INTERNATIONAL AUDIO LABORATORIES ERLANGEN

Beethoven, Bach und Billionen Bytes

Automatisierte Analyse von Musik und Klängen

Meinard Müller

Lehrerfortbildung in Informatik
Dagstuhl, Dezember 2014

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

International Audio Laboratories Erlangen

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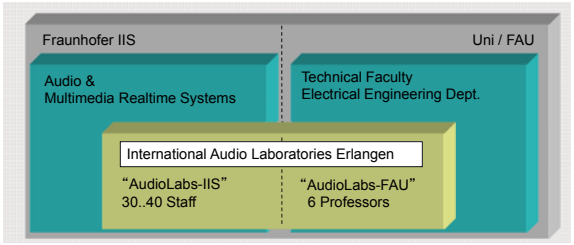

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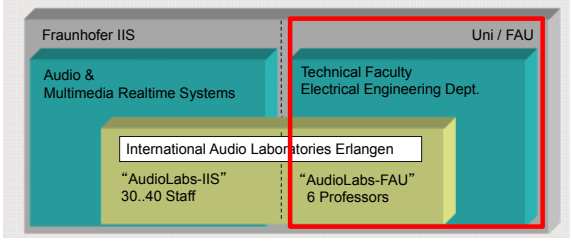

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Audio

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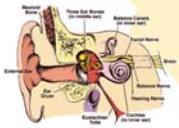
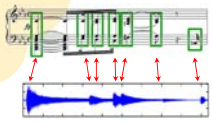
Audio Coding

3D Audio

Audio



Psychoacoustics

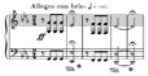


Music Processing

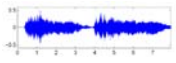
Music

Music Processing

Sheet Music (Image)



CD / MP3 (Audio)



MusicXML (Text)

Dance / Motion (Mocap)

Music

MIDI

Singing / Voice (Audio)

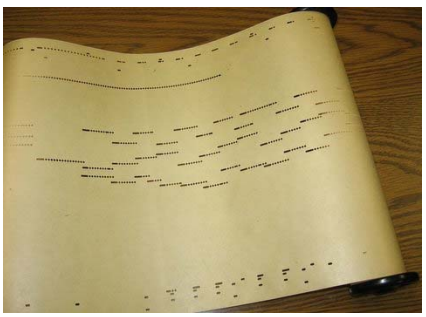
Music Film (Video)

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

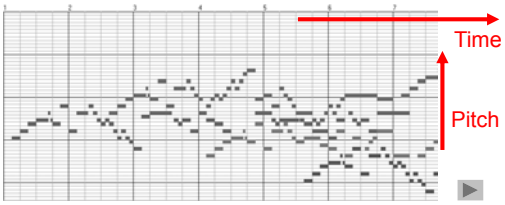


Player Piano (1900)

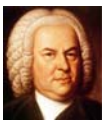
Piano Roll Representation (MIDI)

J.S. Bach, C-Major Fuge

(Well Tempered Piano, BWV 846)

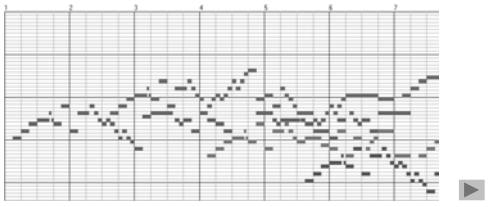


Piano Roll Representation (MIDI)



Query:

Goal: Find all occurrences of the query

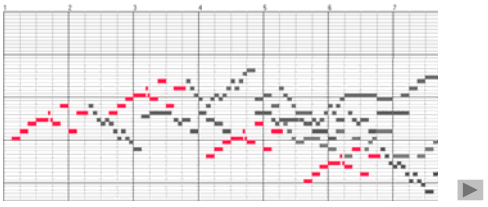


Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

Matches:



Audio Data

Various interpretations – Beethoven's Fifth

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

Audio Data (Memory Requirements)

