Lecture

Music Processing

Beethoven, Bach, and Billions of Bytes

New Alliances between Music and Computer Science

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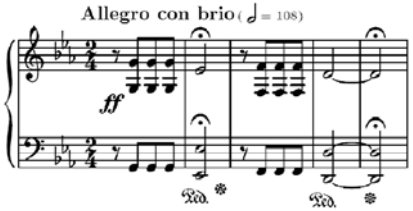
Fraunhofer IIS

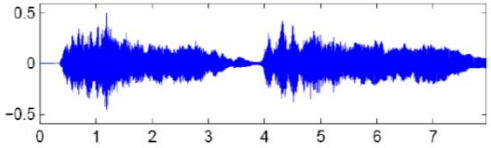
Music

Music Processing

Sheet Music (Image)



CD / MP3 (Audio)



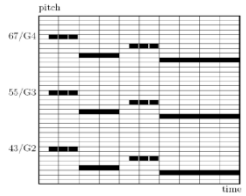
MusicXML (Text)

```
<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)

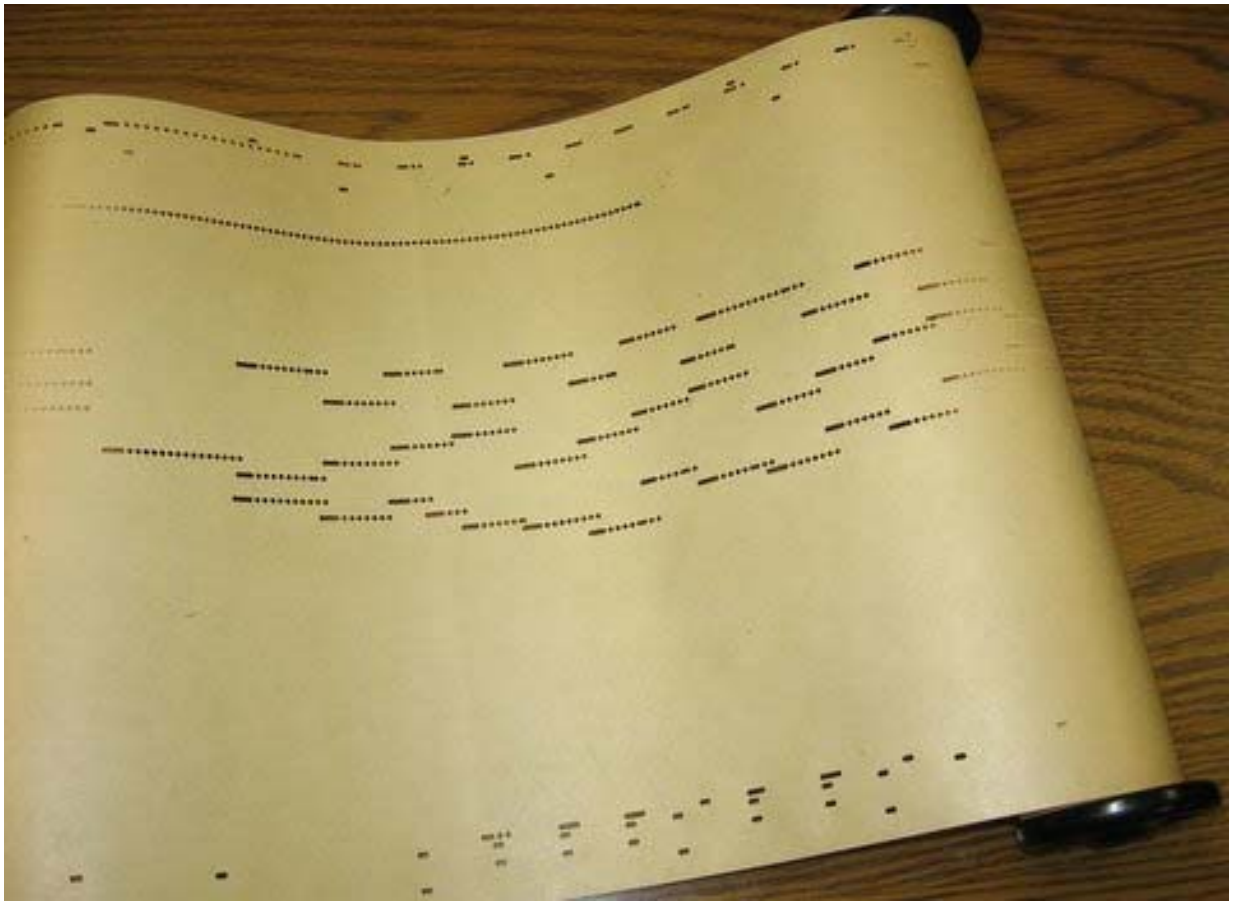
Music Film (Video)

Music Literature (Text)

Research Goals

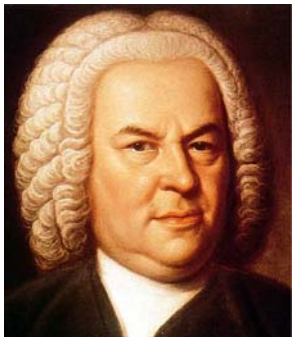
- Music Information Retrieval (MIR) → ISMIR
- Analysis of music signals
  (harmonic, melodic, rhythmic, motivic aspects)
- Design of musically relevant audio features
- Tools for multimodal search and interaction

Piano Roll Representation



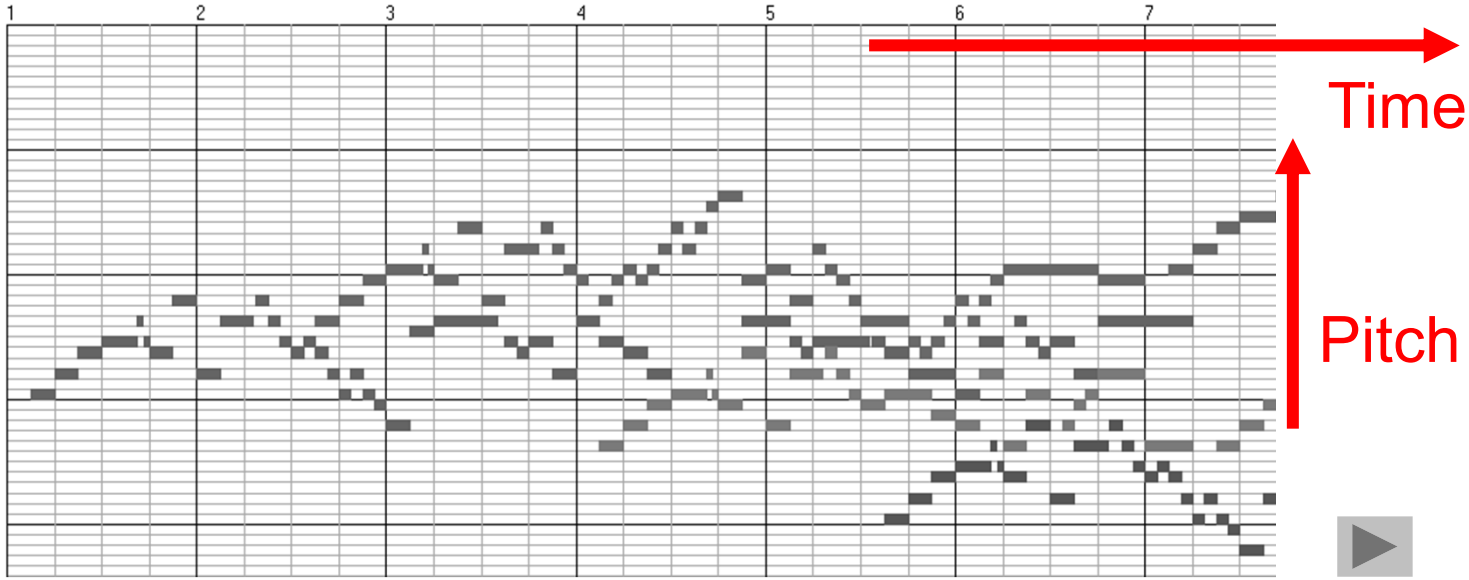
Player Piano (1900)

Piano Roll Representation (MIDI)

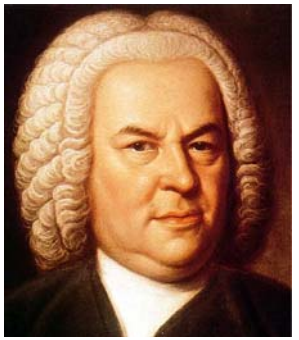


J.S. Bach, C-Major Fuge

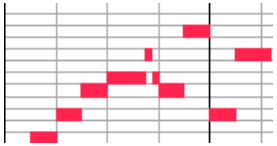
(Well Tempered Piano, BWV 846)



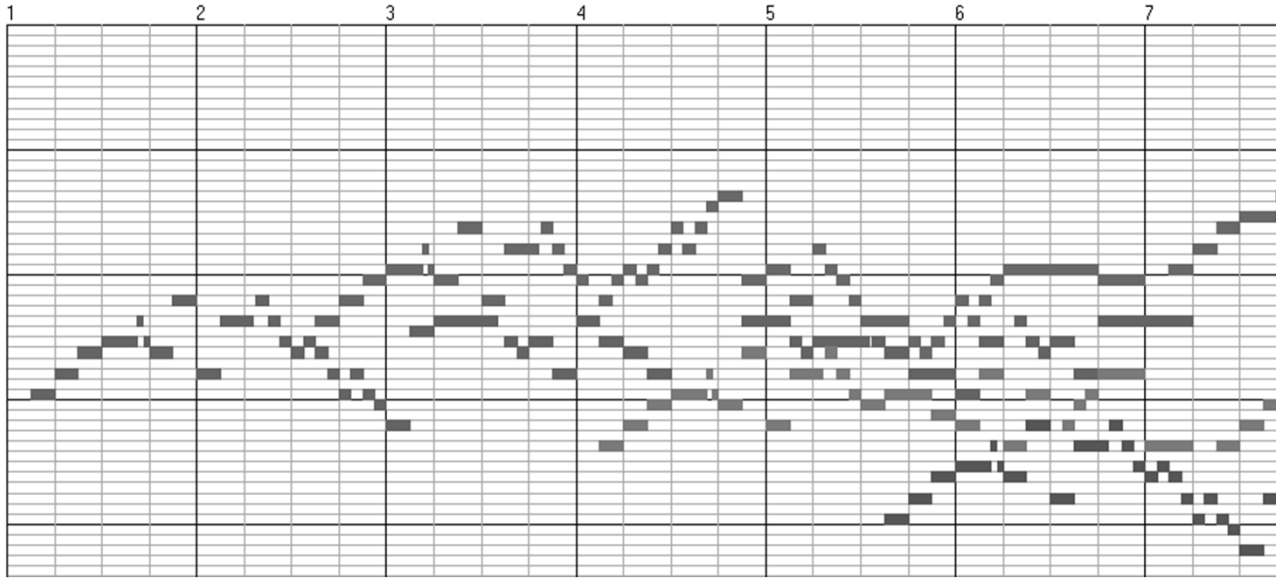
Piano Roll Representation (MIDI)



Query:



Goal: Find all occurrences of the query



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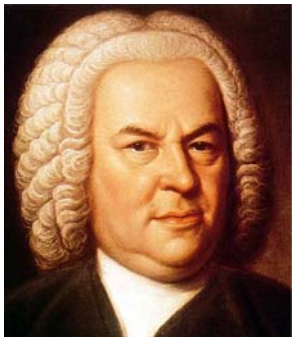
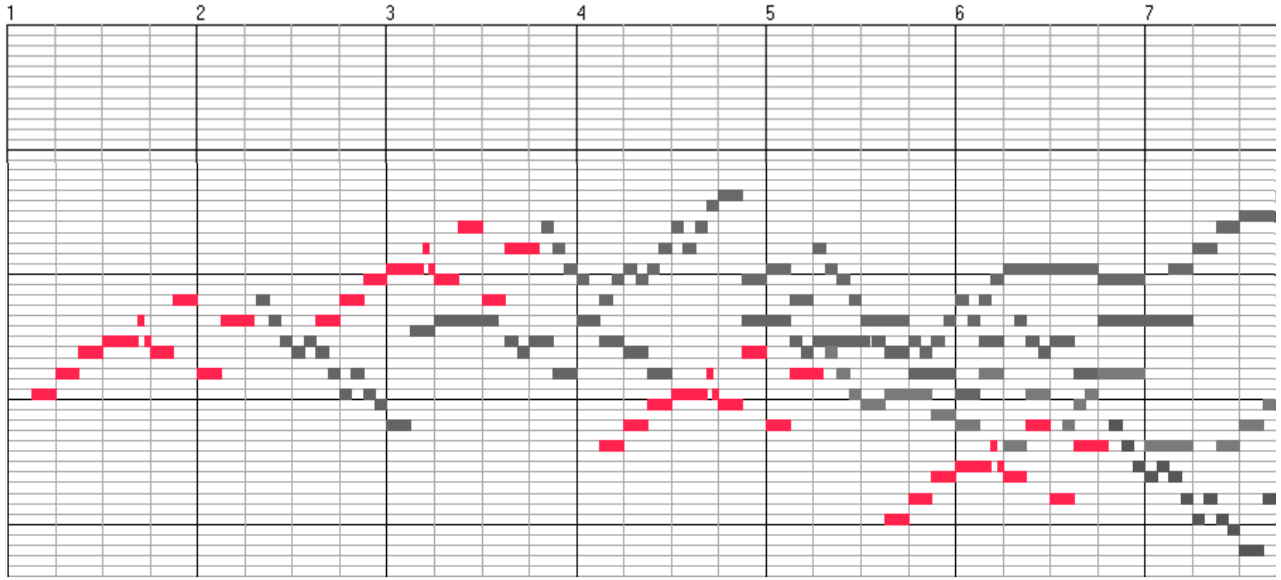


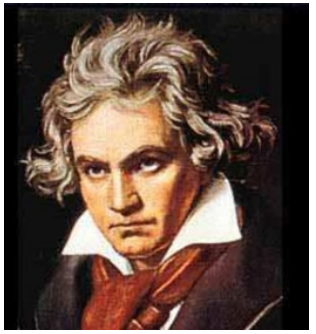
Query:

Goal: Find all occurrences of the query

Matches:



Audio Data



