Lecture

Music Processing

Beethoven, Bach, and Billions of Bytes

Meinard Müller
International Audio Laboratories Erlangen
meinard.mueller@audiolabs-erlangen.de

Prof. Dr. Meinard Müller

- PhD and Habilitation
  Bonn University
- 2007 Senior Researcher
  Multimedia Information Retrieval and Music Processing
  Max-Planck Institut für Informatik, Saarland
- 2012 Professor
  Semantic Audio Processing
  University of Erlangen-Nuremberg

Prof. Dr. Meinard Müller

Teaching assistents and current PhD students

Jonathan Driedger

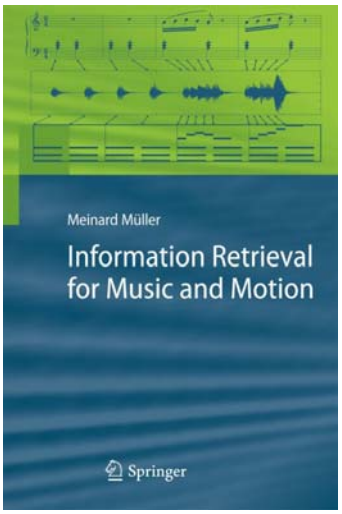
Thomas Prätzlich

Nanzhu Jiang

Prof. Dr. Meinard Müller

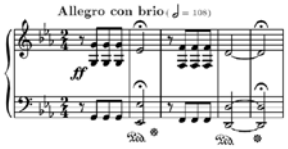
Textbook:

Information Retrieval for Music and Motion

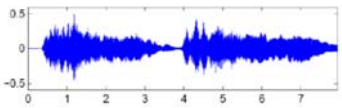


Music Representations

Sheet Music (Image)



CD / MP3 (Audio)