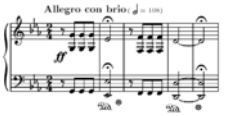
1 Bit	=	1: on 0: off
1 Byte	=	8 Bits
1 Kilobyte (KB)	=	1 Thousand Bytes
1 Megabyte (MB)	=	1 Million Bytes
1 Gigabyte (GB)	=	1 **Billion Bytes**
1 Terabyte (TB)	=	1000 Billion Bytes

Audio Data (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**

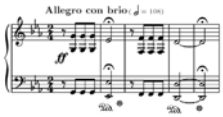
Music Synchronization: Audio-Audio

Beethoven's Fifth

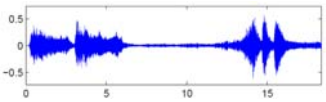


Music Synchronization: Audio-Audio

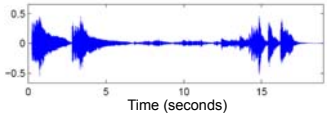
Beethoven's Fifth



Orchester (Karajan)

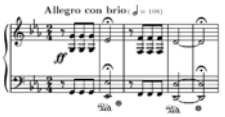


Piano (Scherbakov)



Music Synchronization: Audio-Audio

Beethoven's Fifth



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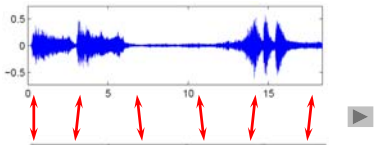

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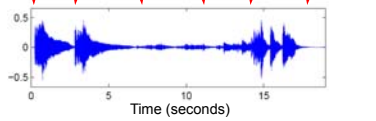
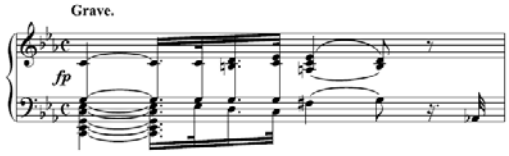


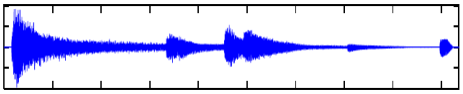
Application: Interpretation Switcher

Music Synchronization: Image-Audio

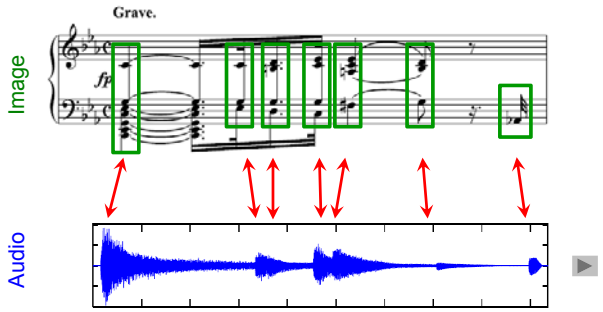
Image



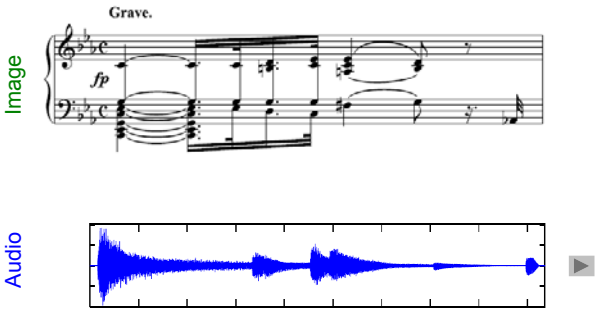
Audio



Music Synchronization: Image-Audio

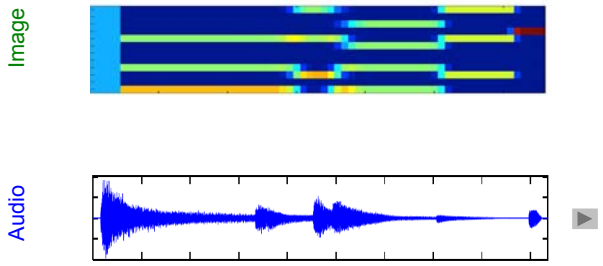


How to make the data comparable?