Various interpretations – Beethoven's Fifth

Bernstein	▶
Karajan	▶
Scherbakov (piano)	▶
MIDI (piano)	▶

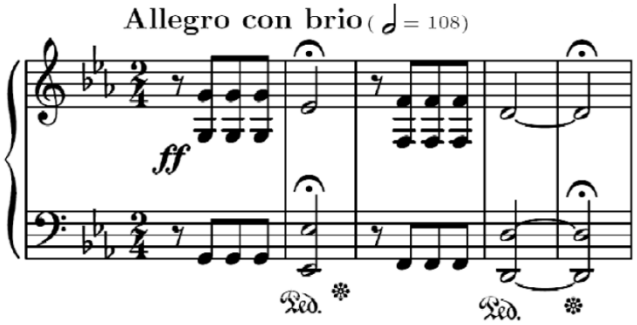
Audio Data (Memory Requirements)

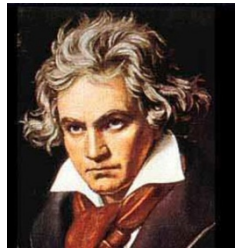
1 Bit	=	1: on, 0: off
1 Byte	=	8 Bits
1 Kilobyte (KB)	=	1 Thousand Bytes
1 Megabyte (MB)	=	1 Million Bytes
1 Gigabyte (GB)	=	1 **Billion Bytes**
1 Terabyte (TB)	=	1000 Billion Bytes

Two audio CDs	>	1 **Billion Bytes**
1000 audio CDs	≃	**Billions of Bytes**
12.000 MIDI files	<	350 MB

Music Synchronization: Audio-Audio

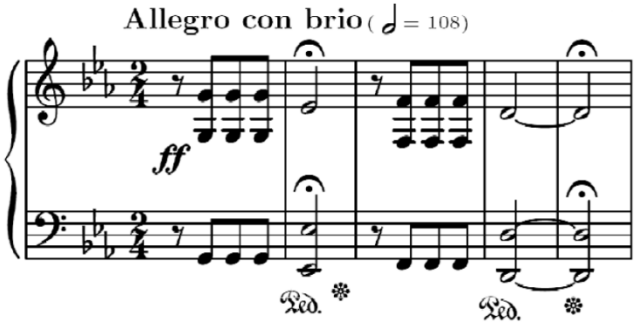
Beethoven’s Fifth

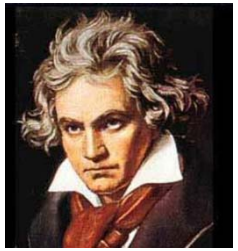




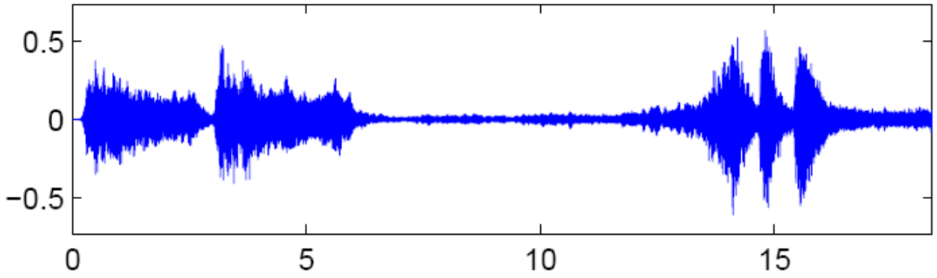
Music Synchronization: Audio-Audio

Beethoven's Fifth

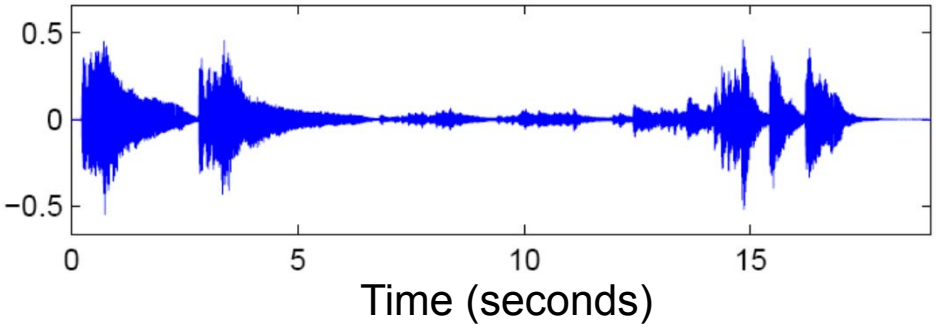




Orchester (Karajan)

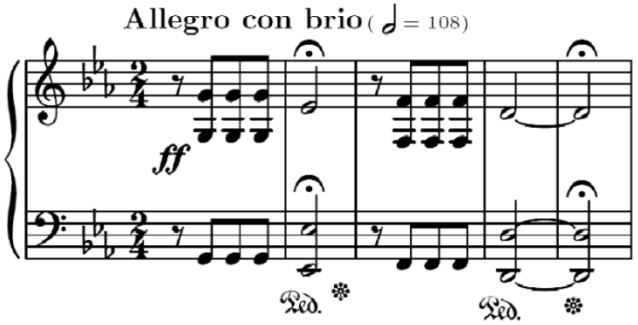


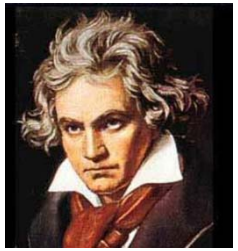
Piano (Scherbakov)



Music Synchronization: Audio-Audio

Beethoven's Fifth





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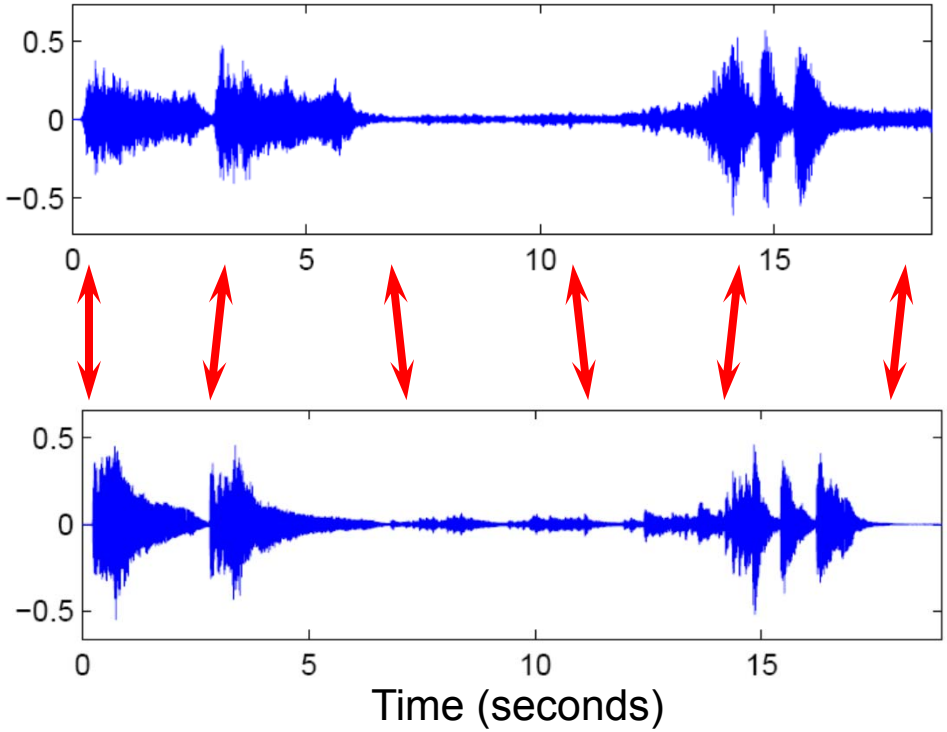
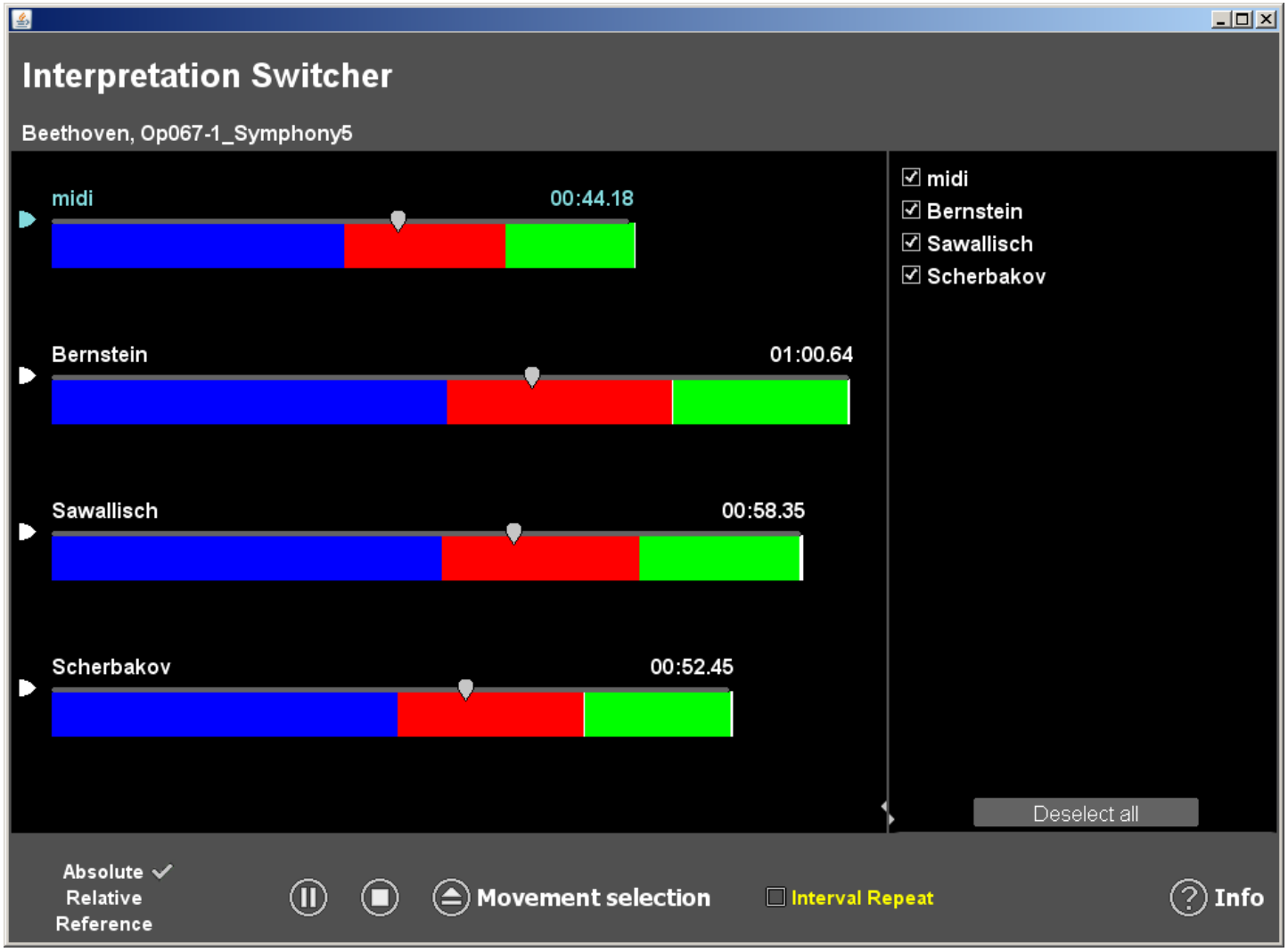
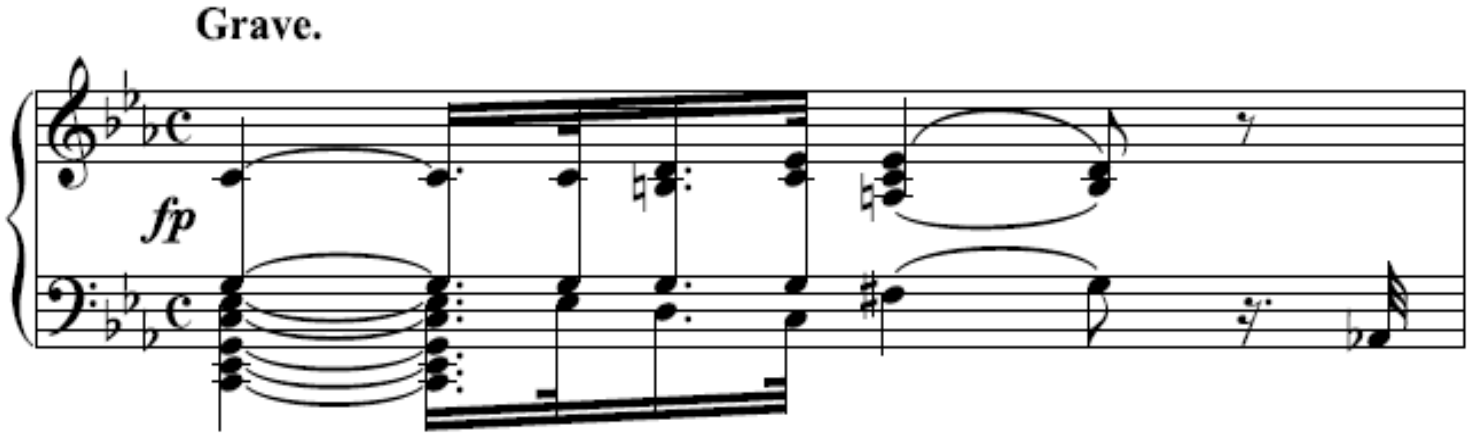


Application: Interpretation Switcher

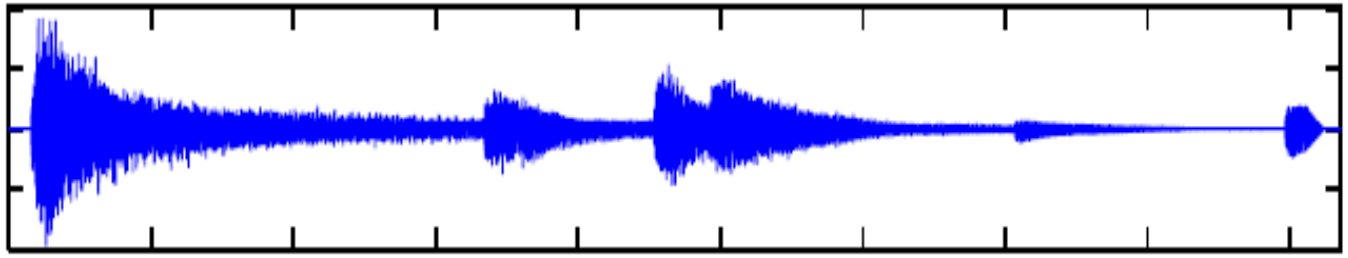


Music Synchronization: Image-Audio

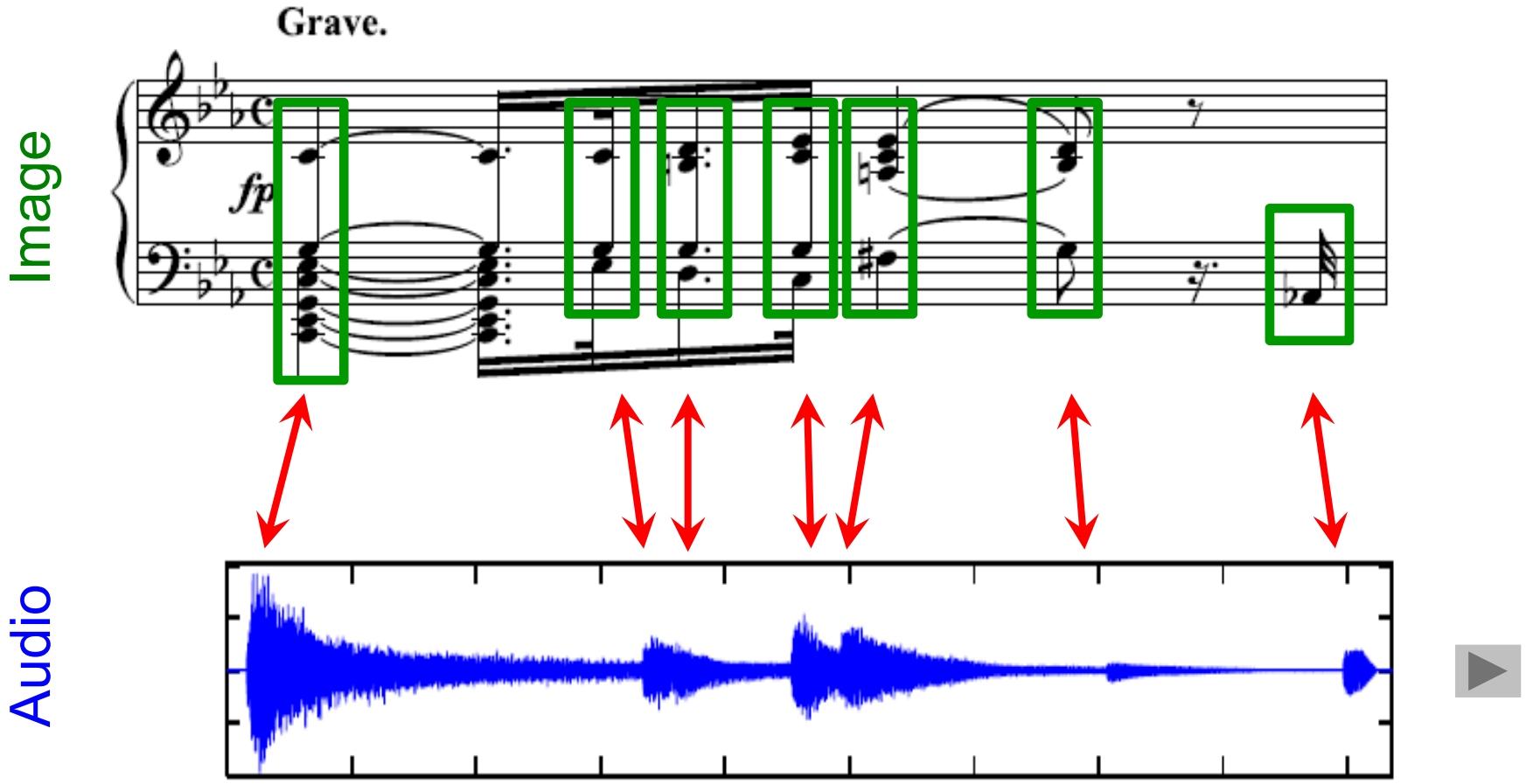
Image



Audio

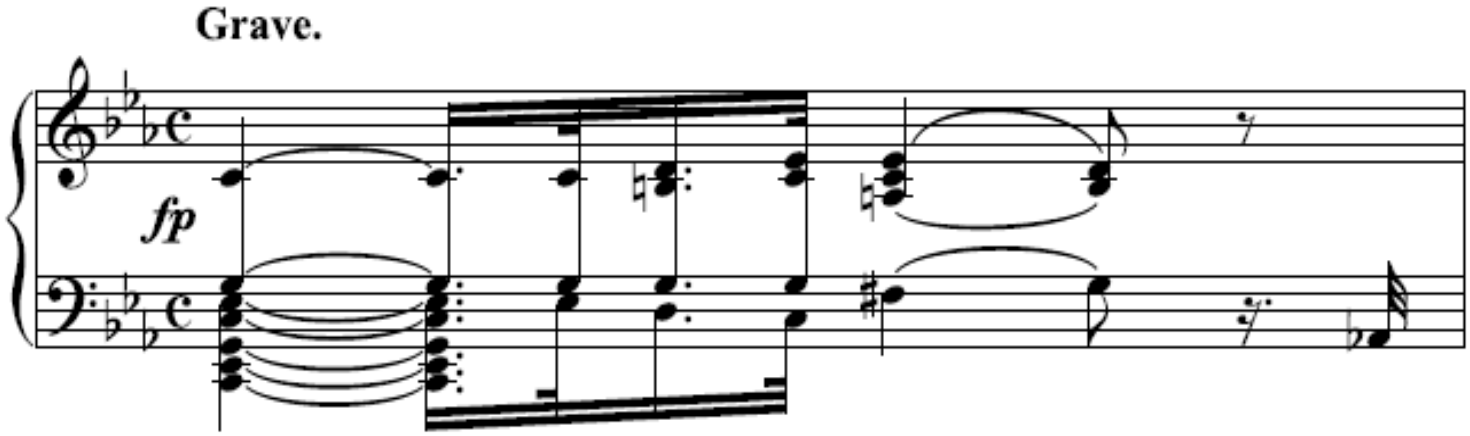


Music Synchronization: Image-Audio

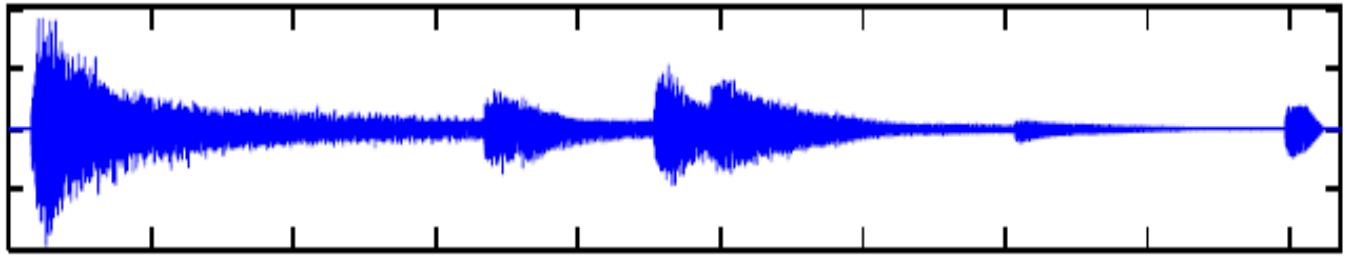


How to make the data comparable?

