Ringvorlesung

Perspektiven der Informatik

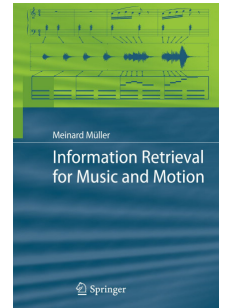**Wintersemester 2011/2012**

Meinard Müller

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meinard@mpi-inf.mpg.de
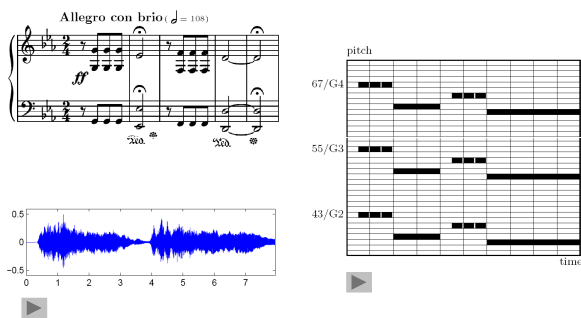
Automatisierte Musikverarbeitung

Priv.-Doz. Dr. Meinard Müller

- 2007 Habilitation, Bonn

- 2007 MPI Informatik, Saarland

- Cluster of Excellence

- 5 PhD Students

Music Data

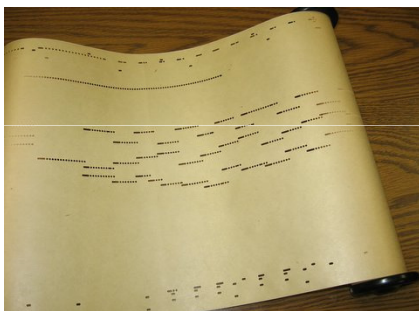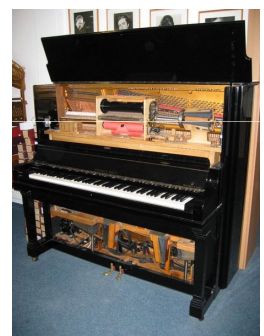## Music Information Retrieval (MIR)

- 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
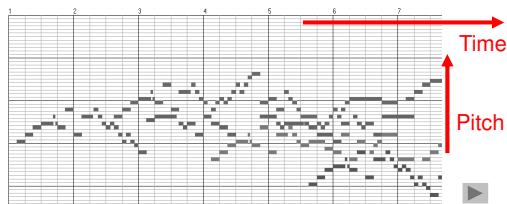

Piano Roll Representation

Piano Roll Representation

Player Piano (1900)

Piano Roll Representation (MIDI)
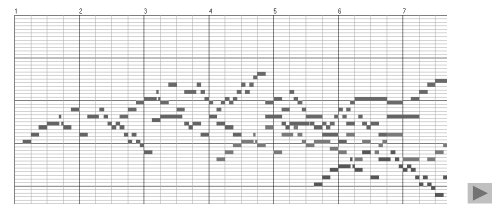
J.S. Bach, C-Major Fuge

(Well Tempered Piano, BWV 846)

Time

Pitch

Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

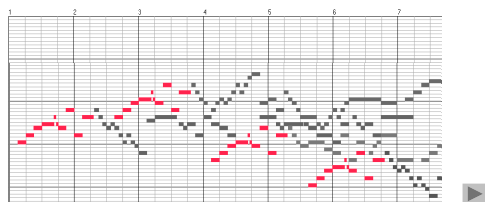## Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

Matches:

Audio Data

Beethoven's Fifth

Various interpretations

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

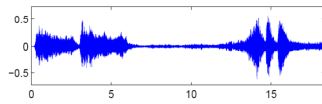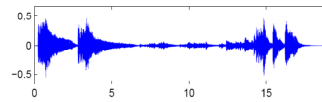|		
12.000 MIDI files	<	350 MB
One audio CD	≈	650 MB
Two audio CDs	>	1 **Billion Bytes**
1000 audio CDs	≈	**Billions of Bytes**

Music Synchronization: Audio-Audio
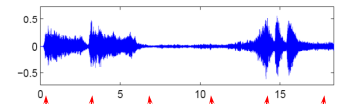
Beethoven's Fifth

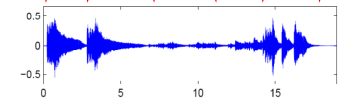Karajan ▶

Scherbakov ▶

Music Synchronization: Audio-Audio
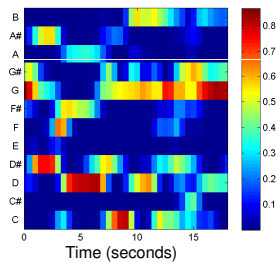
Beethoven's Fifth