How to make the data comparable?

Image Processing: Optical Music Recognition



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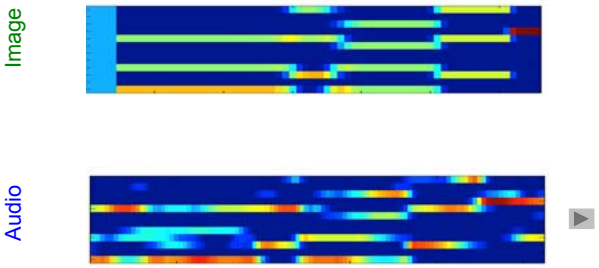
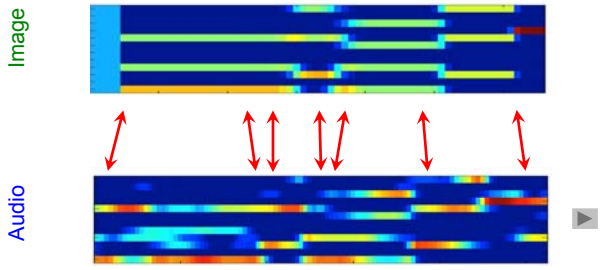


Audio Processing: Fourier Analyse

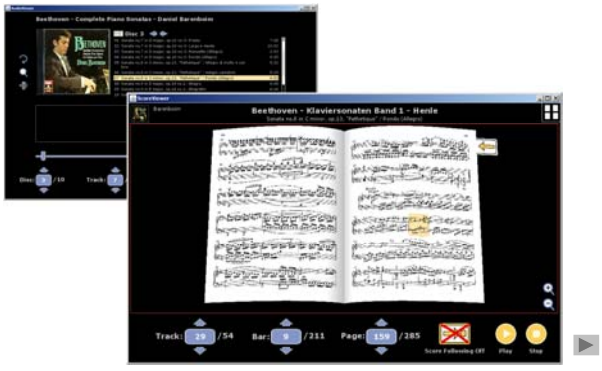
How to make the data comparable?

Image Processing: Optical Music Recognition



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?

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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

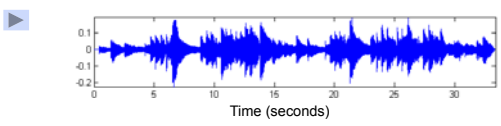
Music Processing

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

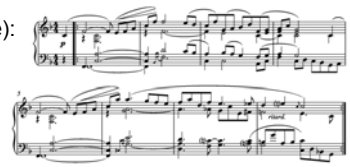
Performance:



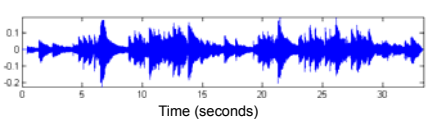
Performance Analysis

Schumann: Träumerei

Score (reference):



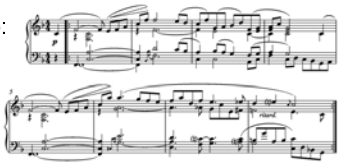
Performance:



Performance Analysis

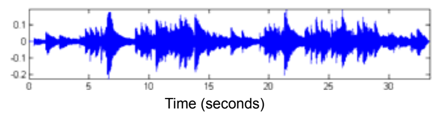
Schumann: Träumerei

Score (reference):



Strategy: Compute score-audio synchronization and derive tempo curve

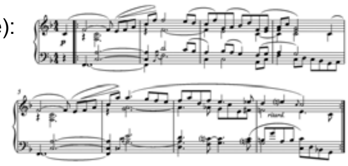
Performance:



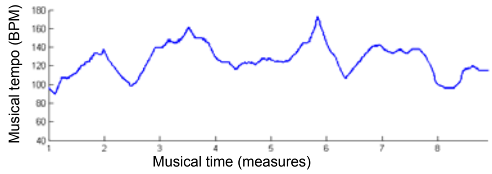
Performance Analysis

Schumann: Träumerei

Score (reference):



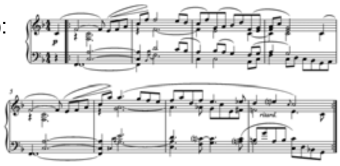
Tempo Curve:



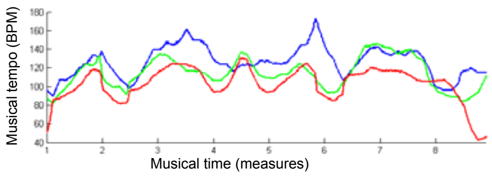
Performance Analysis

Schumann: Träumerei

Score (reference):



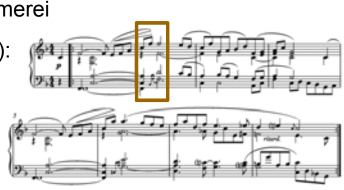
Tempo Curves:



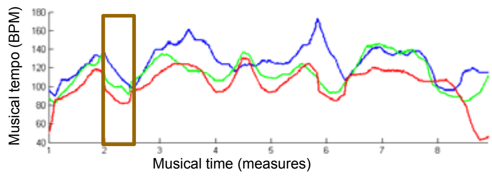
Performance Analysis

Schumann: Träumerei

Score (reference):



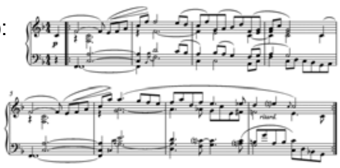
Tempo Curves:



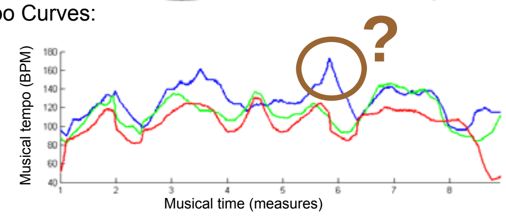
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:

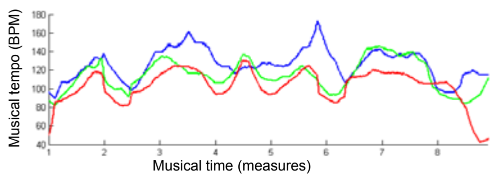


Performance Analysis

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

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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**

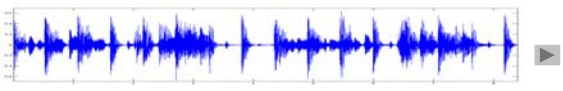
Tempo Estimation and Beat Tracking

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

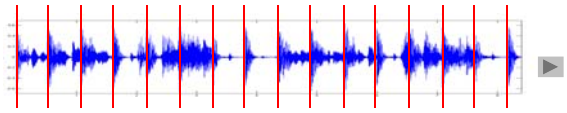


Time (seconds)

Tempo Estimation and Beat Tracking

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

Example: Queen – Another One Bites The Dust

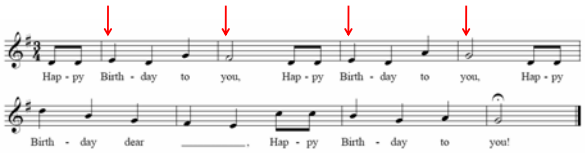


Time (seconds)

Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

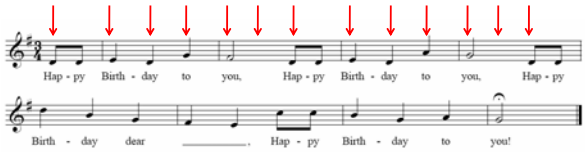
Pulse level: **Measure**



Tempo Estimation and Beat Tracking

Example: Happy Birthday to you

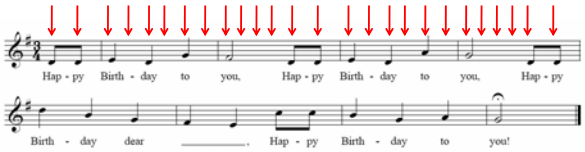
Pulse level: **Tactus (beat)**



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: ???