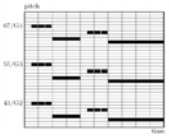
MusicXML (Text)

```
<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)

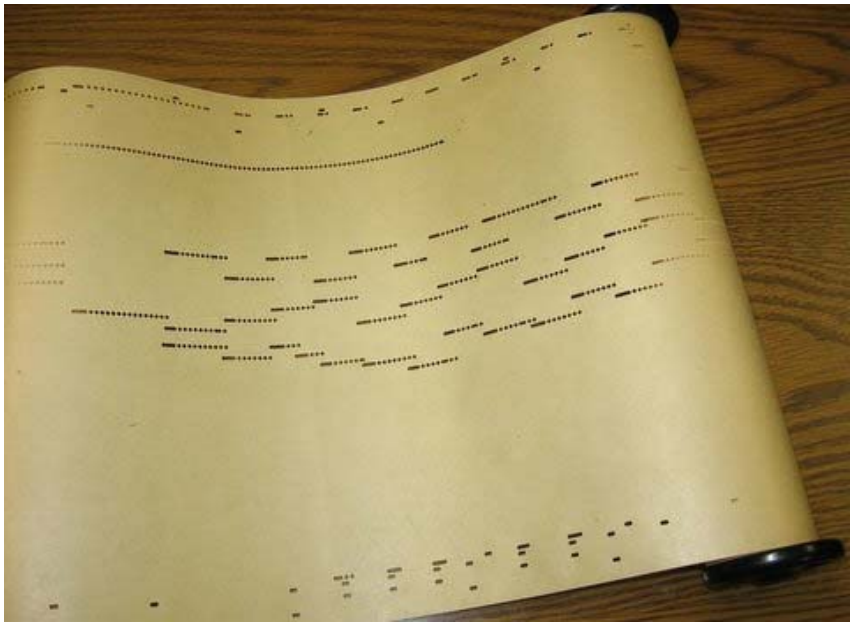
Music Film (Video)

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

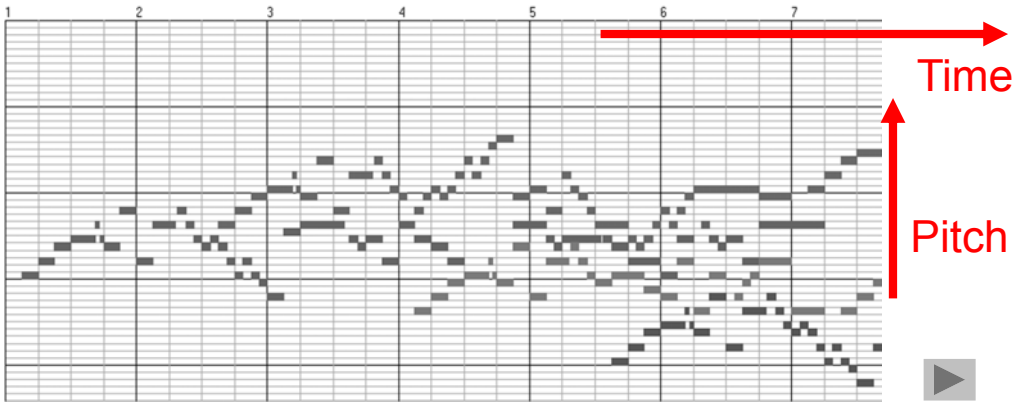


Player Piano (1900)

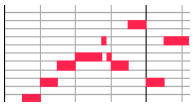
Piano Roll Representation (MIDI)

J.S. Bach, C-Major Fuge

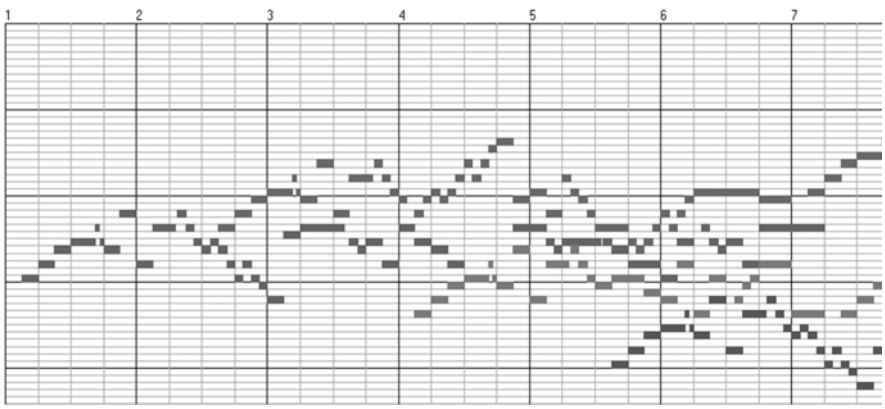
(Well Tempered Piano, BWV 846)



Piano Roll Representation (MIDI)

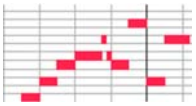
Query: 

Goal: Find all occurrences of the query



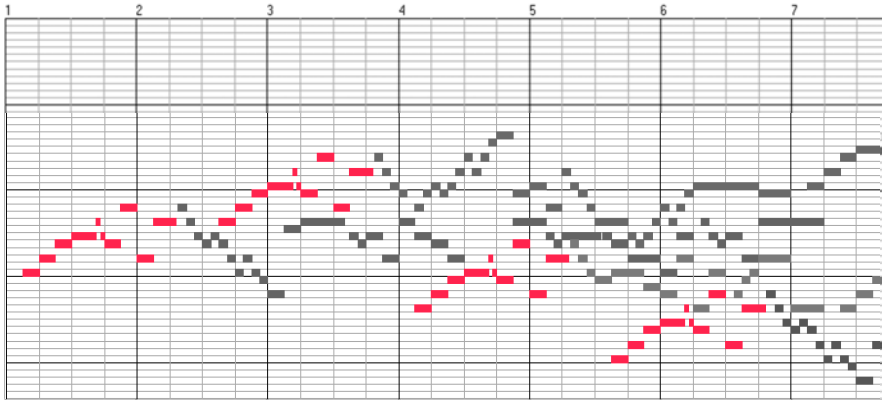
Piano Roll Representation (MIDI)

Query:



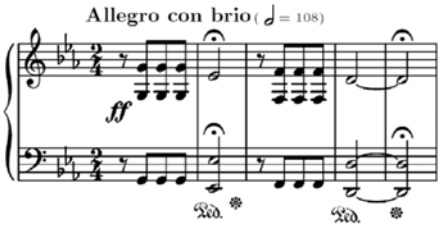
Goal: Find all occurrences of the query

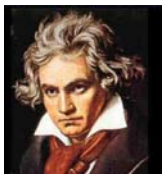
Matches:



Music Synchronization: Audio-Audio

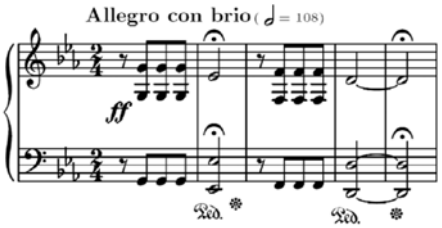
Beethoven's Fifth

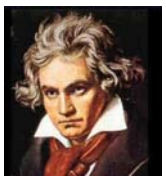




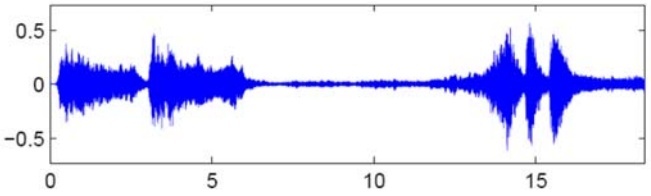
Music Synchronization: Audio-Audio

Beethoven's Fifth

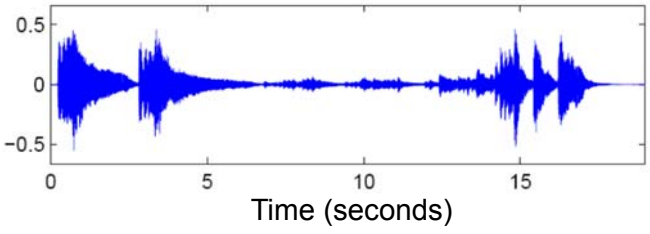




Orchester (Karajan)

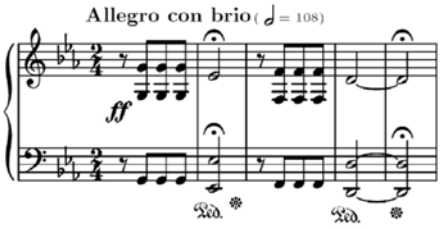


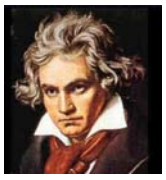
Piano (Scherbakov)



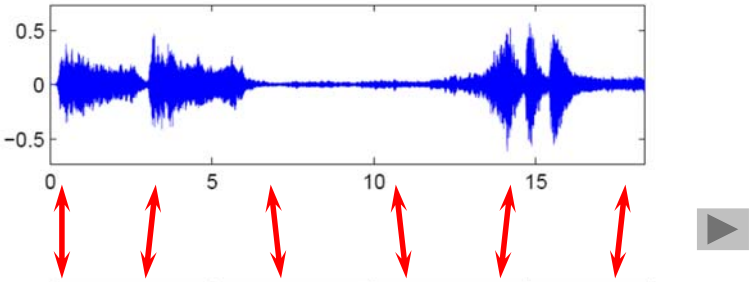
Music Synchronization: Audio-Audio

Beethoven's Fifth



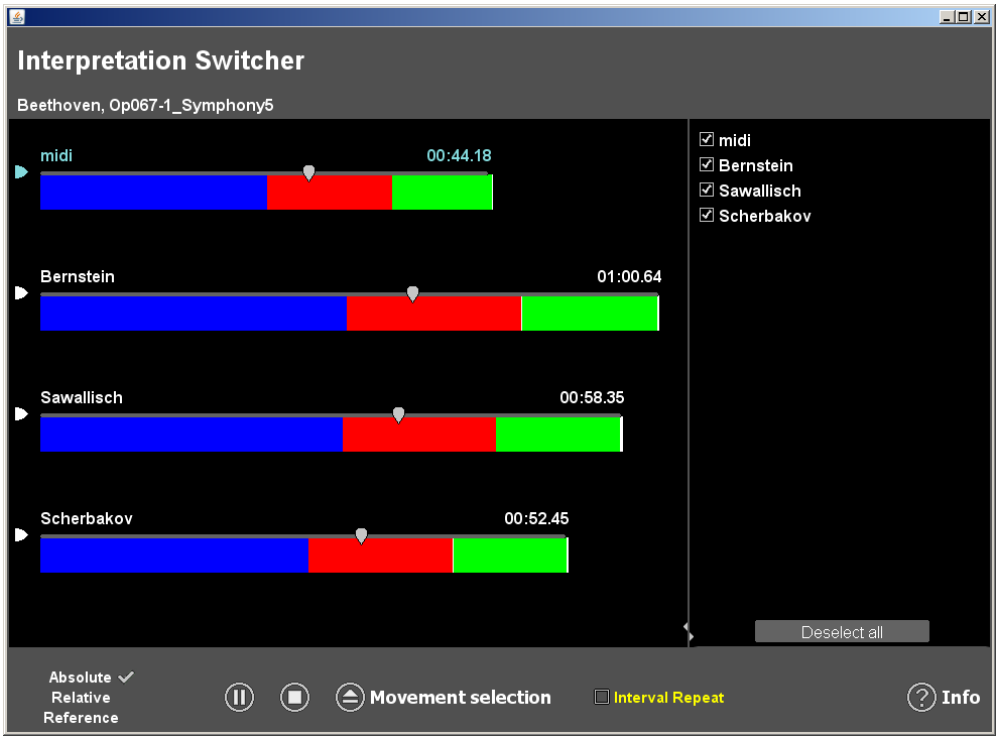


Orchester (Karajan)



