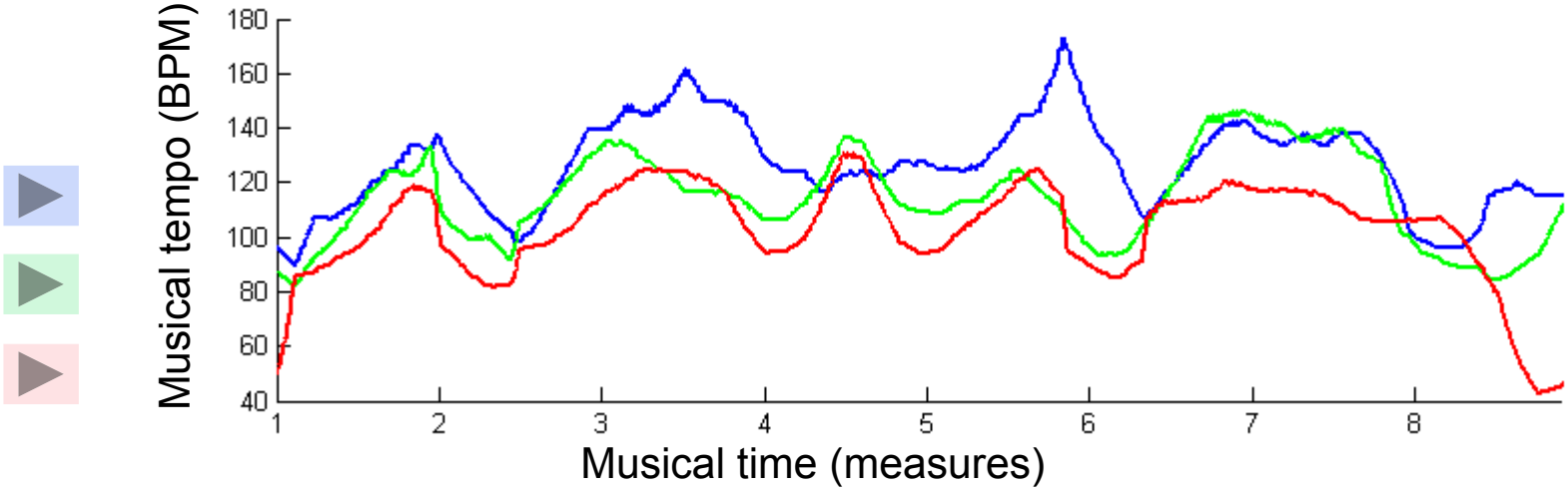
Performance Analysis

Schumann: Träumerei

Score (reference):



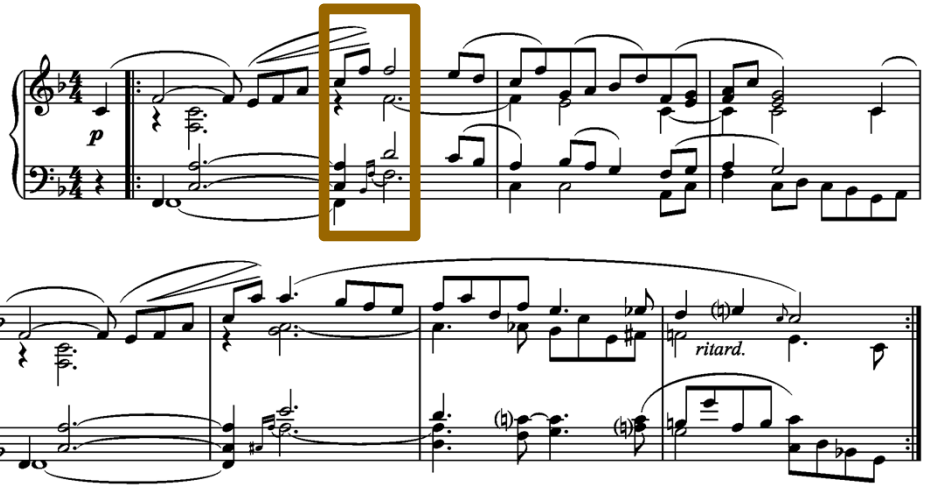
Tempo Curves:



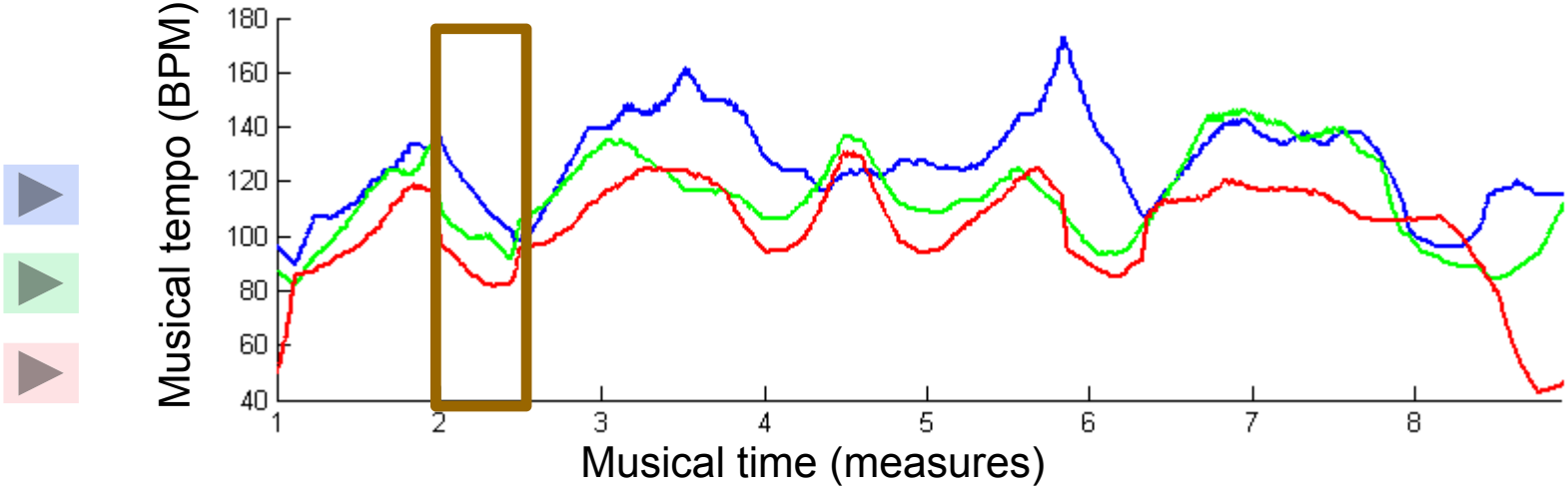
Performance Analysis

Schumann: Träumerei

Score (reference):



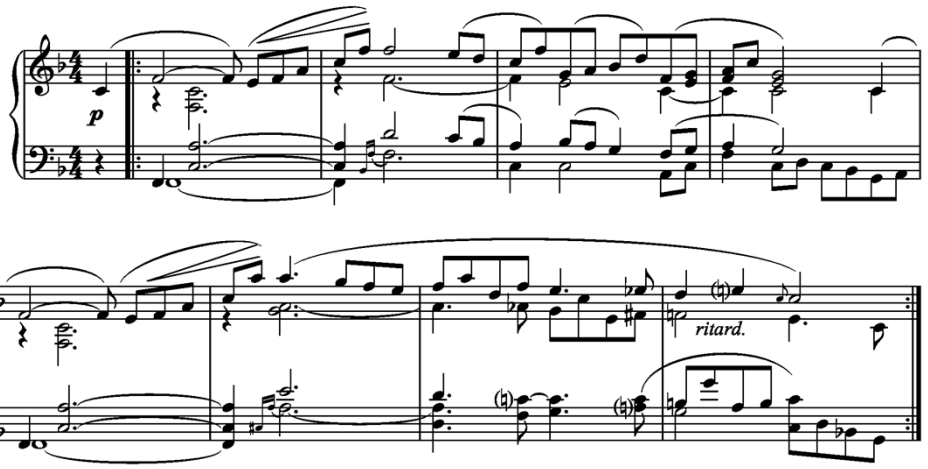
Tempo Curves:



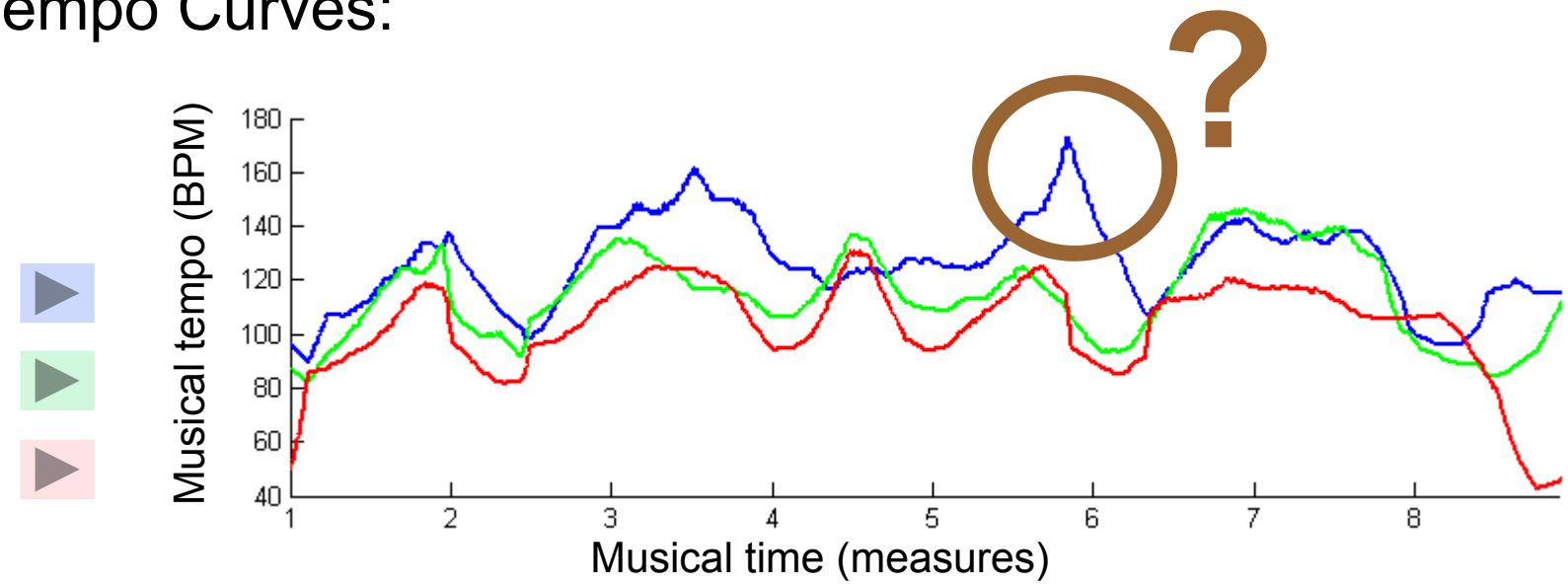
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:

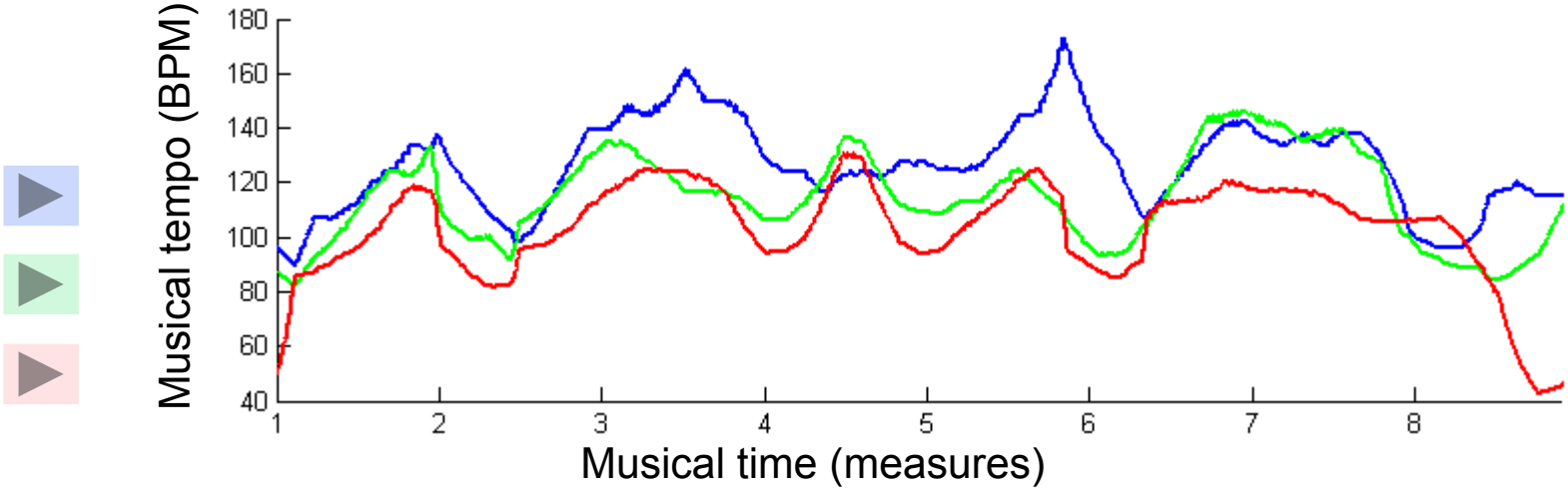


Performance Analysis

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**
Given: Several versions	Given: One version
Comparison of extracted parameters	Direct interpretation of extracted parameters

Music Processing

Relative	**Absolute**
Given: Several versions	Given: One version
Comparison of extracted parameters	Direct interpretation of extracted parameters
Extraction errors have often no consequence on final result	Extraction errors immediately become evident

Music Processing

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Given: Several versions	Given: One version
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: **Music Synchronization** **Genre Classification**	Example tasks: **Music Transcription** **Tempo Estimation**

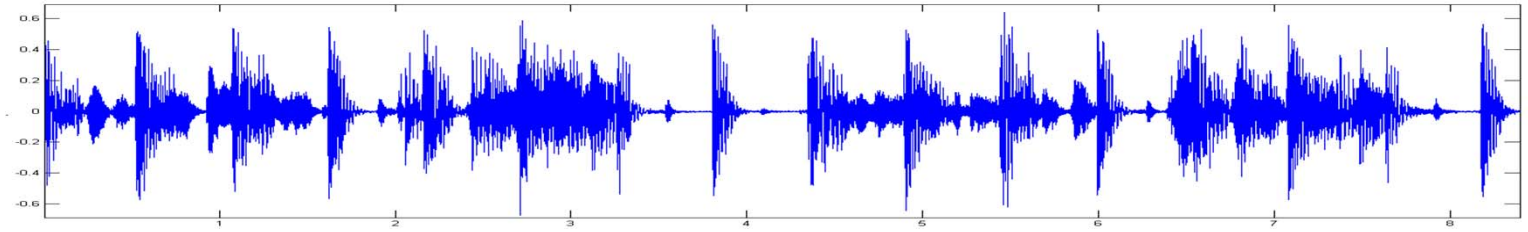
Tempo Estimation and Beat Tracking

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

Tempo Estimation and Beat Tracking

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

Example: Queen – Another One Bites The Dust

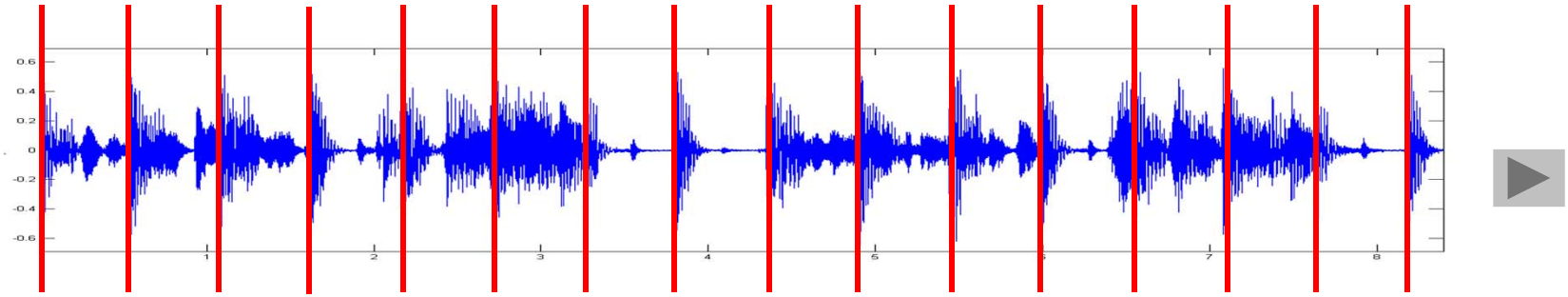


Time (seconds)

Tempo Estimation and Beat Tracking

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

Example: Queen – Another One Bites The Dust

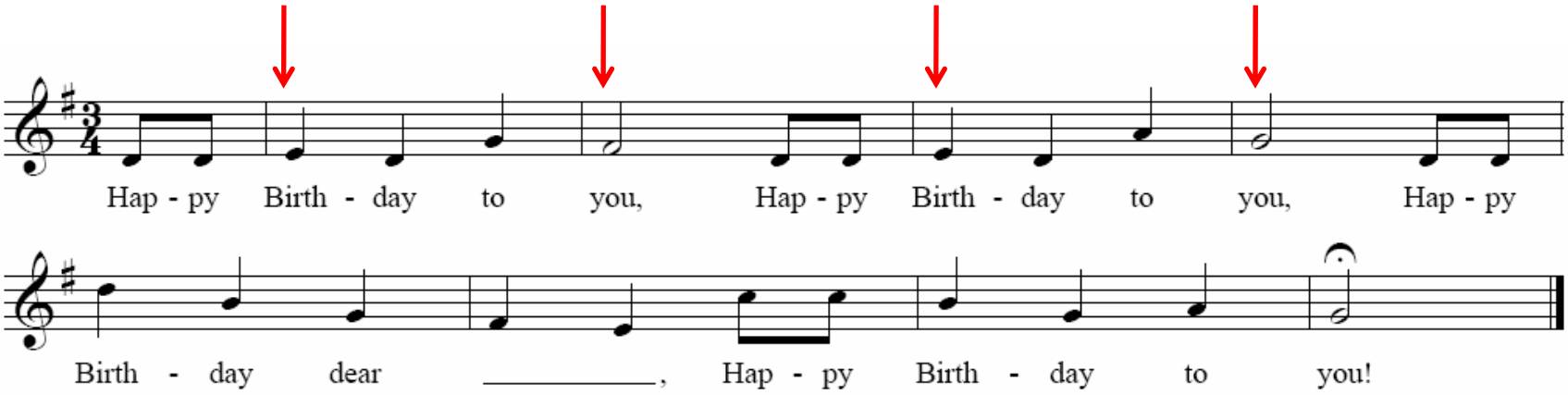


Time (seconds)

Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

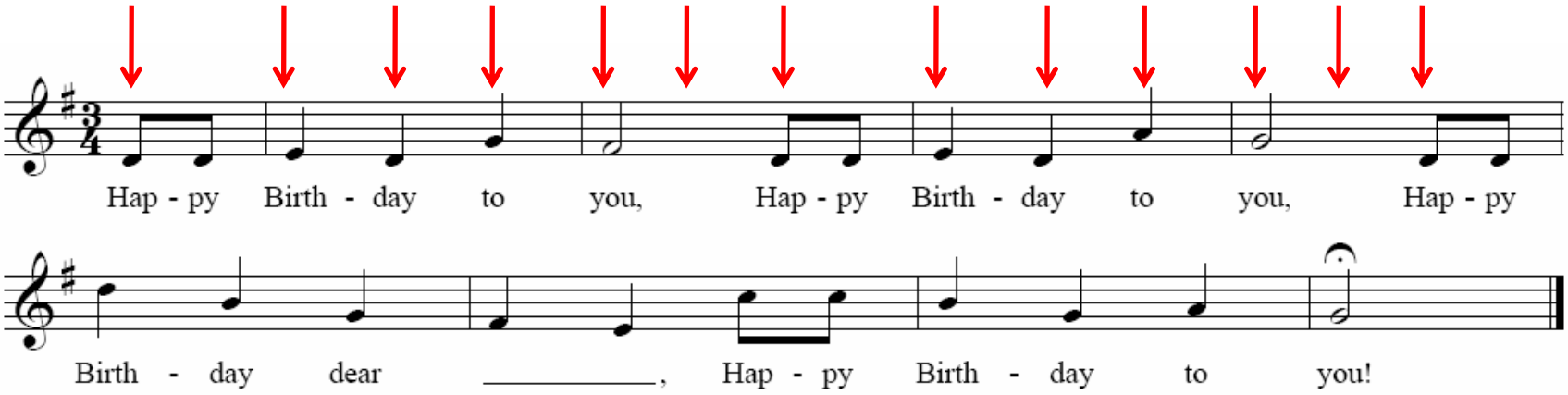
Pulse level: **Measure**



Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

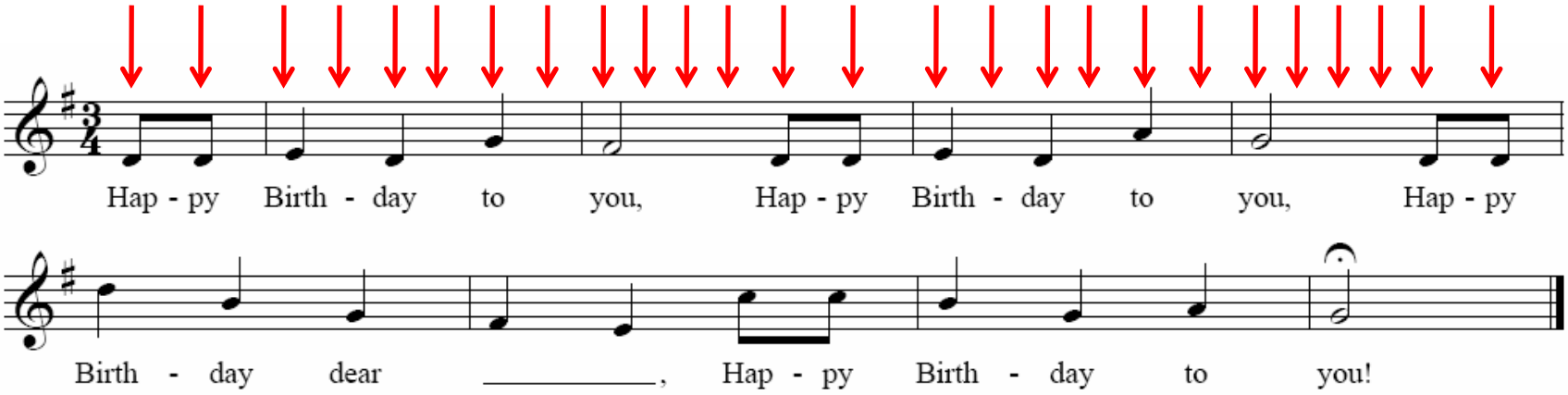
Pulse level: **Tactus (beat)**



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: ???

