Advanced Course Computer Science

Music Processing

Summer Term 2009

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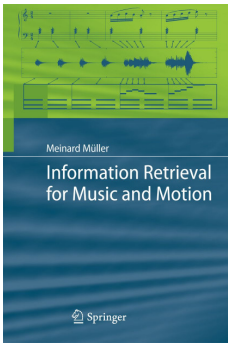
Beethoven, Bach, and Billions of Bytes

New Alliances between Music and Computer Science

Bonn University

- Prof. Dr. Michael Clausen
- PD Dr. Frank Kurth
- Dipl.-Inform. Christian Fremerey
- Dipl.-Inform. David Damm
- Dipl.-Inform. Sebastian Ewert

Habilitation



Bonn University

- Prof. Dr. Michael Clausen
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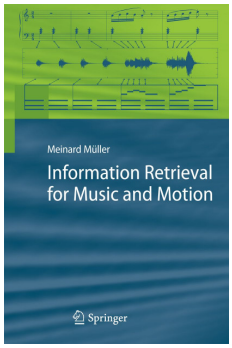
- Dipl.-Inform. David Damm
- Dipl.-Inform. Sebastian Ewert

Dec. 2007

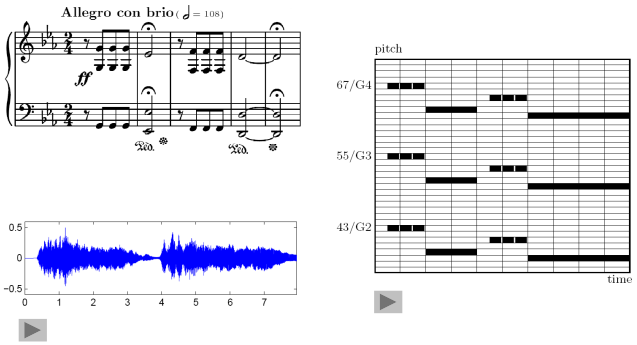
PhD students

- Dipl.-Inform. Andreas Baak (DFG)
- Dipl.-Math. Verena Konz (MMCI)
- Dipl.-Ing. Peter Grosche (MMCI)
- Dipl.-Inform. Thomas Helten (DFG)

Habilitation



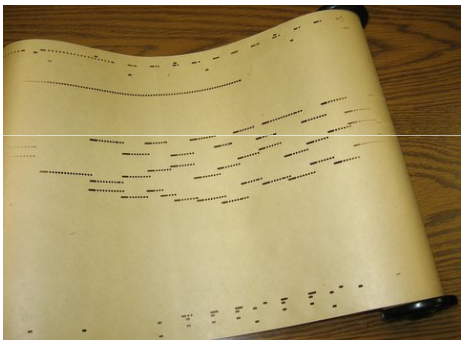
Music Data



Music Information Retrieval (MIR)

- Detection of semantic relations, e.g., harmonic, rhythmic, or motivic similarity
- Extraction of musical entities such as note events, instrumentation, or musical form
- Tools and methods for multimodal search, navigation, and interaction

Piano Roll Representation



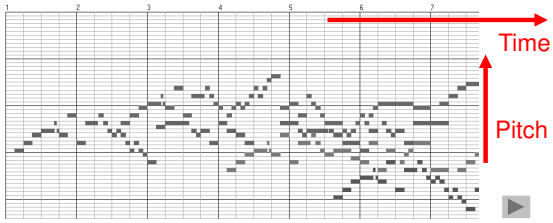
Piano Roll Representation

Player Piano (1900)

Piano Roll Representation (MIDI)

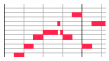
J.S. Bach, C-Major Fuge

(Well Tempered Piano, BWV 846)

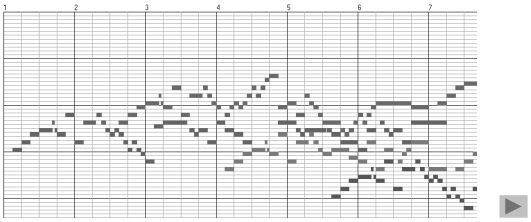


Piano Roll Representation (MIDI)

Query:



Goal: Find all occurrences of the query



Piano Roll Representation (MIDI)