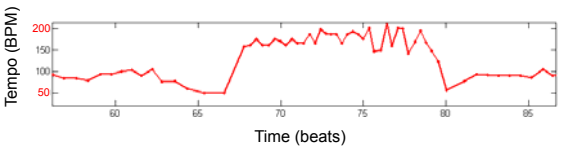
Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: 50-200 BPM

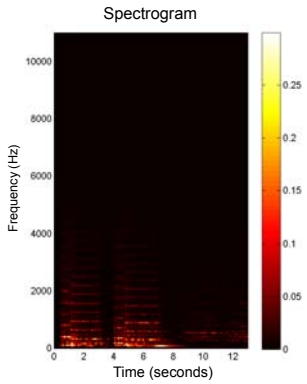
Tempo curve



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)

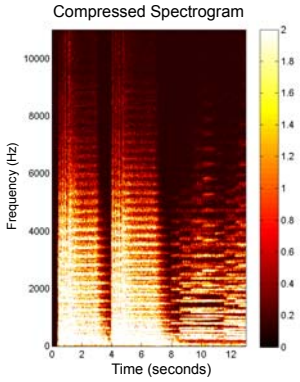
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram

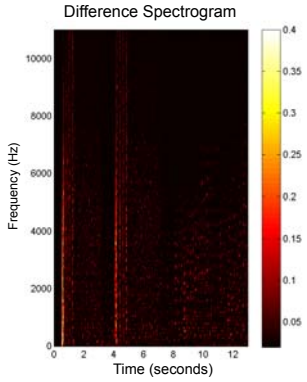
Tempo Estimation and Beat Tracking



Steps:

1. Spectrogram
2. Log Compression

Tempo Estimation and Beat Tracking



Steps:

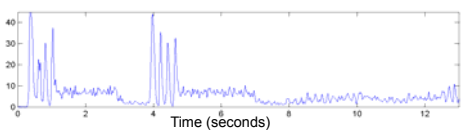
1. Spectrogram
2. Log Compression
3. Differentiation

Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve

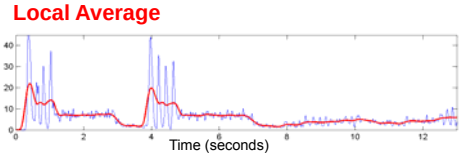


Tempo Estimation and Beat Tracking

Steps:

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

Novelty Curve
Local Average

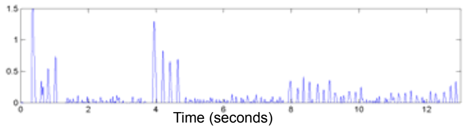


Tempo Estimation and Beat Tracking

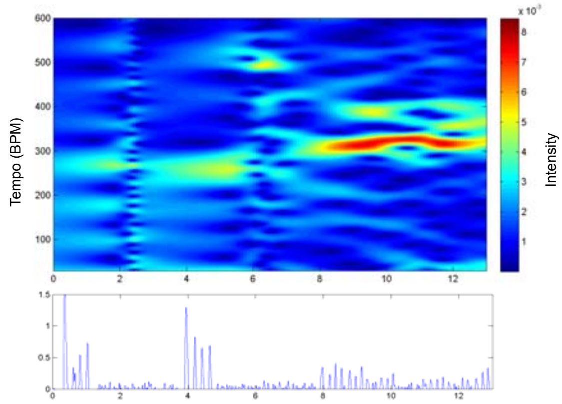
Steps:

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

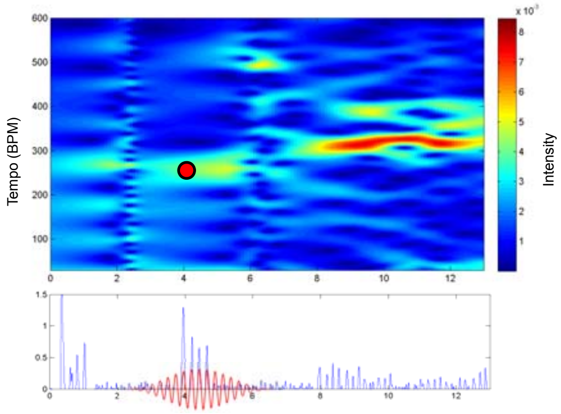
Novelty Curve



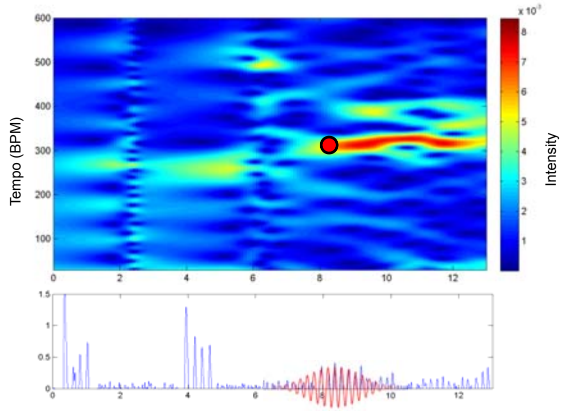
Tempo Estimation and Beat Tracking



Tempo Estimation and Beat Tracking



Tempo Estimation and Beat Tracking



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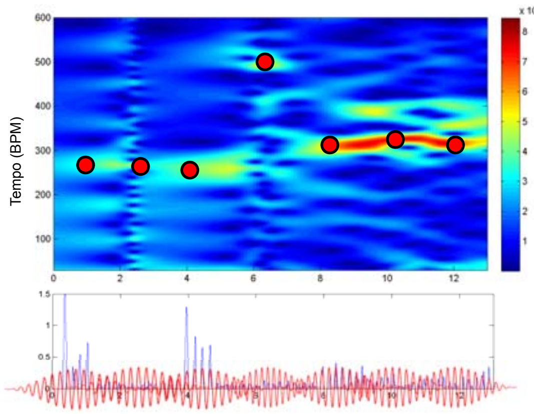
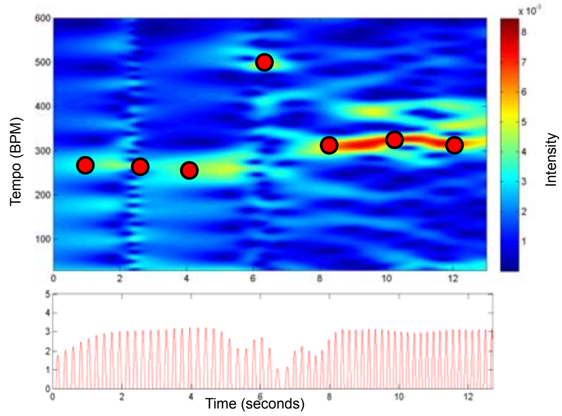
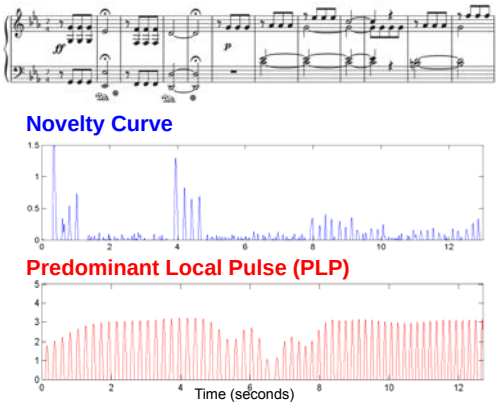