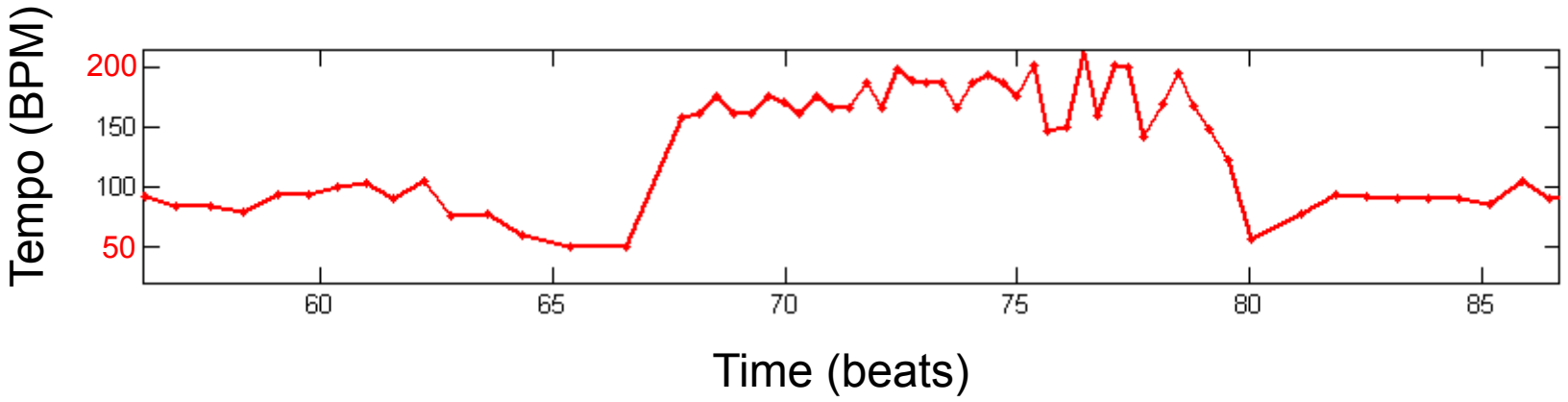
Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: 50-200 BPM

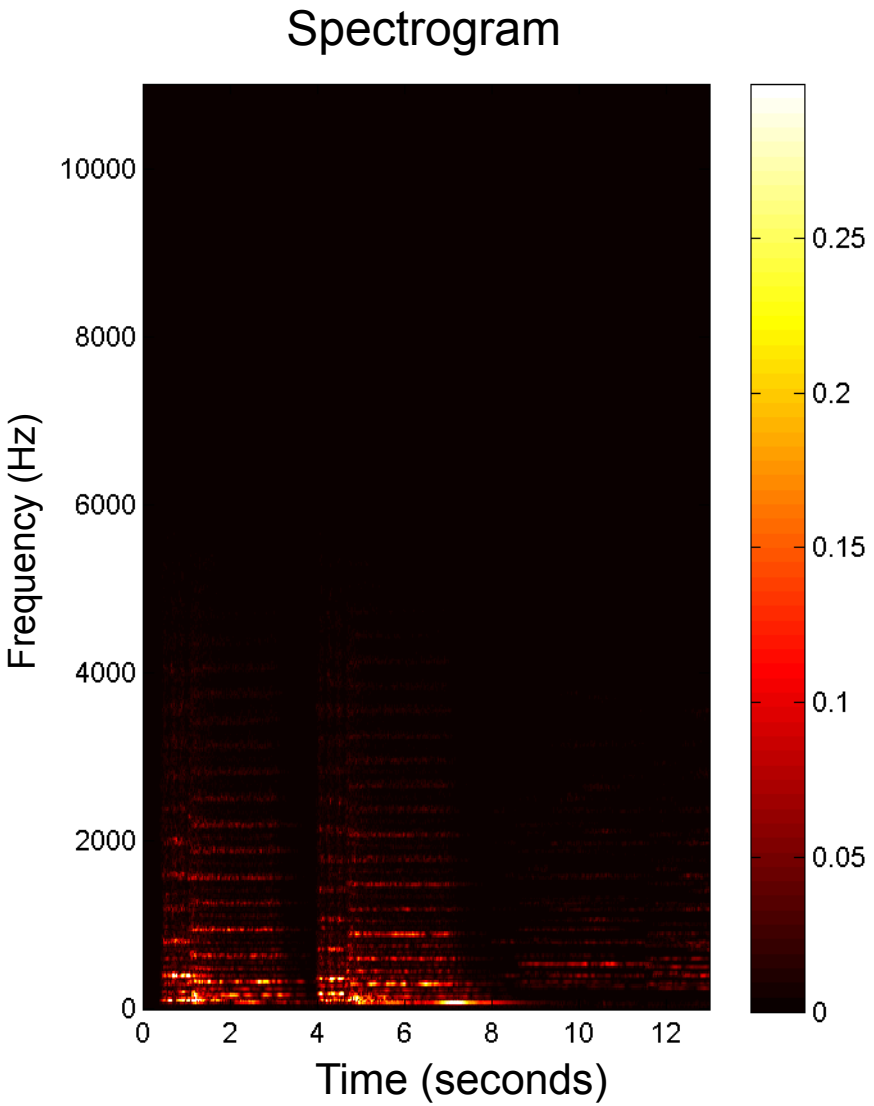
Tempo curve



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)

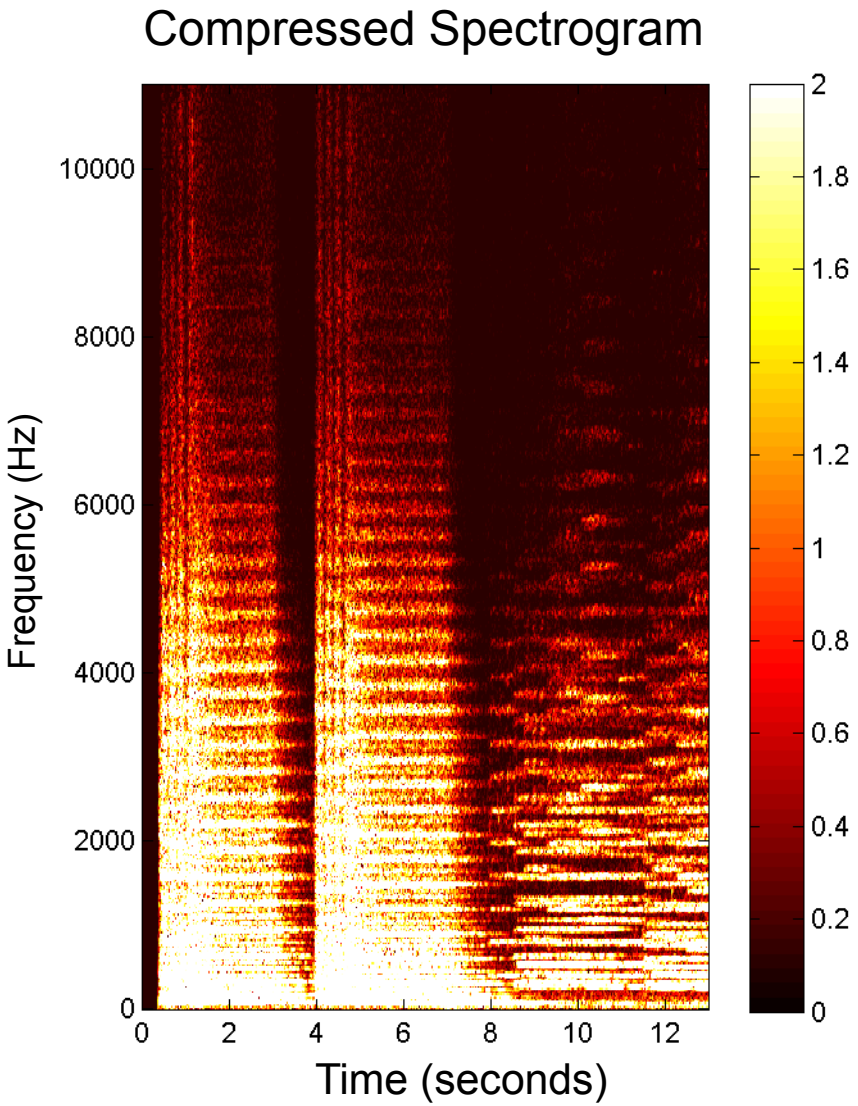
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram

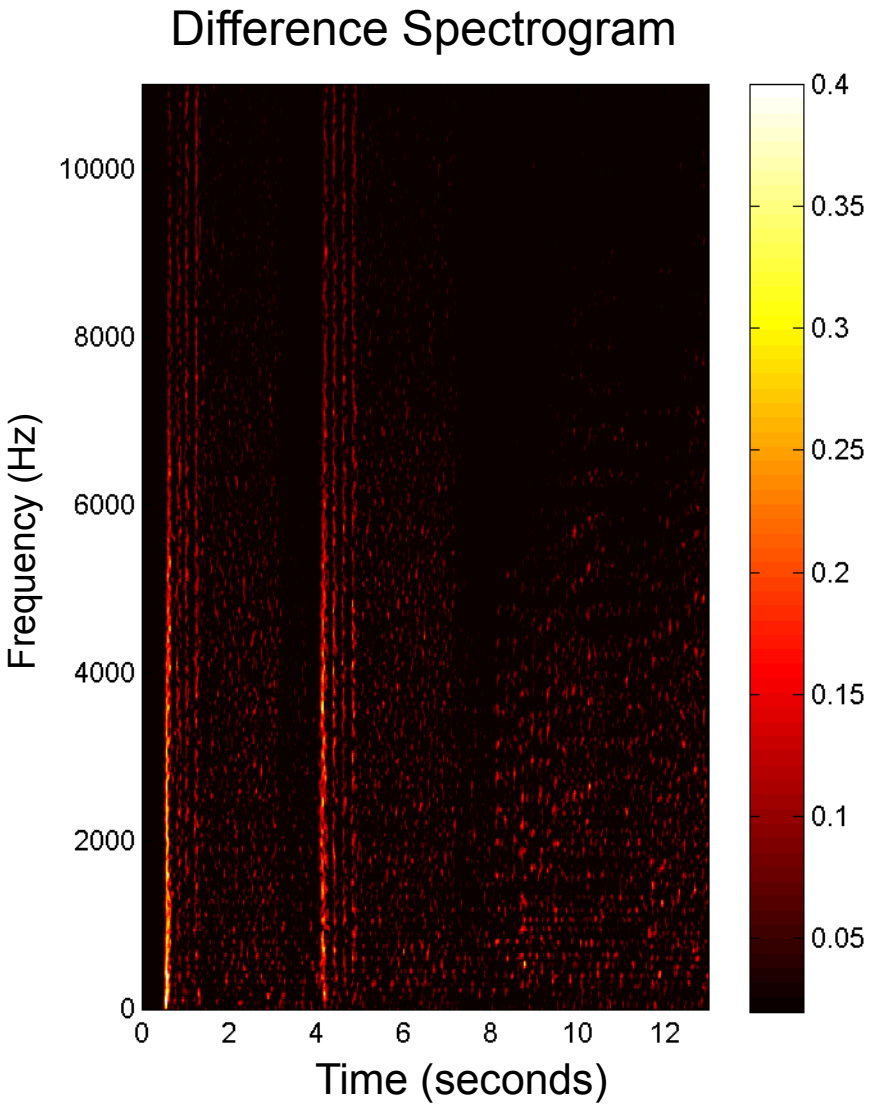
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram
2. Log Compression

Tempo Estimation and Beat Tracking



Steps:

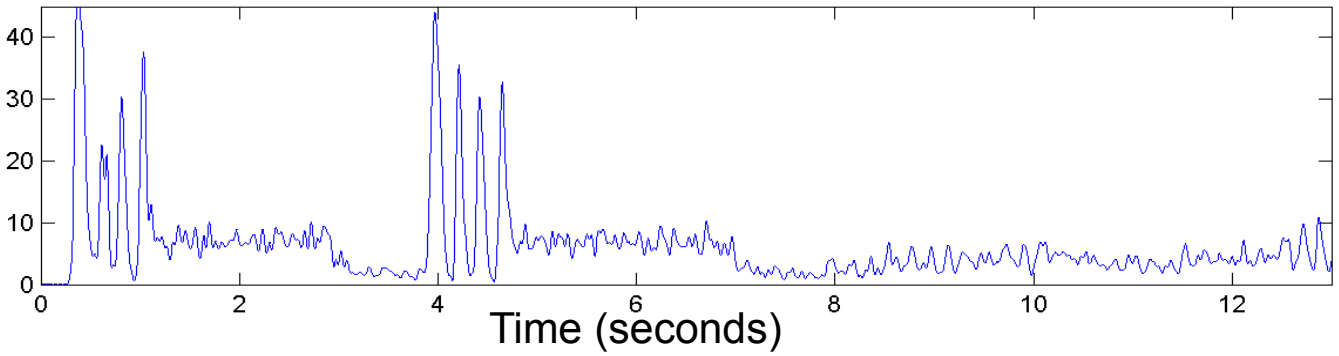
1. Spectrogram
2. Log Compression
3. Differentiation

Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve

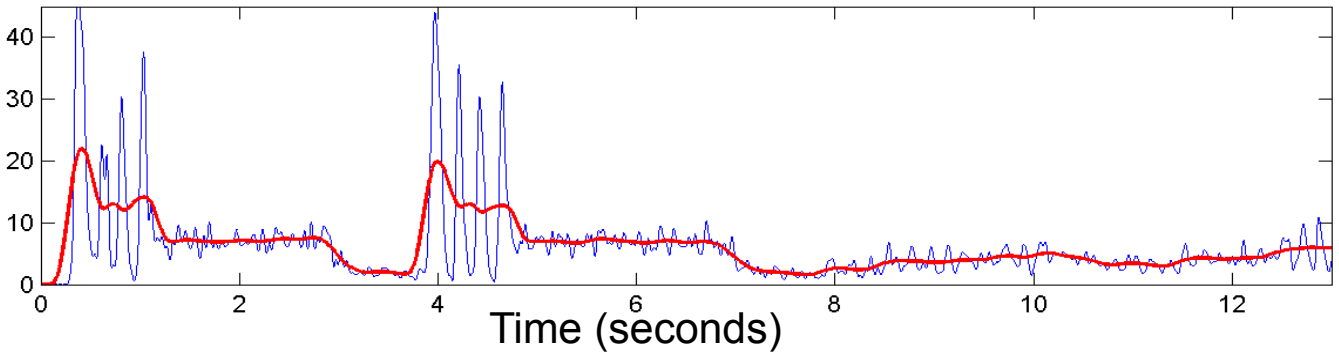


Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve
Local Average

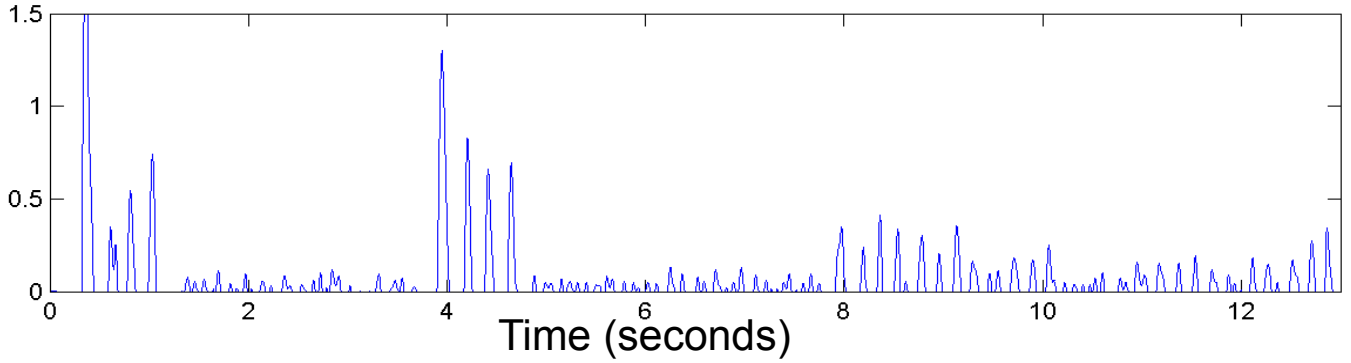


Tempo Estimation and Beat Tracking

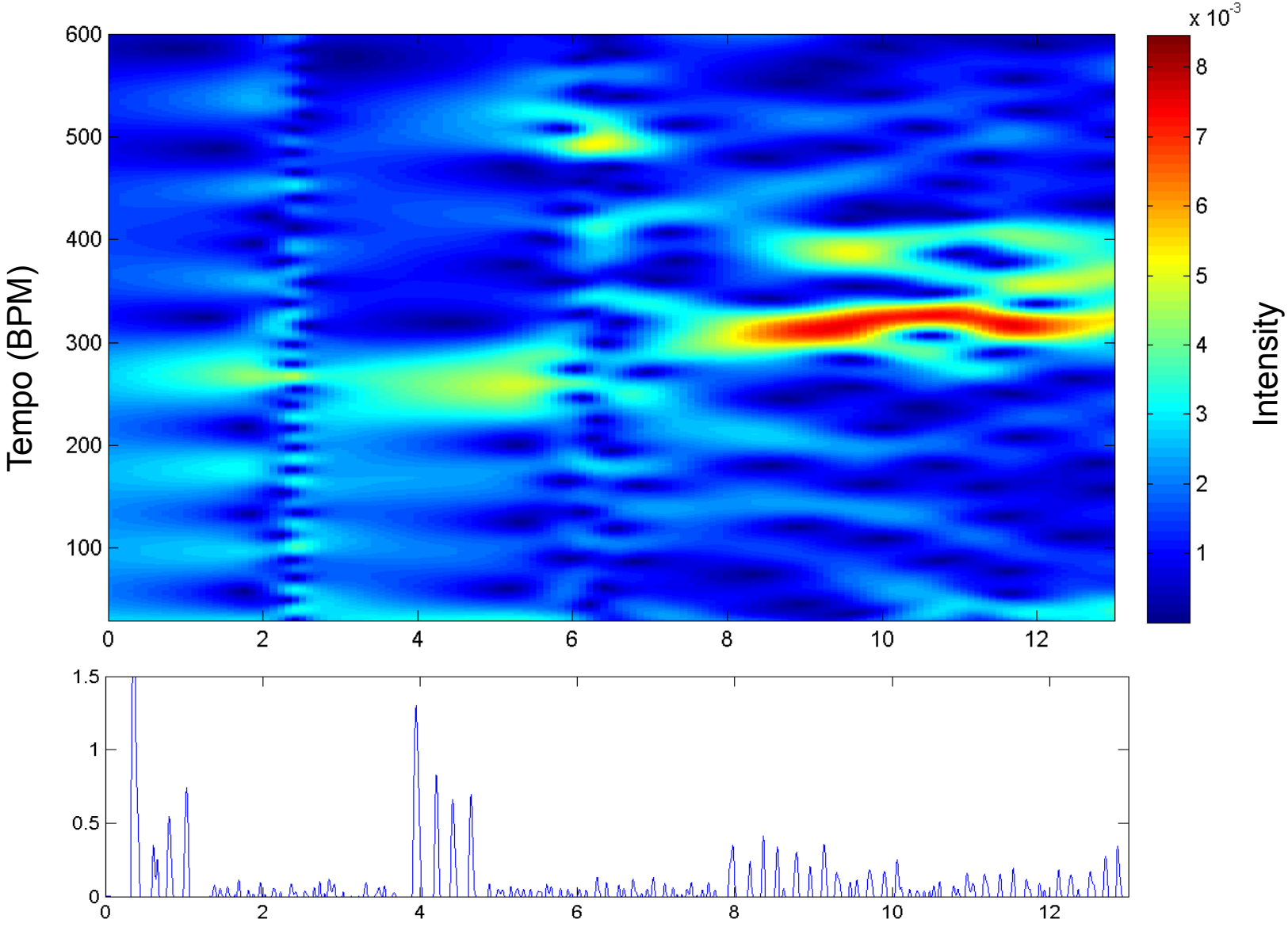
Steps:

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

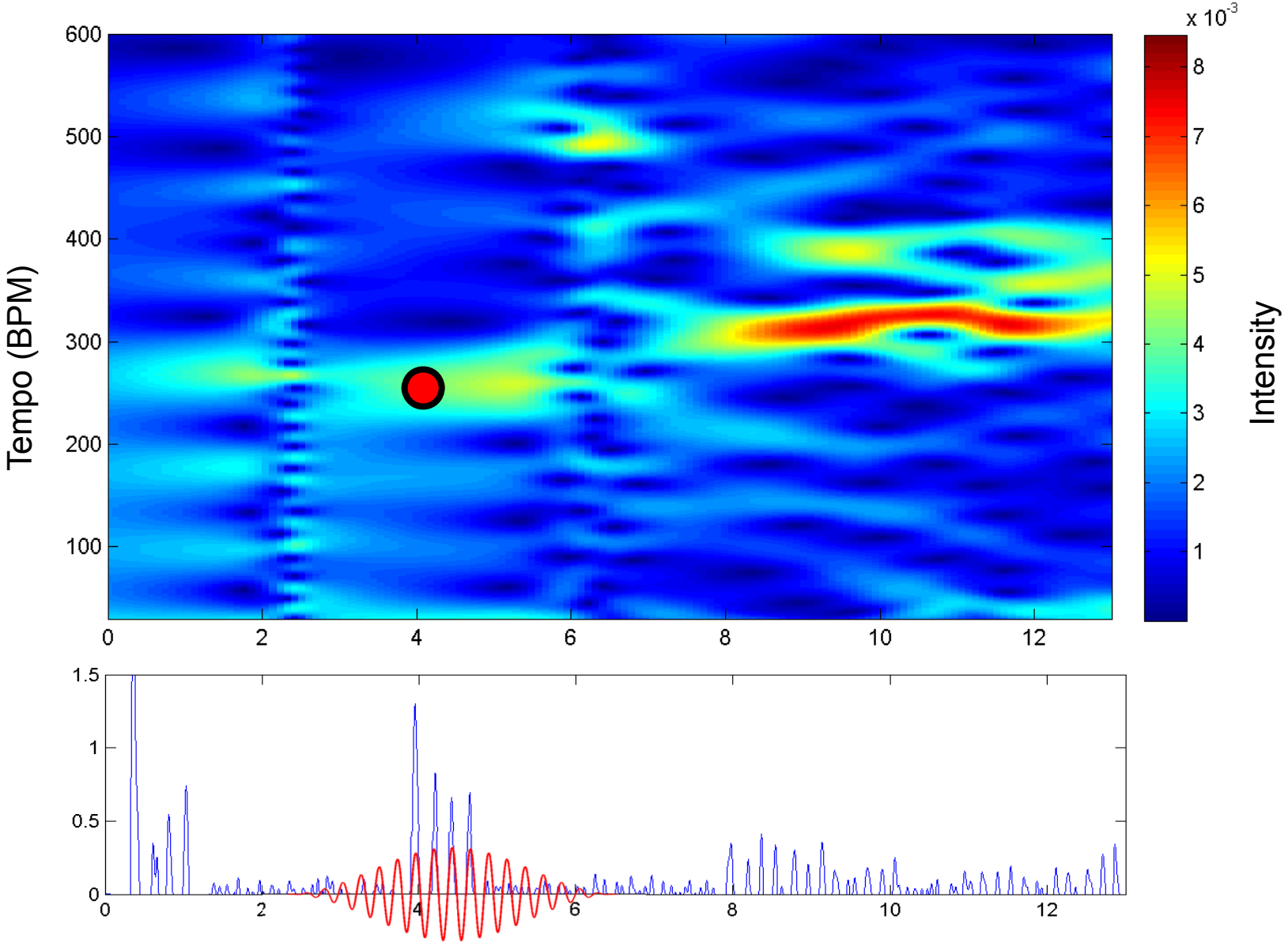
Novelty Curve



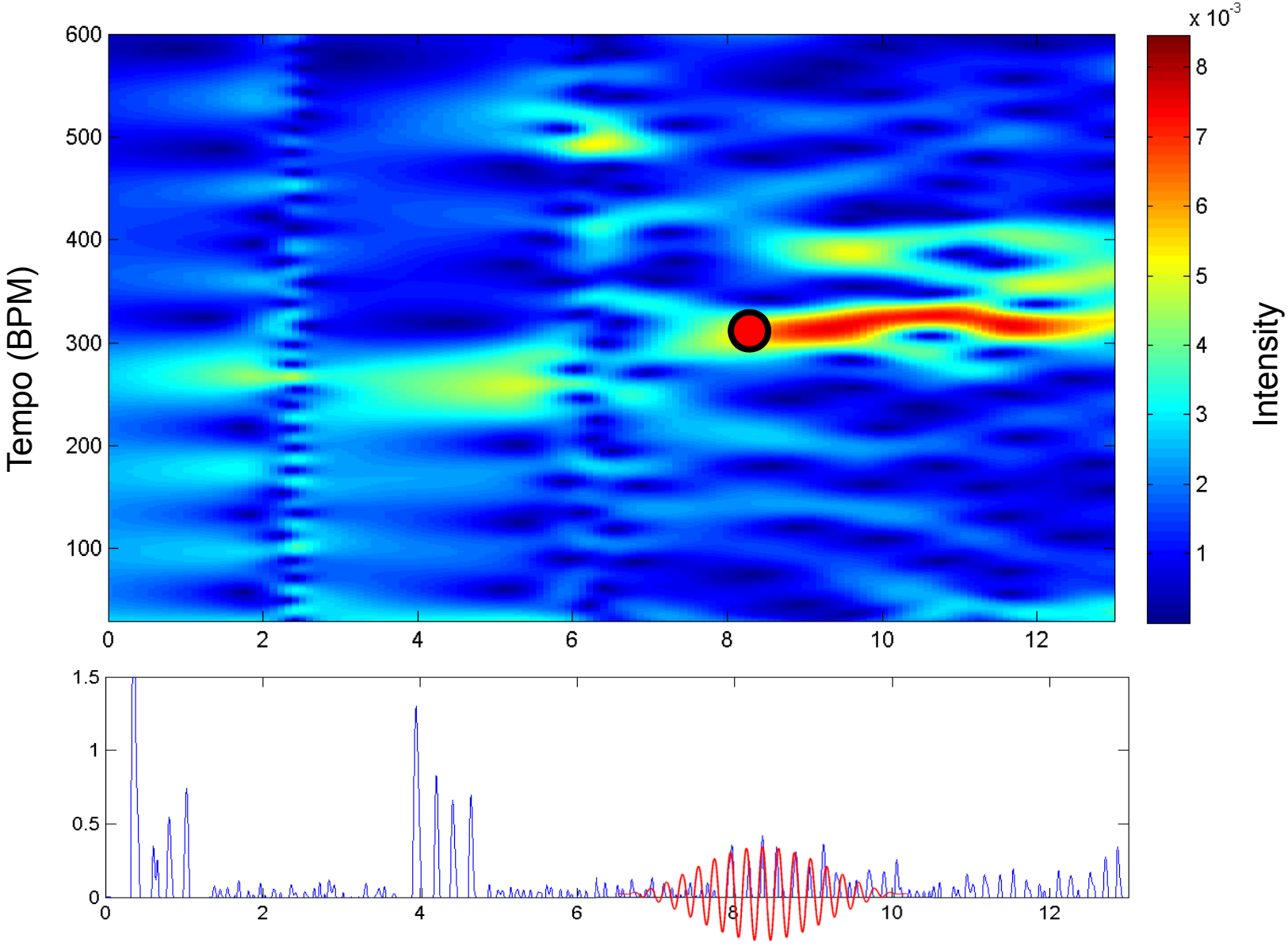
Tempo Estimation and Beat Tracking



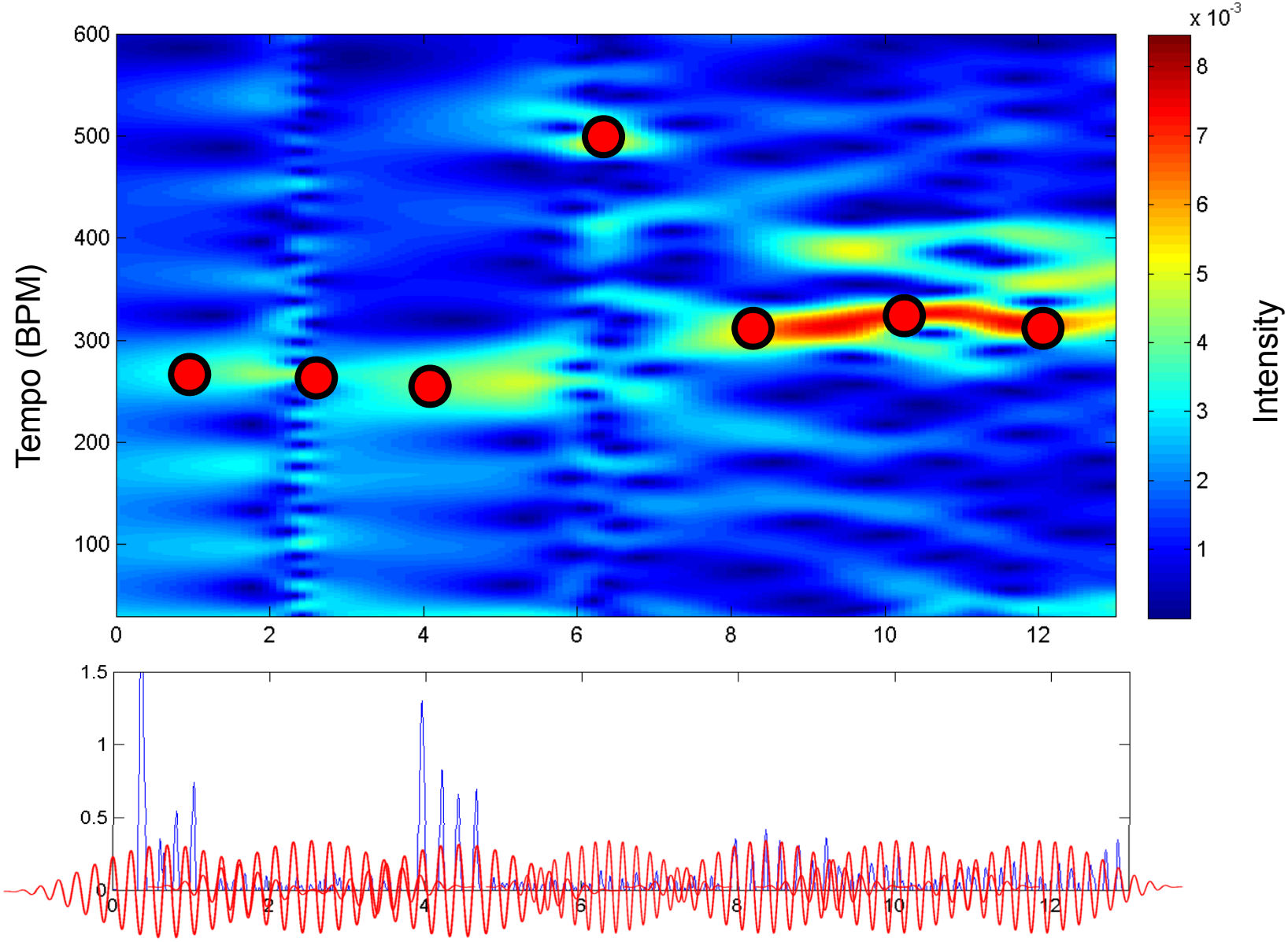
Tempo Estimation and Beat Tracking



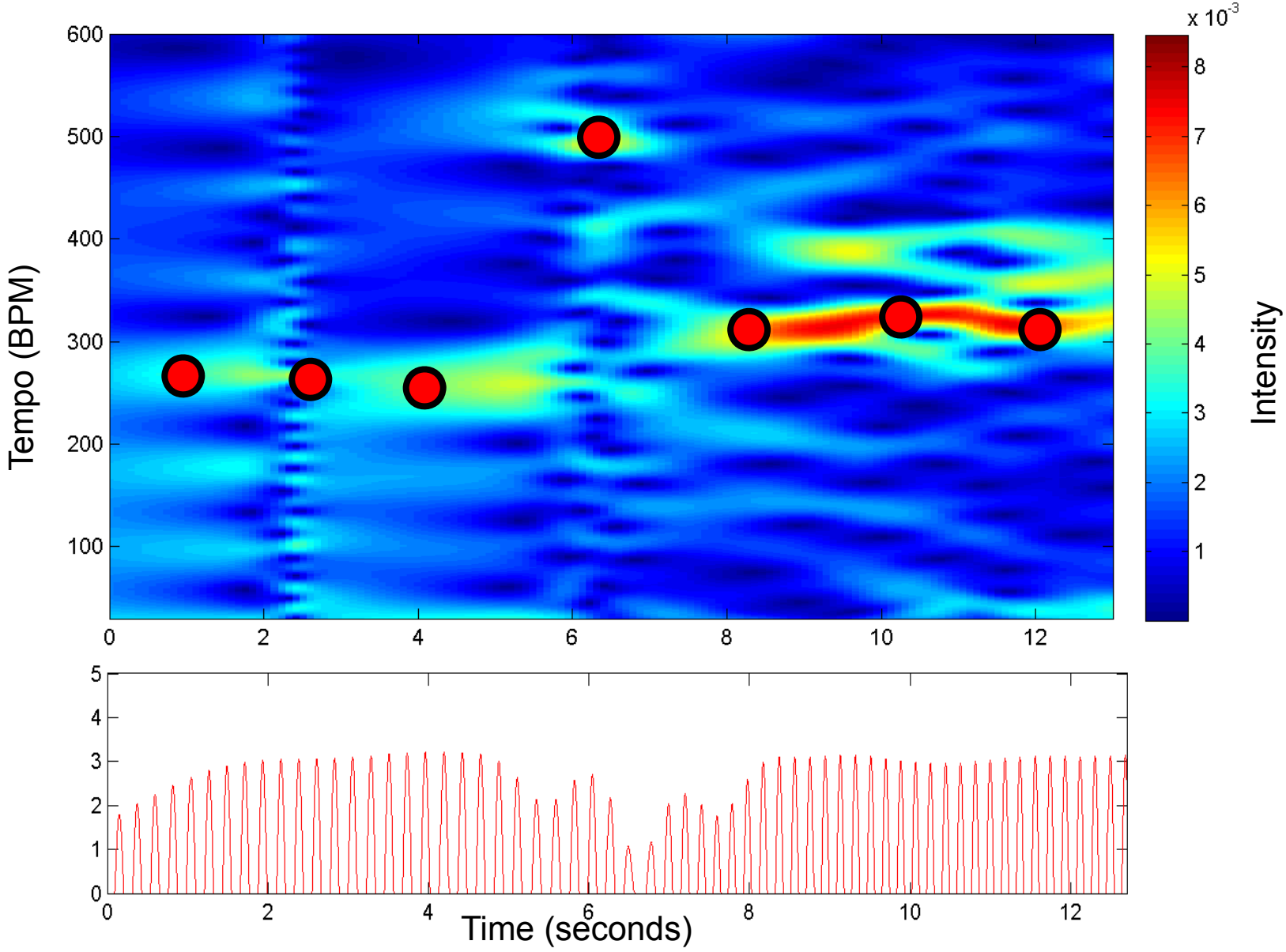
Tempo Estimation and Beat Tracking



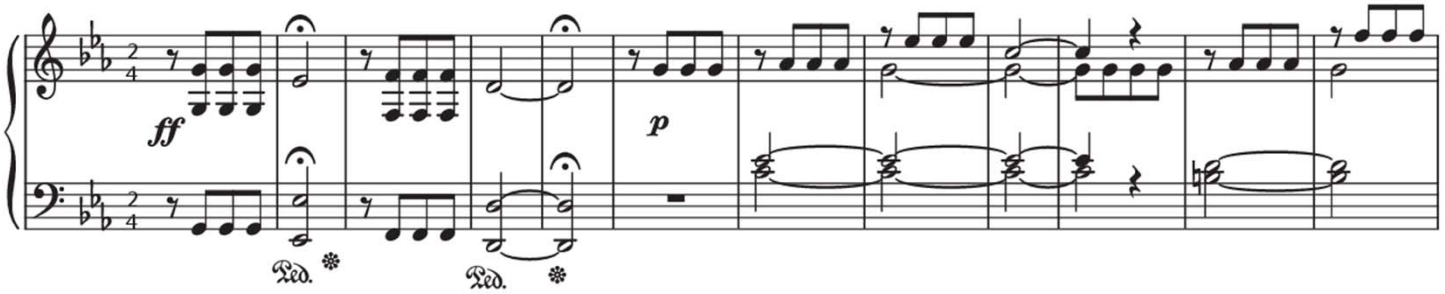
Tempo Estimation and Beat Tracking



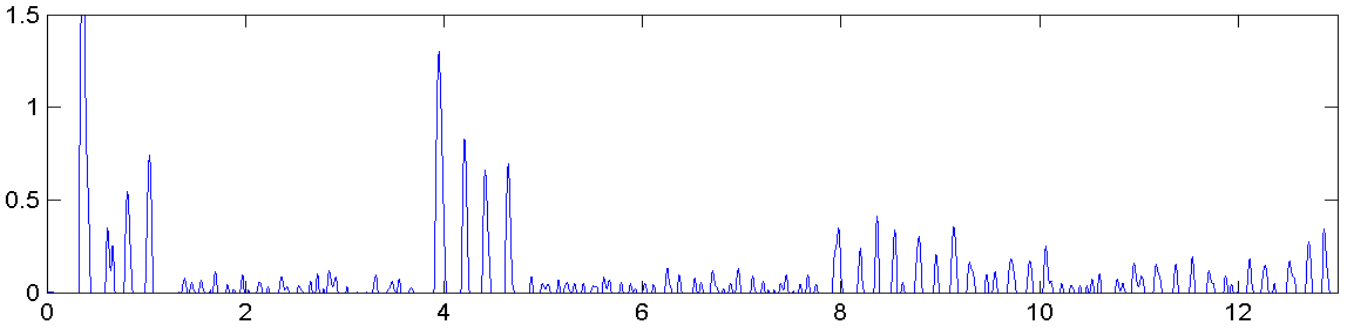
Tempo Estimation and Beat Tracking



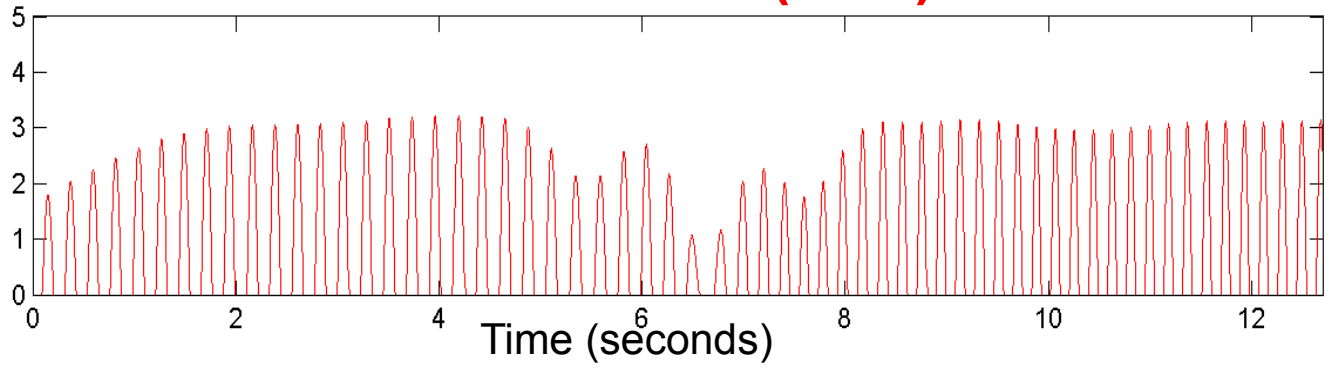
Tempo Estimation and Beat Tracking



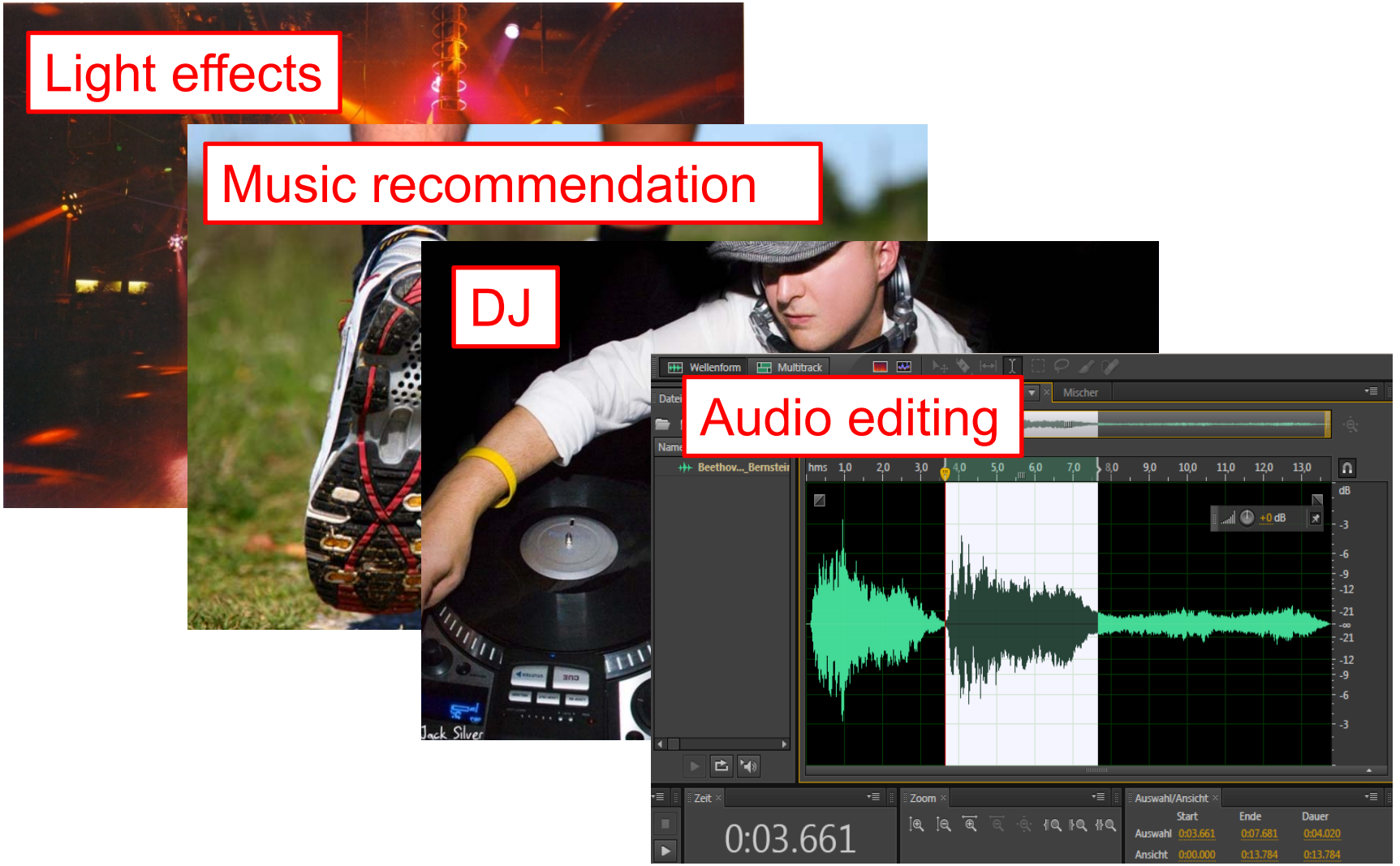
Novelty Curve



Predominant Local Pulse (PLP)

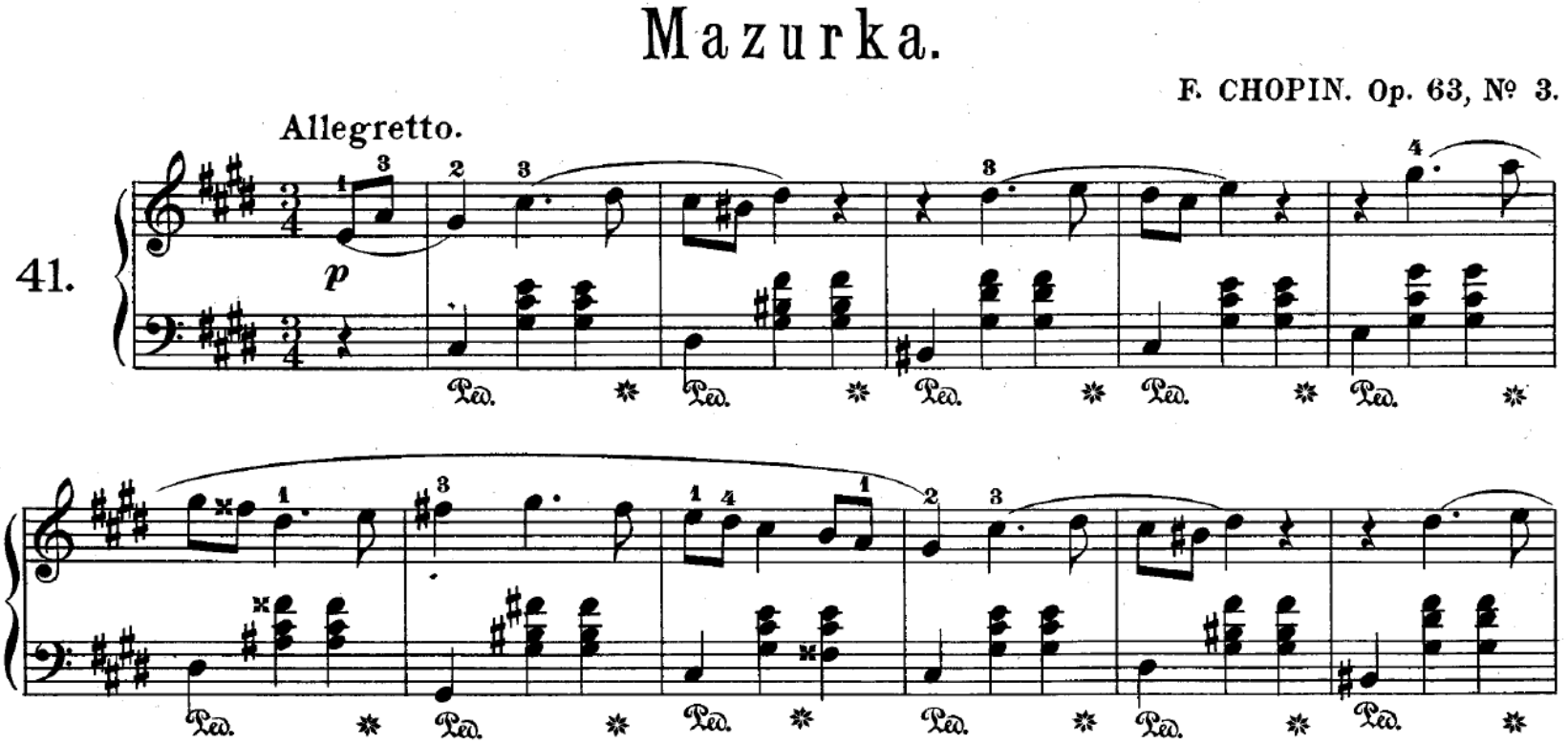


Tempo Estimation and Beat Tracking



Why is Music Processing Challenging?