Piano (Scherbakov)

Application: Interpretation Switcher



Music Synchronization: Audio-Audio

Two main steps:

1.) Audio features

- Robust but discriminative
- Chroma features
- Robust to variations in instrumentation, timbre, dynamics
- Correlate to harmonic progression

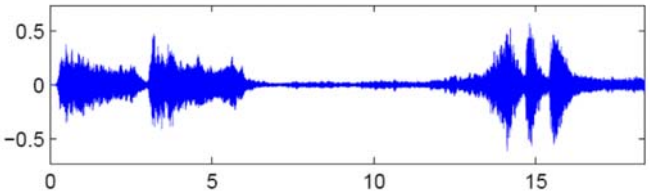
2.) Alignment procedure

- Deals with local and global tempo variations
- Needs to be efficient

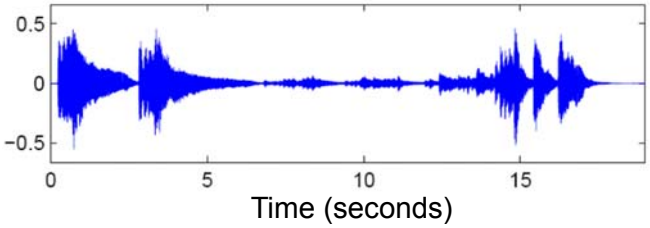
Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester (Karajan)



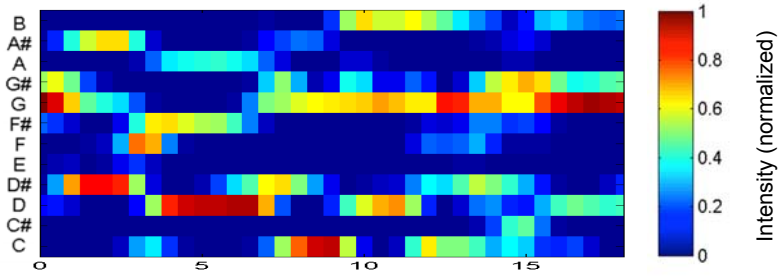
Piano (Scherbakov)



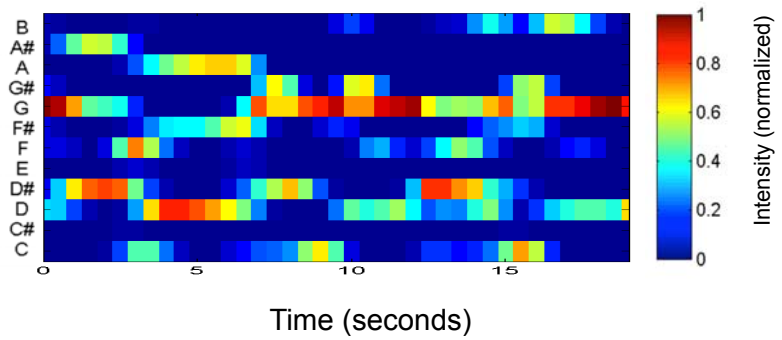
Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester (Karajan)



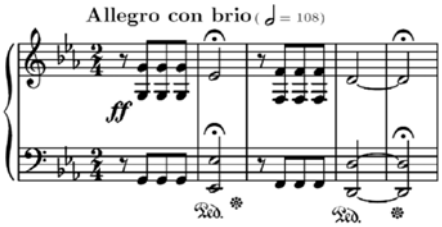
Piano (Scherbakov)



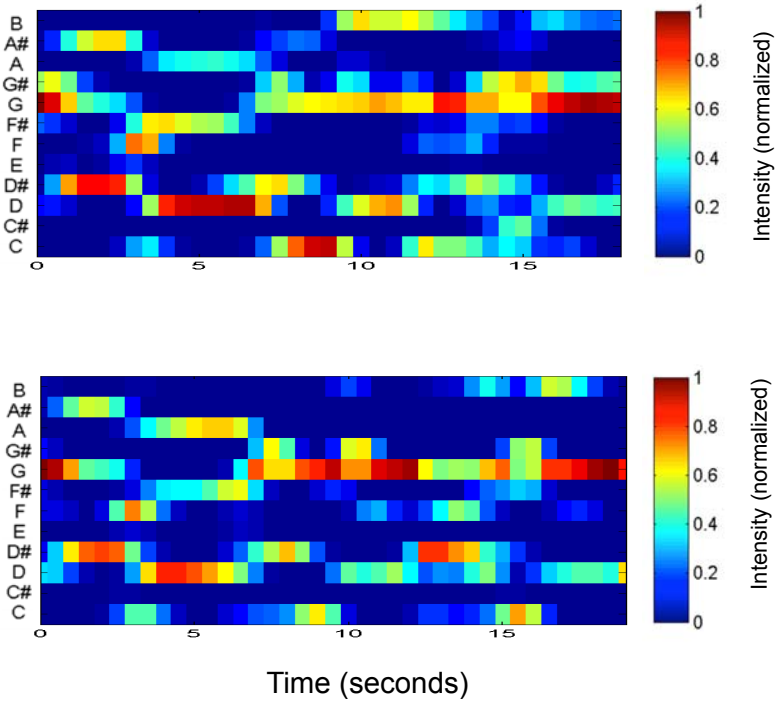
Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester
(Karajan)



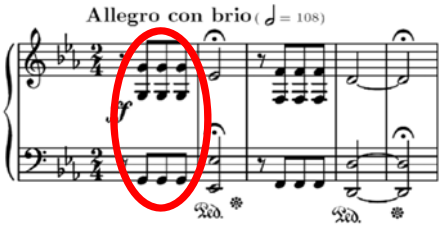
Piano
(Scherbakov)



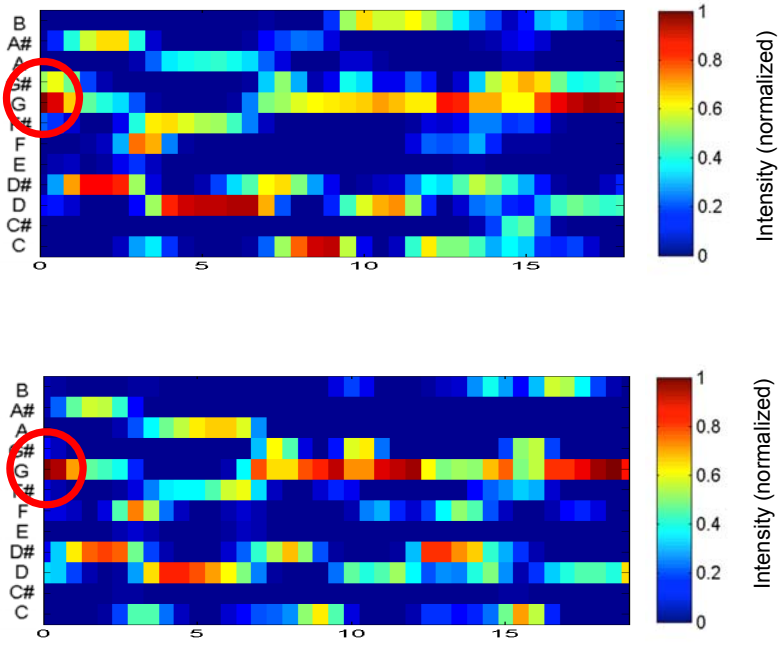
Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester
(Karajan)



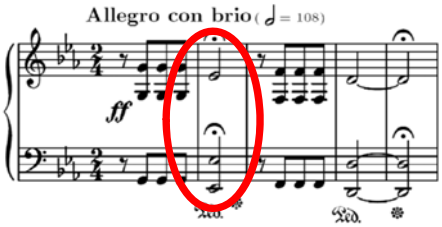
Piano
(Scherbakov)



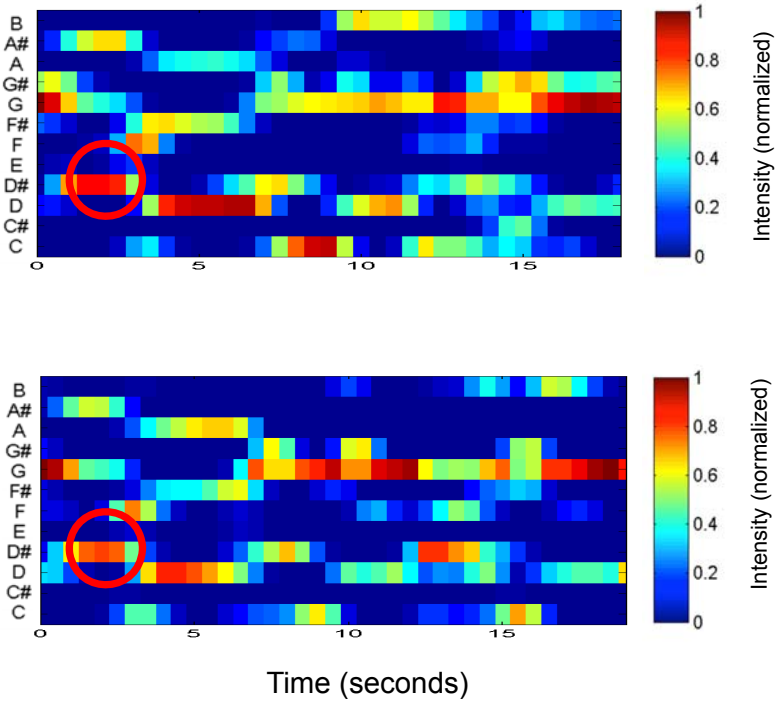
Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester
(Karajan)



Piano
(Scherbakov)

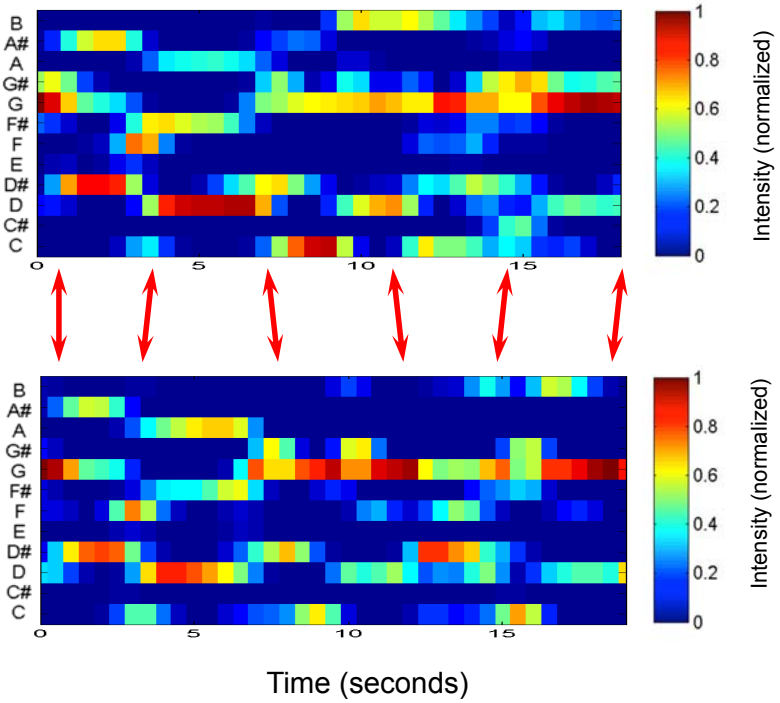


Music Synchronization: Audio-Audio

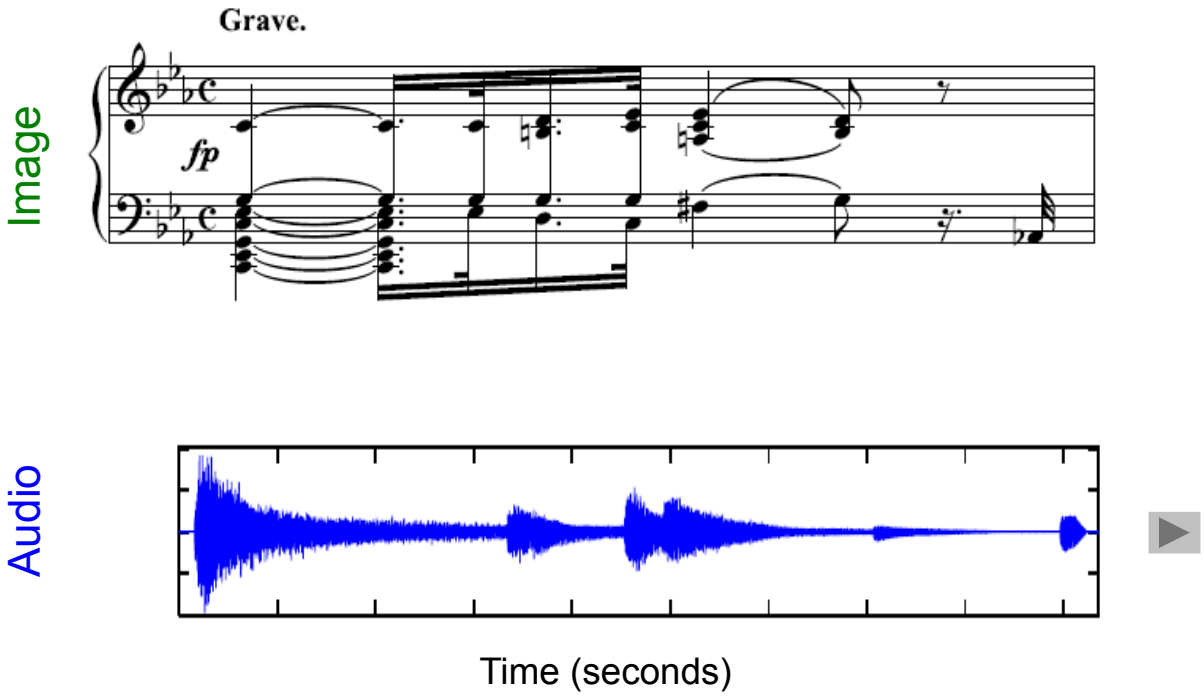
Beethoven's Fifth

Orchester
(Karajan)