Image



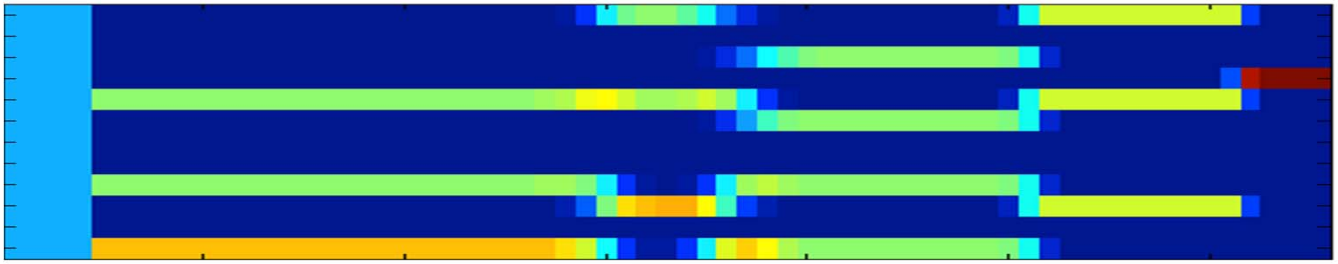
Audio



How to make the data comparable?

Image Processing: Optical Music Recognition

Image



Audio

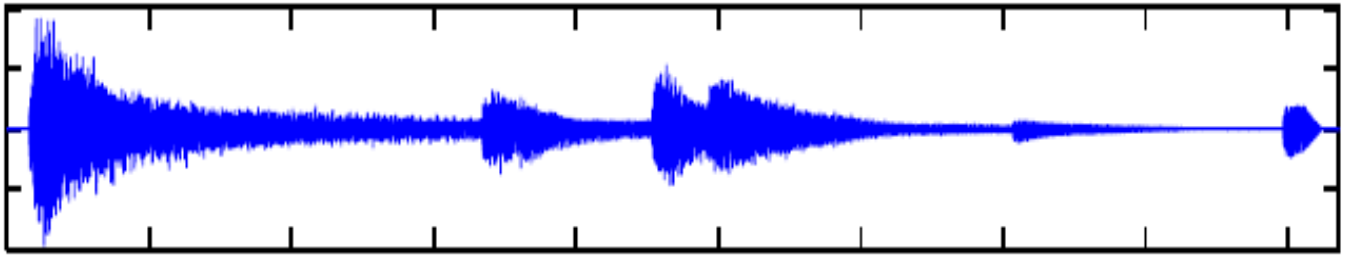


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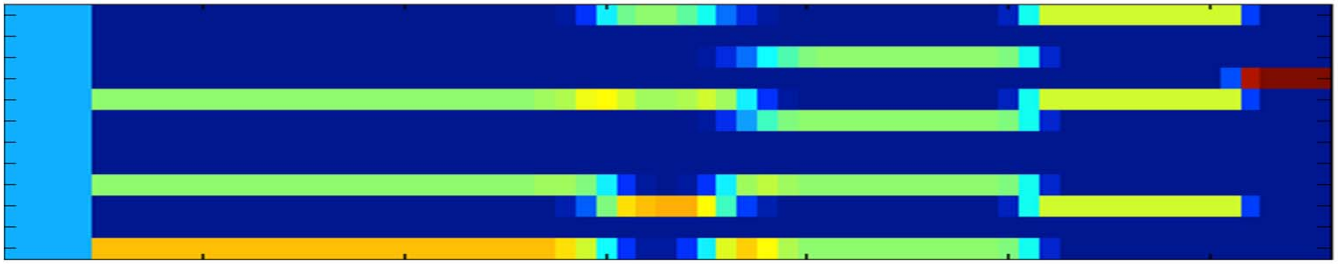
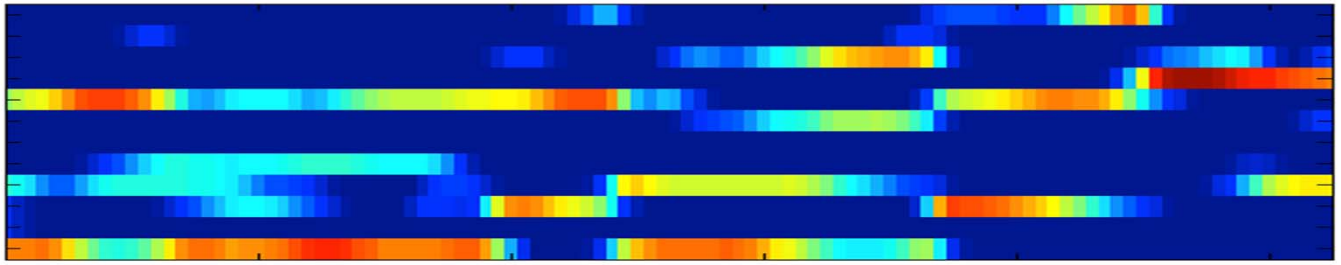
Image



Audio

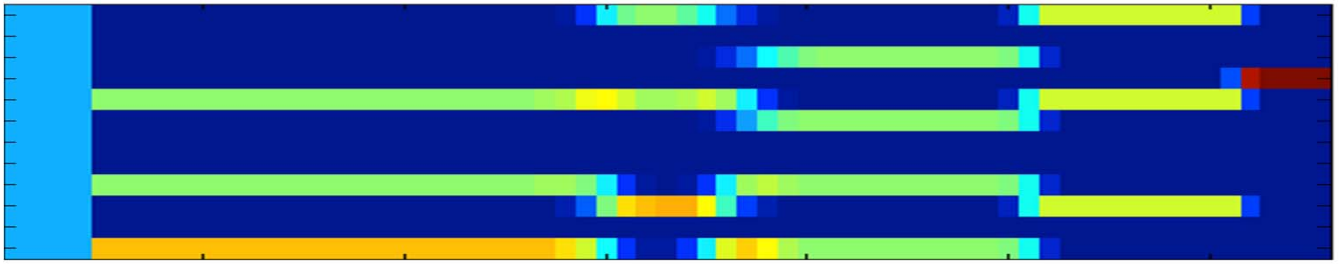


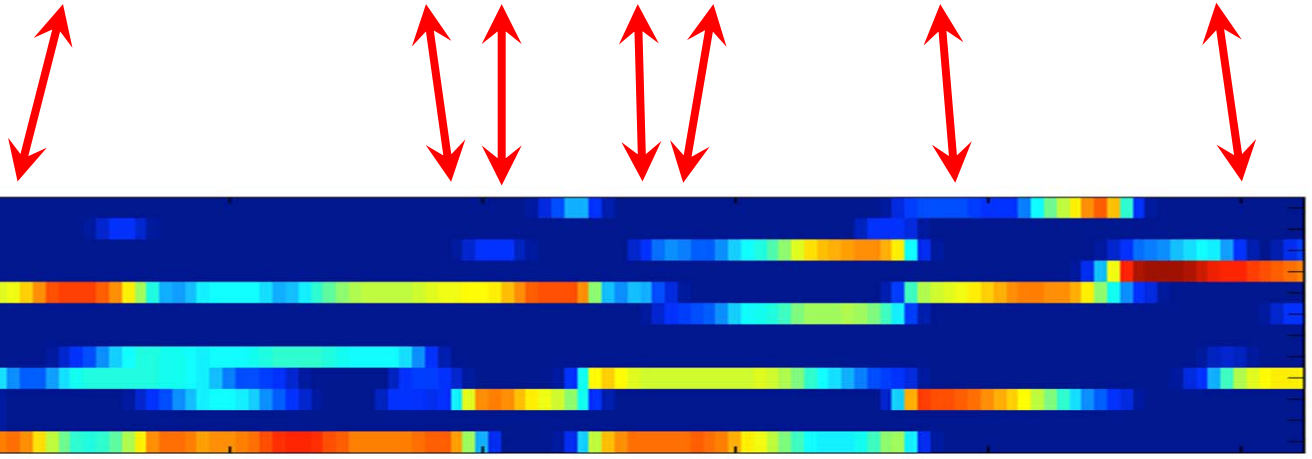
Audio Processing: Fourier Analyse

How to make the data comparable?

Image Processing: Optical Music Recognition

Image

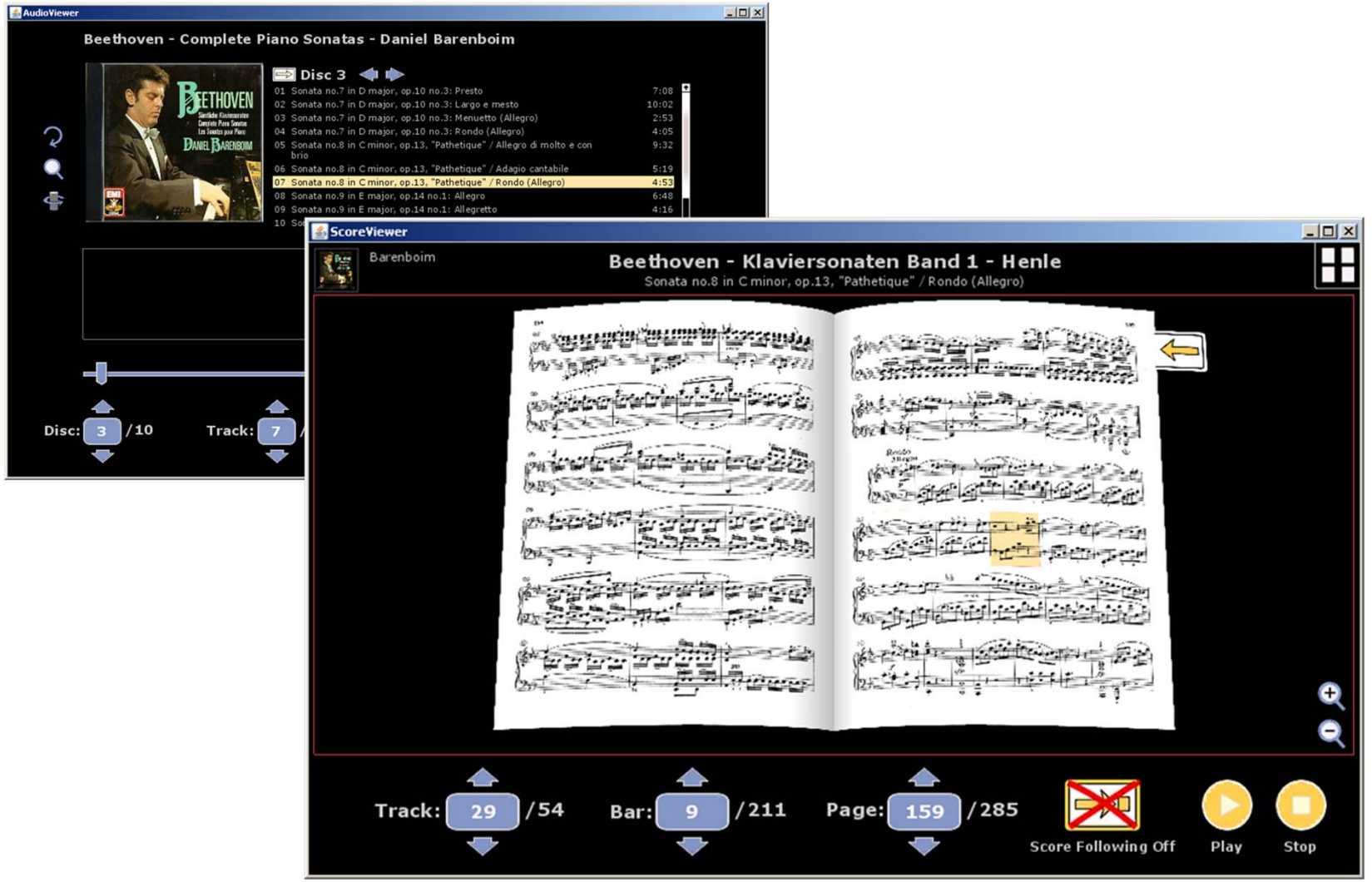




Audio

Audio Processing: Fourier Analyse

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

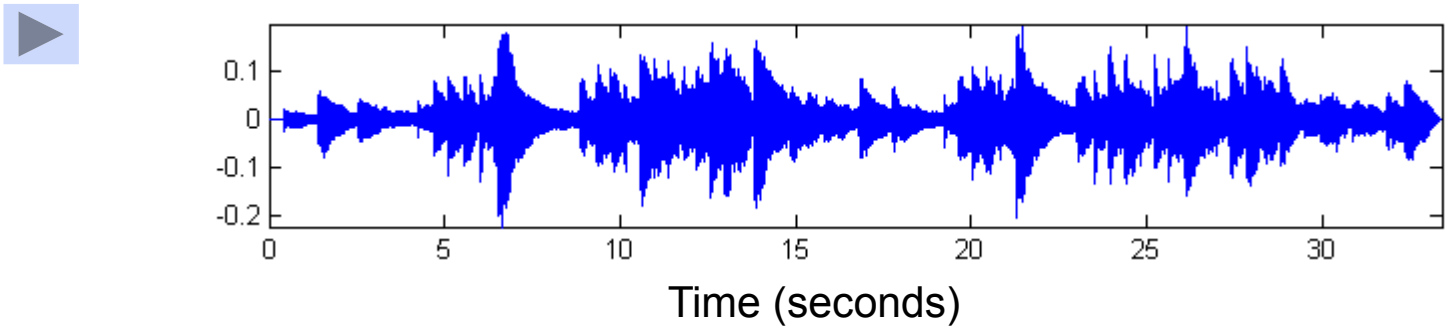
Music Processing

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

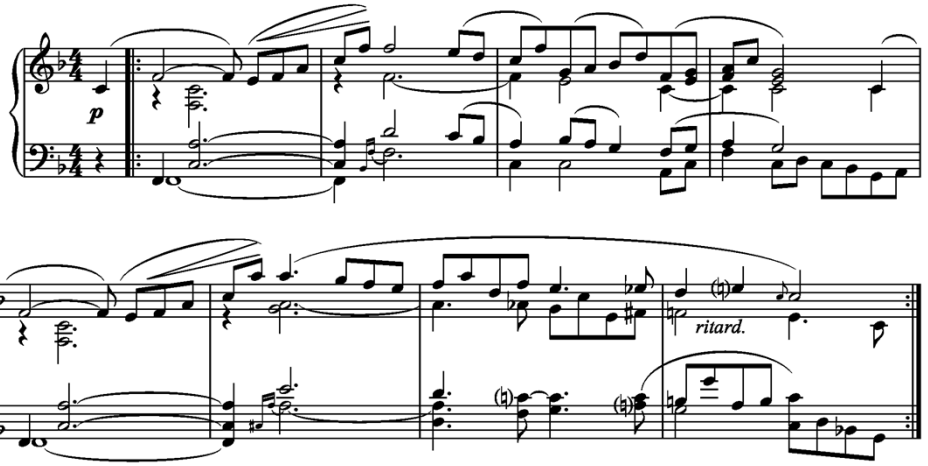
Performance:



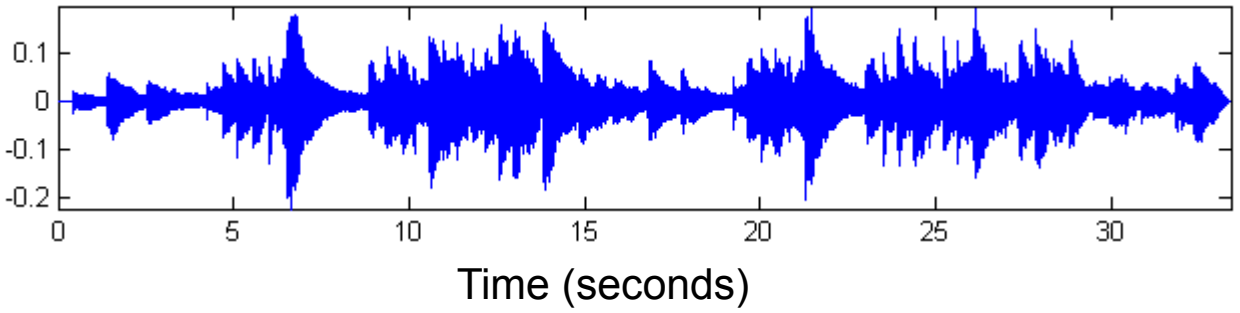
Performance Analysis