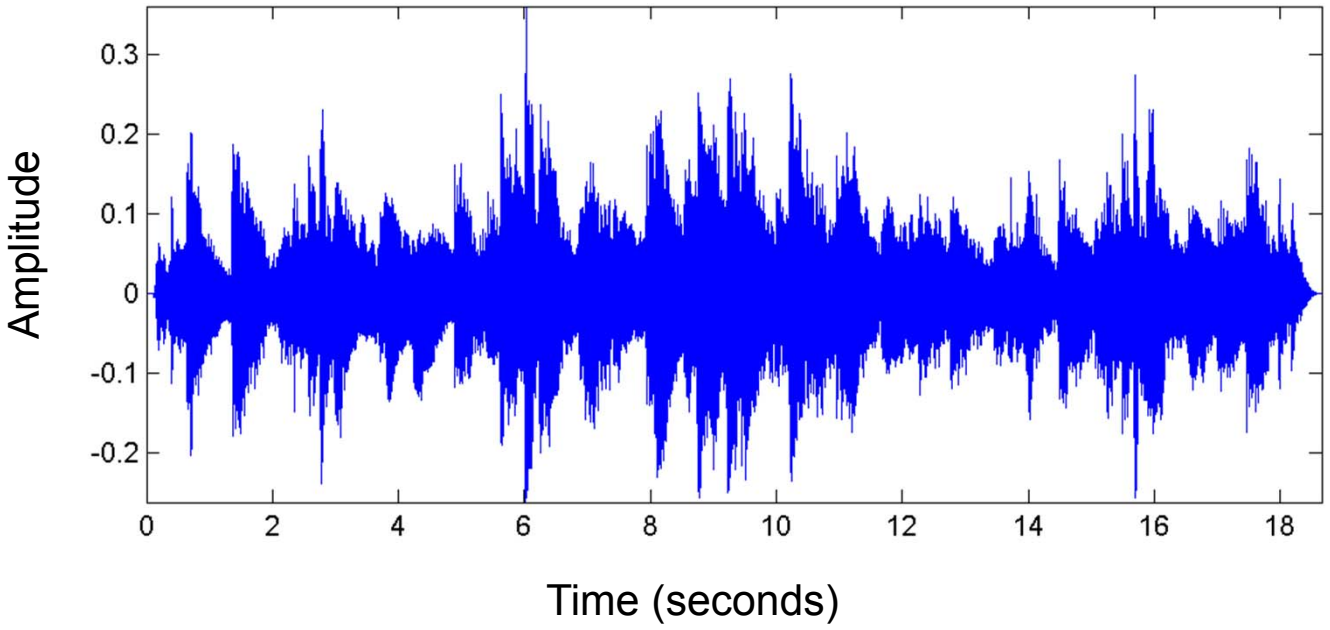
Example: Chopin, Mazurka Op. 63 No. 3



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

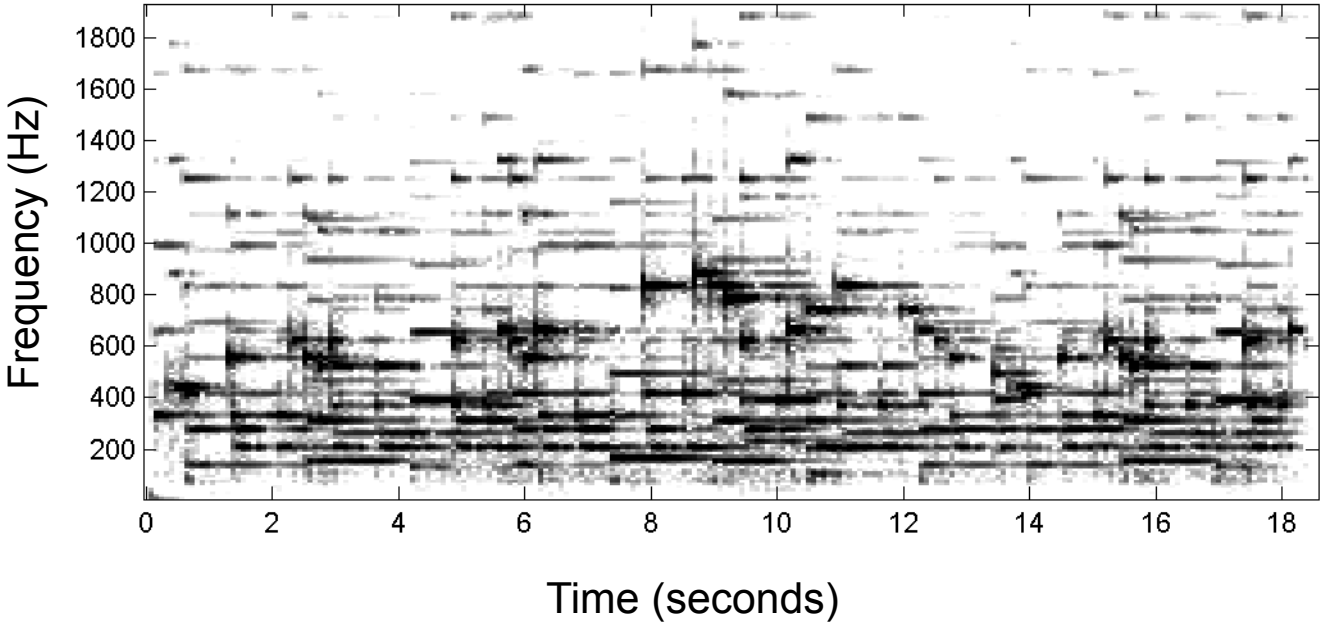
- Waveform



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram



Why is Music Processing Challenging?

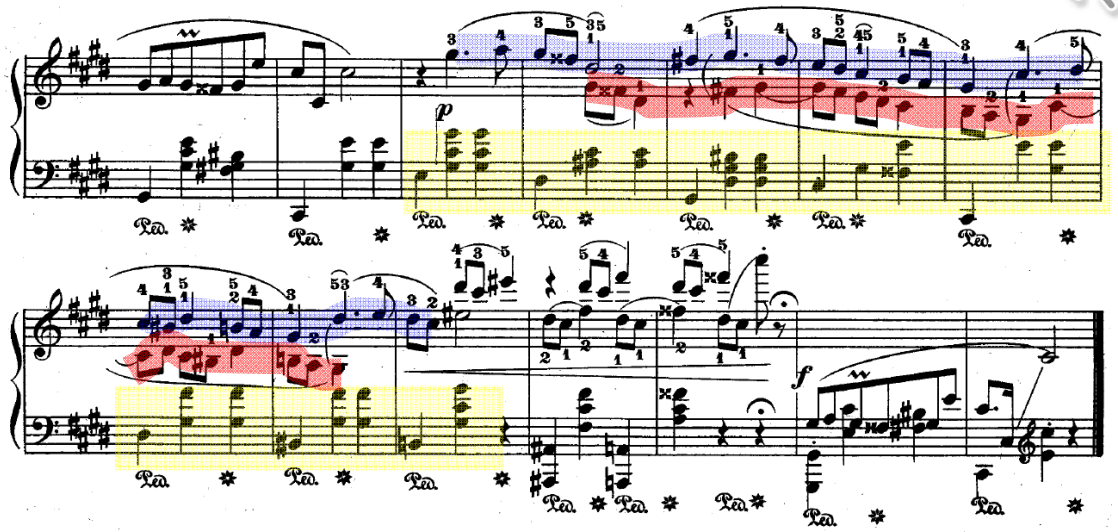
Example: Chopin, Mazurka Op. 63 No. 3

- 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

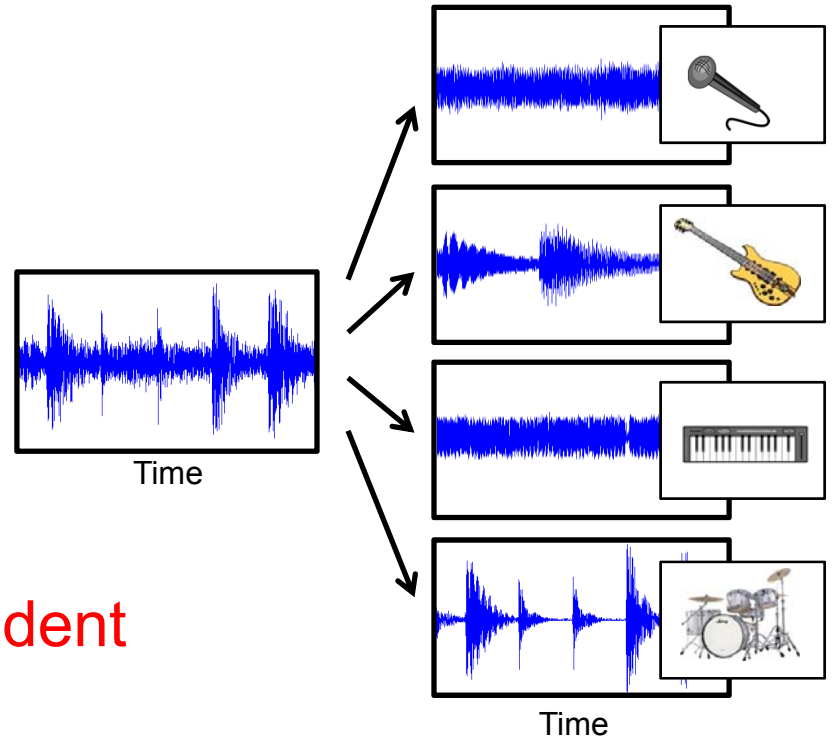
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”

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)

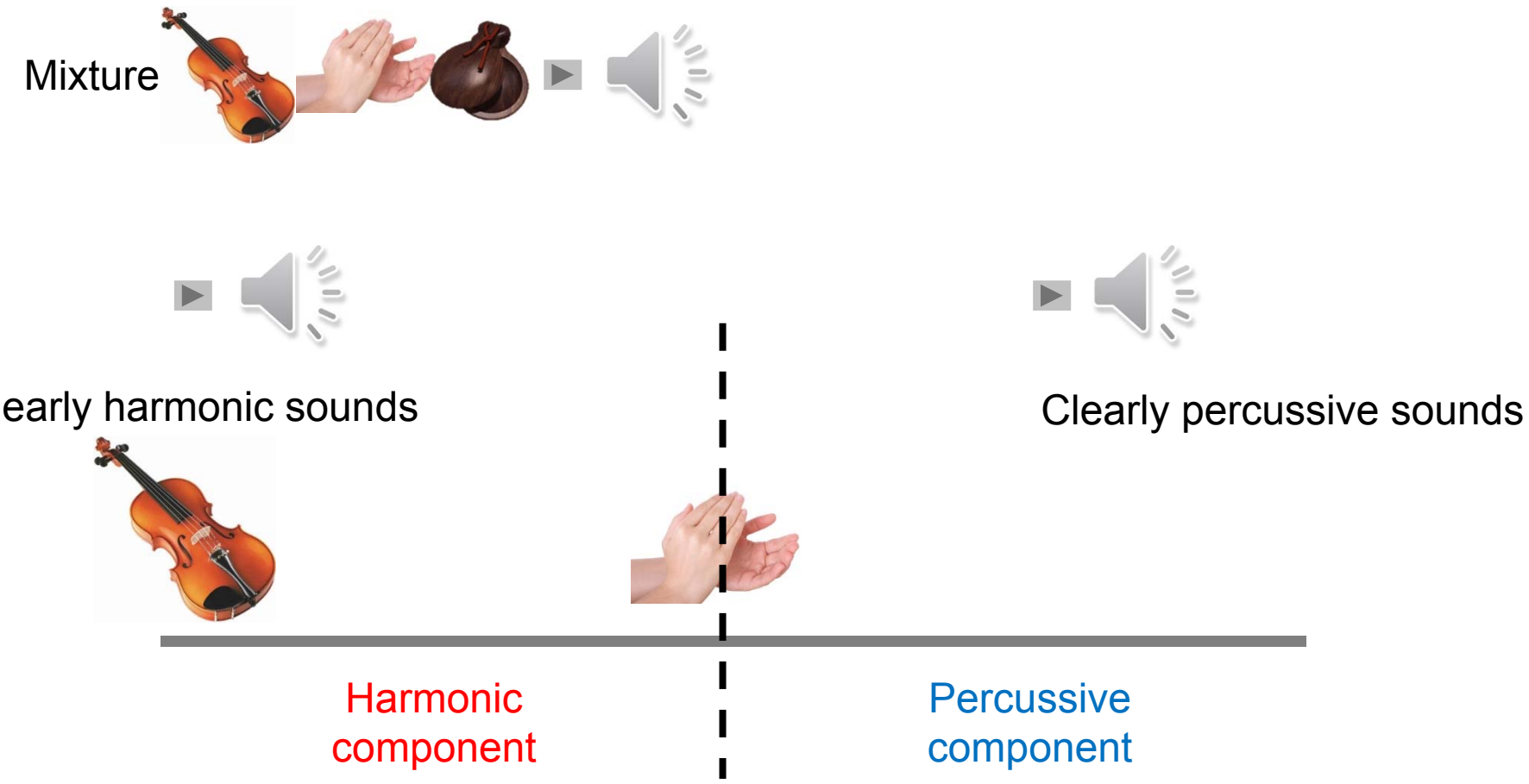
- Main melody, accompaniment, drum track
- Instrumental voices
- Individual note events
- Only mono or stereo
- Sources are often highly dependent