Karajan ▶

Scherbakov ▶

Synchronization: Karajan → Scherbakov ▶
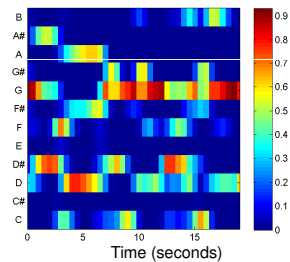
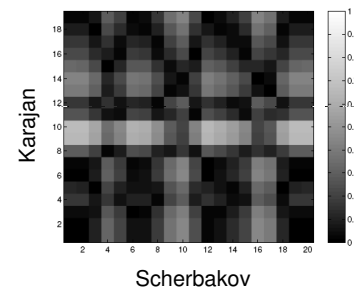## Music Synchronization: Audio-Audio

Feature extraction: chroma features
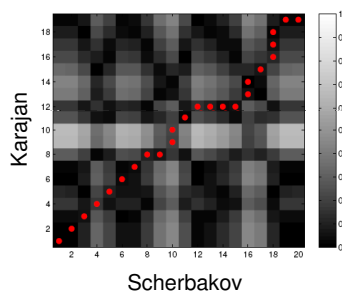
Karajan ▶   Scherbakov ▶

Music Synchronization: Audio-Audio
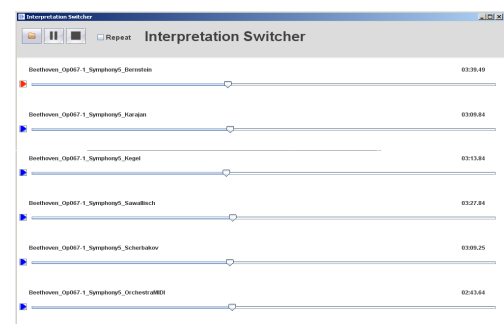
Cost matrix
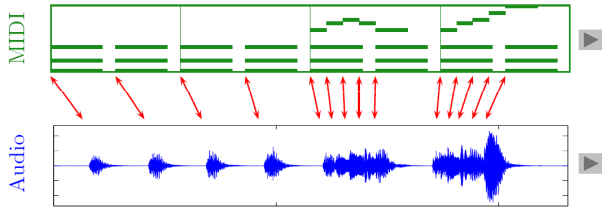
Music Synchronization: Audio-Audio

Cost-minimizing warping path

Application: Interpretation Switcher

Music Synchronization: MIDI-Audio

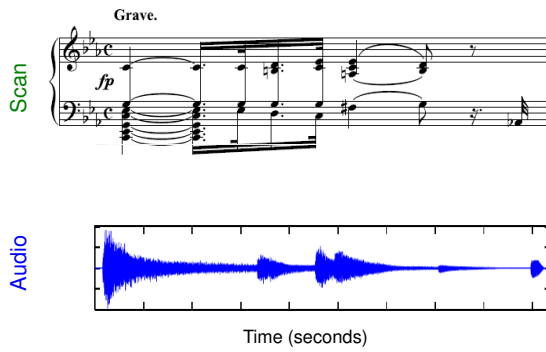## Music Synchronization: MIDI-Audio

MIDI = meta data

Automated annotation

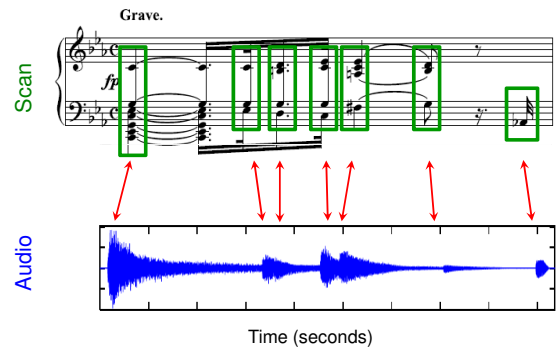Audio recording

Sonification of annotations
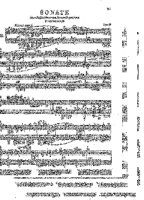
Music Synchronization: Scan-Audio
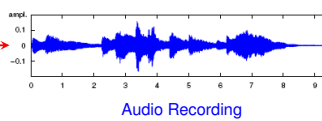