Schumann: Träumerei

Score (reference):



Performance:



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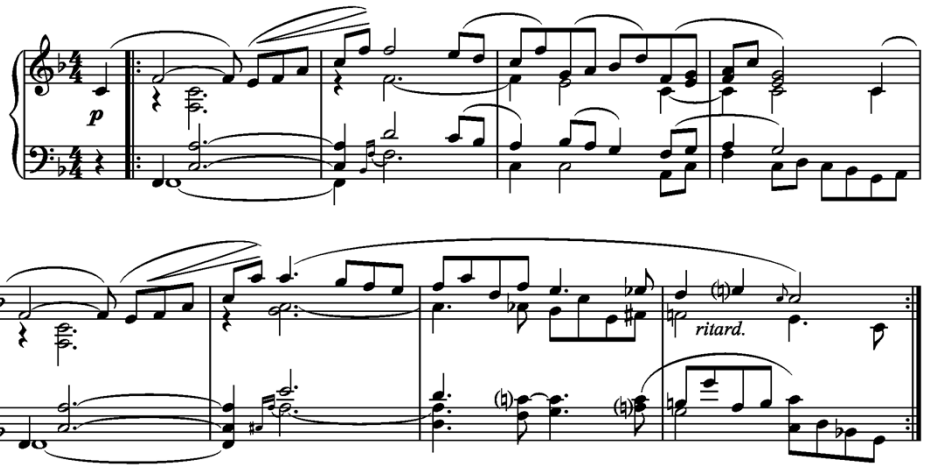
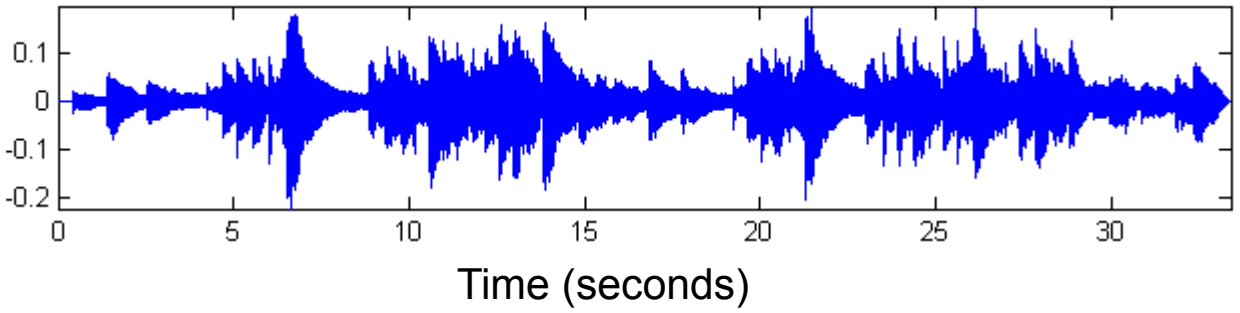


Strategy: Compute score-audio synchronization and derive tempo curve

Performance:



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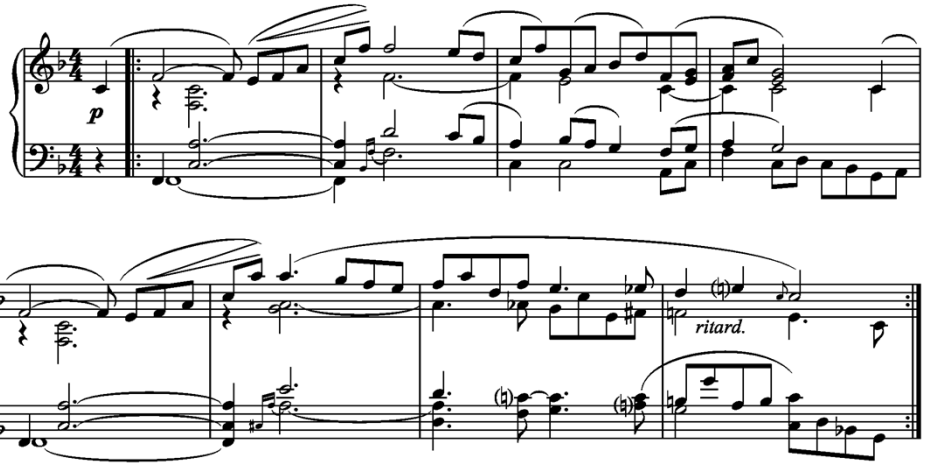
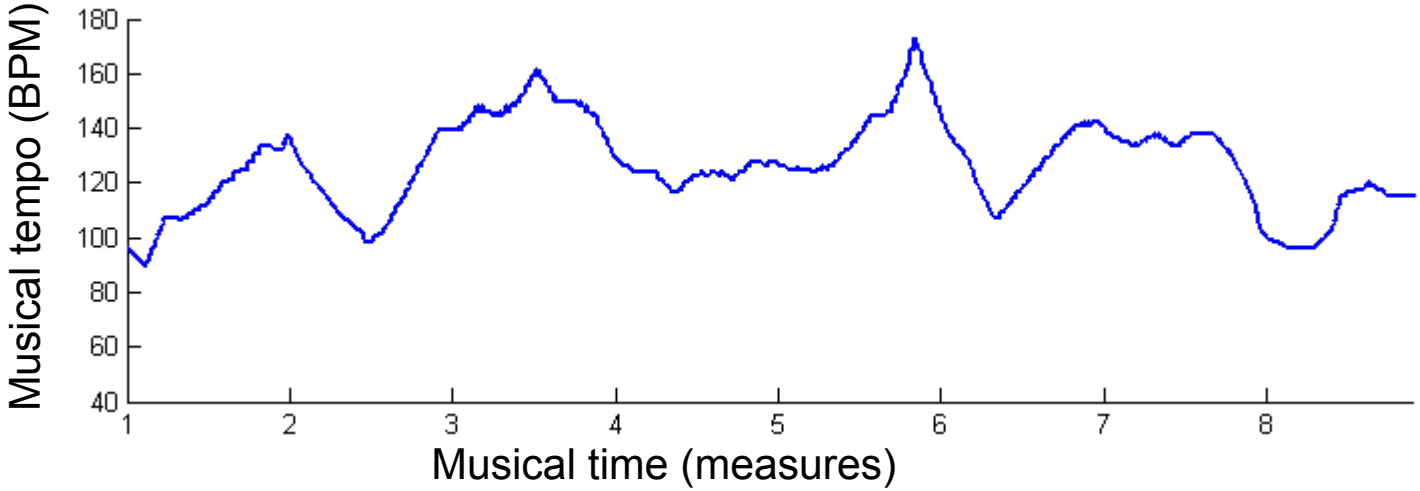


Tempo Curve:



Performance Analysis

Schumann: Träumerei

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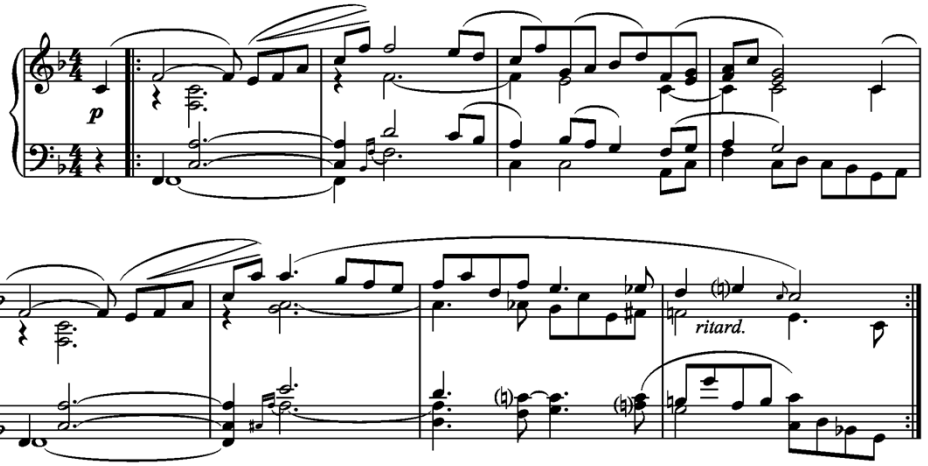
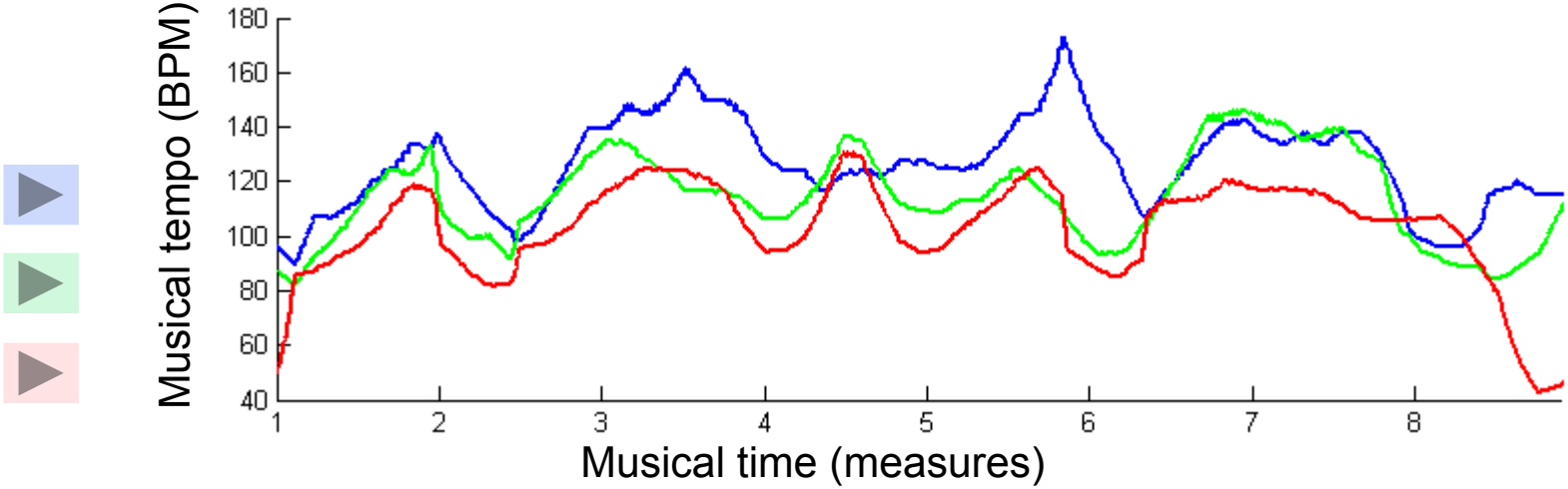


Tempo Curves:



Performance Analysis

Schumann: Träumerei

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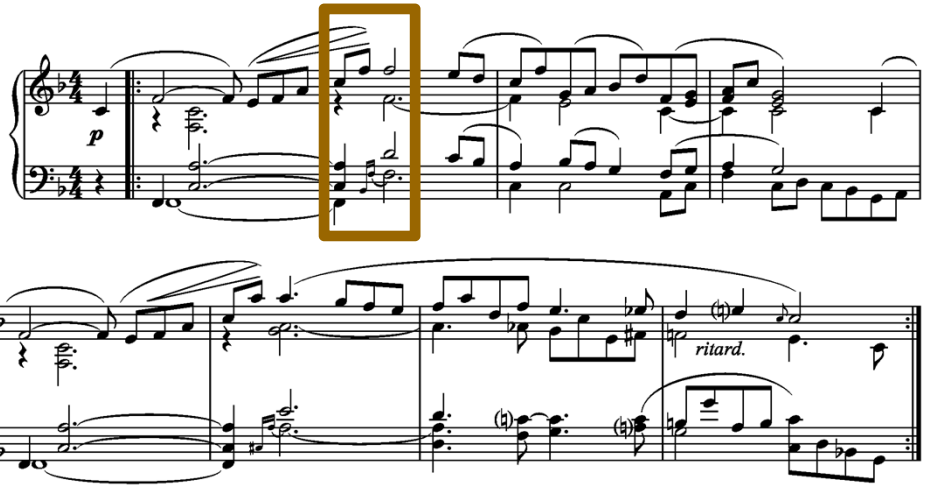

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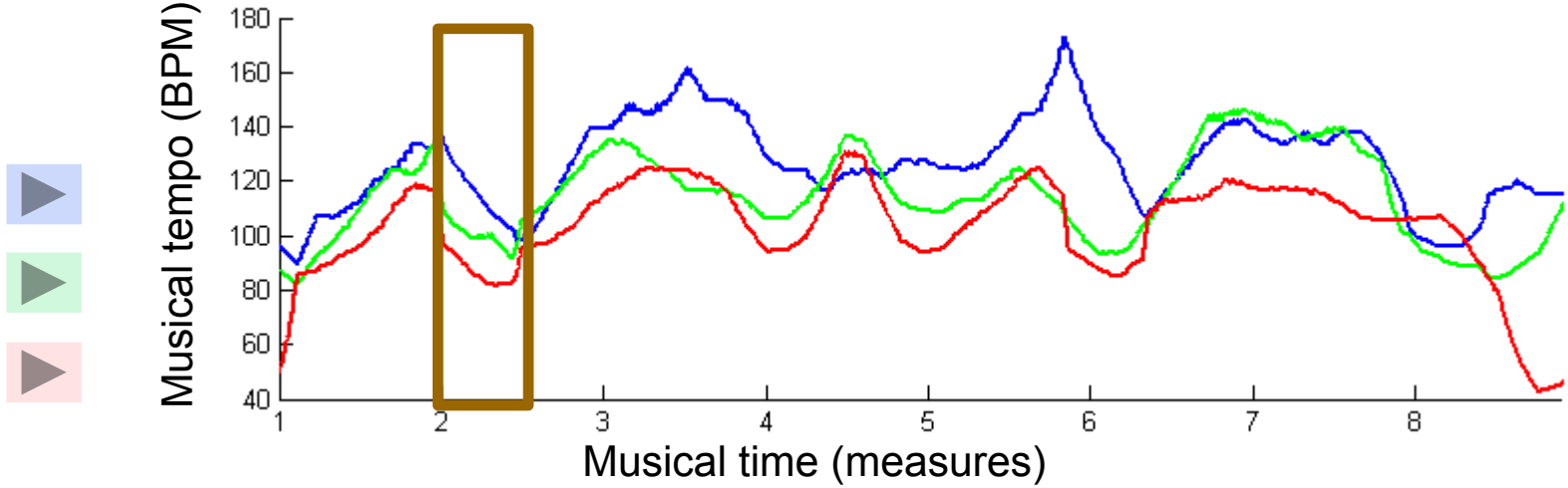

Performance Analysis

Schumann: Träumerei