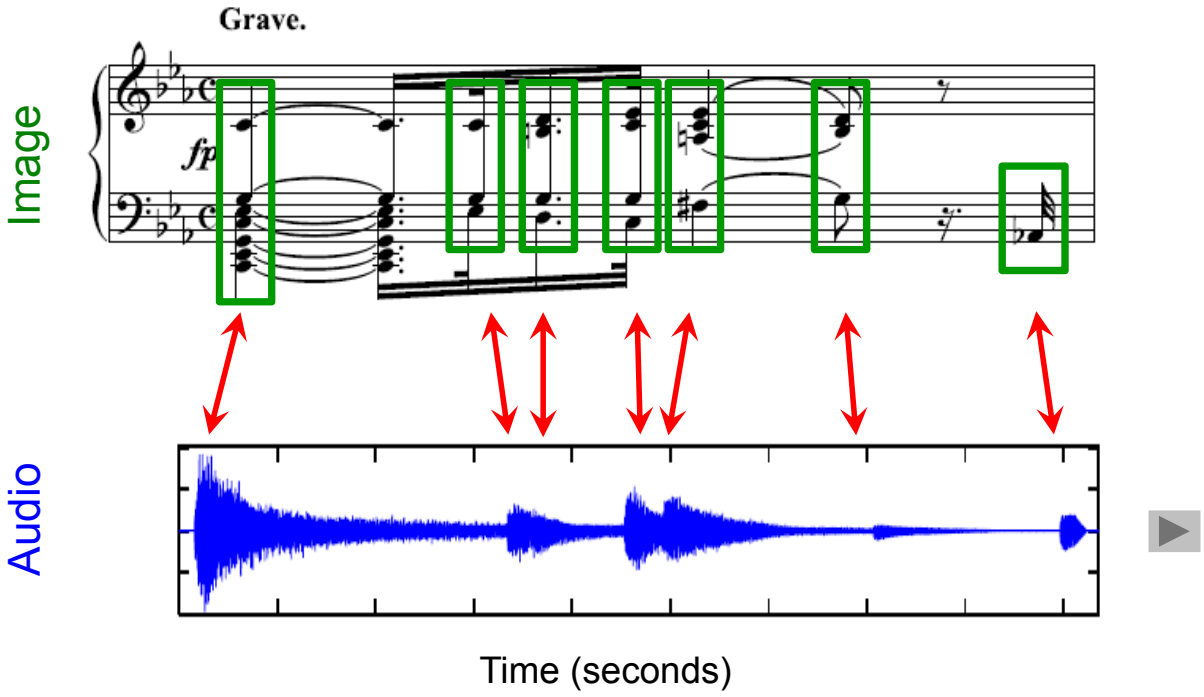
Piano
(Scherbakov)



Music Synchronization: Image-Audio

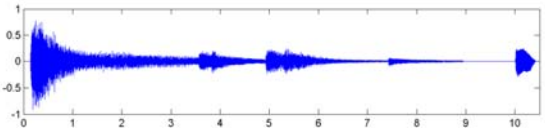


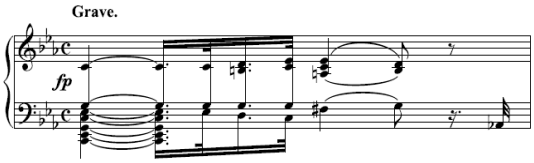
Music Synchronization: Image-Audio



Music Synchronization: Image-Audio

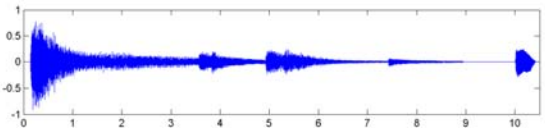
Convert into common mid-level feature representation

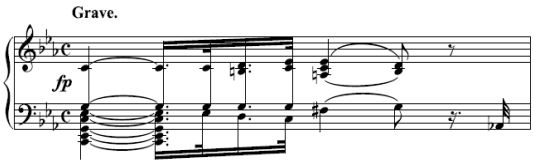




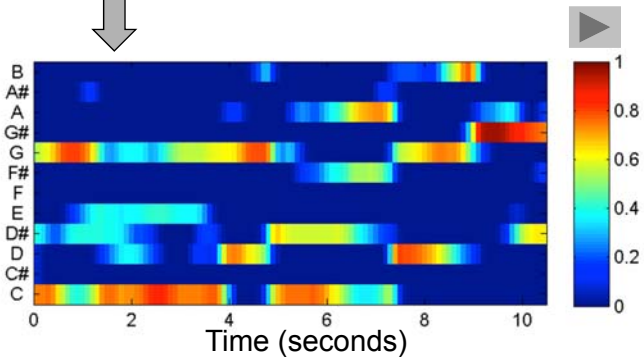
Music Synchronization: Image-Audio

Convert into common mid-level feature representation





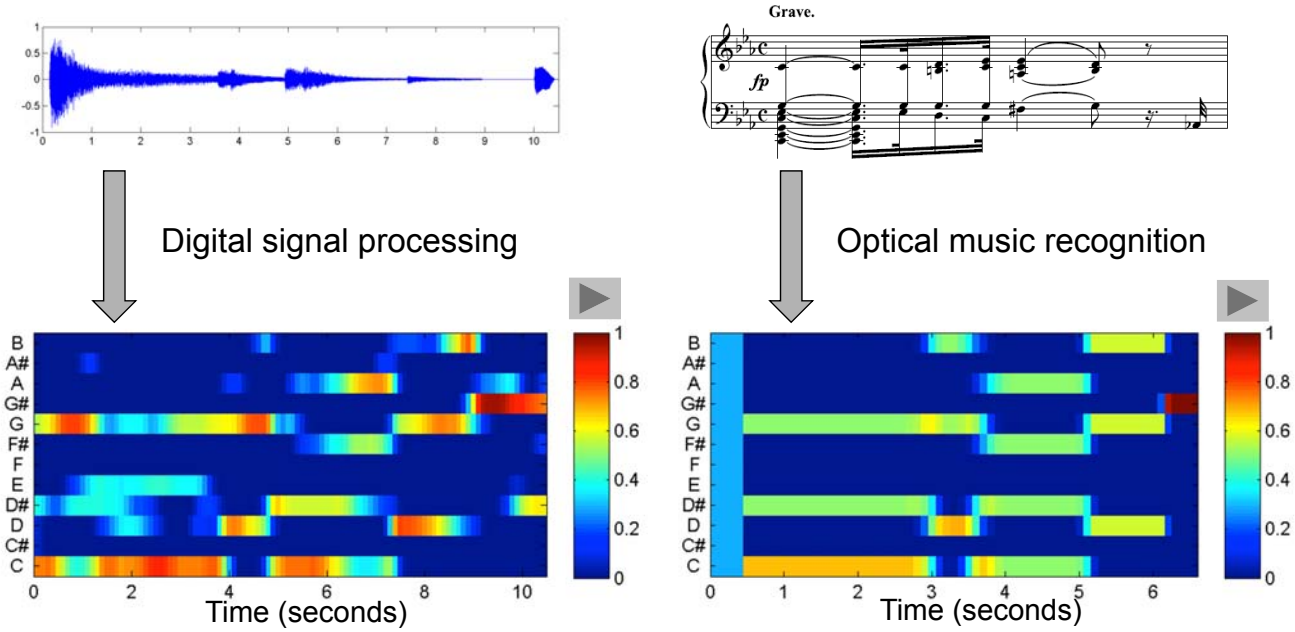
Digital signal processing



Audio chroma representation

Music Synchronization: Image-Audio

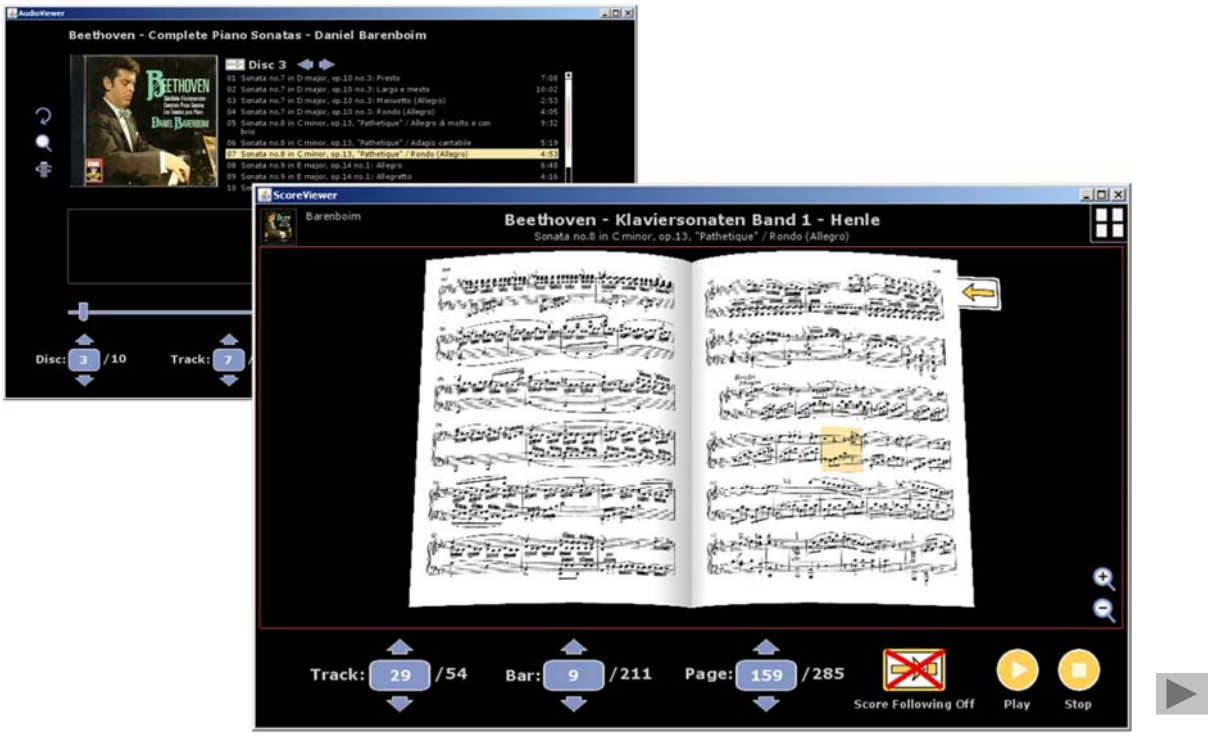
Convert into common mid-level feature representation



Audio chroma representation

Image chroma representation

Application: Score Viewer

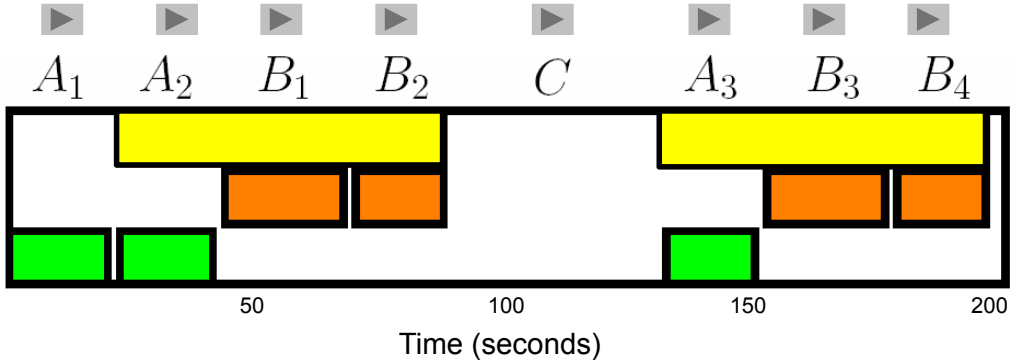


Audio Structure Analysis

Given: CD recording

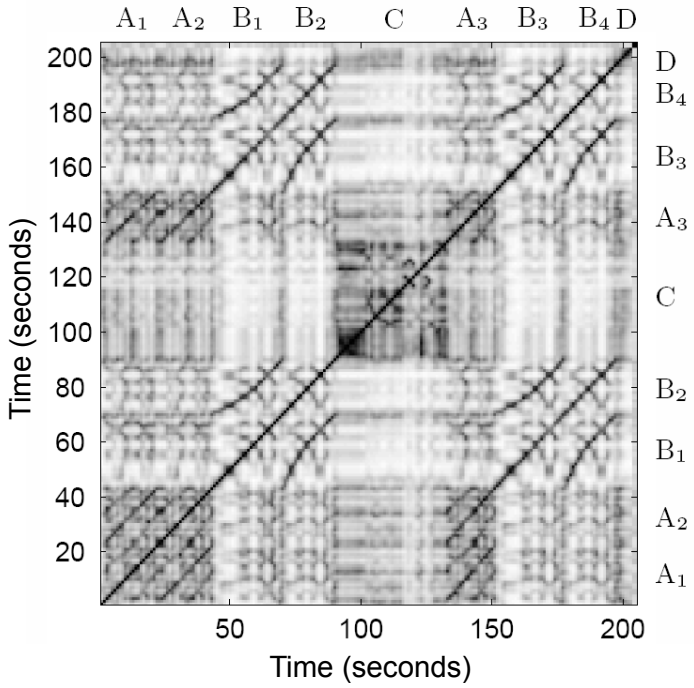
Goal: Automatic extraction of the repetitive structure
(or of the musical form)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

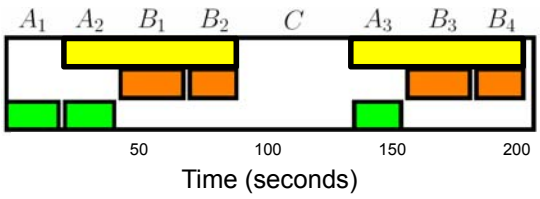


Basic Procedure

Self-similarity matrix

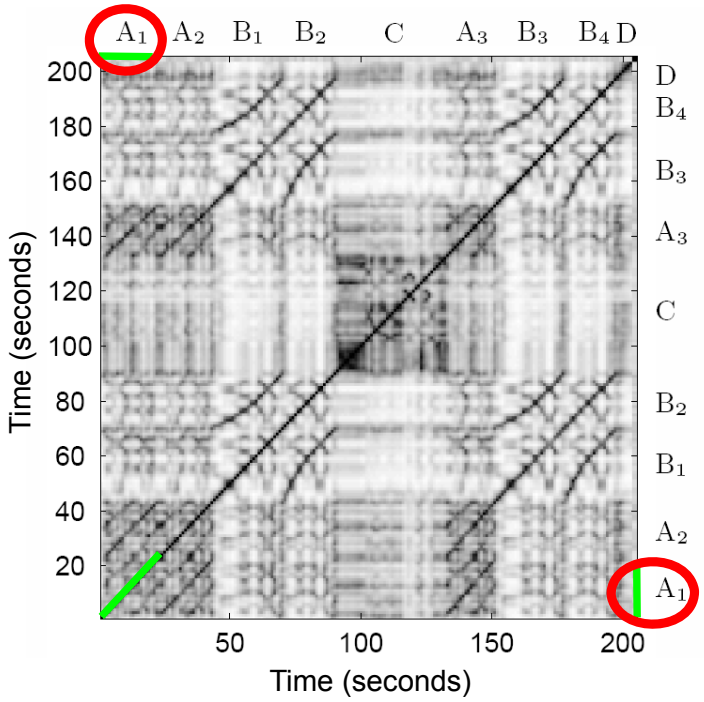


Similarity structure

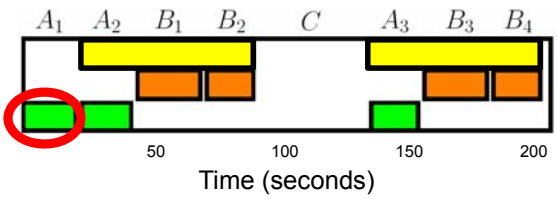


Basic Procedure

Self-similarity matrix

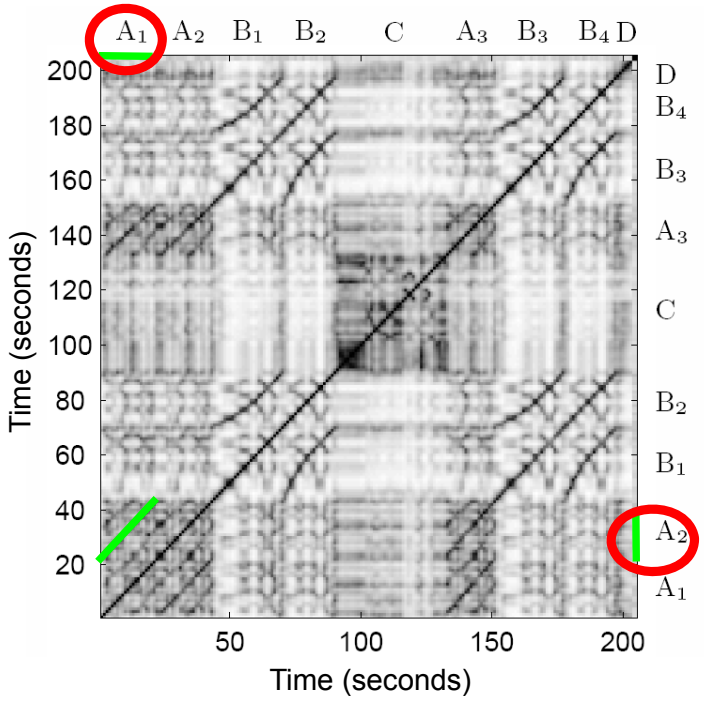