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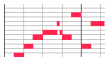
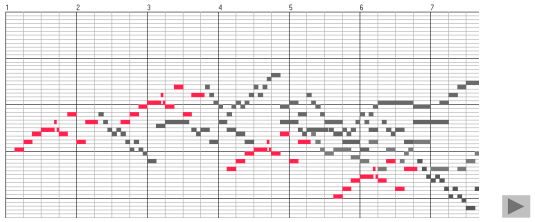


Goal: Find all occurrences of the query

Matches:



Audio Data

Various interpretations – Beethoven's Fifth

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

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

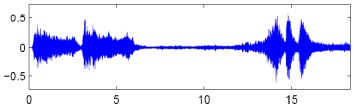
Memory Requirements

12.000 MIDI files	<	350 MB
One audio CD	≈	650 MB
Two audio CDs	>	1 **Billion Bytes**
1000 audio CDs	≈	**Billions of Bytes**

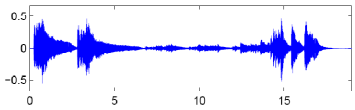
Music Synchronization: Audio-Audio

Beethoven's Fifth

Karajan



Scherbakov

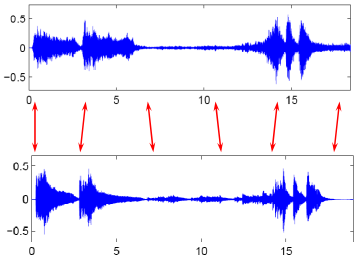


Music Synchronization: Audio-Audio

Beethoven's Fifth

Karajan

Scherbakov

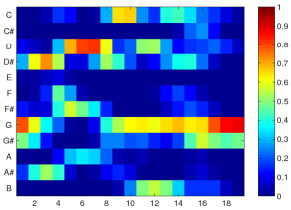


Synchronization: Karajan → Scherbakov