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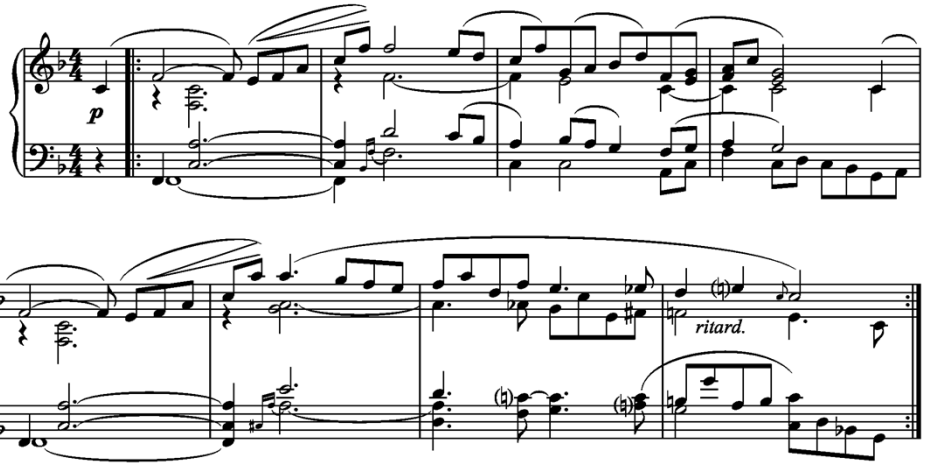
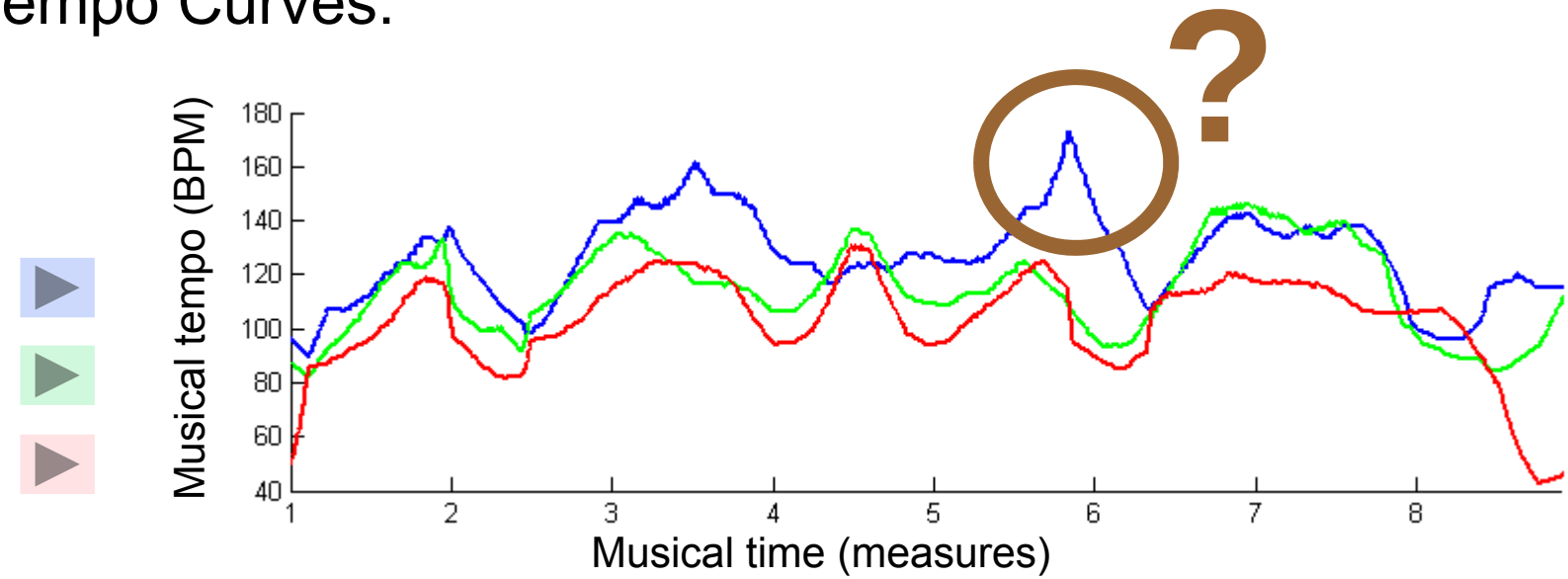


Tempo Curves:

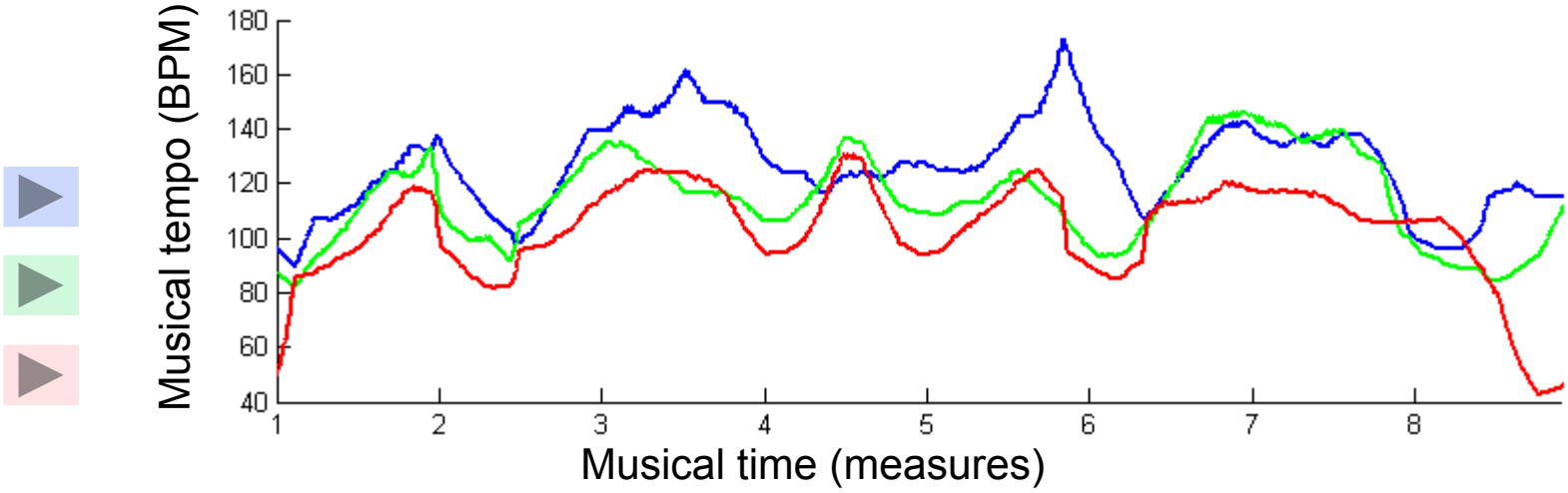


Performance Analysis

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

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Comparison of extracted parameters	Direct interpretation of extracted parameters

Music Processing

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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

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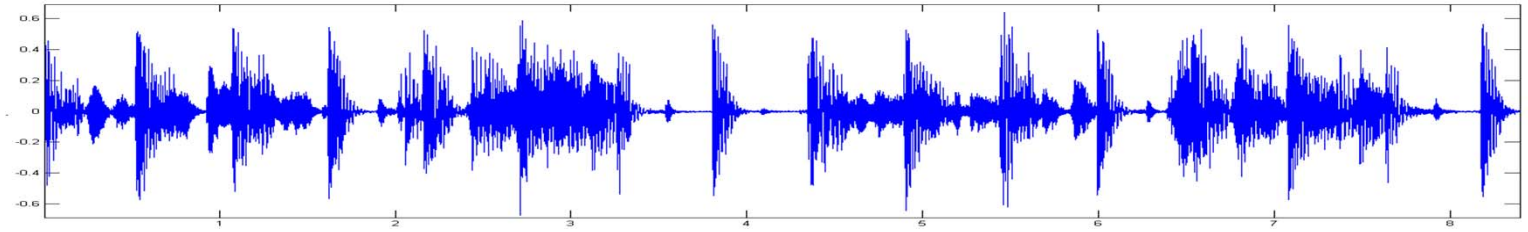
Example: Queen – Another One Bites The Dust

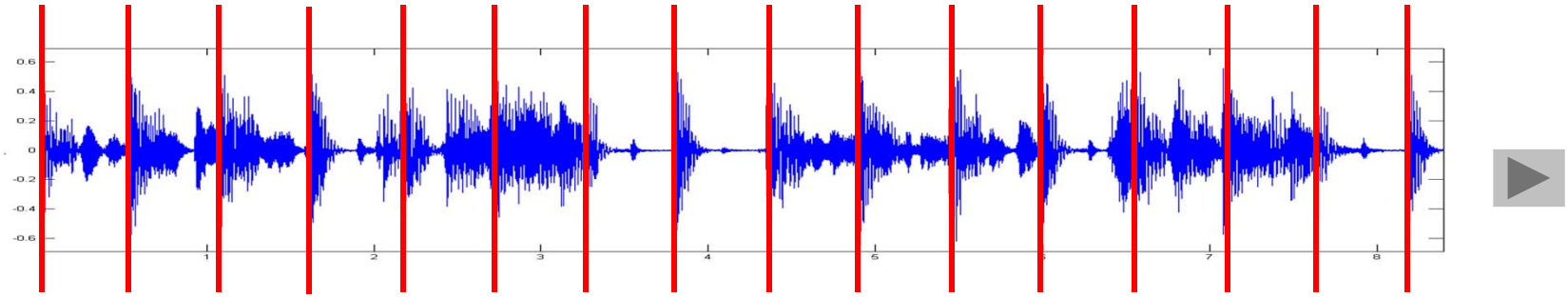


Time (seconds)

Tempo Estimation and Beat Tracking

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

Example: Queen – Another One Bites The Dust

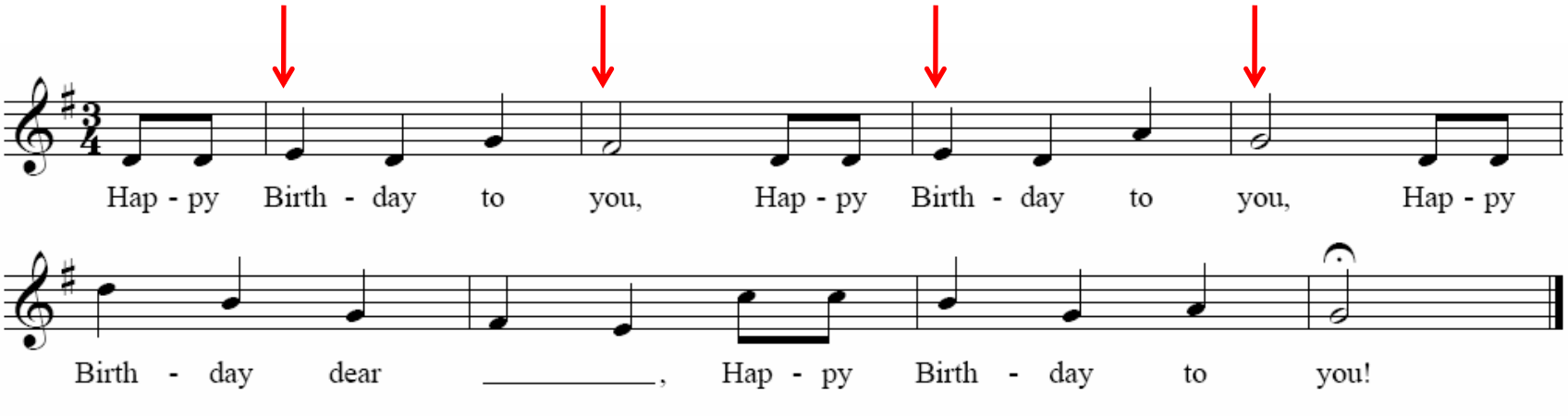


Time (seconds)

Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