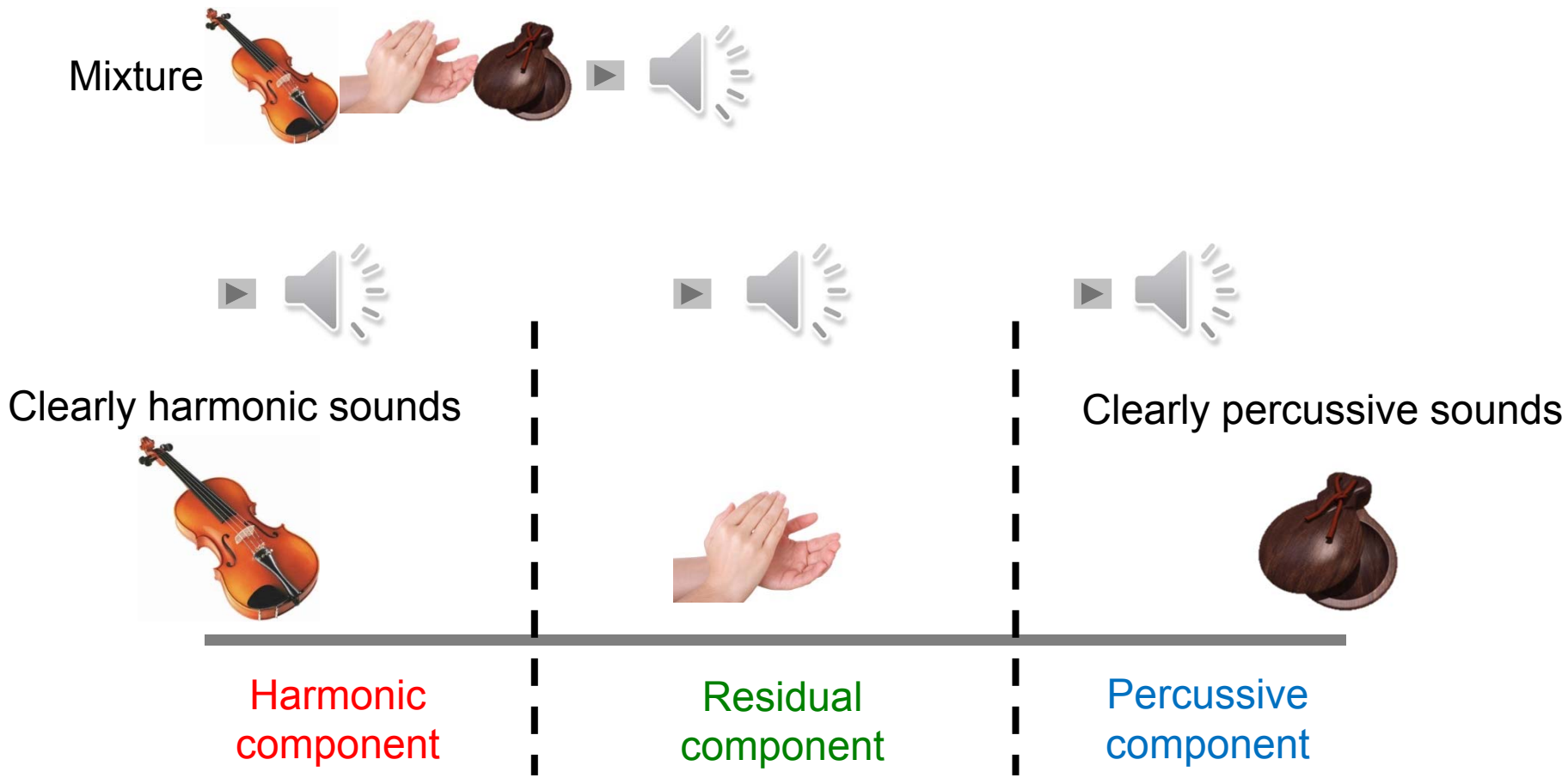
Harmonic-Percussive Decomposition

Mixture 

Harmonic-Percussive Decomposition

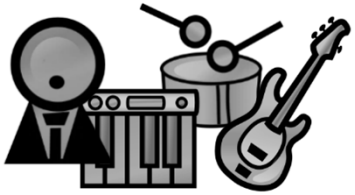


Harmonic-Percussive Decomposition



Harmonic-Percussive Decomposition

Mixture:



- Clearly harmonic sounds of singing voice and accompaniment

- Noise-like sounds
- Vibrato/glissando sounds

- Drum hits
- Fricatives & plosives in singing voice

Harmonic component

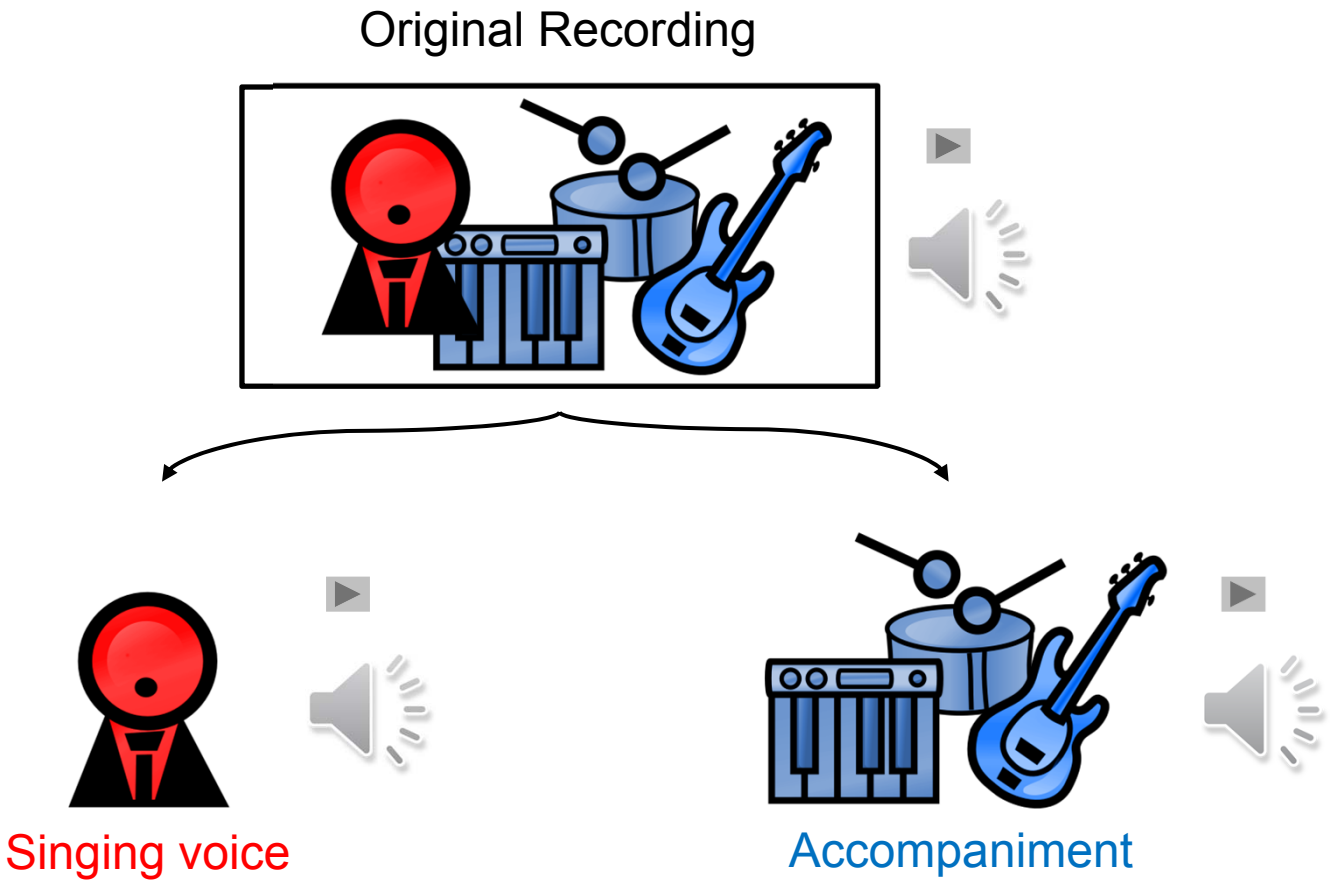
Residual component

Percussive component

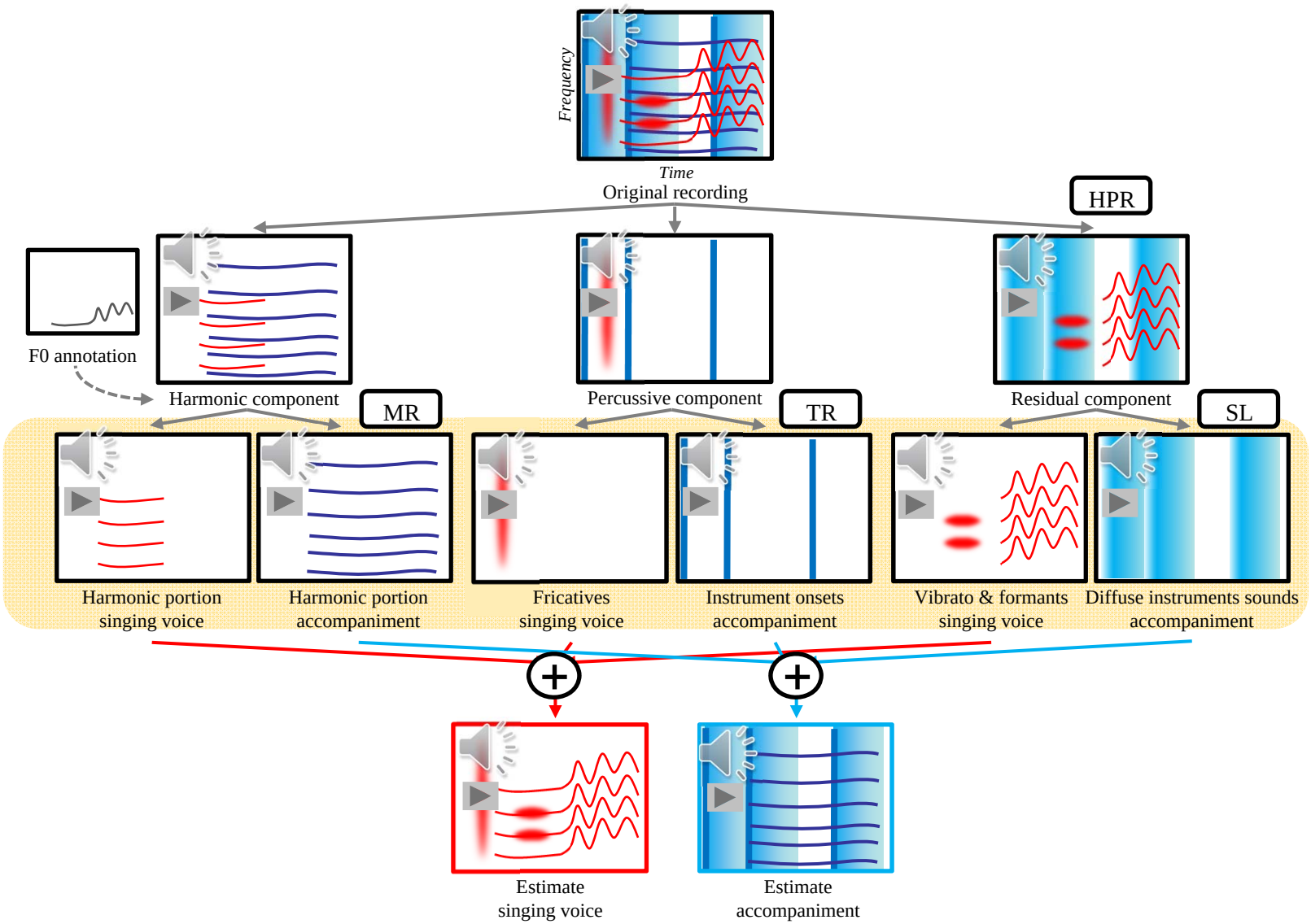
Literature: [Driedger/Müller/Disch, ISMIR 2014]