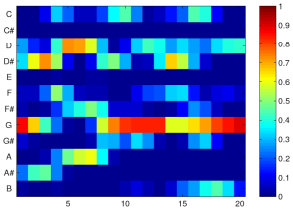
Music Synchronization: Audio-Audio

Feature extraction: chroma features

Karajan

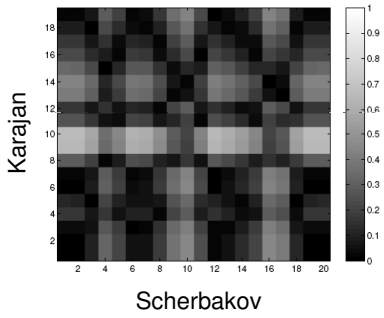


Scherbakov



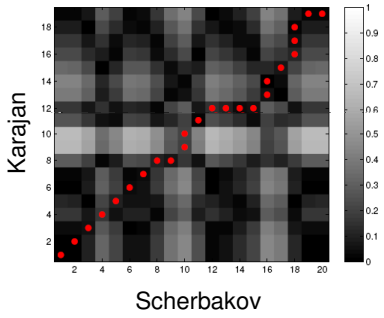
Music Synchronization: Audio-Audio

Cost matrix

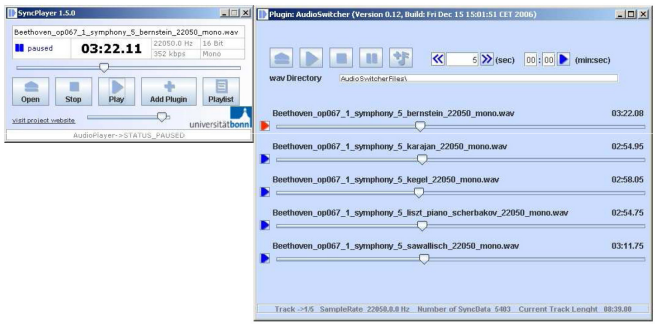


Music Synchronization: Audio-Audio

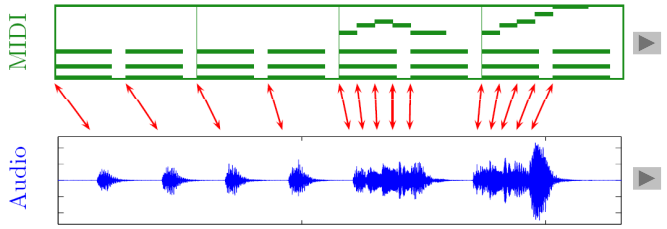
Cost-minimizing warping path



System: SyncPlayer/AudioSwitcher



Music Synchronization: MIDI-Audio



Music Synchronization: MIDI-Audio

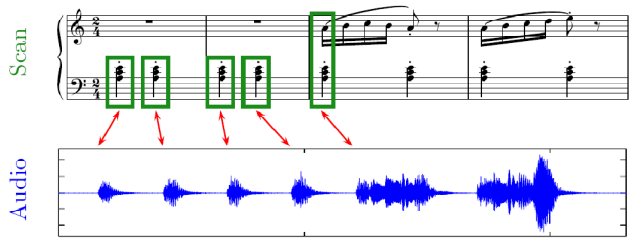
MIDI = meta data

Automated annotation

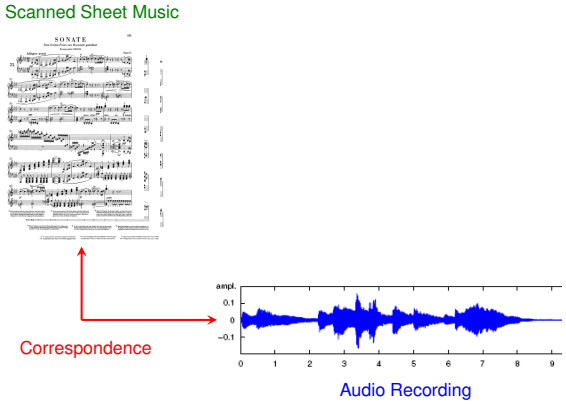
Audio recording

Sonification of annotations

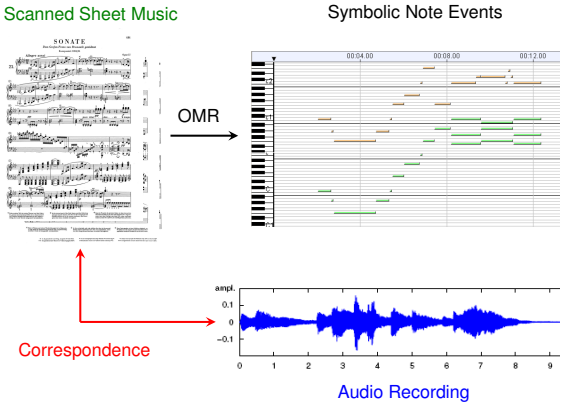
Music Synchronization: Scan-Audio



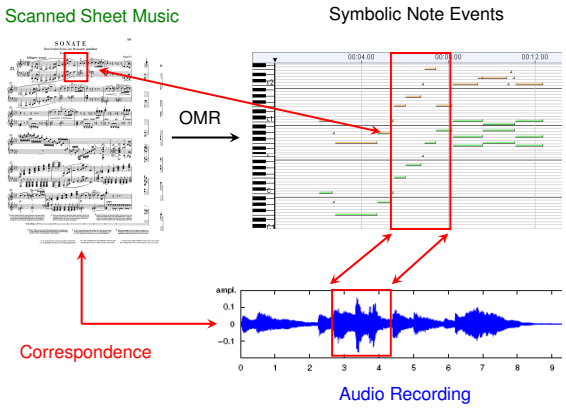
Music Synchronization: Scan-Audio