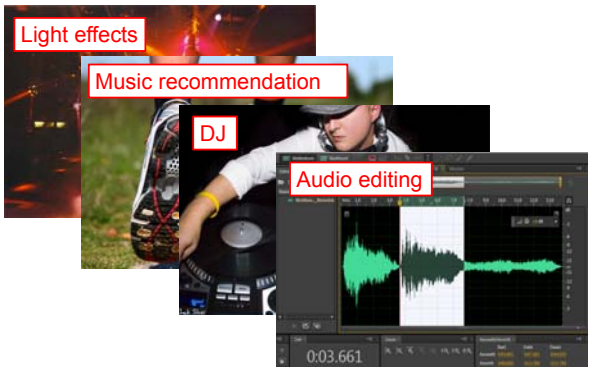
Tempo Estimation and Beat Tracking



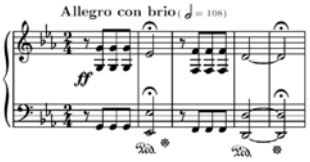
Tempo Estimation and Beat Tracking



Tempo Estimation and Beat Tracking

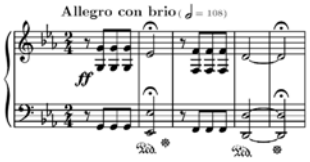


Motivic Similarity



Beethoven's Fifth (1st Mov.)

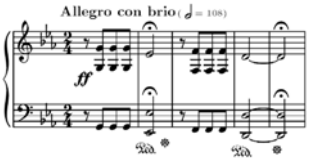
Motivic Similarity



Beethoven's Fifth (1st Mov.)

Beethoven's Fifth (3rd Mov.)

Motivic Similarity

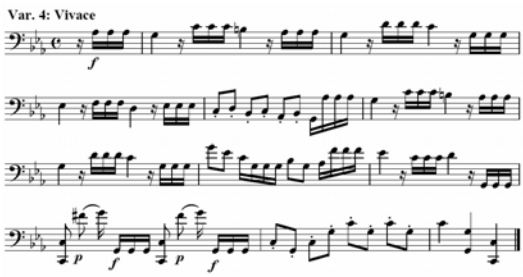


Beethoven's Fifth (1st Mov.)

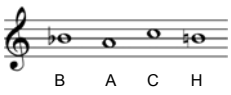
Beethoven's Fifth (3rd Mov.)

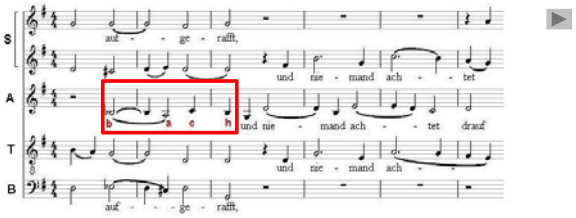
Beethoven's Appassionata

Motivic Similarity



Motivic Similarity





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- Verena Konz (Saarland University)
- Joachim Veit (Hochschule für Musik Detmold)
- Rainer Kleinertz (Saarland University)

Book Project

A First Course on Music Processing

Textbook (approx. 500 pages)

1. Music Representations
2. Fourier Analysis of Signals
3. Music Synchronization
4. Music Structure Analysis
5. Chord Recogntion
6. Tempo and Beat Tracking
7. Content-based Audio Retrieval
8. Informed Audio Decomposition

Springer

To appear (plan):
End of 2015

Project & Cooperations

- DFG-Project Harmonic Analysis Wagner
  Computergestützte Analyse harmonischer Strukturen
  Cooperation: Rainer Kleinertz
  2015-2018
- DFG-Project: SIAMUS: Source Separation
  Notentext-Informierte Audioparametrisierung von Musiksignalen
  2014-2017
- BMBF-Project: Freischütz Digital
  Freischütz Digital – Paradigmatische Umsetzung eines genuin digitalen Editionskonzepts
  Cooperation : Joachim Veit, Thomas Betzwieser, Gerd Szwillus
  2012-2015
- DFG-Project: METRUM: Structure Analysis
  Mehrschichtige Analyse und Strukturierung von Musiksignalen
  Cooperation: Michael Clausen
  Laufzeit: 2011-2015