Demo: https://www.audiolabs-erlangen.de/resources/2014-ISMIR-ExtHPSep/

Singing Voice Extraction

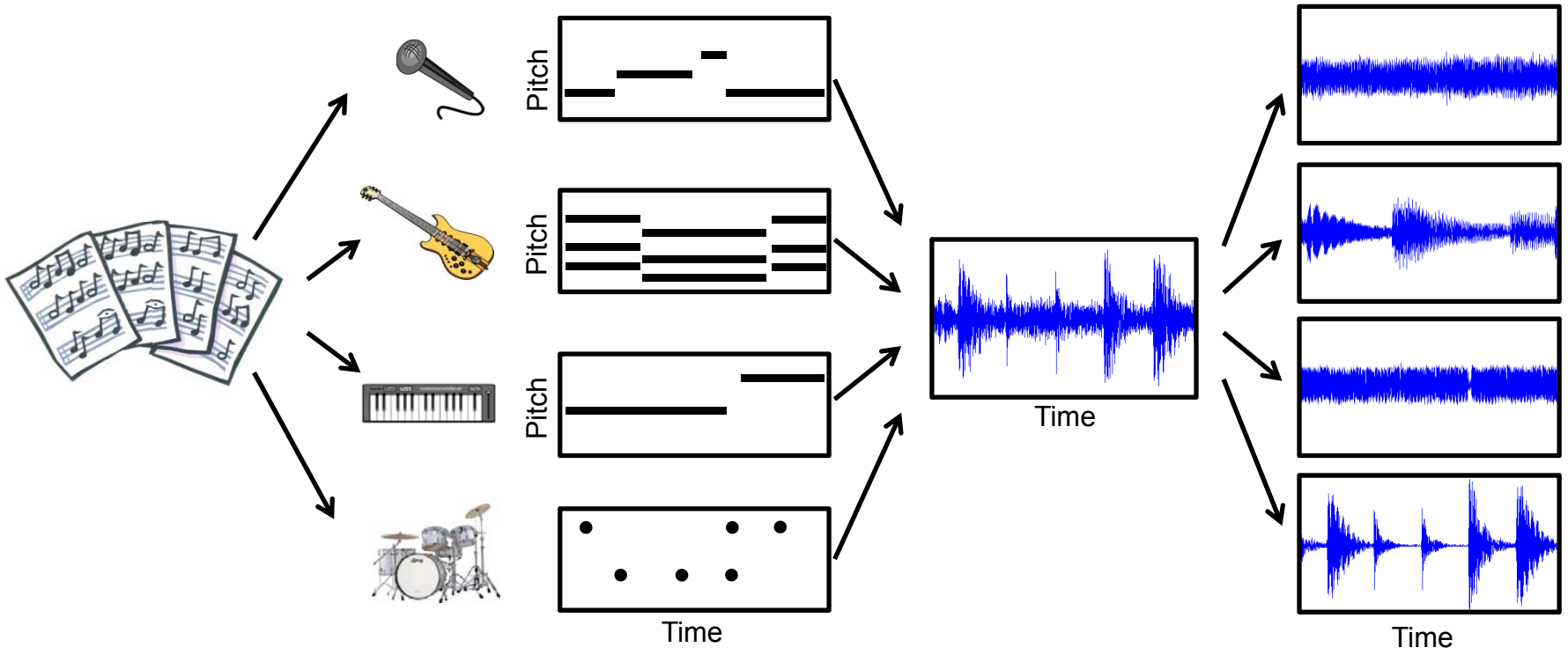


Singing Voice Extraction



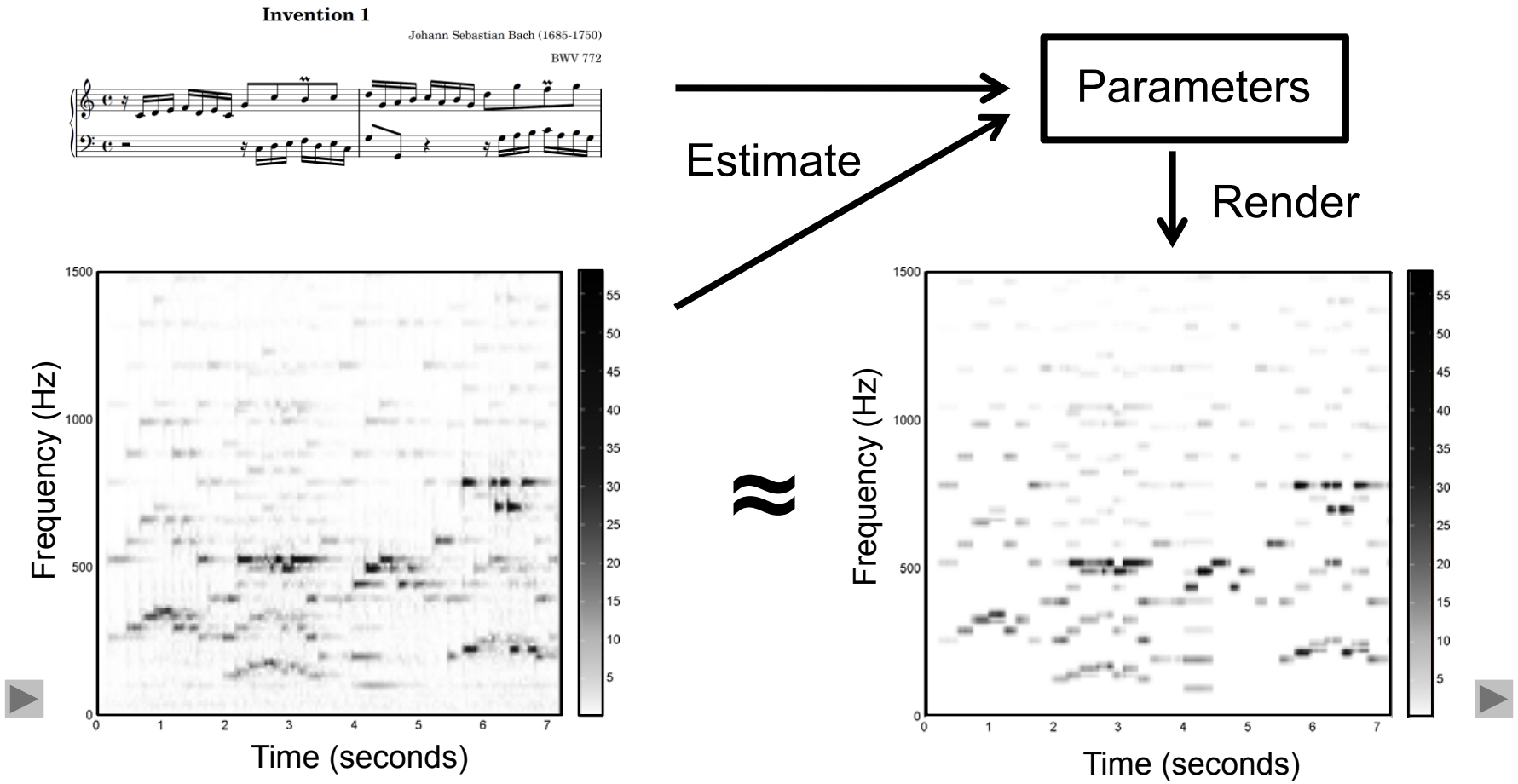
Score-Informed Source Separation

Exploit musical score to support separation process

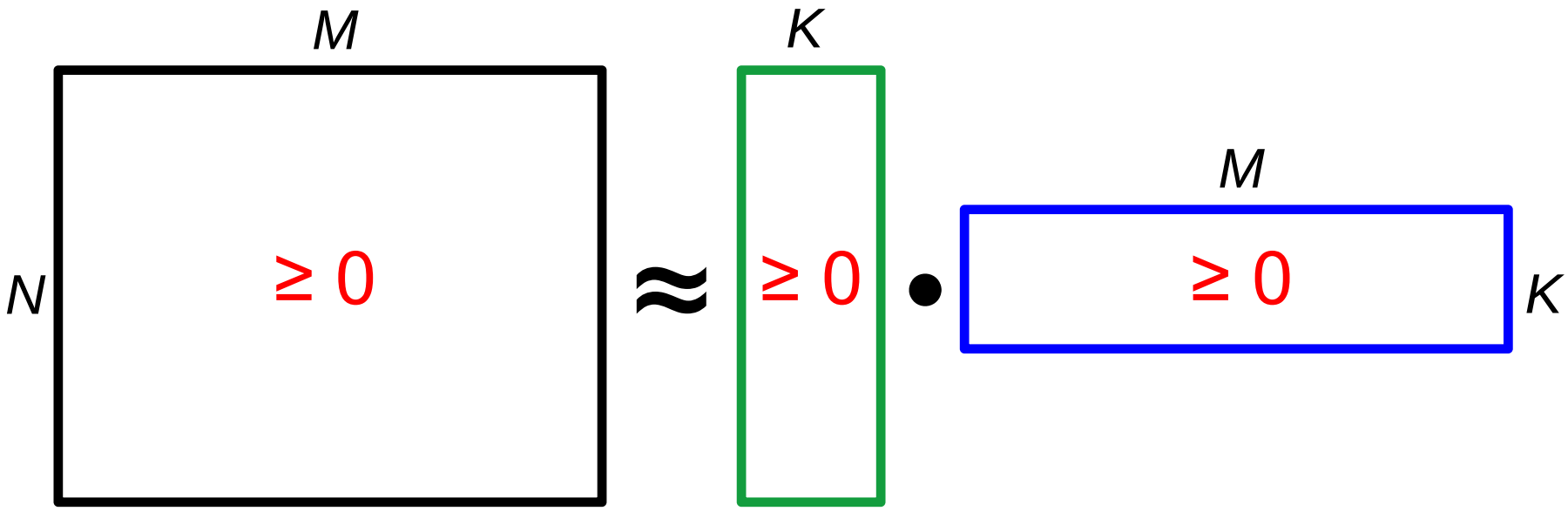


Parametric Model Approach

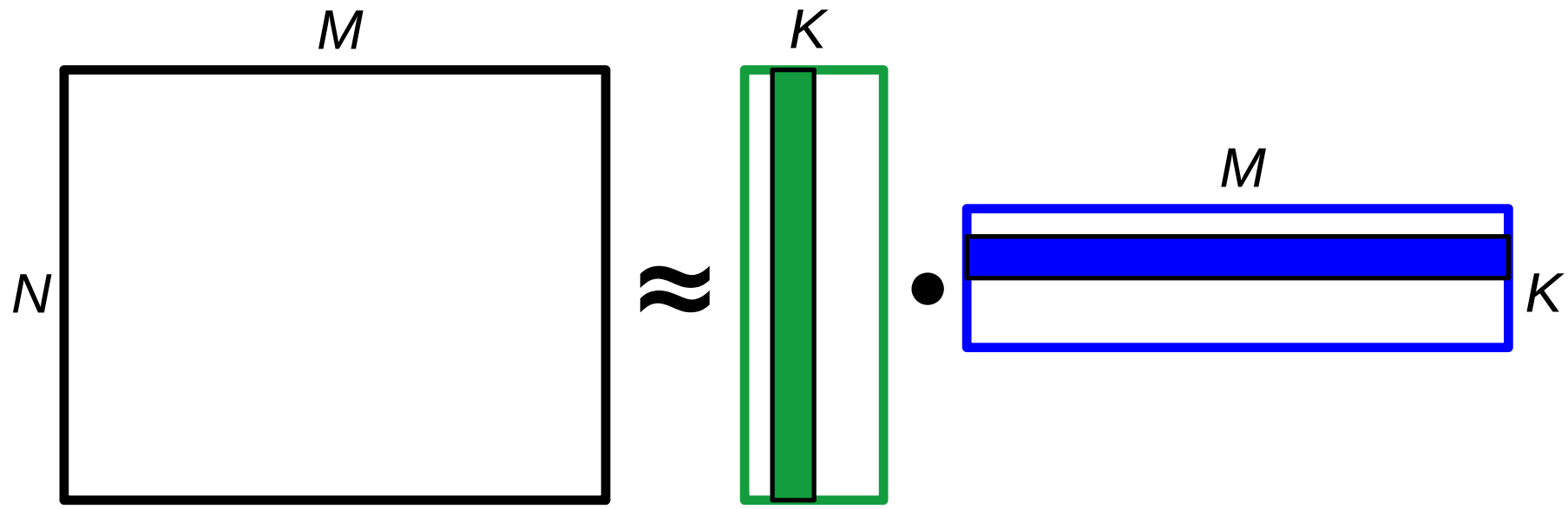
Rebuild spectrogram information



NMF (Nonnegative Matrix Factorization)



NMF (Nonnegative Matrix Factorization)

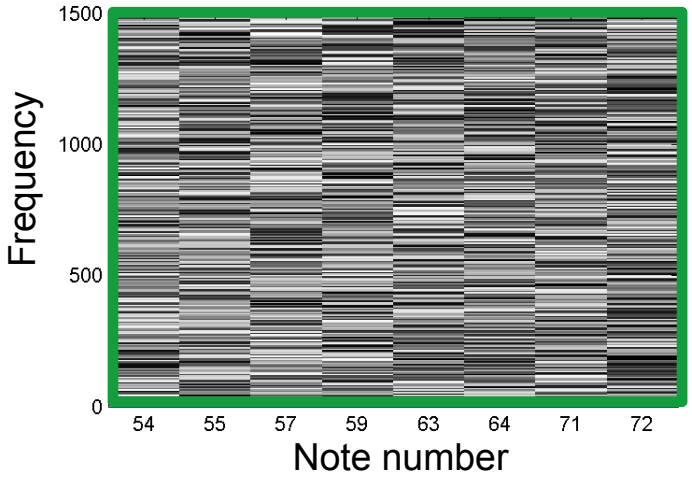


Templates: Pitch + Timbre — "How does it sound"

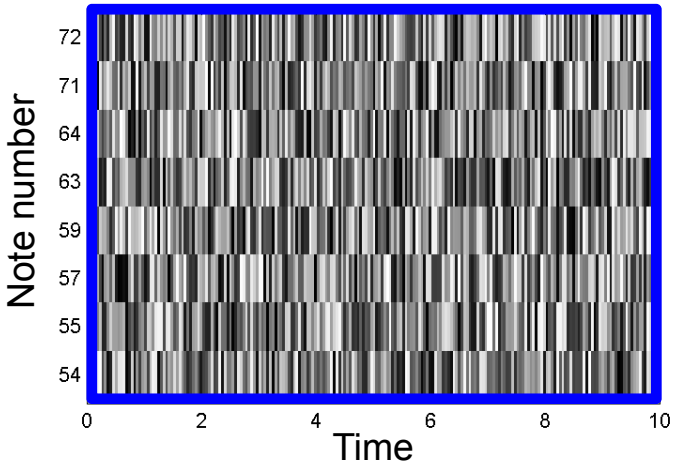
Activations: Onset time + Duration — "When does it sound"

NMF-Decomposition

Initialized template

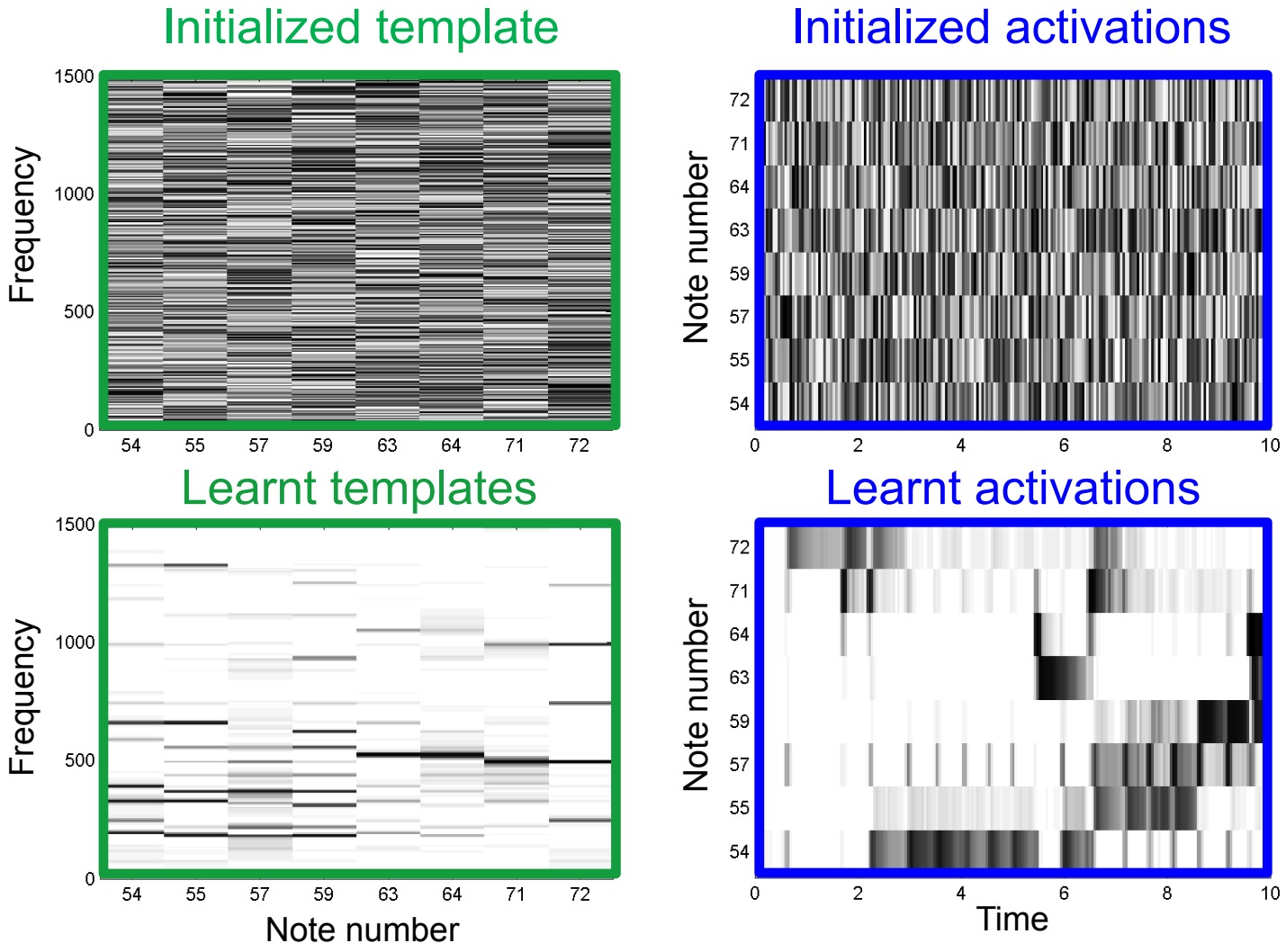


Initialized activations



Random initialization

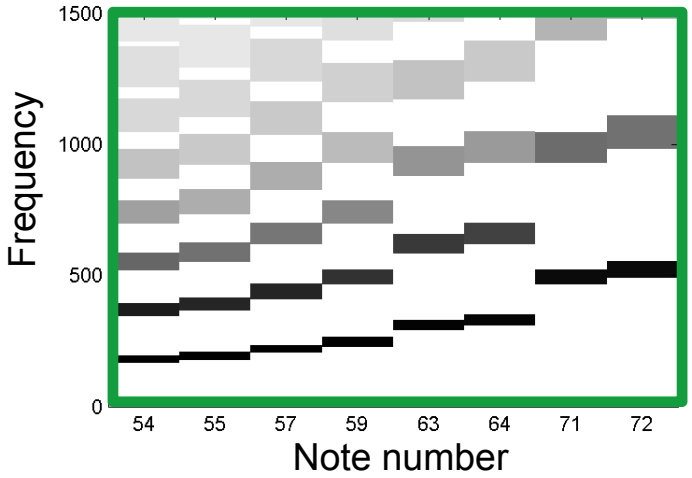
NMF-Decomposition



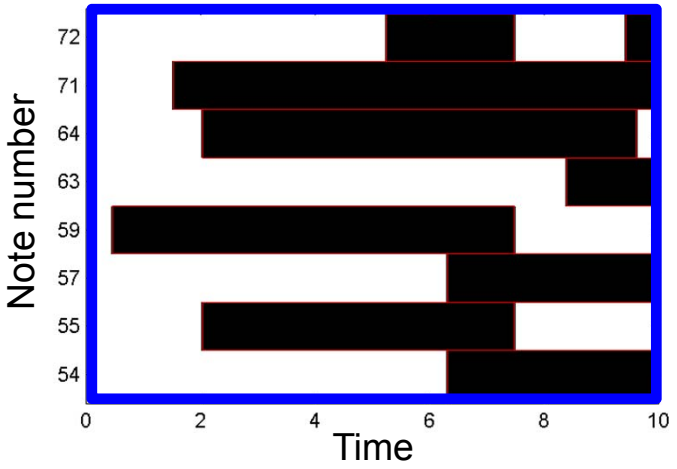
Random initialization → No semantic meaning