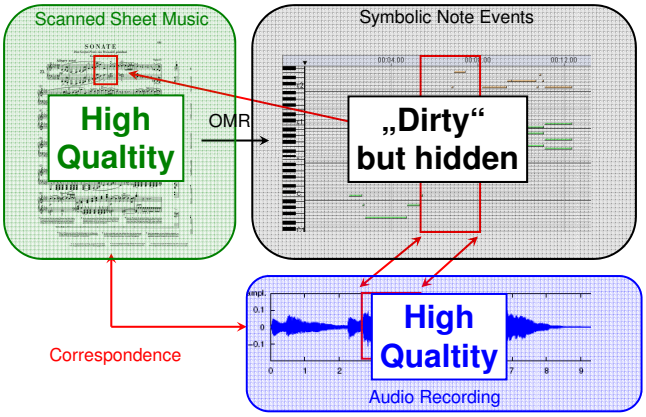
Music Synchronization: Scan-Audio



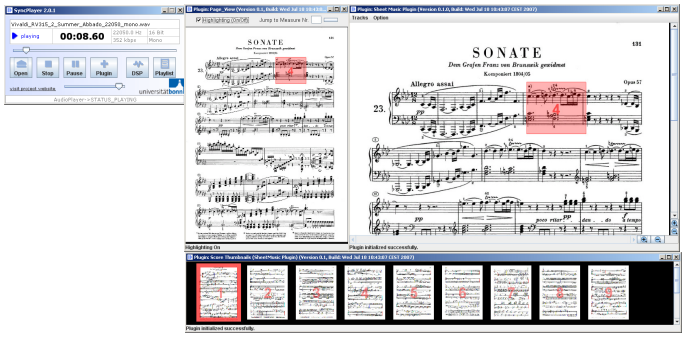
Music Synchronization: Scan-Audio



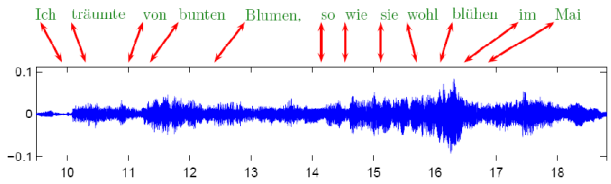
Music Synchronization: Scan-Audio



System: SyncPlayer/SheetMusic

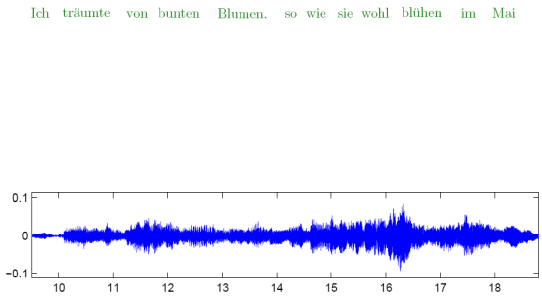


Music Synchronization: Lyrics-Audio

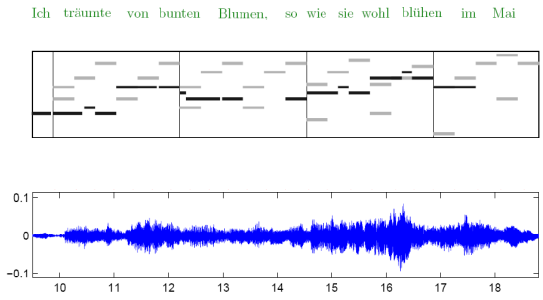


Difficult!

Music Synchronization: Lyrics-Audio

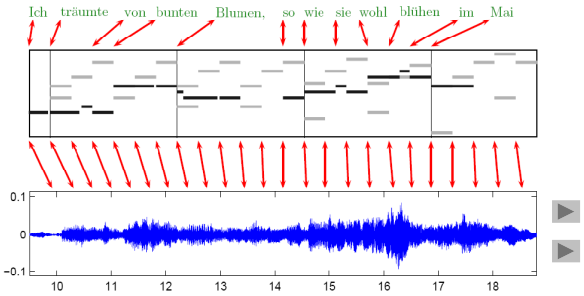


Music Synchronization: Lyrics-Audio



Music Synchronization: Lyrics-Audio

Lyrics-Audio → Lyrics-MIDI + MIDI-Audio

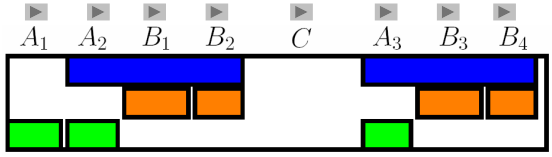


Audio Structure Analysis

Given: CD recording

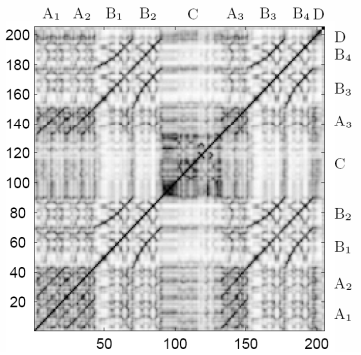
Goal: Automatic extraction of the repetitive structure (or of the musical form)

Example: Brahms Hungarian Dance No. 5 (Ormandy)