Similarity structure

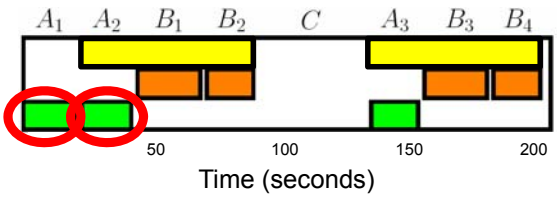


Basic Procedure

Self-similarity matrix

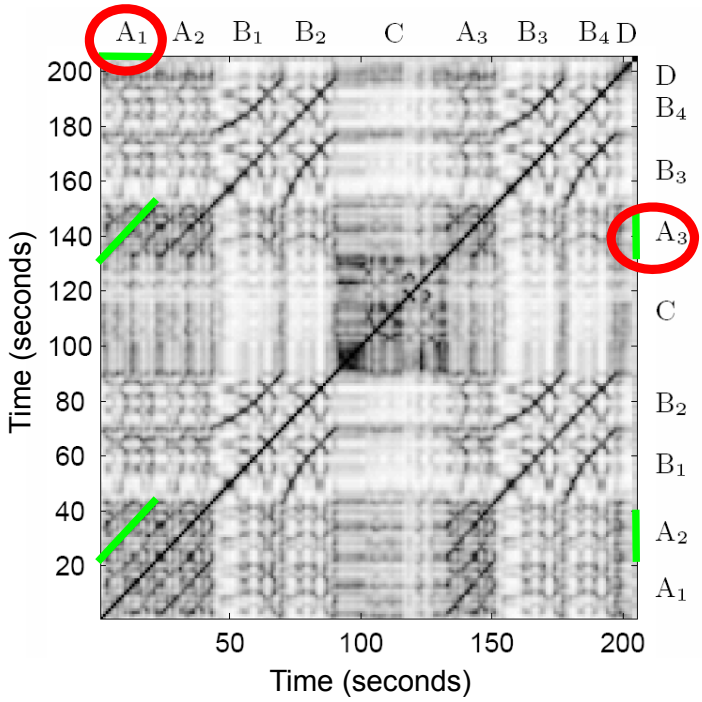


Similarity structure

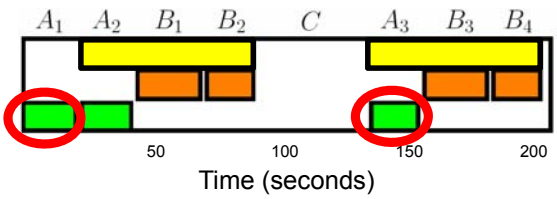


Basic Procedure

Self-similarity matrix

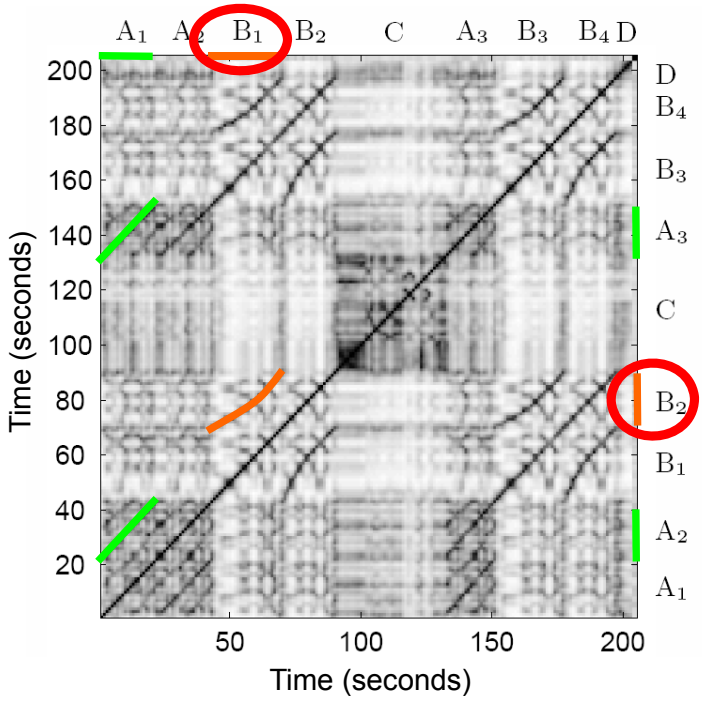


Similarity structure

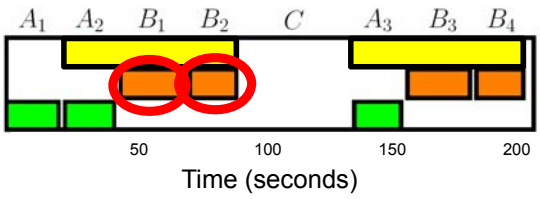


Basic Procedure

Self-similarity matrix

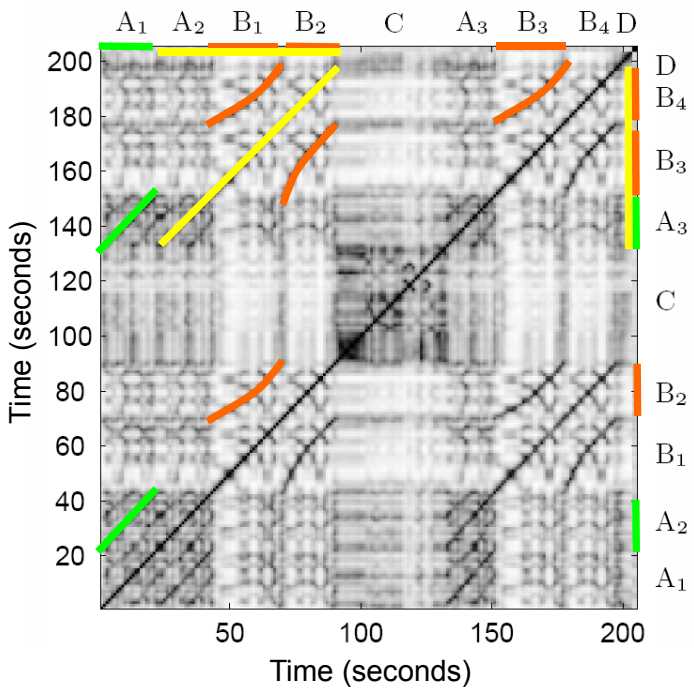


Similarity structure

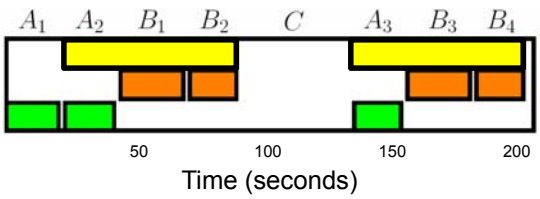


Basic Procedure

Self-similarity matrix



Similarity structure



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**

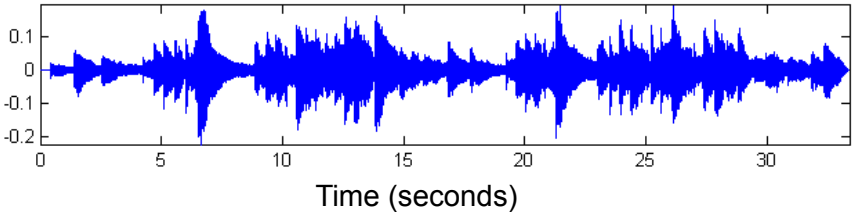
Performance Analysis

1. Capture nuances regarding tempo, dynamics, articulation, timbre, …
2. Discover commonalities between different performances and derive general performance rules
3. Characterize the style of a specific musician (``Horowitz Factor´´)

Performance Analysis: Tempo Curves

Schumann: Träumerei

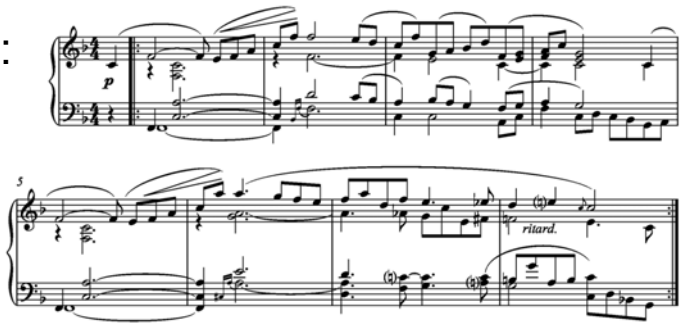
Performance:



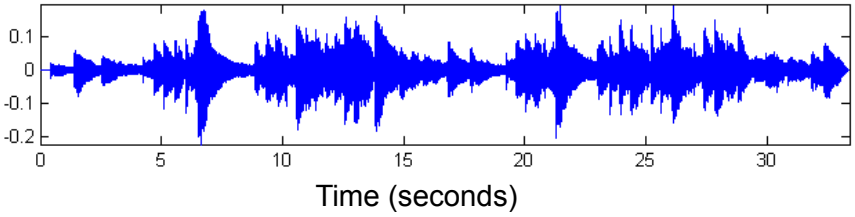
Performance Analysis: Tempo Curves

Schumann: Träumerei

Score (reference):



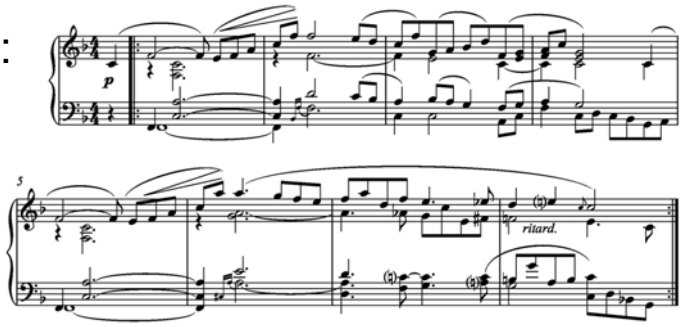
Performance:



Performance Analysis: Tempo Curves

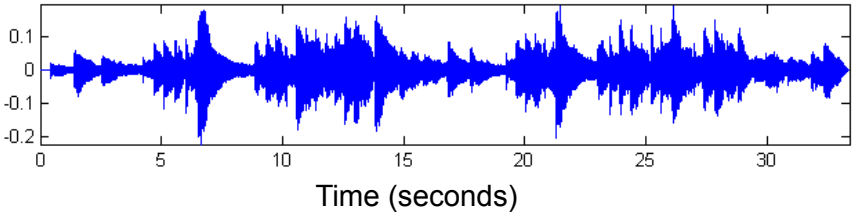
Schumann: Träumerei

Score (reference):



Strategy: Compute score-audio synchronization and derive tempo curve