NMF-Decomposition

Initialized template



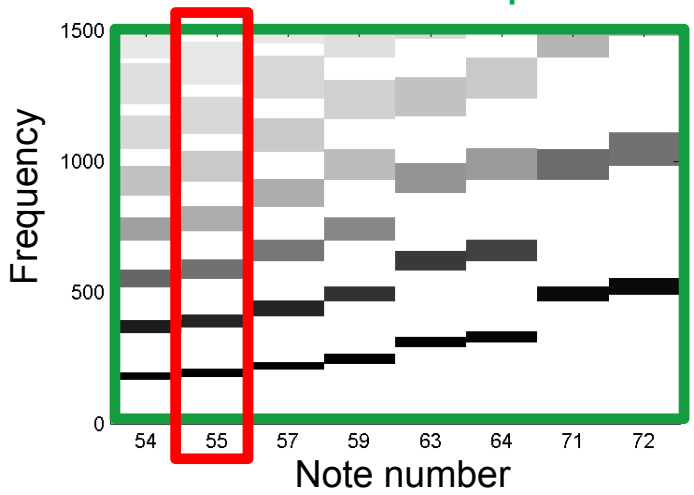
Initialized activations



Constrained initialization

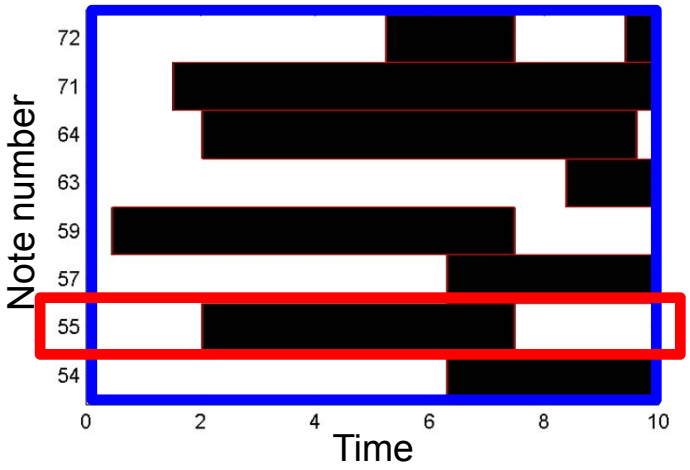
NMF-Decomposition

Initialized template



Template constraint for p=55

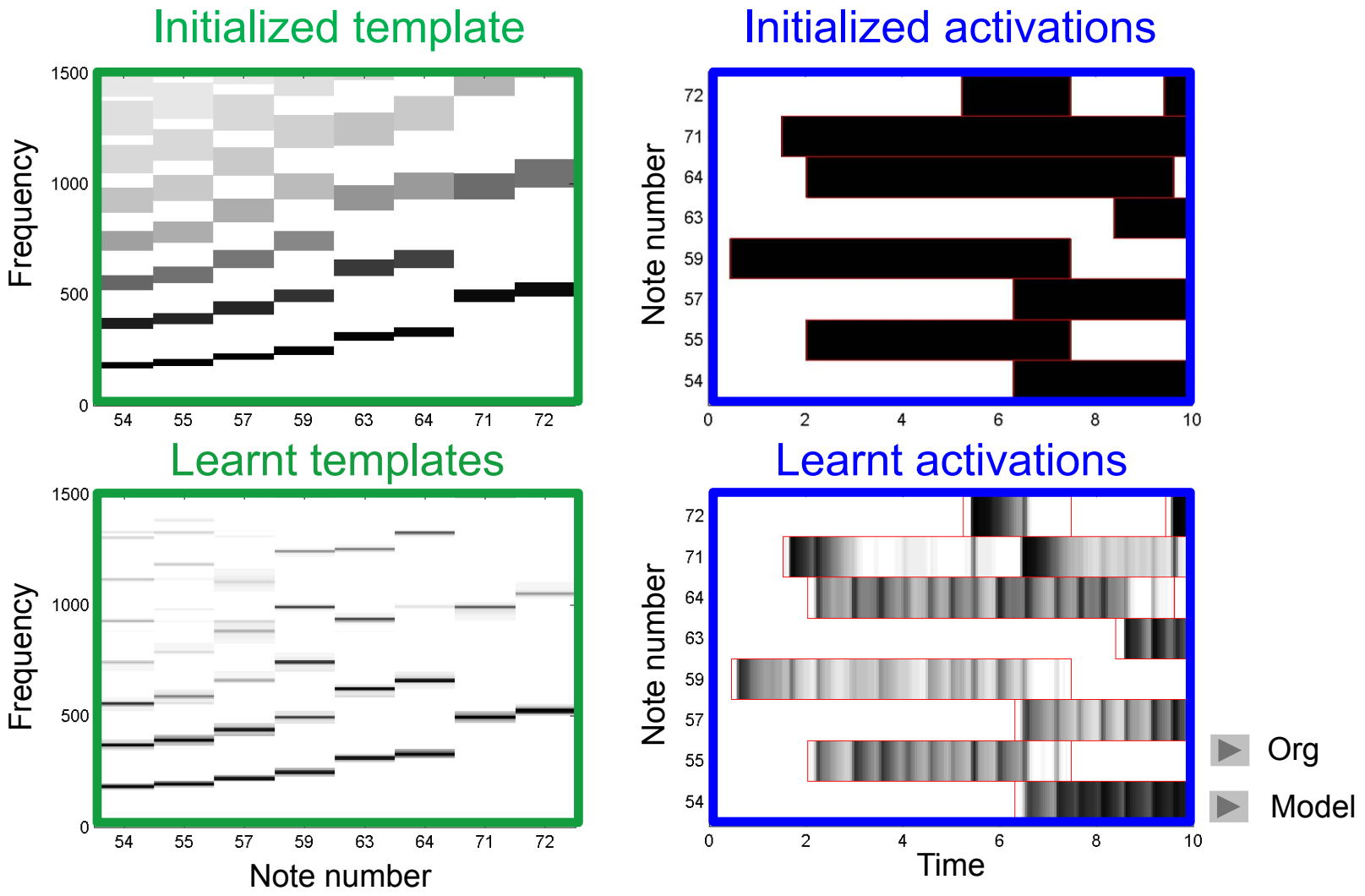
Initialized activations



Activation constraints for p=55

Constrained initialization

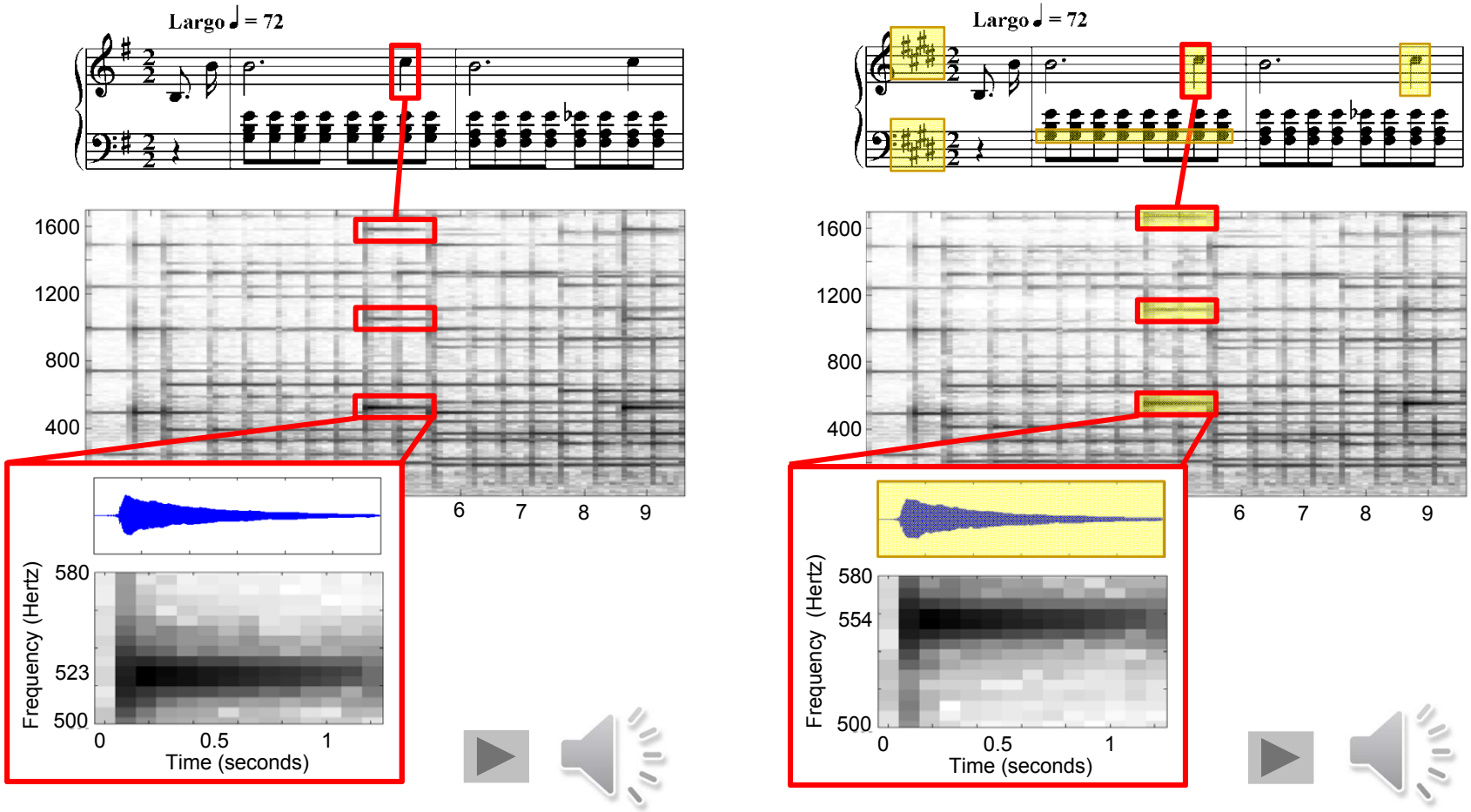
NMF-Decomposition



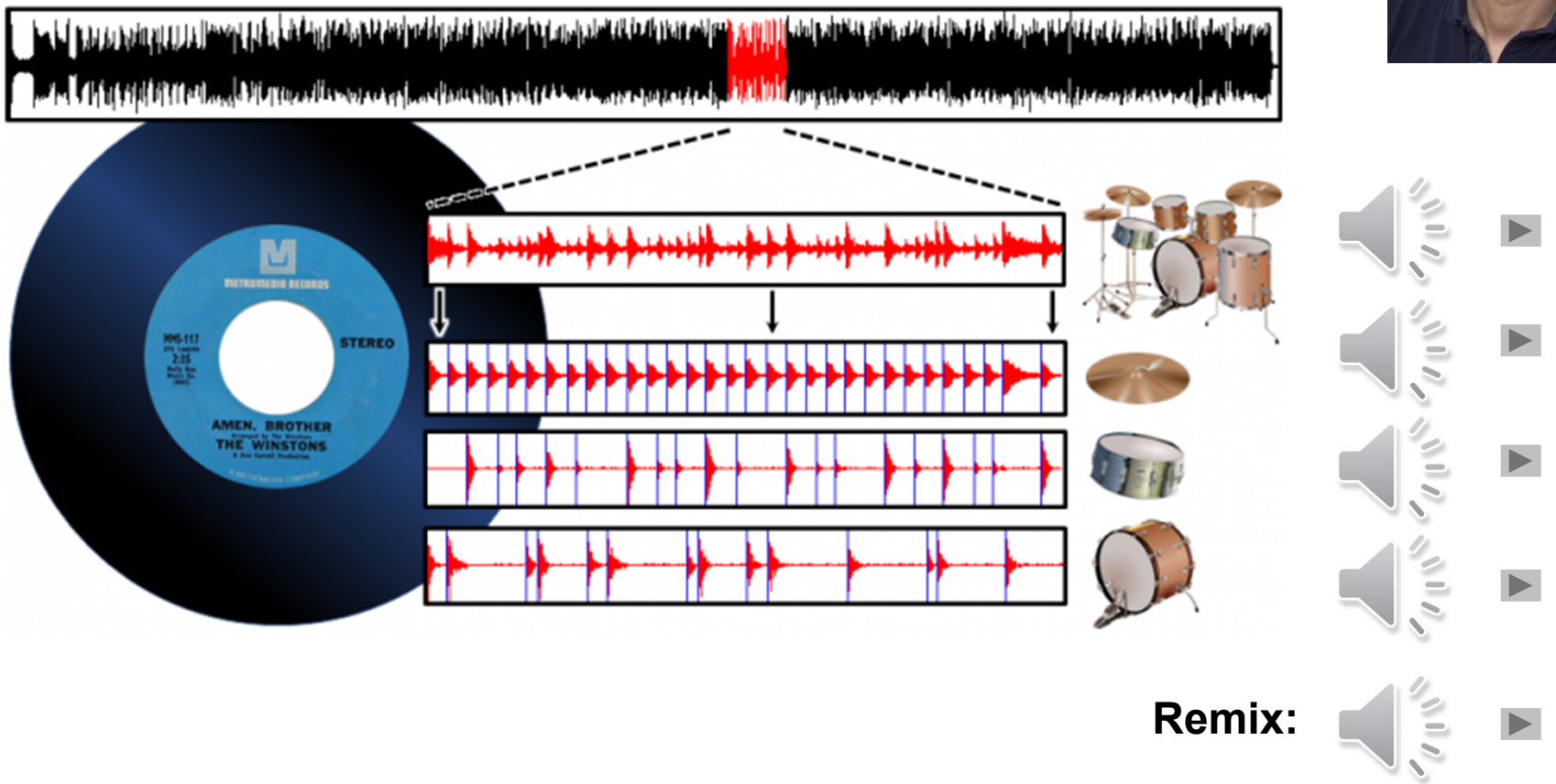
Constrained initialization → NMF as refinement

Score-Informed Audio Decomposition

Application: Audio editing



Informed Drum-Sound Decomposition

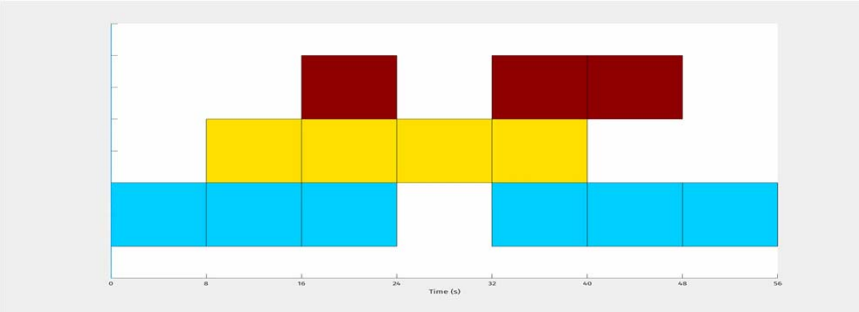


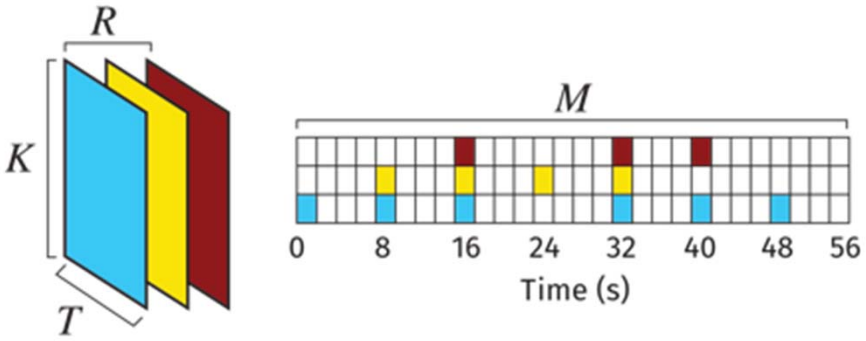
Remix:

Literature: [Dittmar/Müller, IEEE/ACM-TASLP 2016]

Demo: https://www.audiolabs-erlangen.de/resources/MIR/2016-IEEE-TASLP-DrumSeparation

Loop Decomposition of EDM



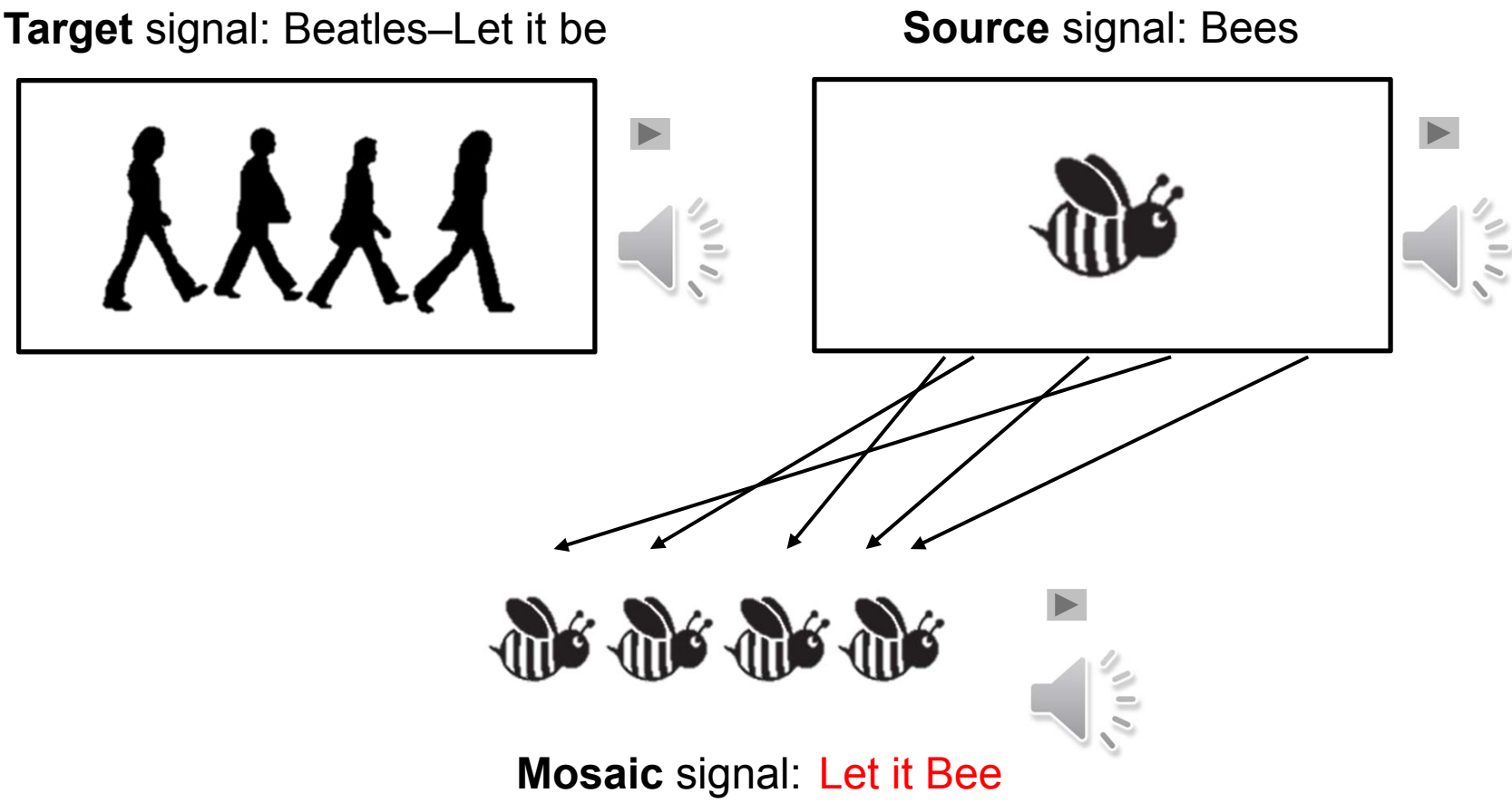


Decomposition Patterns Activations

Literature: [López-Serrano/Dittmar/Müller, ISMIR 2016]

Demo: https://www.audiolabs-erlangen.de/resources/MIR/2016-ISMIR-EMLoop

Audio Mosaicing

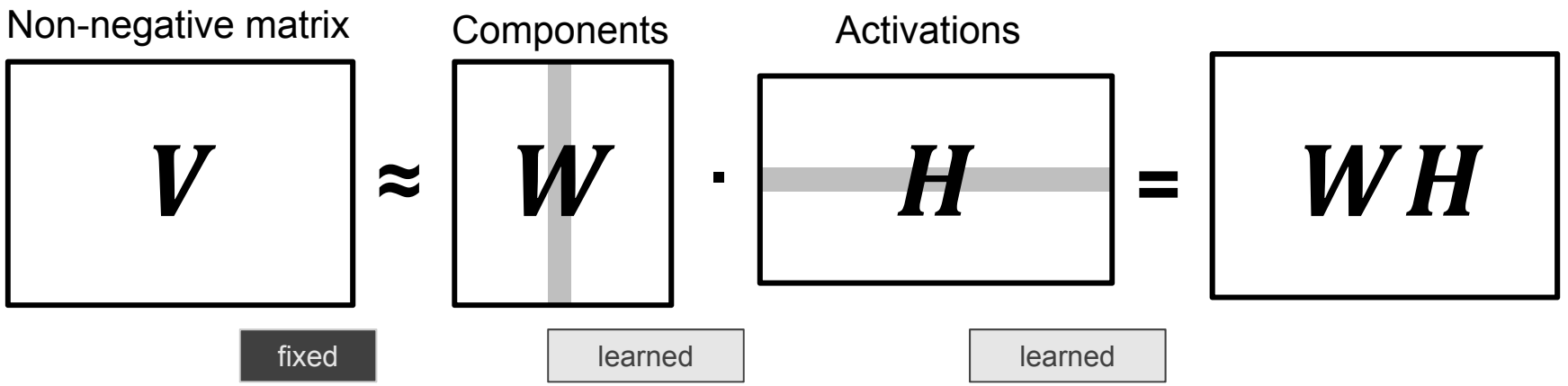


Literature: [Driedger/Müller, ISMIR 2015]

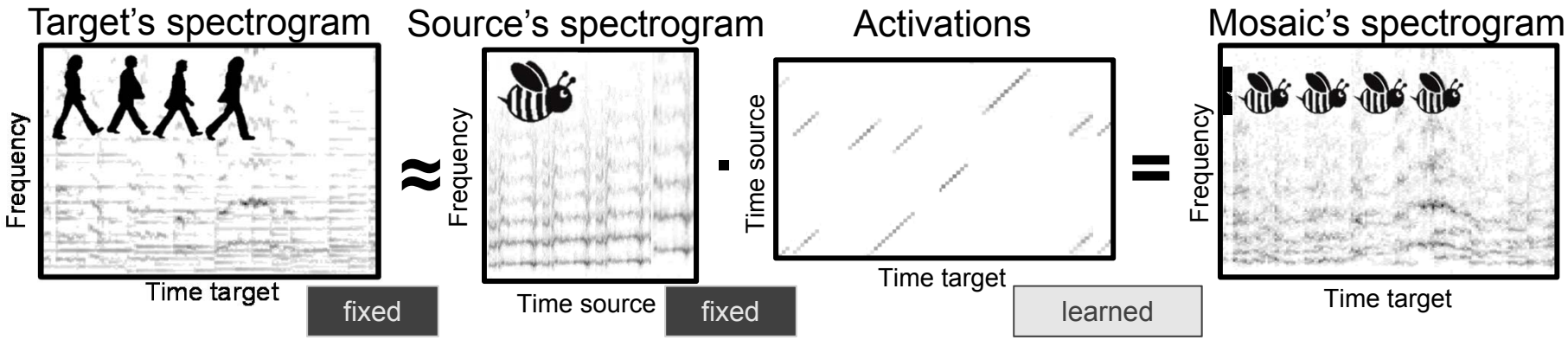
Demo: https://www.audiolabs-erlangen.de/resources/MIR/2015-ISMIR-LetItBee

NMF-Inspired Audio Mosaicing

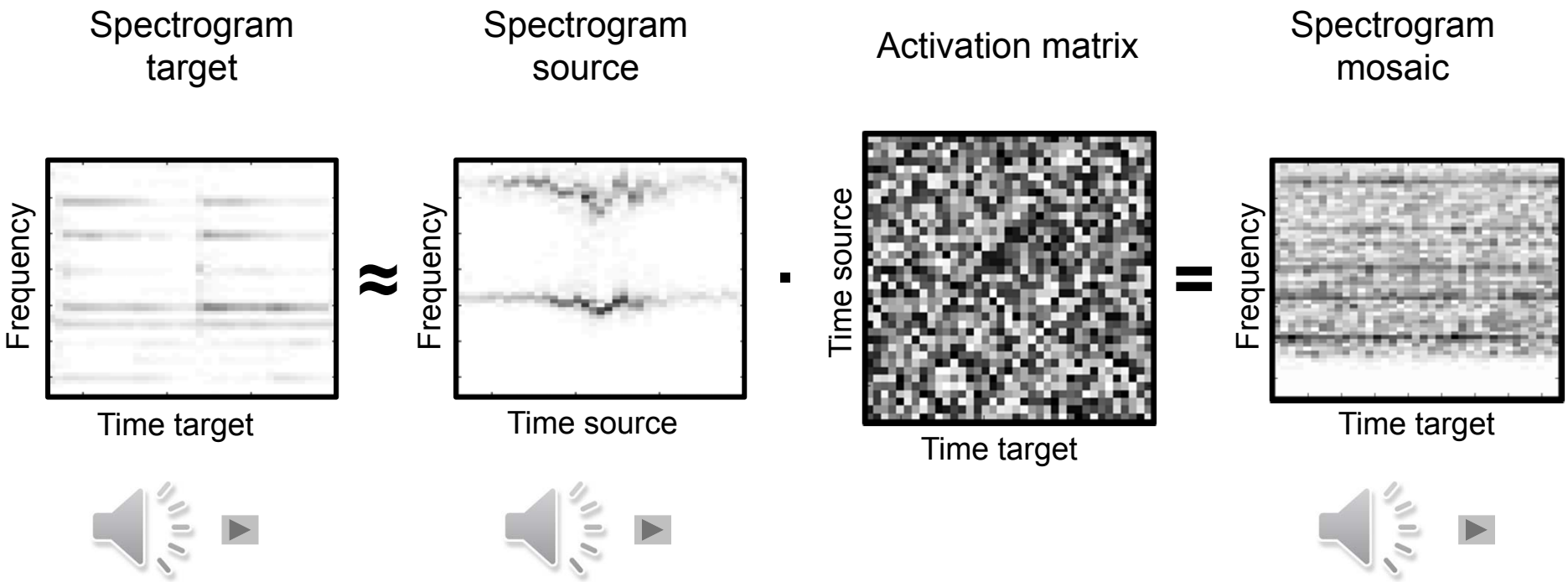
Non-negative matrix factorization (NMF)