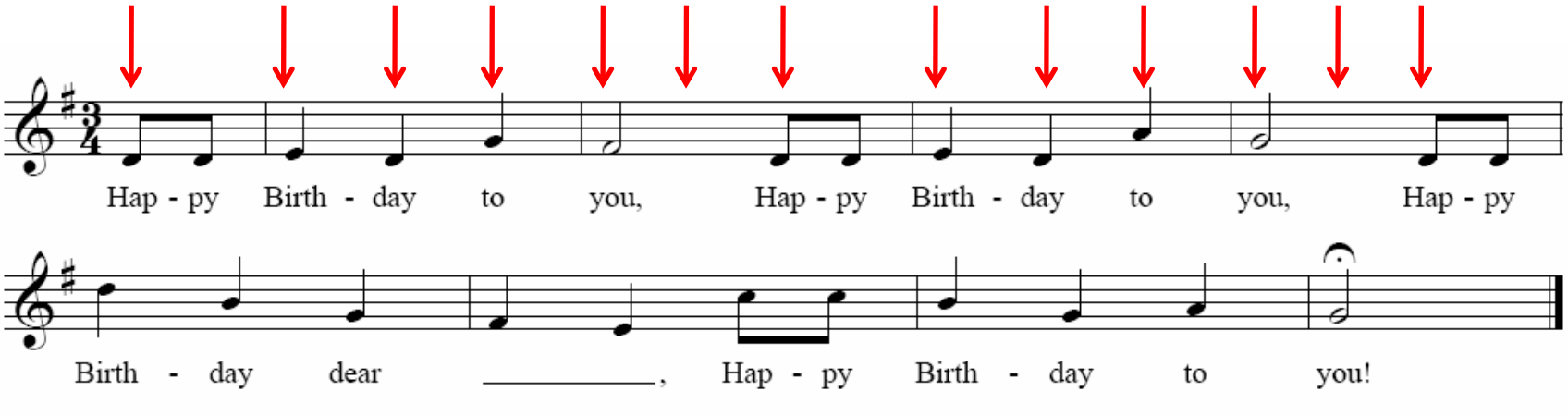
Pulse level: **Measure**



Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

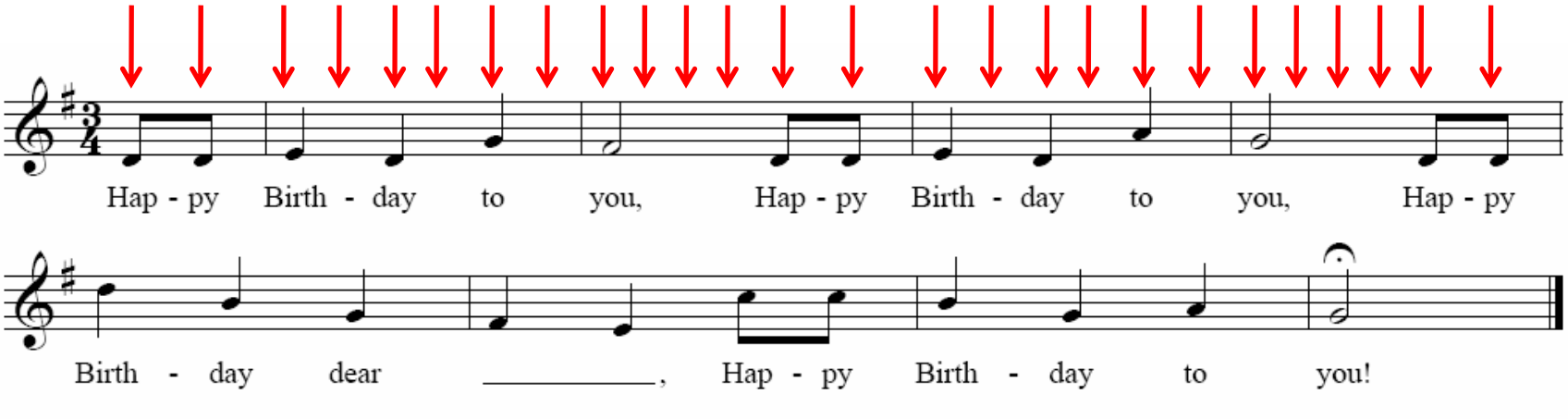
Pulse level: **Tactus (beat)**



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: ???

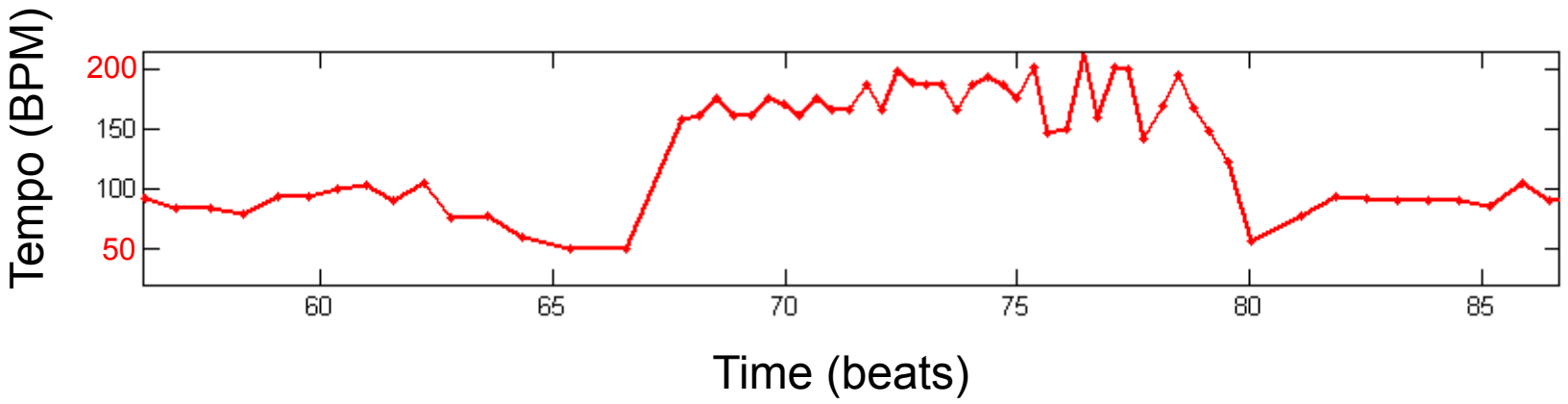
Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: 50-200 BPM

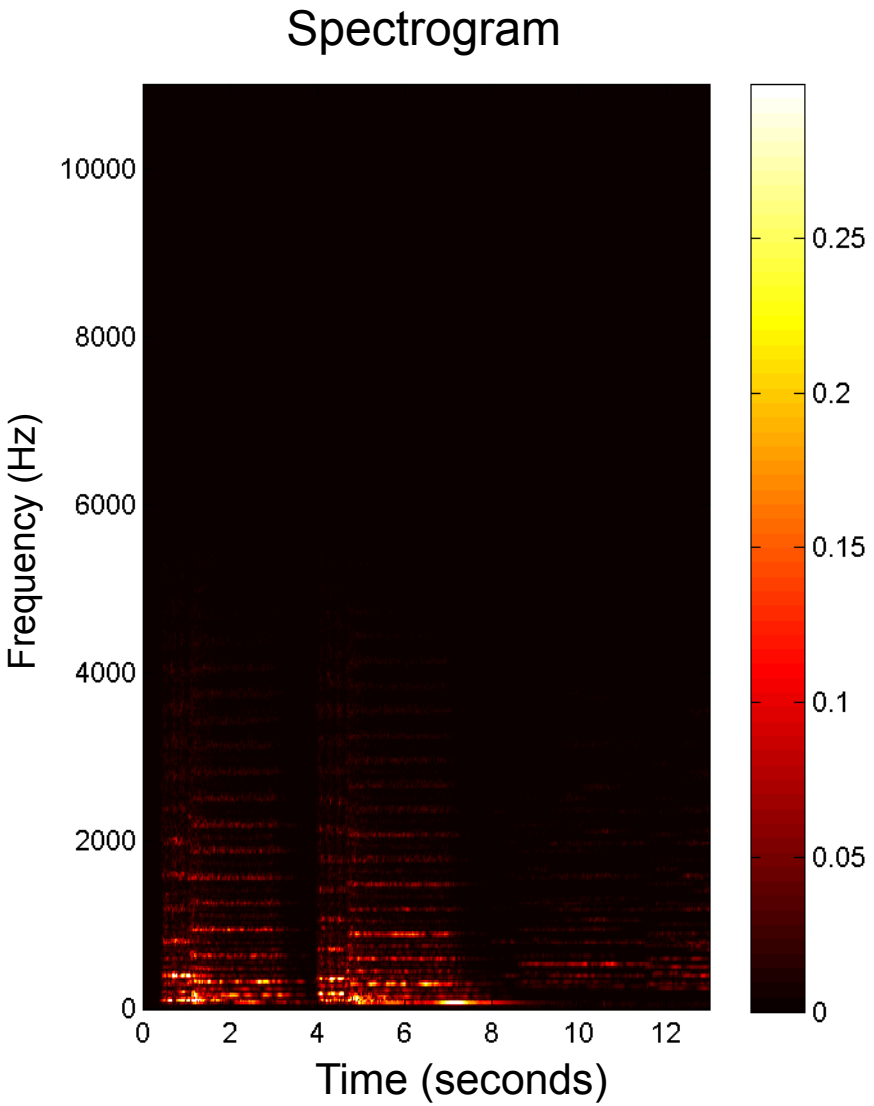
Tempo curve



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)

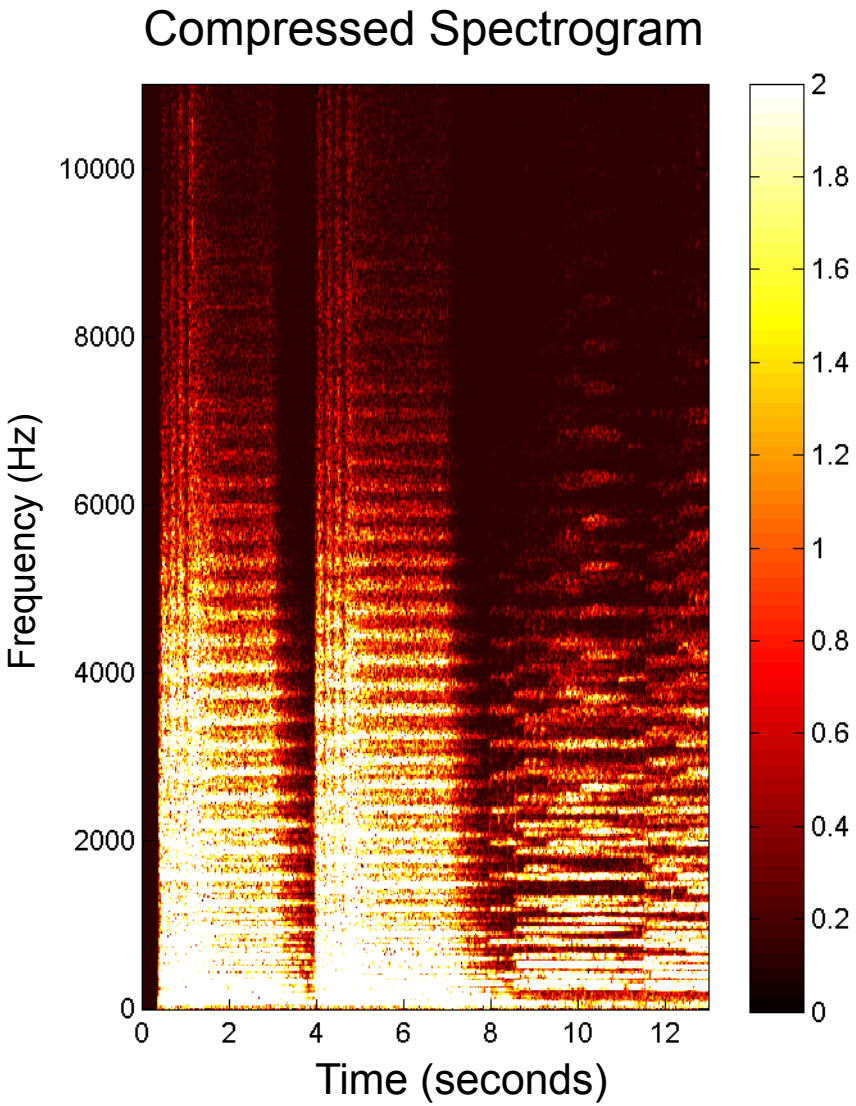
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram

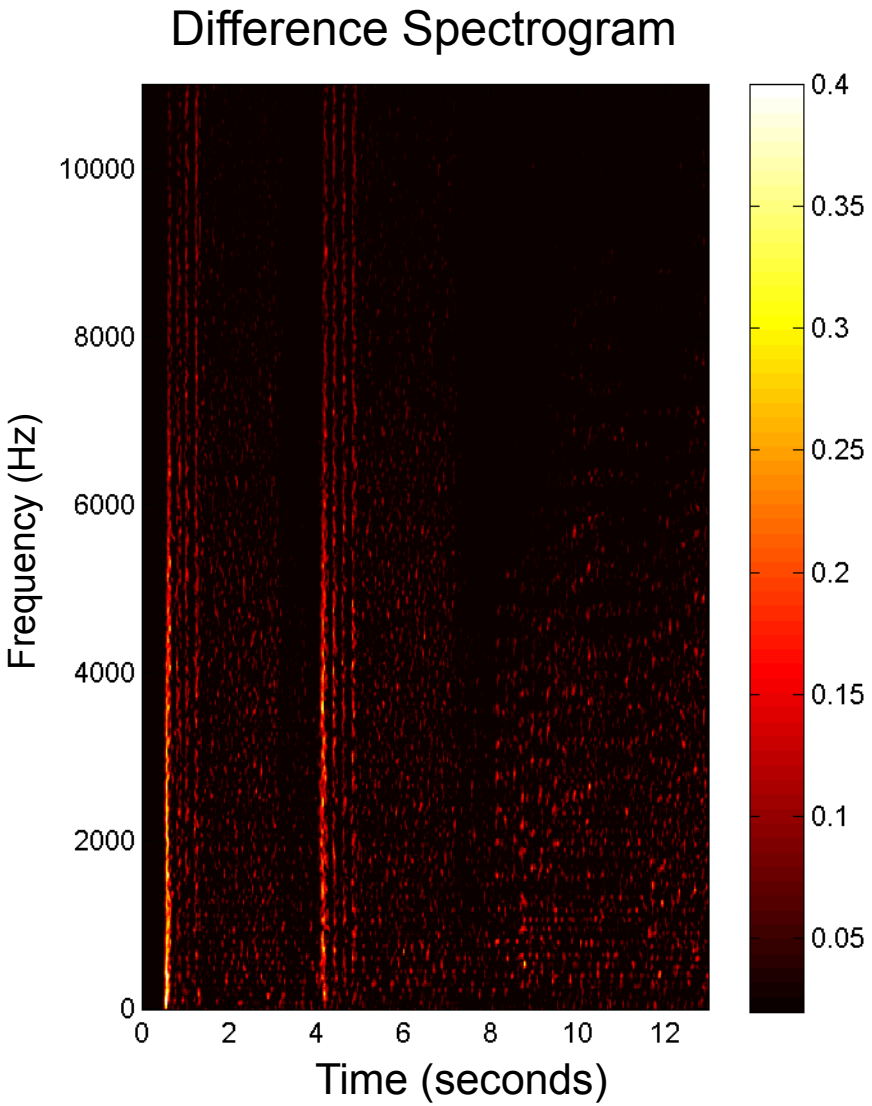
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram
2. Log Compression

Tempo Estimation and Beat Tracking



Steps:

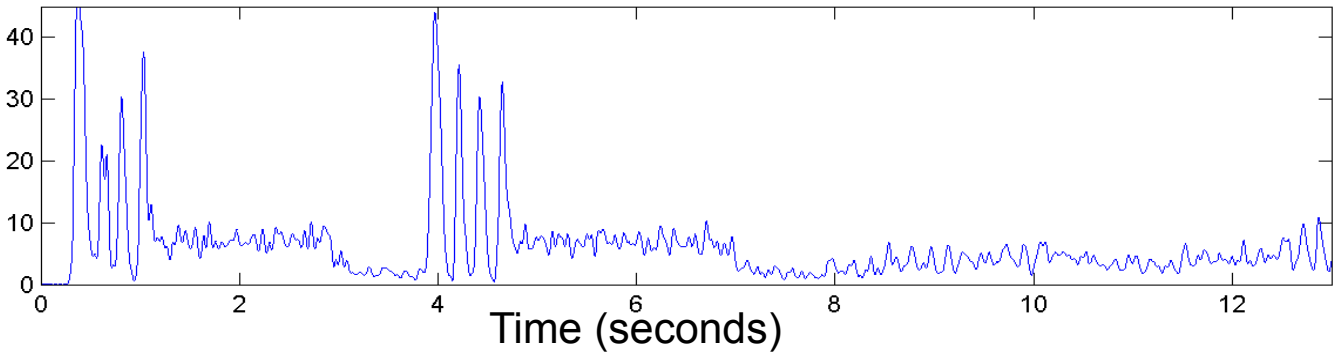
1. Spectrogram
2. Log Compression
3. Differentiation

Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve

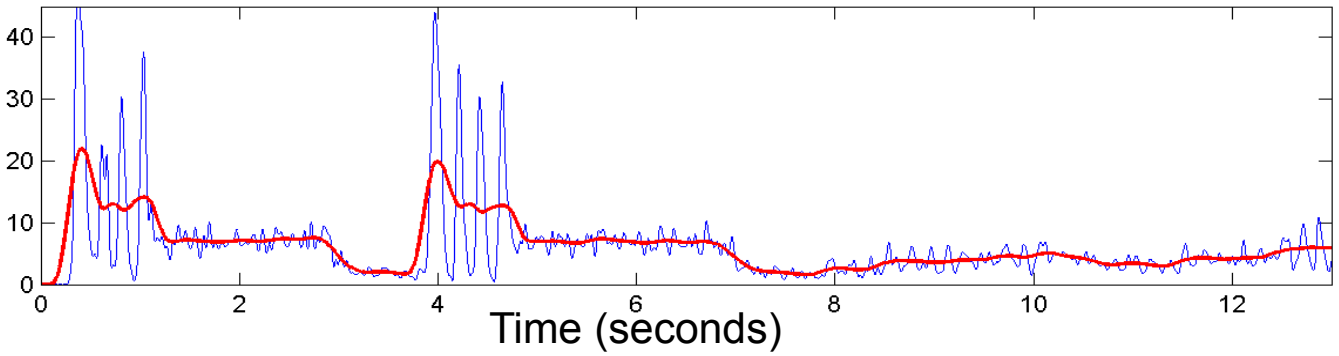


Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve
Local Average

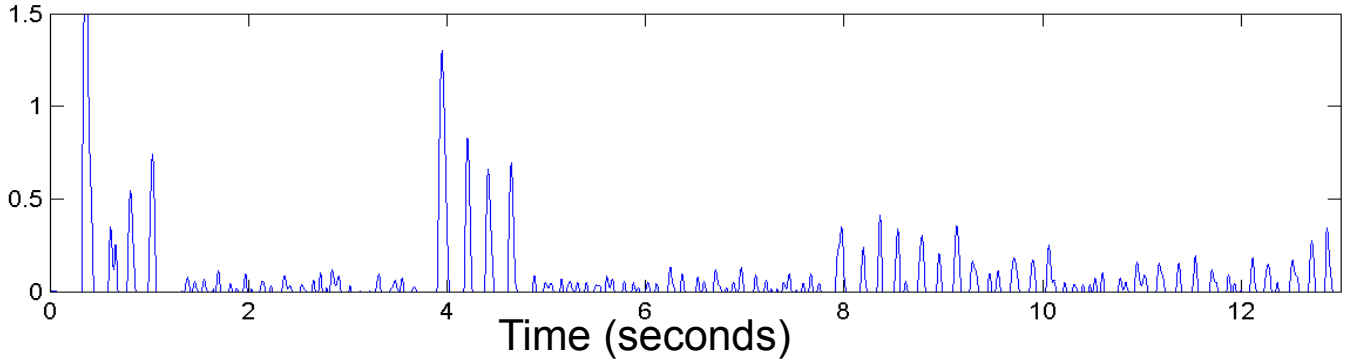


Tempo Estimation and Beat Tracking

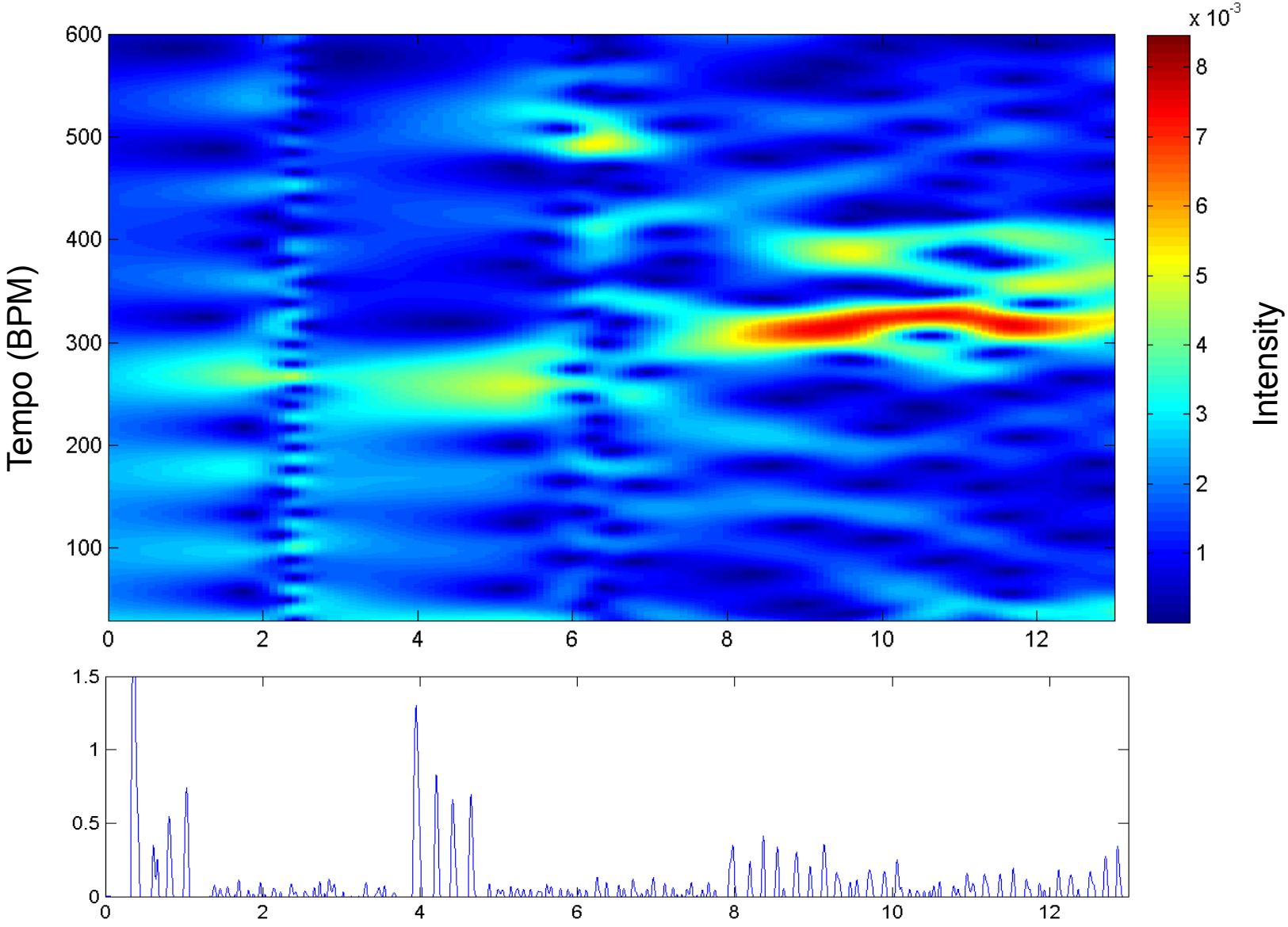
Steps:

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

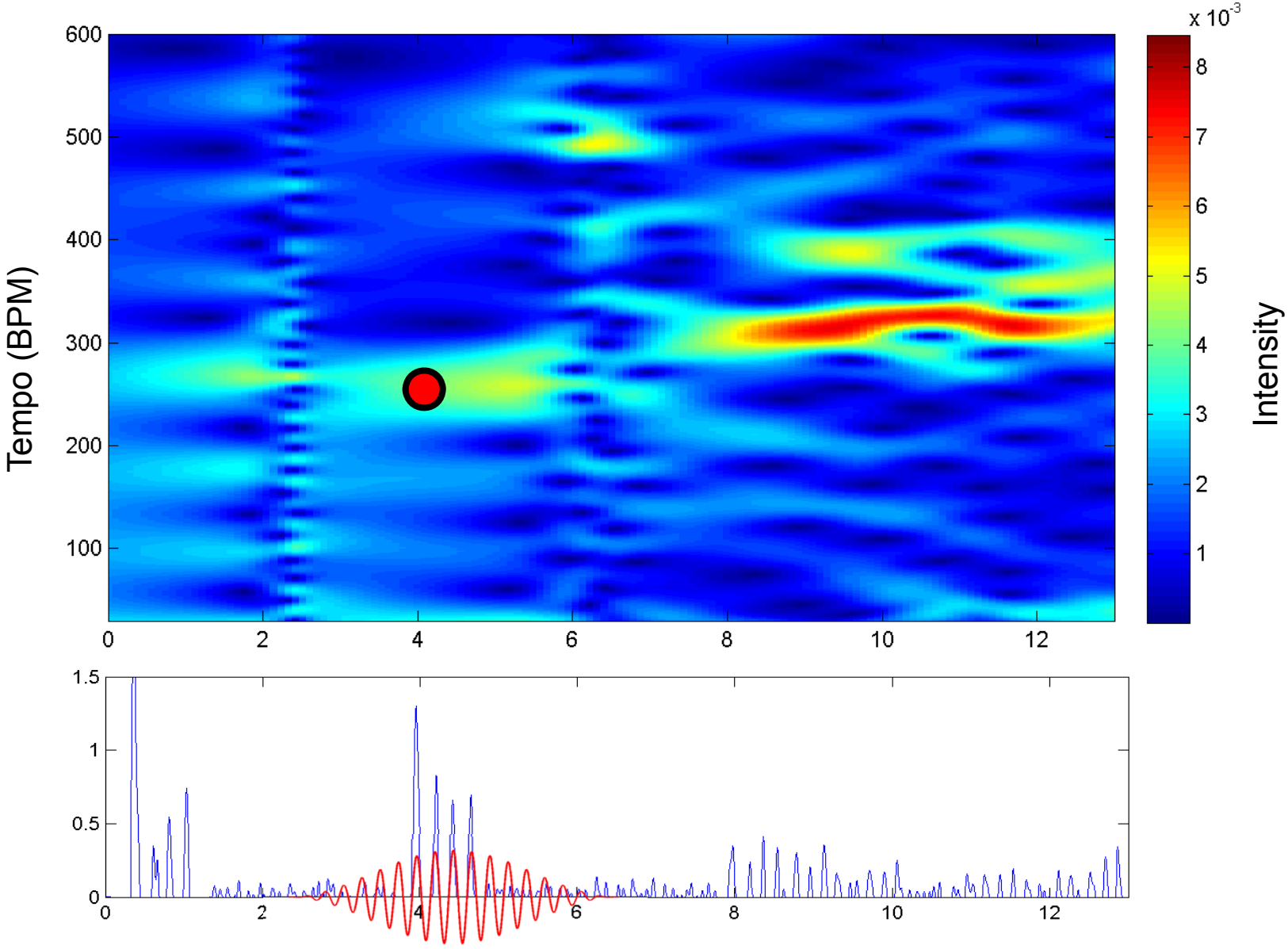
Novelty Curve



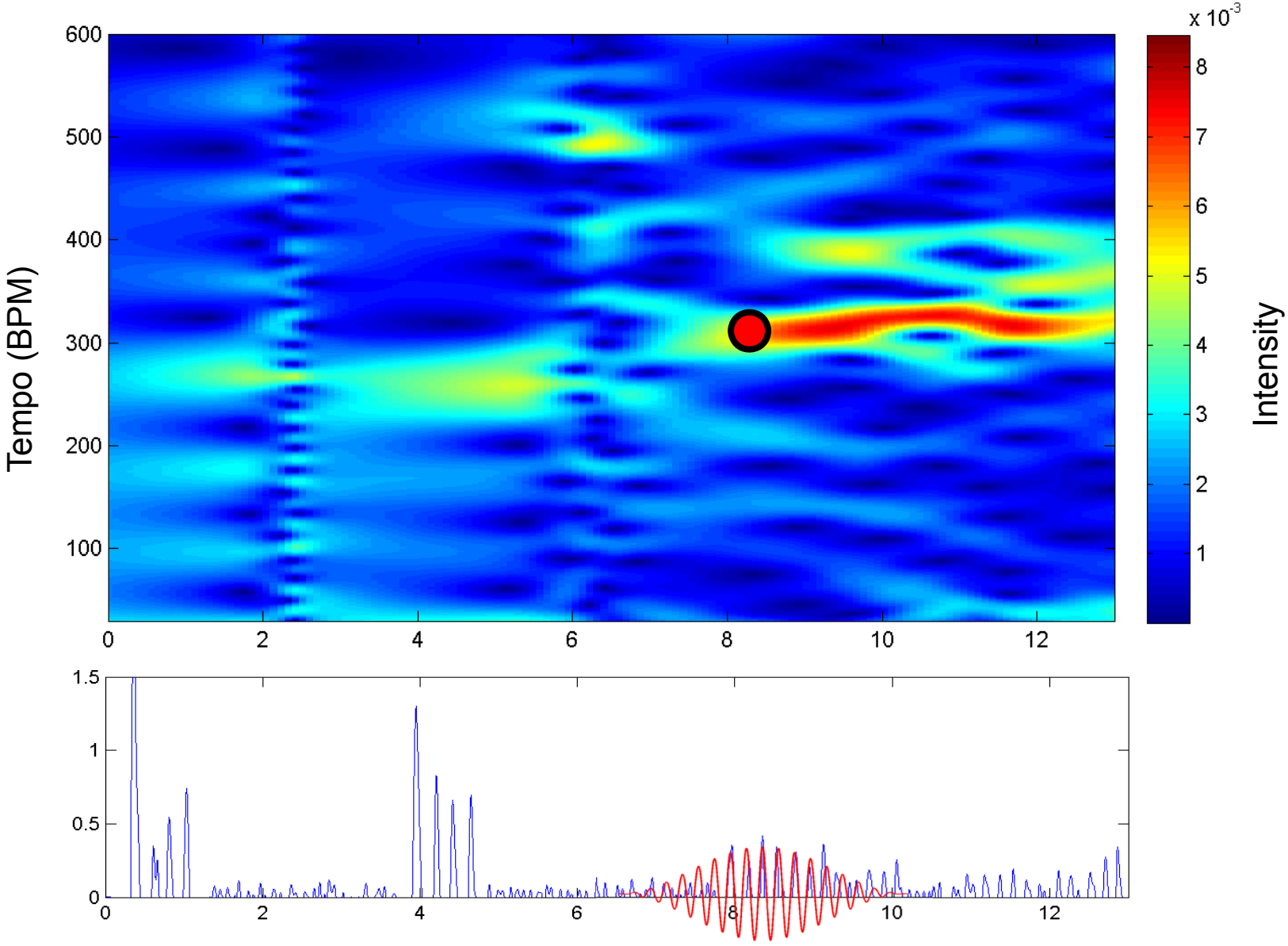
Tempo Estimation and Beat Tracking



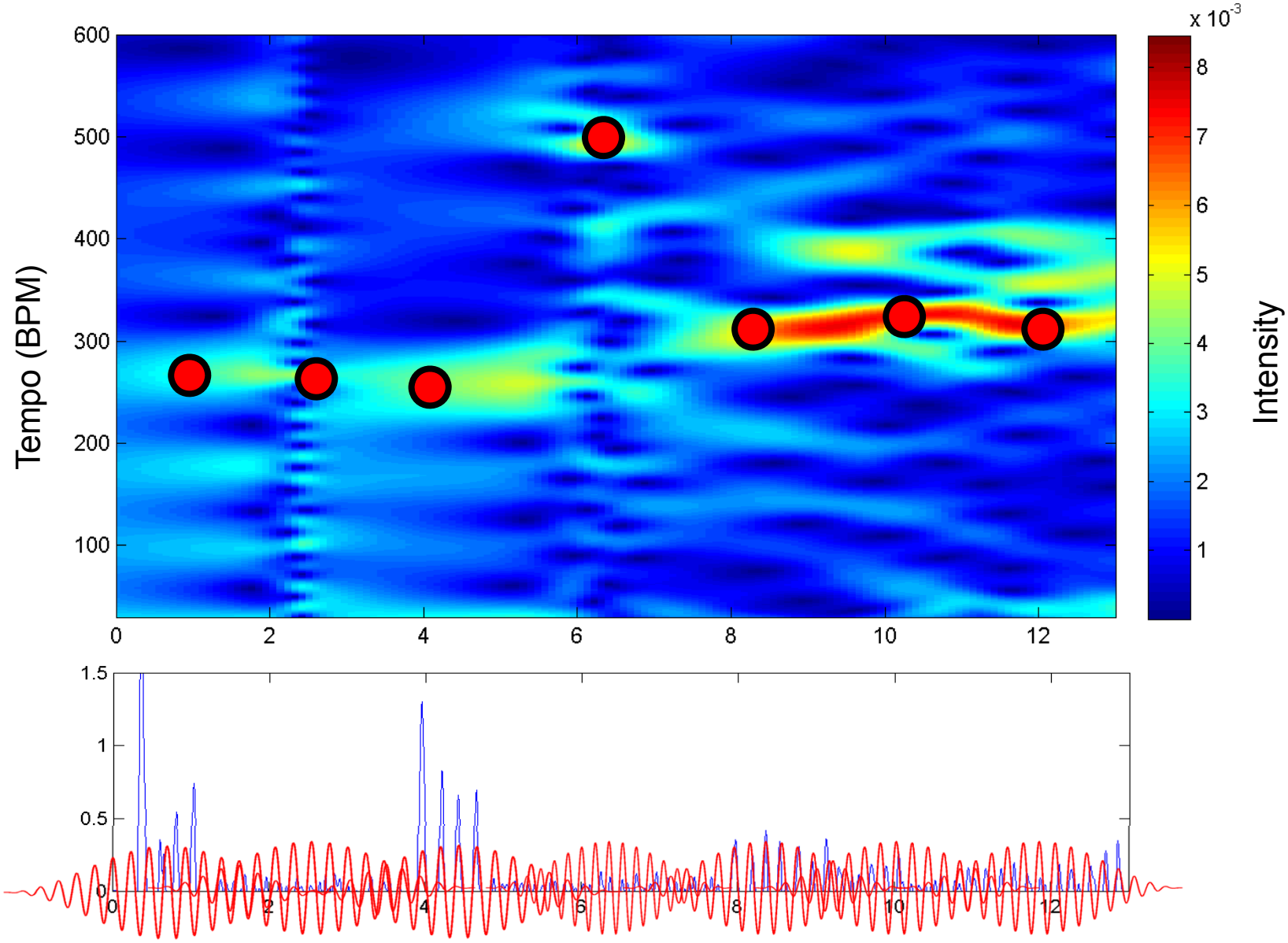
Tempo Estimation and Beat Tracking



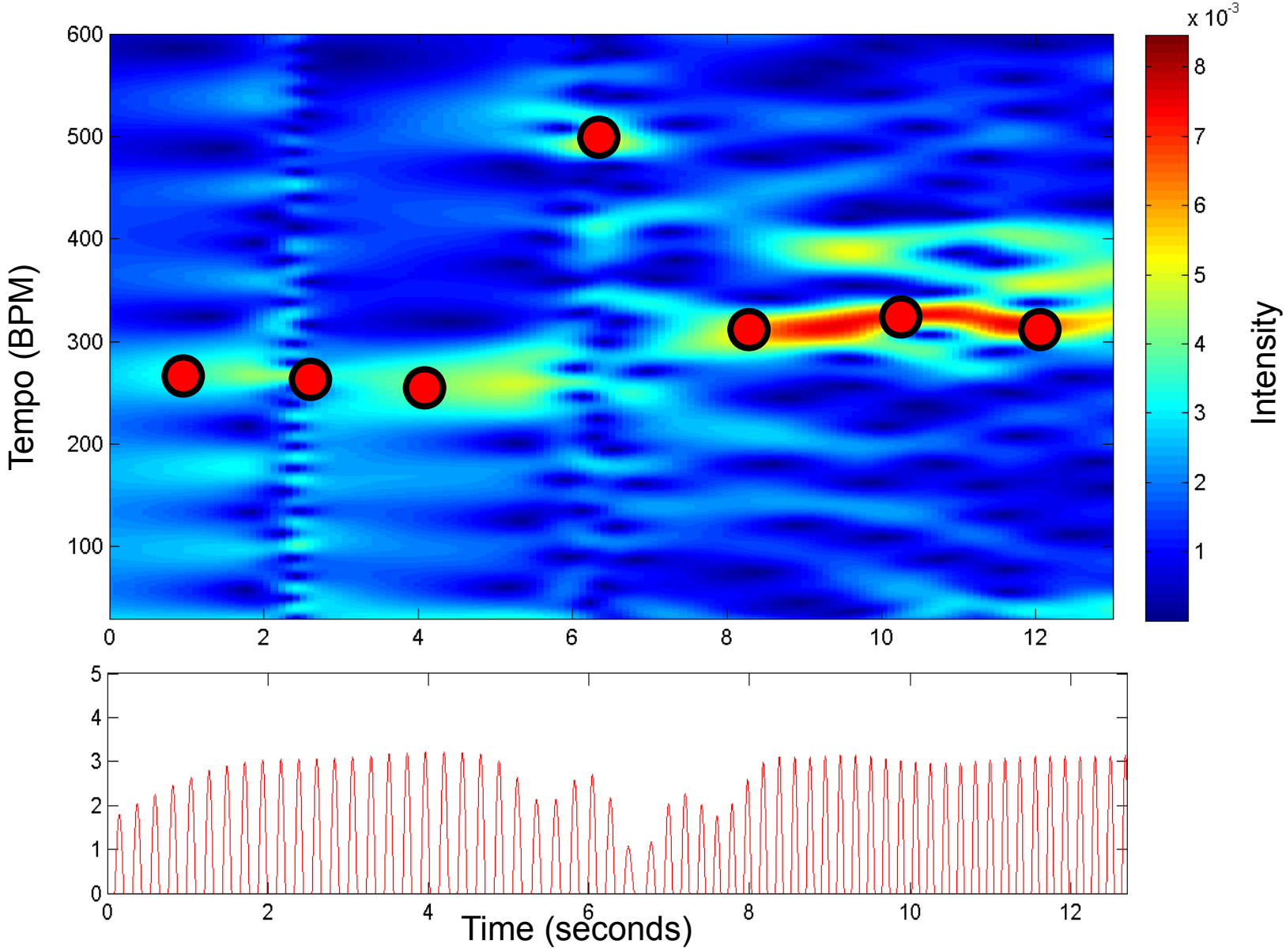
Tempo Estimation and Beat Tracking



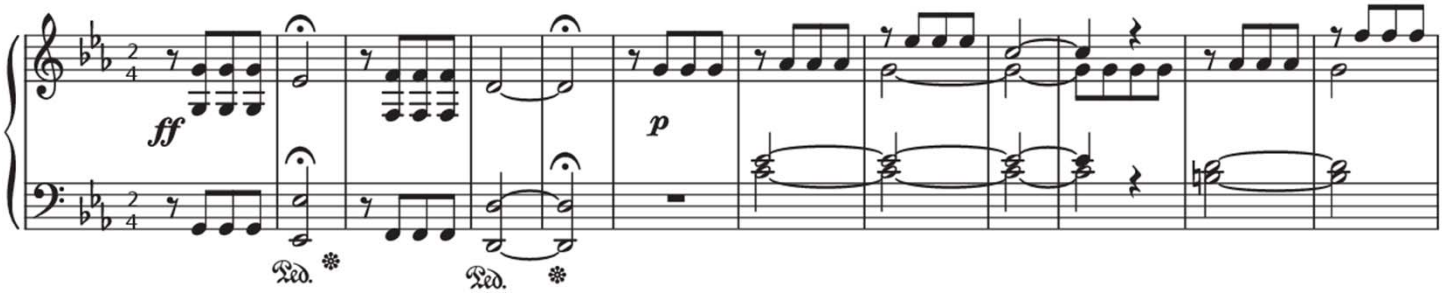
Tempo Estimation and Beat Tracking



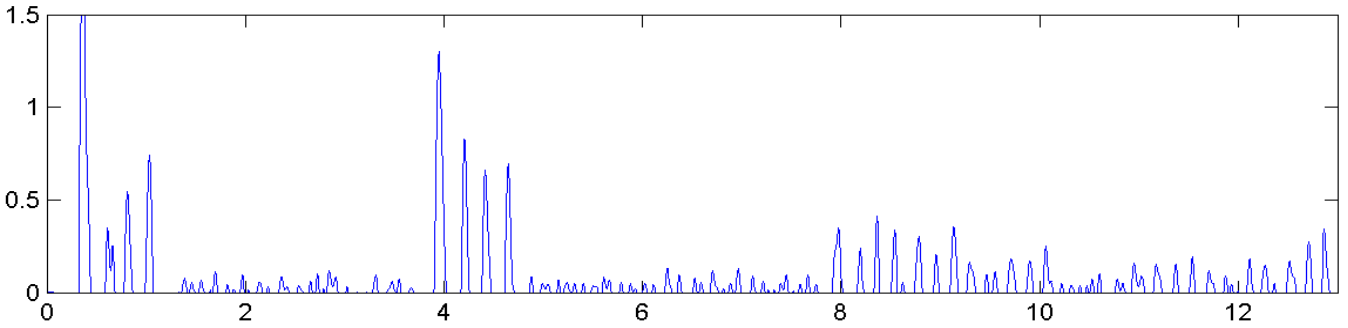
Tempo Estimation and Beat Tracking



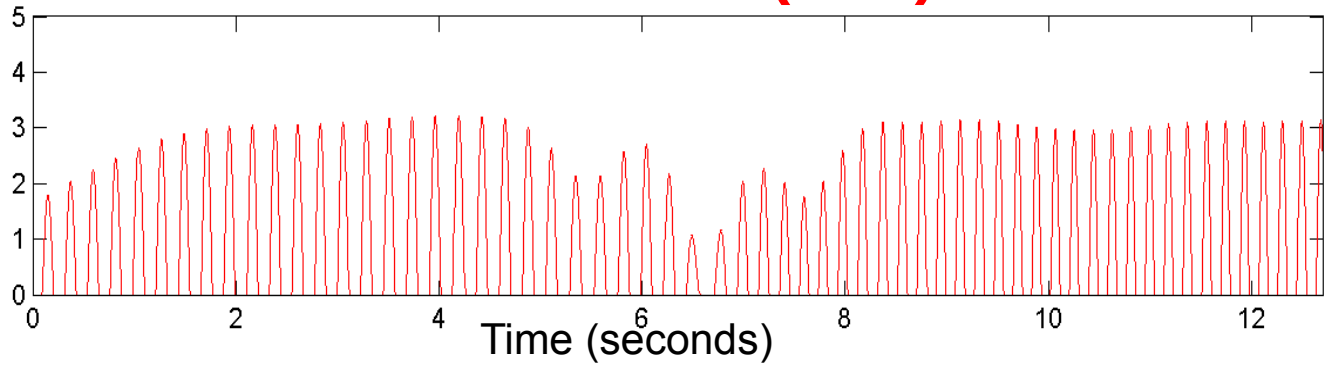
Tempo Estimation and Beat Tracking



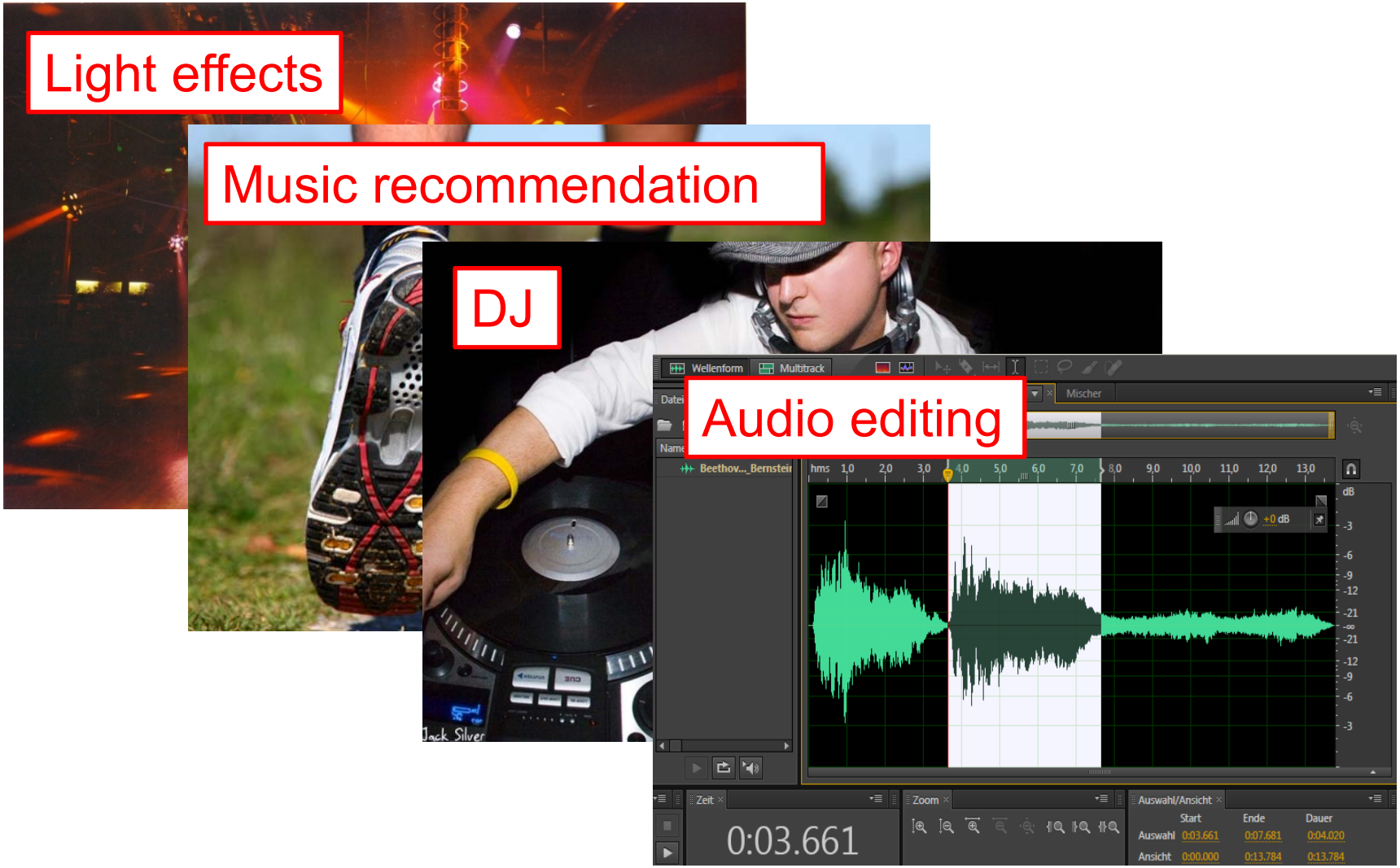
Novelty Curve



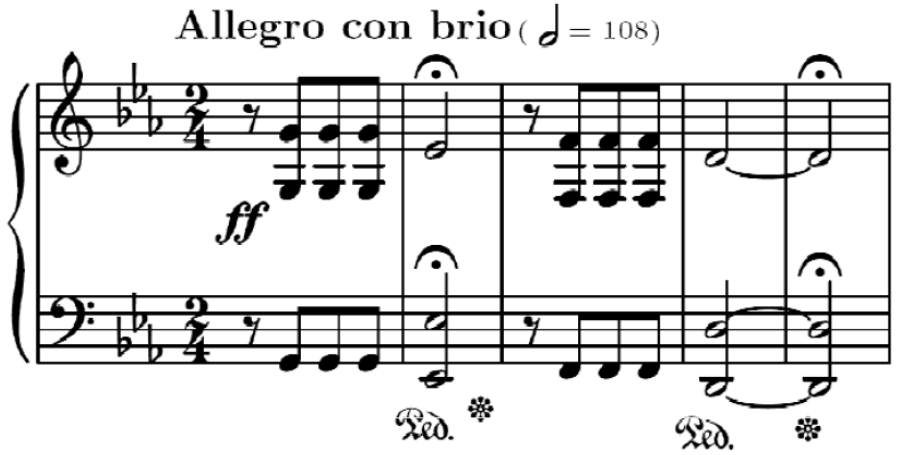
Predominant Local Pulse (PLP)



Tempo Estimation and Beat Tracking