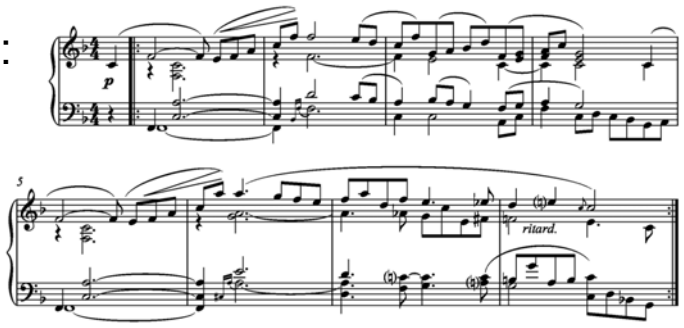
Performance:



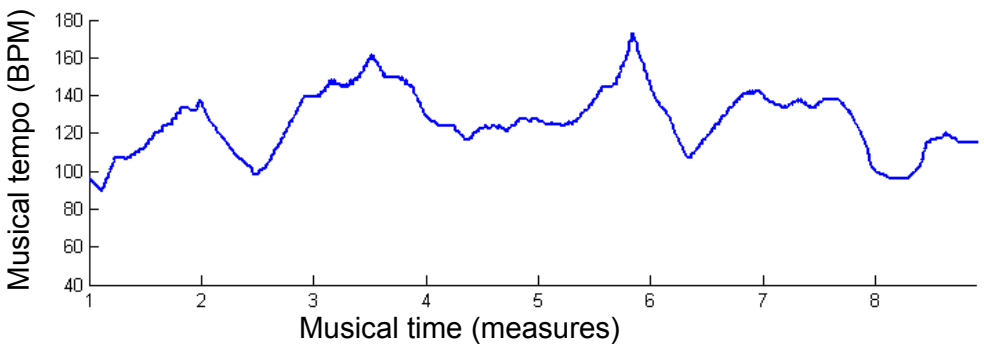
Performance Analysis: Tempo Curves

Schumann: Träumerei

Score (reference):



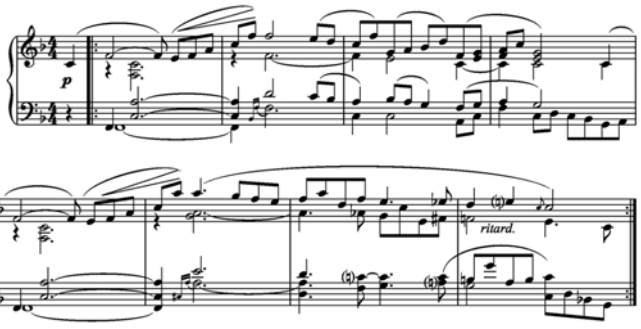
Tempo Curve:



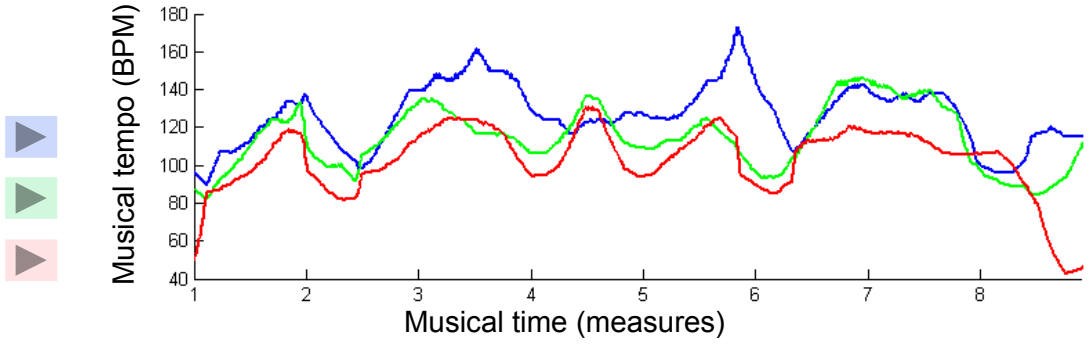
Performance Analysis: Tempo Curves

Schumann: Träumerei

Score (reference):



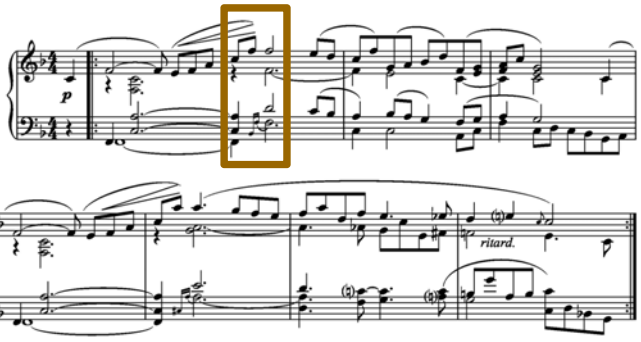
Tempo Curves:



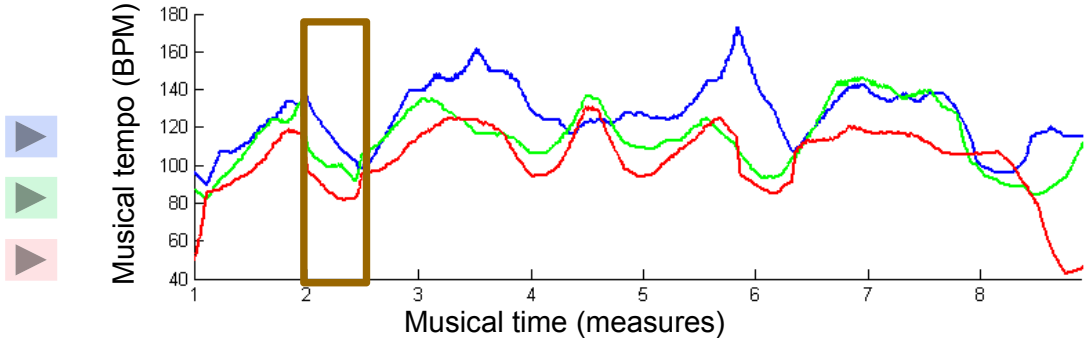
Performance Analysis: Tempo Curves

Schumann: Träumerei

Score (reference):



Tempo Curves:

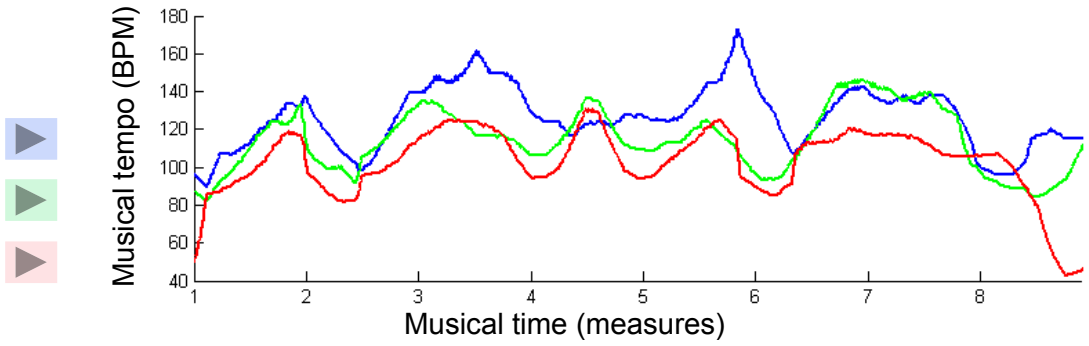


Performance Analysis

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

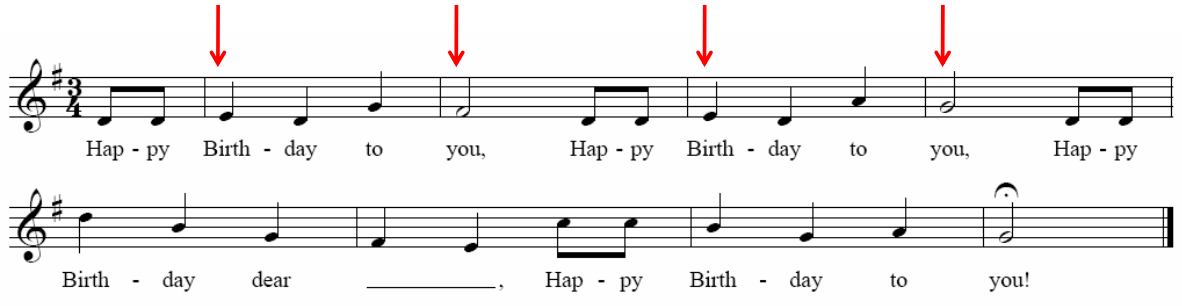
Relative	**Absolute**
Given: Several versions	Given: One version
Comparison of extracted parameters	Direct interpretation of extracted parameters
Extraction errors have often no consequence on final result	Extraction errors immediately become evident

Music Processing

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
Example tasks: **Music Synchronization** **Genre Classification**	Example tasks: **Music Transcription** **Tempo Estimation**

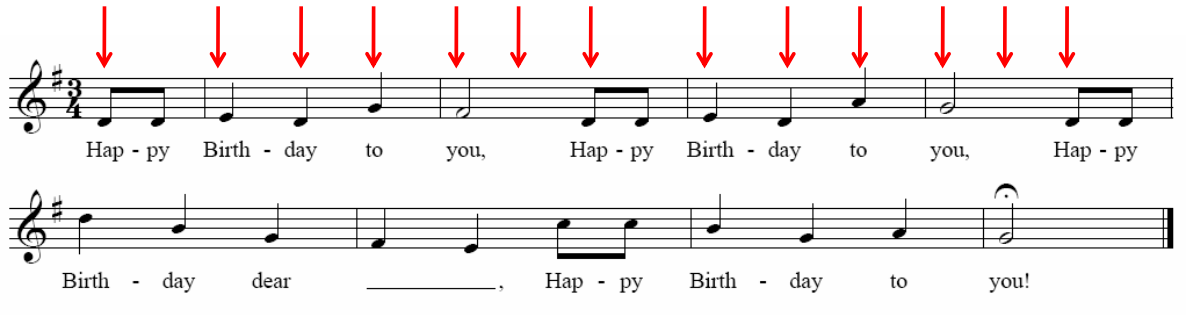
Tempo Estimation

Measure



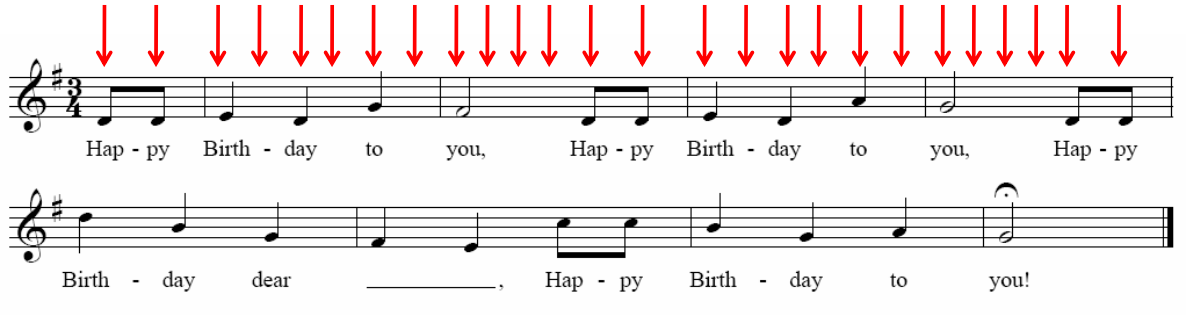
Tempo Estimation

Tactus (beat)



Tempo Estimation

Tatum (temporal atom)



Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: ???