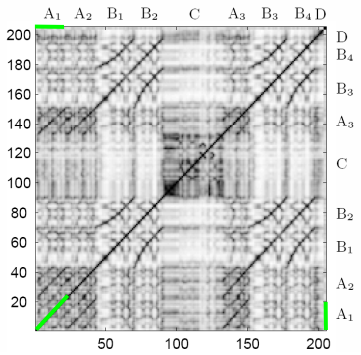
Audio Structure Analysis

Self-similarity matrix



Audio Structure Analysis

Self-similarity matrix



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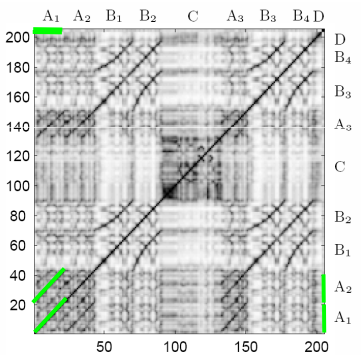

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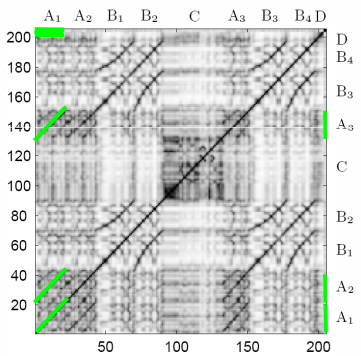
Self-similarity matrix



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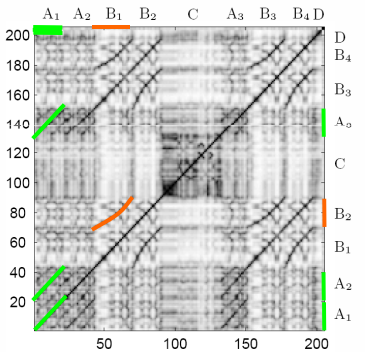

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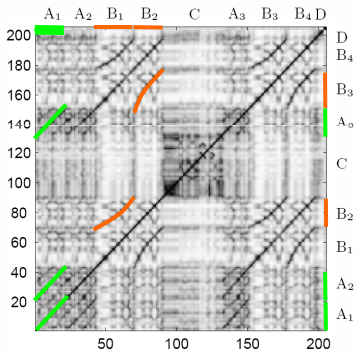

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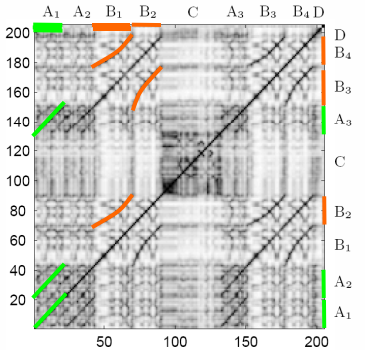

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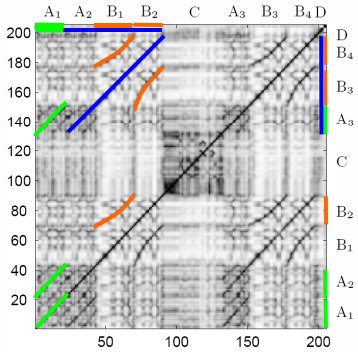

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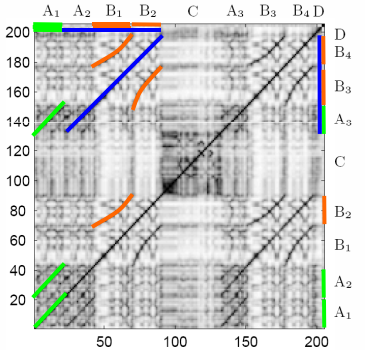
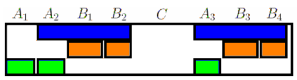


Similarity cluster



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

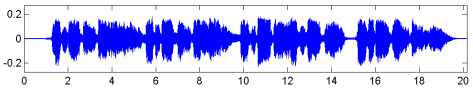
Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?
Identify despite of differences	Identify the differences
Example tasks: **Audio Matching** **Cover Song Identification**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

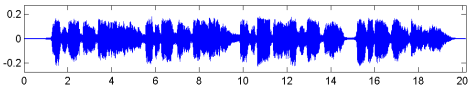
Performance Analysis

Performance:

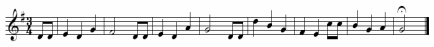


Performance Analysis

Performance:

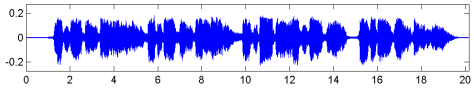


Score (reference):



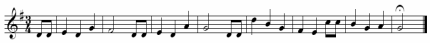
Performance Analysis

Performance:



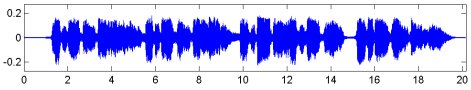
Strategy: Compute score-audio synchronization and derive tempo curve

Score (reference):

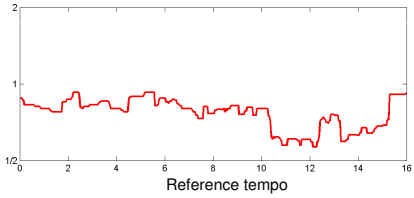


Performance Analysis

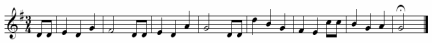
Performance:



Tempo curve:

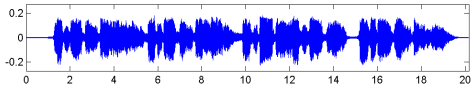


Score (reference):



Performance Analysis

Performance:



What can be done if no reference is available?

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

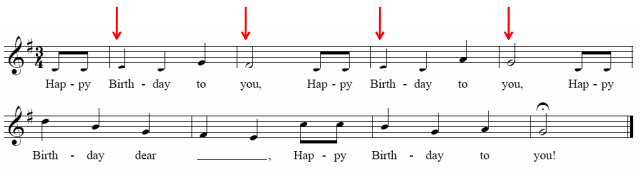
Relative	**Absolute**
Given: Several versions	Given: One version
Comparison of extracted parameters	Direct interpretation of extracted parameters
Extraction errors have often no consequence on final result	Extraction errors immediately become evident

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**

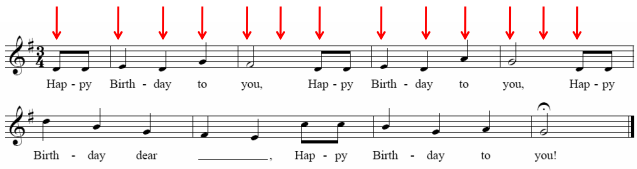
Tempo Estimation

Measure



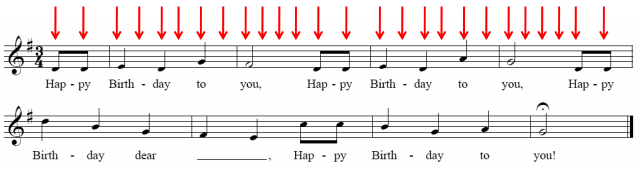
Tempo Estimation

Tactus (beat)



Tempo Estimation

Tatum (temporal atom)