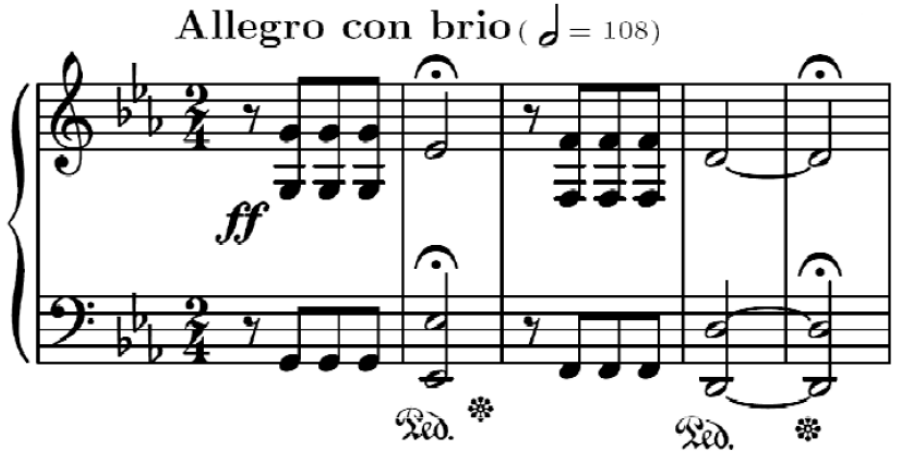


Motivic Similarity



Beethoven’s Fifth (1st Mov.)

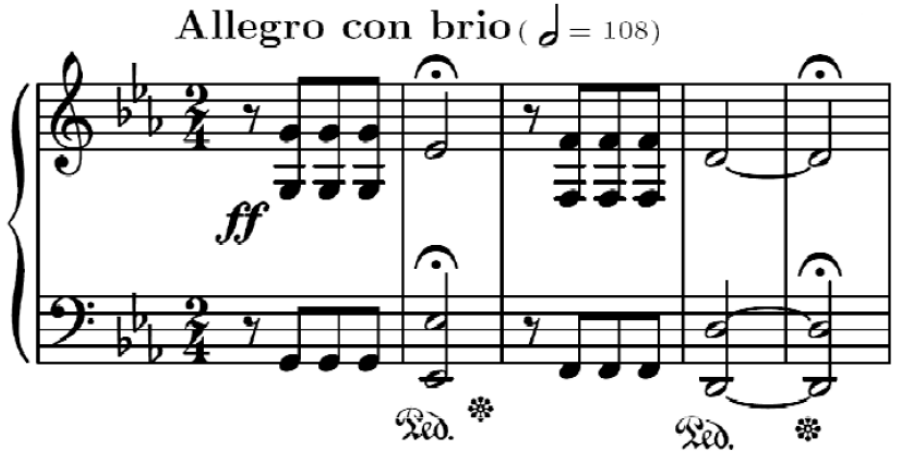
Motivic Similarity



Beethoven’s Fifth (1st Mov.)

Beethoven’s Fifth (3rd Mov.)

Motivic Similarity

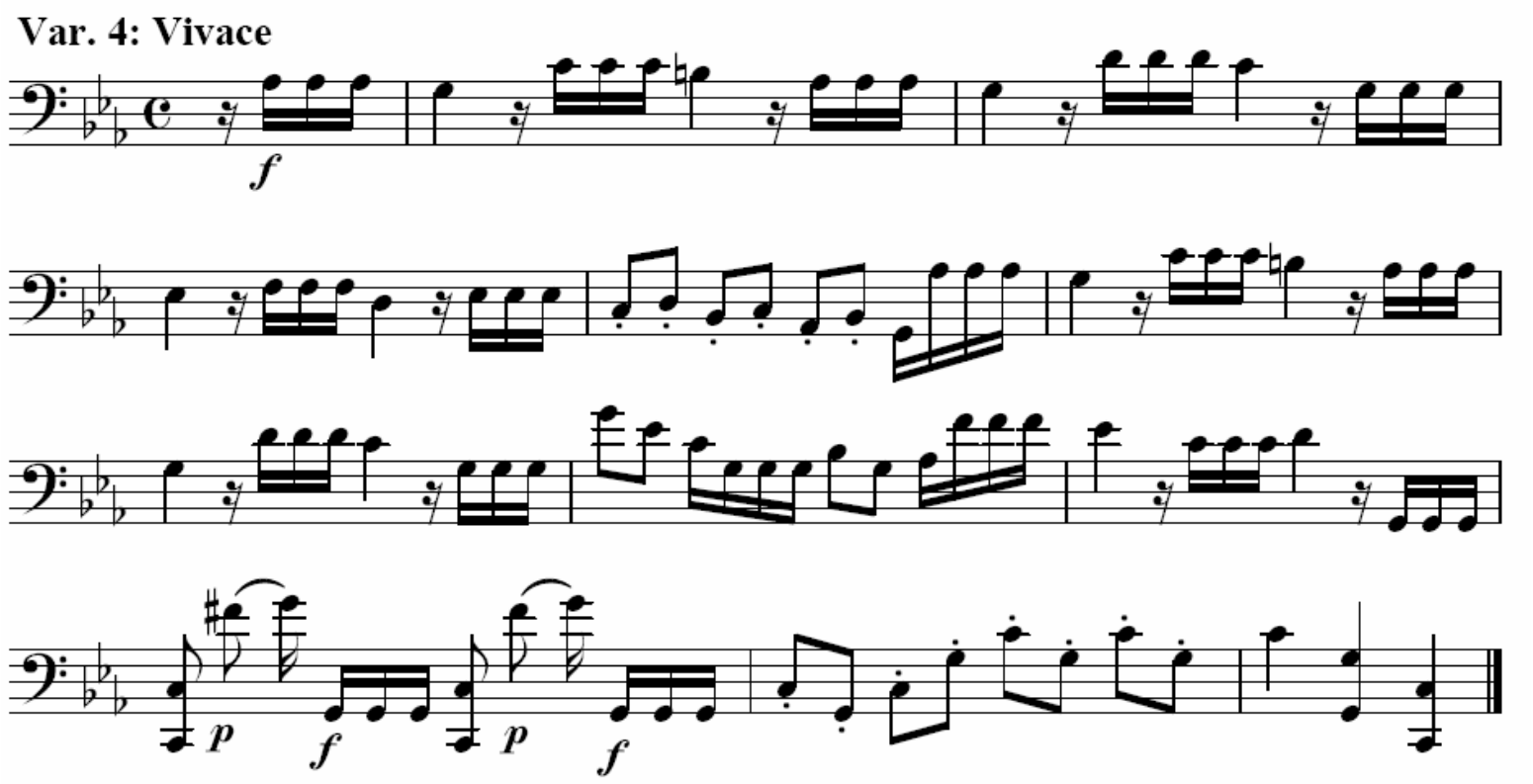


Beethoven’s Fifth (1st Mov.)

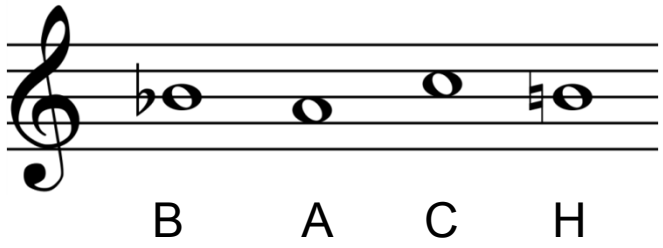
Beethoven’s Fifth (3rd Mov.)

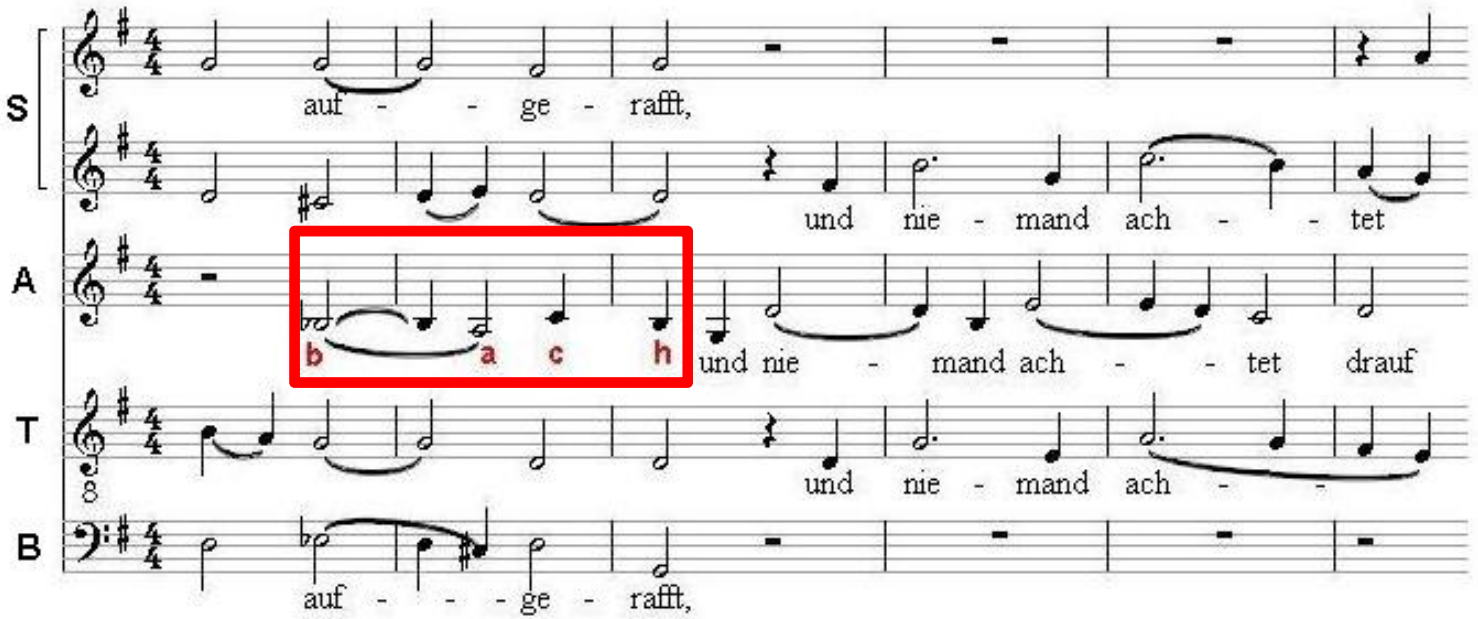
Beethoven’s Appassionata

Motivic Similarity

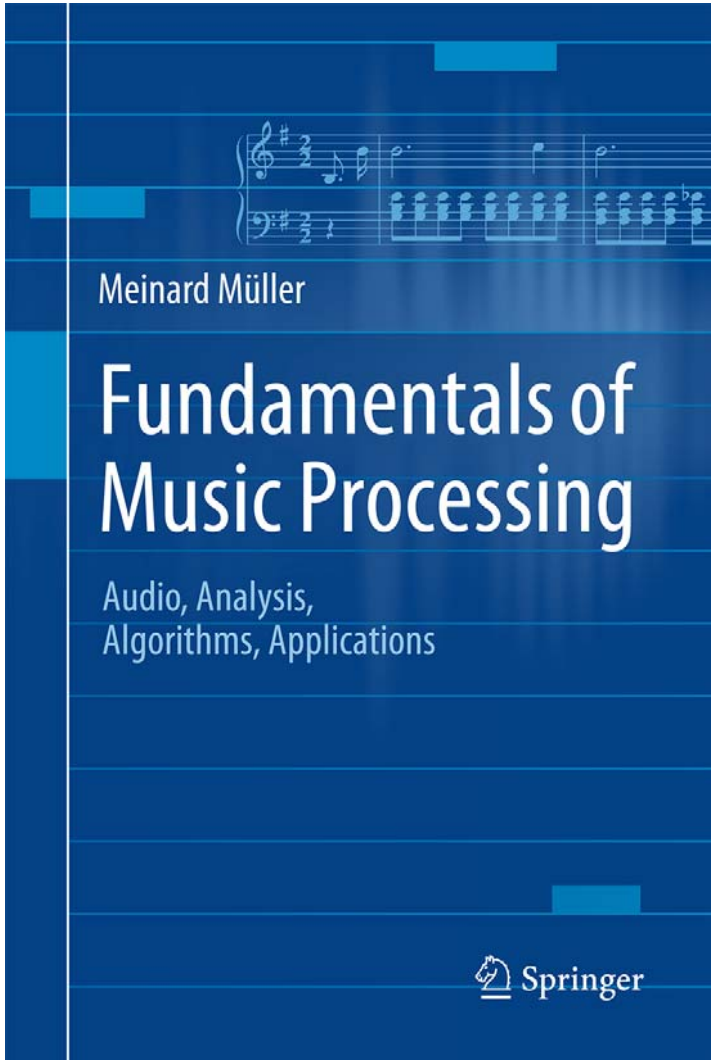


Motivic Similarity





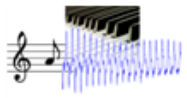
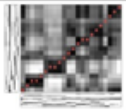
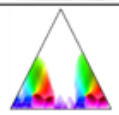
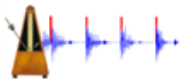
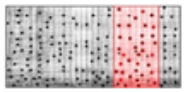
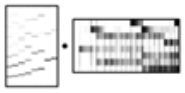
Book: Fundamentals of Music Processing



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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