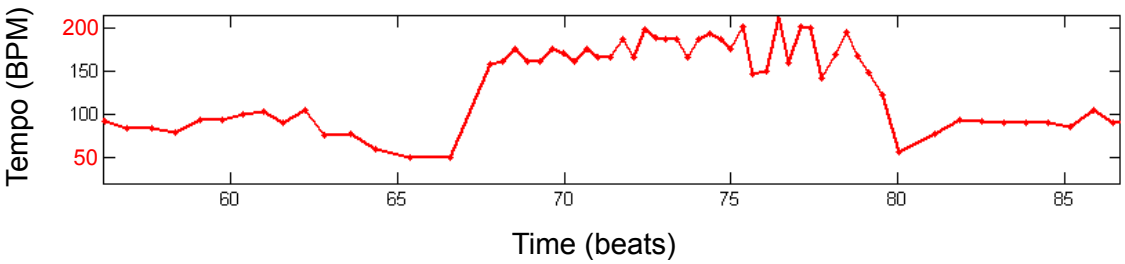
Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: 50-200 BPM

Tempo curve

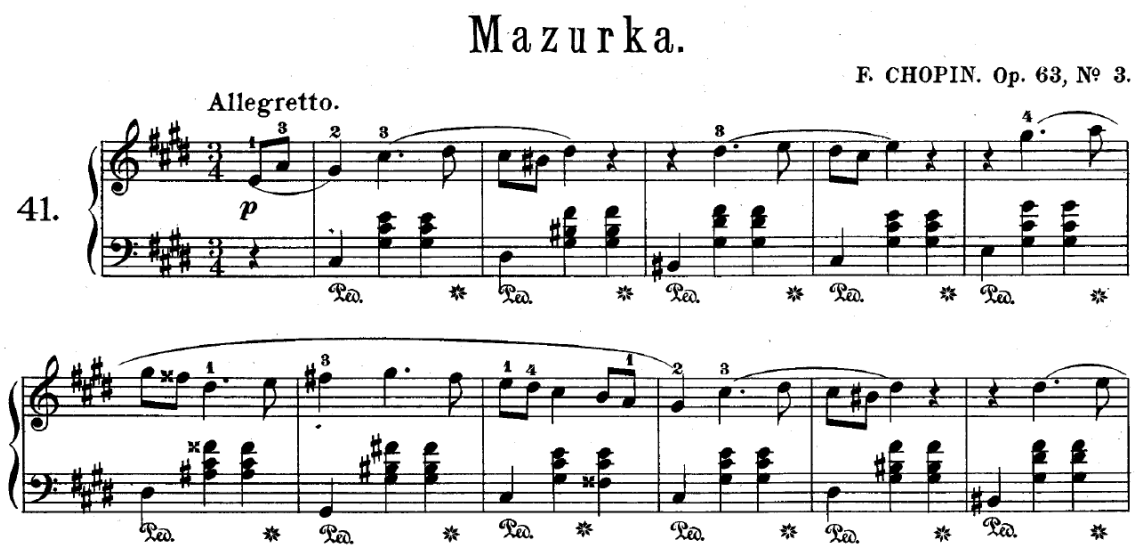


Tempo Estimation

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

Why is Music Processing Challenging?

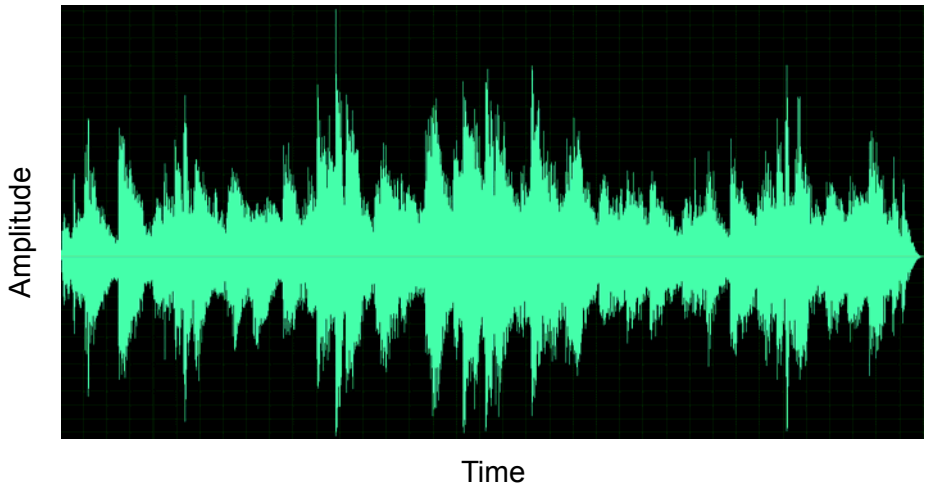
Example: Chopin, Mazurka Op. 63 No. 3 ▶



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

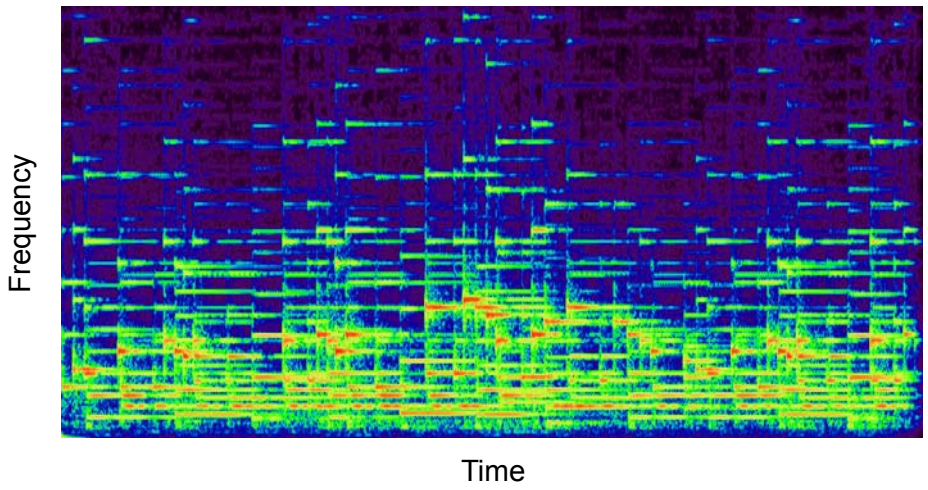
- Waveform



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram



Why is Music Processing Challenging?

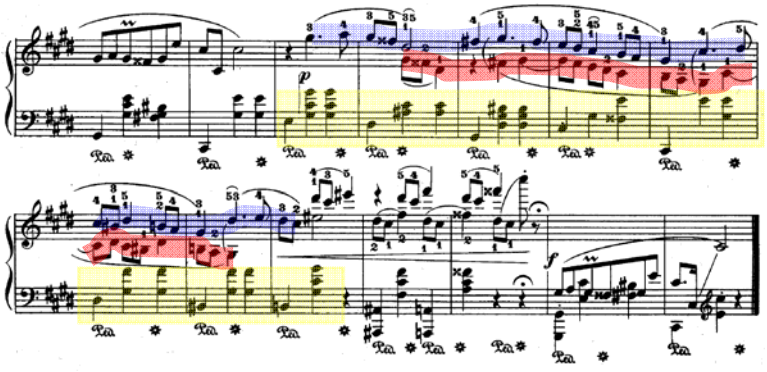
Example: Chopin, Mazurka Op. 63 No. 3

- 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



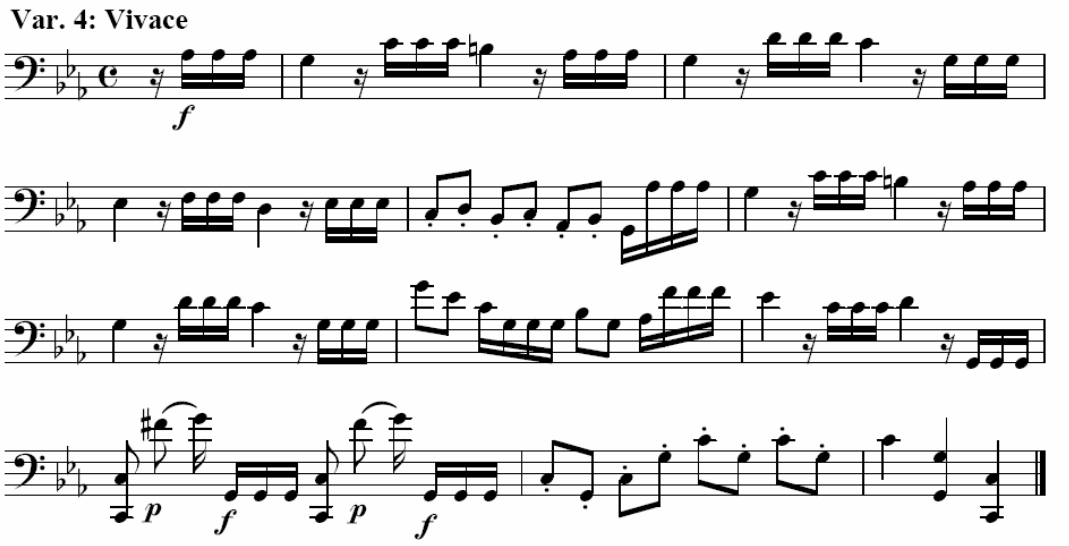
- Polyphony

Main Melody

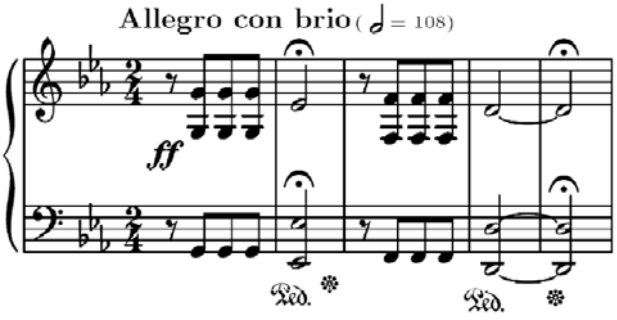
Additional melody line

Accompaniment

Motivic Similarity

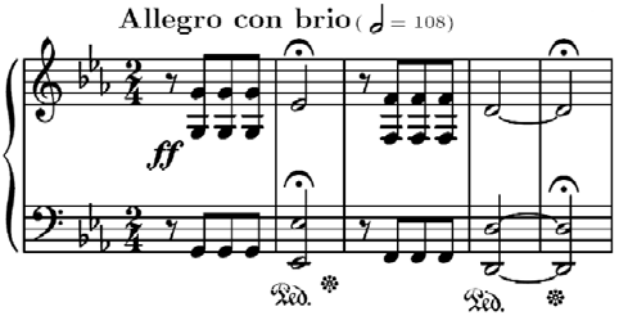


Motivic Similarity



Beethoven's Fifth (1st Mov.)

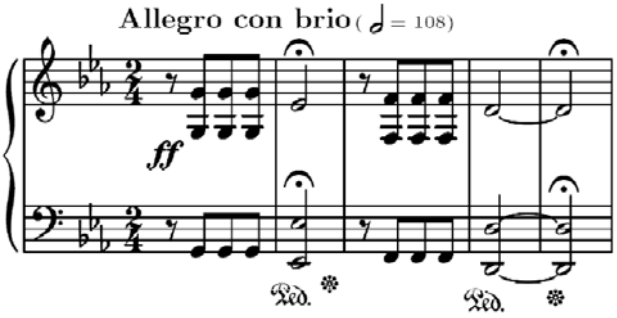
Motivic Similarity



Beethoven's Fifth (1st Mov.)

Beethoven's Fifth (3rd Mov.)

Motivic Similarity

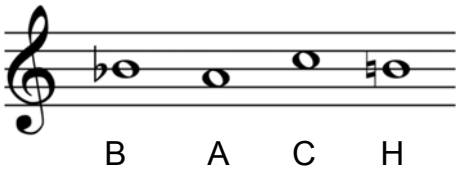


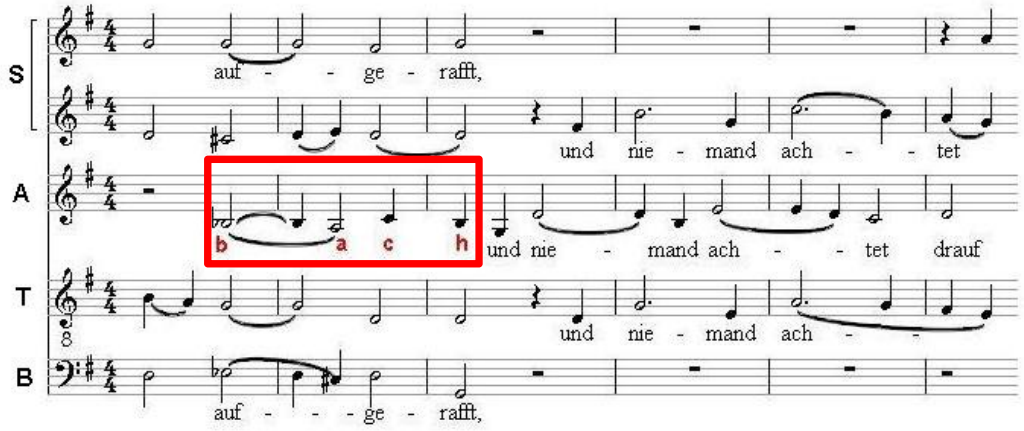
Beethoven's Fifth (1st Mov.)

Beethoven's Fifth (3rd Mov.)

Beethoven's Appassionata

Motivic Similarity





Thanks

- Sebastian Ewert (Bonn University)
- Peter Grosche (Saarland University)