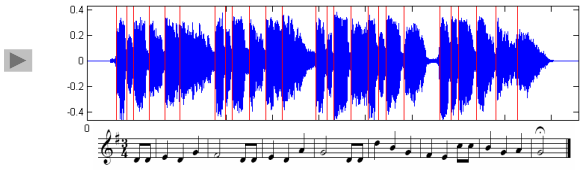


Tempo Estimation

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

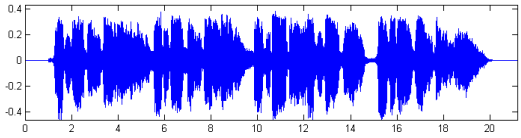
Tempo Estimation

Performance



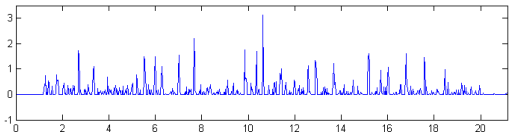
Tempo Estimation

Performance



Tempo Estimation

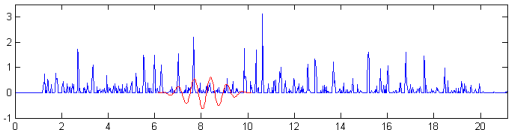
Novelty Curve



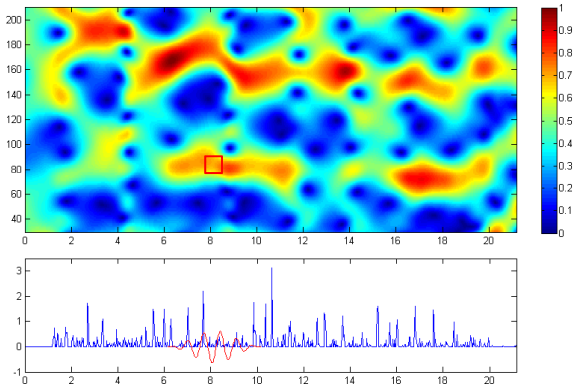
Tempo Estimation

Novelty Curve

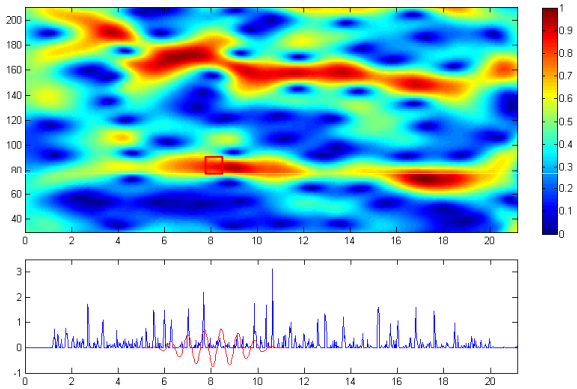
Periodicity Analysis



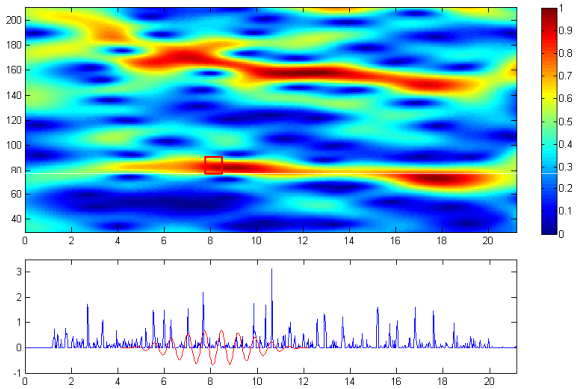
Tempo Estimation: Tempogram



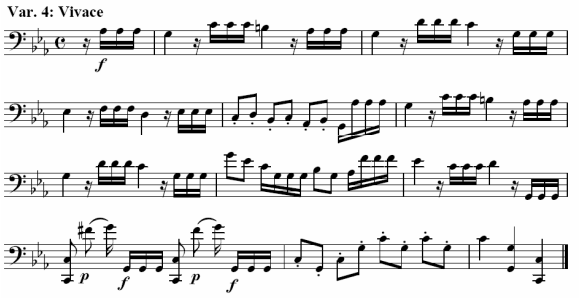
Tempo Estimation: Tempogram



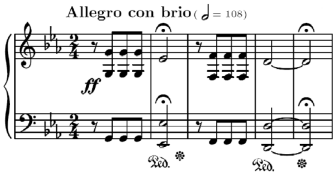
Tempo Estimation: Tempogram



Motivic Similarity

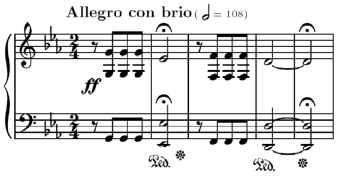


Motivic Similarity



Beethoven‘s Fifth (1st Mov.)

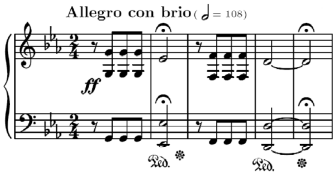
Motivic Similarity



Beethoven‘s Fifth (1st Mov.)

Beethoven‘s Fifth (3rd Mov.)

Motivic Similarity



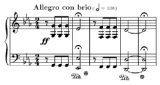
Beethoven‘s Fifth (1st Mov.)

Beethoven‘s Fifth (3rd Mov.)

Beethoven‘s Appassionata

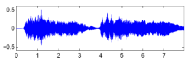
Multimodal Computing and Interaction

Sheet Music (Image)



MIDI

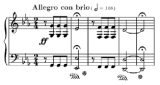
CD / MP3 (Audio)



Music

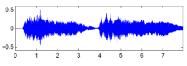
Multimodal Computing and Interaction

Sheet Music (Image)



MIDI

CD / MP3 (Audio)



MusicXML (Text)

Music

Singing / Voice (Audio)

Music Literature (Text)

Music Film (Video)

Dance / Motion (Mocap)

Collaborations (Music Processing)

- RG Michael Clausen (Bonn University) → Music Processing
- Hochschule der Musik Saar (HDM) → Music Education
- RG Björn Schuller (TU München) → Music & Speech
- RG Gerhard Weikum (MPI Saarbrücken) → Music & Text
- Utrecht University → Folk Songs
- Goldsmiths College/ London → Beatles Songs