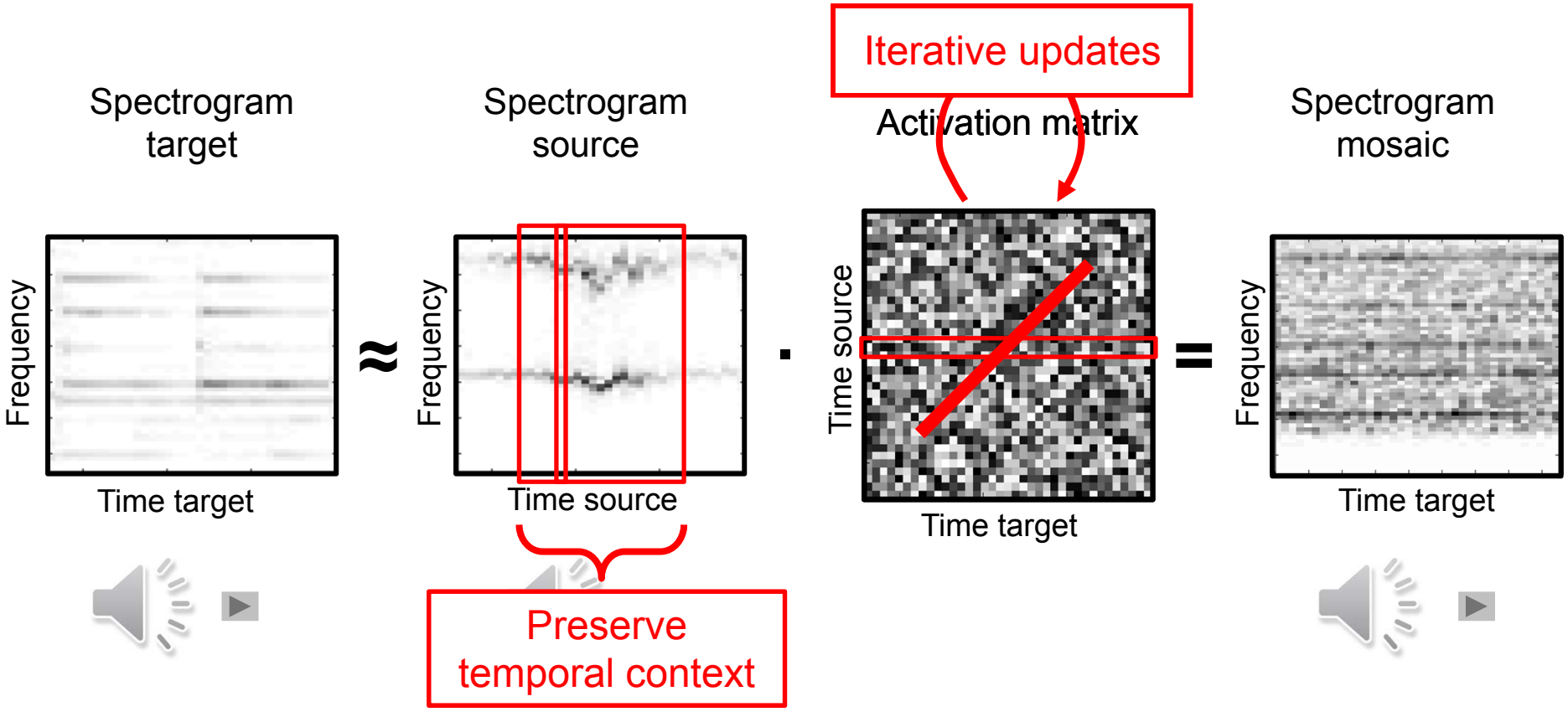
Proposed audio mosaicing approach



NMF-Inspired Audio Mosaicing

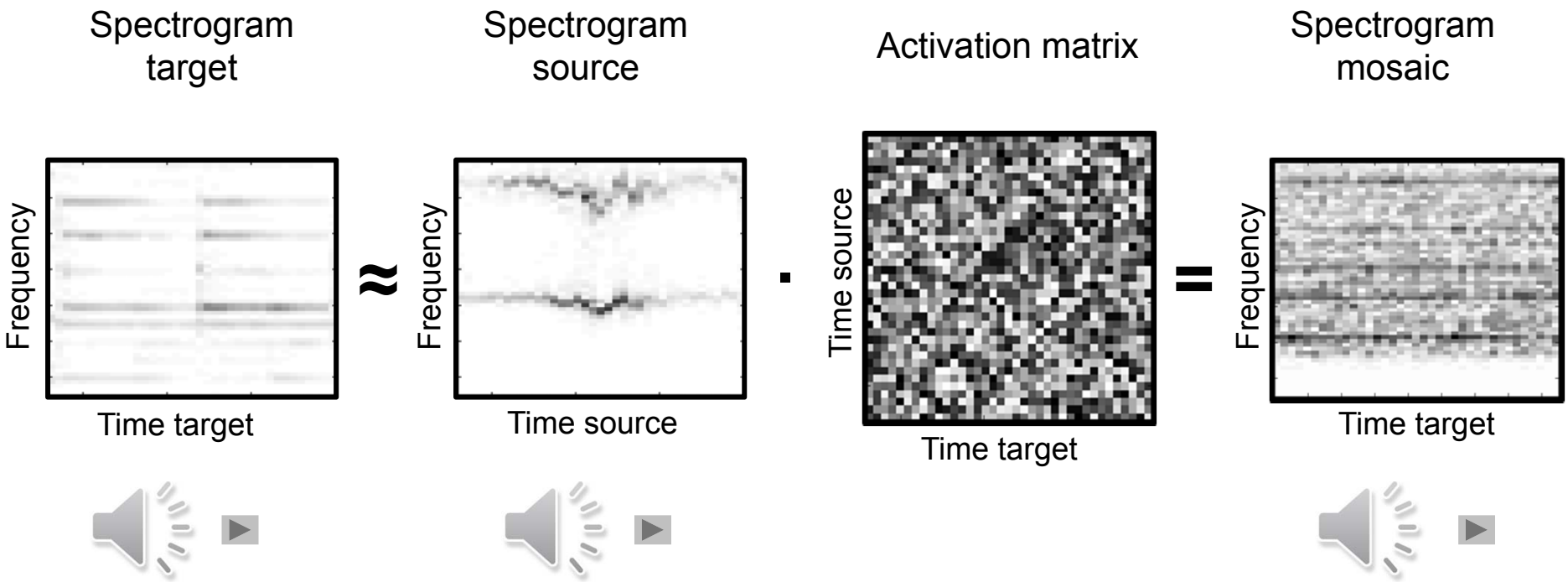


NMF-Inspired Audio Mosaicing

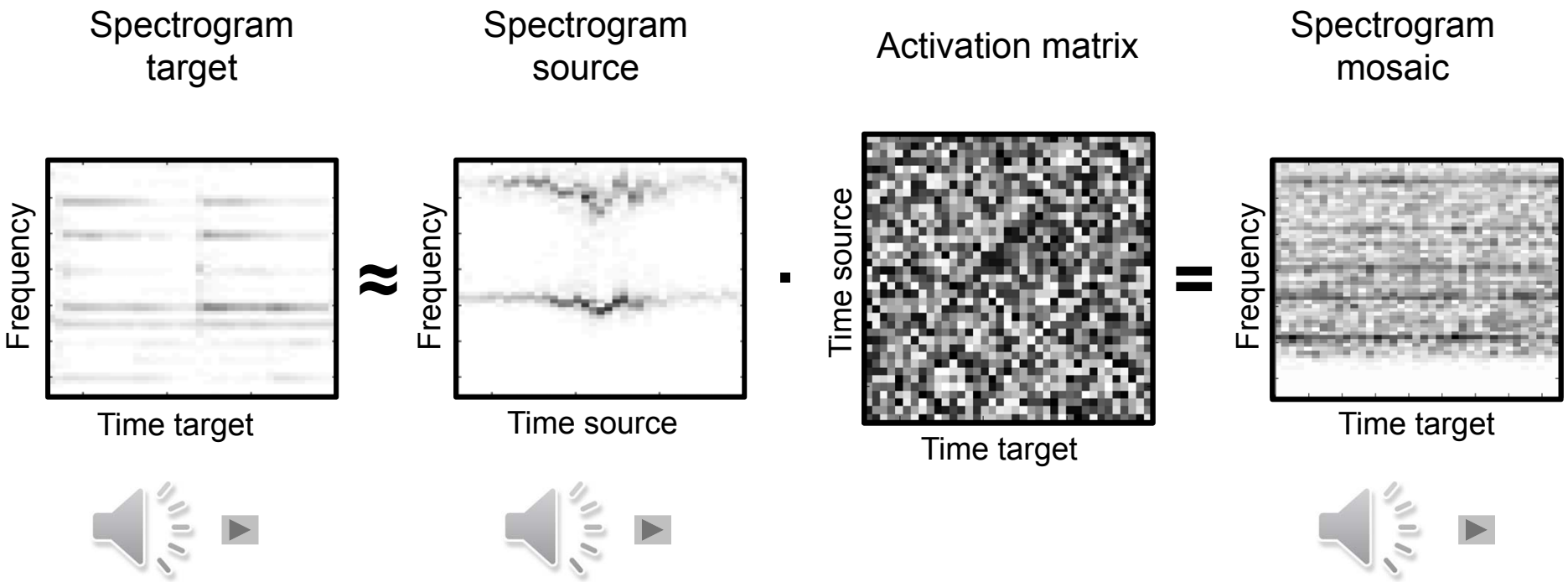


Core idea: support the development of sparse diagonal activation structures

NMF-Inspired Audio Mosaicing



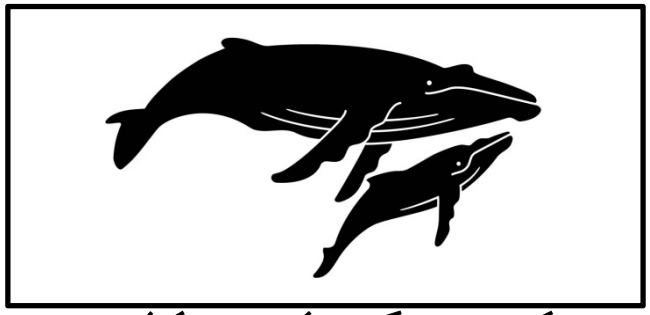
NMF-Inspired Audio Mosaicing



Audio Mosaicing

Target signal: Chic–Good times

Source signal: Whales

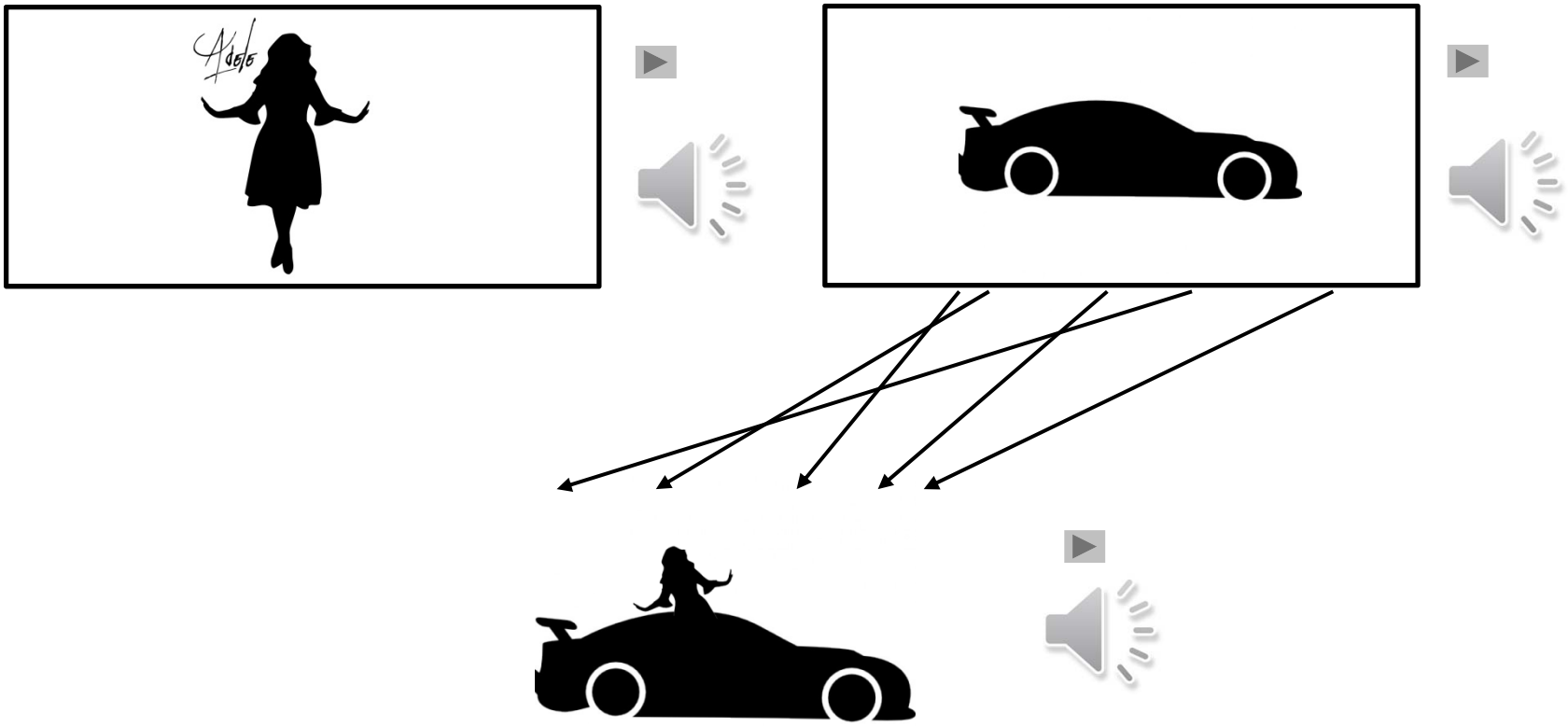


Mosaic signal

Audio Mosaicing

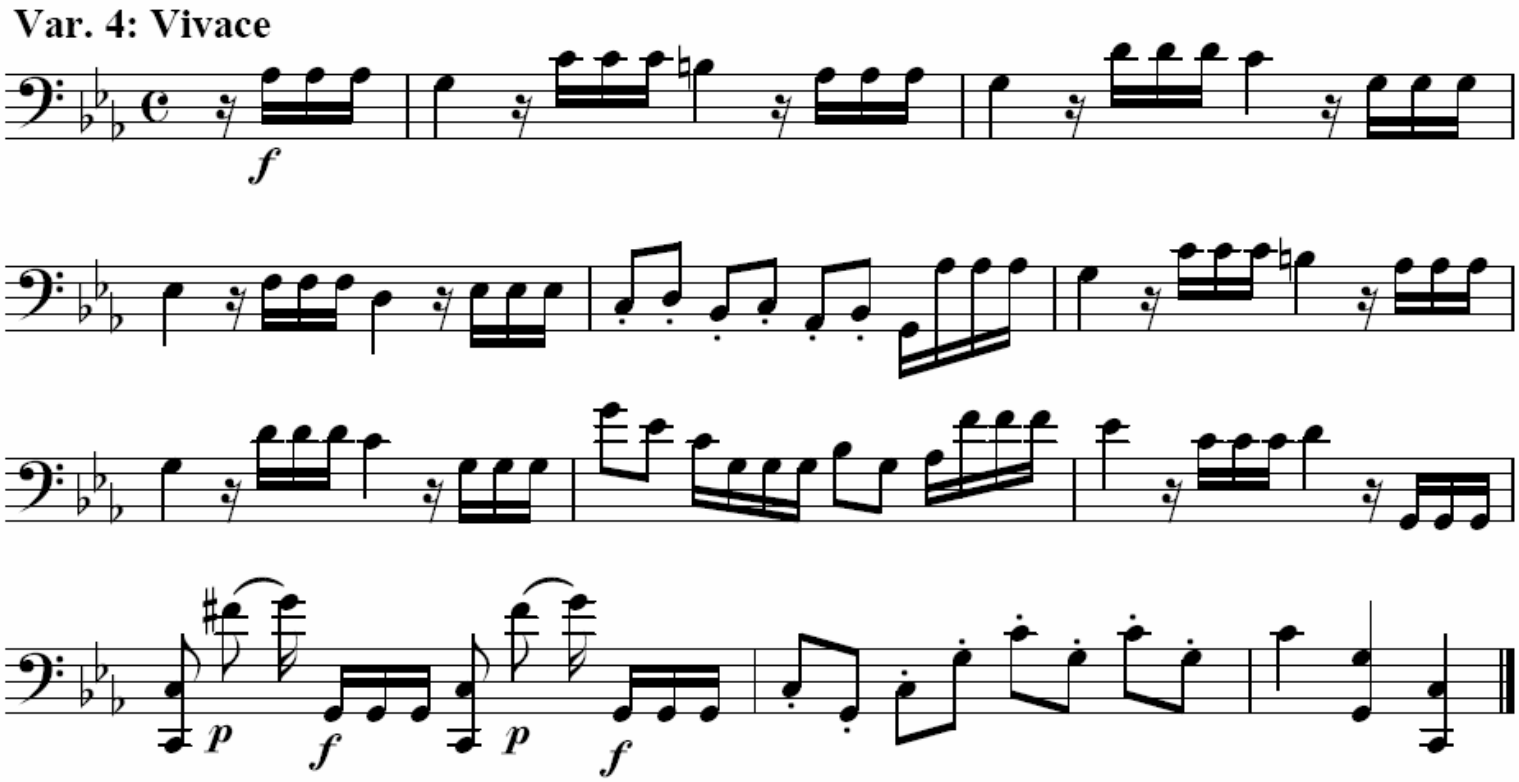
Target signal: Adele–Rolling in the Deep

Source signal: Race car

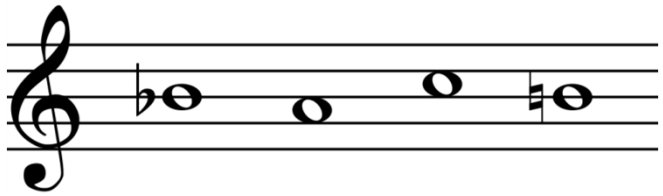


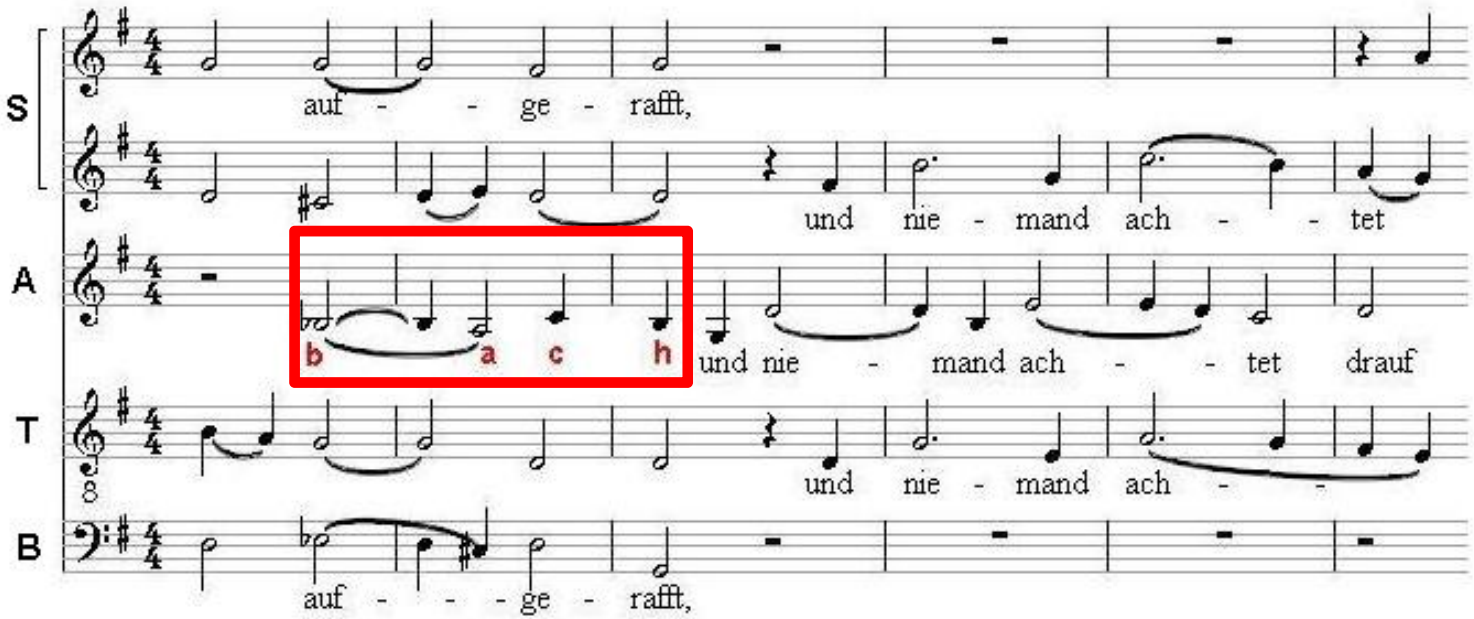
Mosaic signal

Motivic Similarity



Motivic Similarity

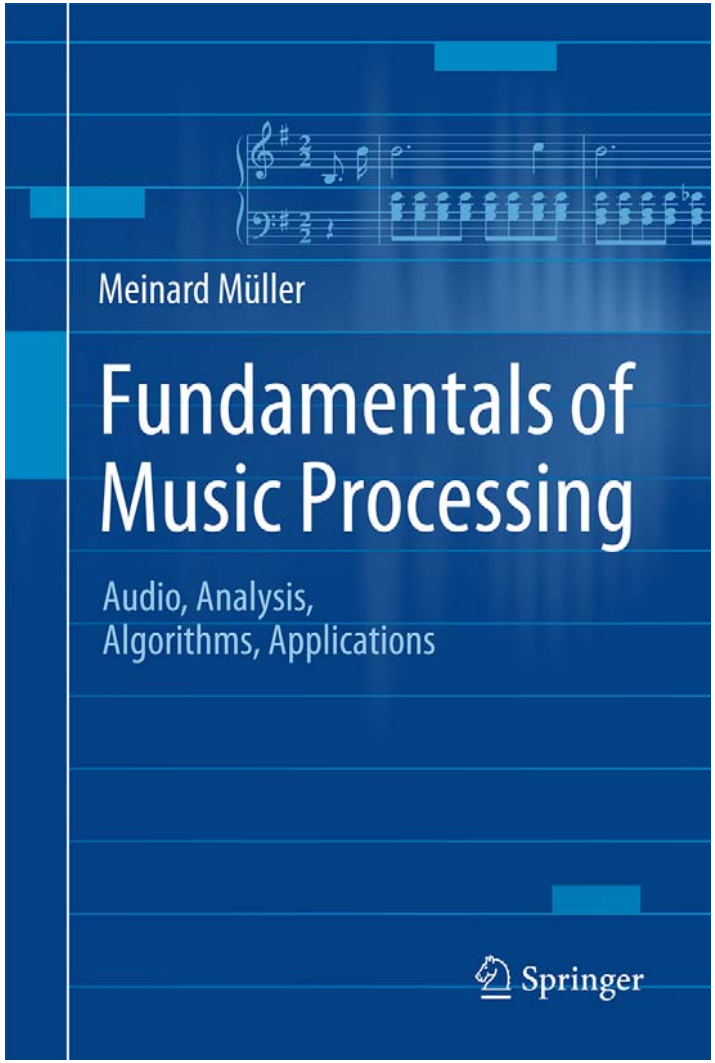




Summary

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

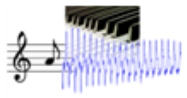
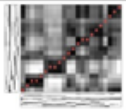
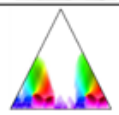
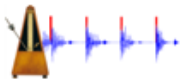
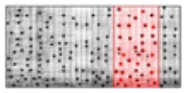
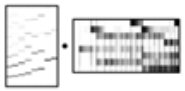
Book: Fundamentals of Music Processing



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

Book: Fundamentals of Music Processing

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

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MIR-Related Events in Germany

AES Conference on
Semantic Audio
22 – 24 June 2017
Erlangen

GI Jahrestagung
25 – 29 September 2017
Chemnitz

Gesellschaft
für Informatik

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