- Verena Konz (Saarland University)
- Christian Fremerey (Bonn University)
- David Damm (Bonn University)
- Verena Thomas (Bonn University)
- Michael Clausen (Bonn University)
- Frank Kurth (Fraunhofer-FKIE, Wachtberg)
- Jonathan Driedger (University of Erlangen-Nuremberg)
- Thomas Prätzlich (University of Erlangen-Nuremberg)
- Nanzhu Jiang (University of Erlangen-Nuremberg)

Selected Publications (Music Processing)

- M. Müller, P.W. Ellis, A. Klapuri, G. Richard (2011):
  Signal Processing for Music Analysis.
  IEEE Journal of Selected Topics in Signal Processing, Vol. 5, No. 6, pp. 1088-1110.

- P. Grosche and M. Müller (2011):
  Extracting Predominant Local Pulse Information from Music Recordings.
  IEEE Trans. on Audio, Speech & Language Processing, Vol. 19, No. 6, pp. 1688-1701.

- M. Müller, M. Clausen, V. Konz, S. Ewert, C. Fremerey (2010):
  A Multimodal Way of Experiencing and Exploring Music.
  Interdisciplinary Science Reviews (ISR), Vol. 35, No. 2.

- M. Müller and S. Ewert (2010):
  Towards Timbre-Invariant Audio Features for Harmony-Based Music.
  IEEE Trans. on Audio, Speech & Language Processing, Vol. 18, No. 3, pp. 649-662.

- F. Kurth, M. Müller (2008):
  Efficient Index-Based Audio Matching.
  IEEE Trans. Audio, Speech & Language Processing, Vol. 16, No. 2, 382-395.

- M. Müller (2007):
  Information Retrieval for Music and Motion.
  Monograph, Springer, 318 pages