Music Synchronization: Scan-Audio

Music Synchronization: Scan-Audio

Music Synchronization: Scan-Audio

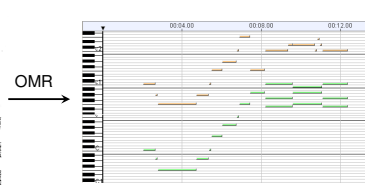## Music Synchronization: Scan-Audio

Scanned Sheet Music

OMR

Symbolic Note Events

Correspondence

Audio Recording

Music Synchronization: Scan-Audio

Scanned Sheet Music

High Qualtity

OMR

Symbolic Note Events

„Dirty" but hidden

Correspondence

High Qualtity
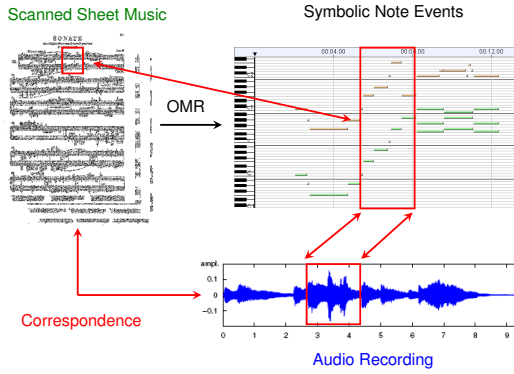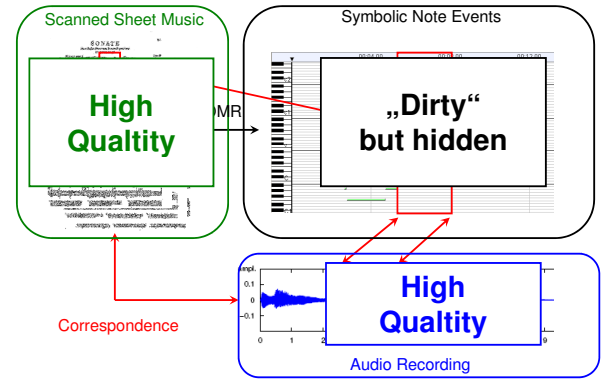
Audio Recording

Application: Score Viewer

Beethoven - Complete Piano Sonatas - Daniel Barenboim

Disc: 8 /10   Track: 7

Beethoven - Klaviersonaten Band 1 - Henle
Sonata no.8 in C minor, op.13, "Pathetique" / Rondo (Allegro)

Track: 29 /54   Bar: 9 /211   Page: 159 /285
Scores Following Off   Play   Stop
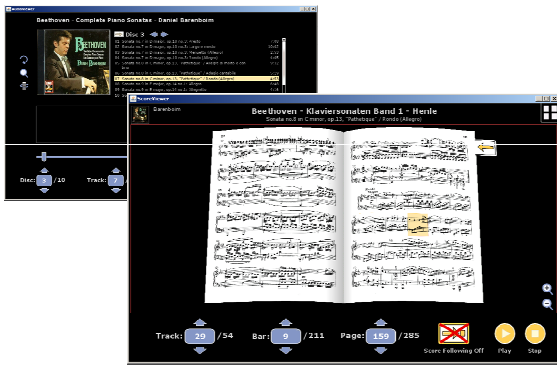
Audio Structure Analysis
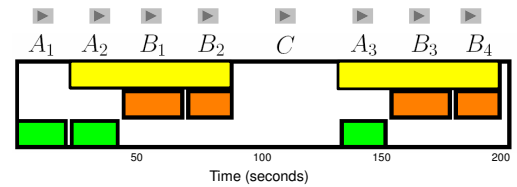
Given: CD recording

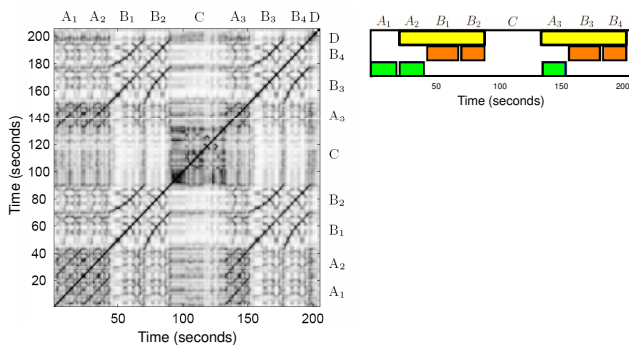**Goal:** Automatic extraction of the repetitive structure
(or of the musical form)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

A_1 A_2 B_1 B_2 C A_3 B_3 B_4

Time (seconds)

Basic Procedure

Self-similarity matrix

Time (seconds)

Time (seconds)

Similarity structure

Time (seconds)

Basic Procedure

Self-similarity matrix

Time (seconds)

Time (seconds)

Similarity structure

Time (seconds)
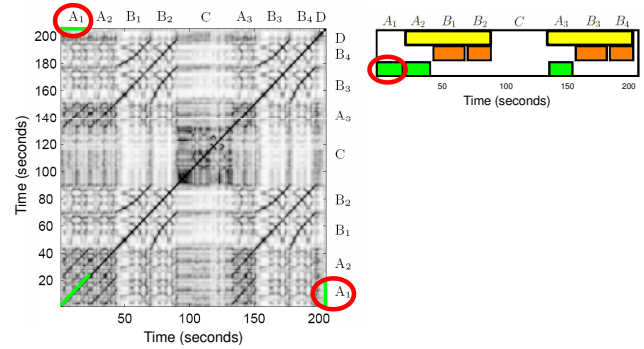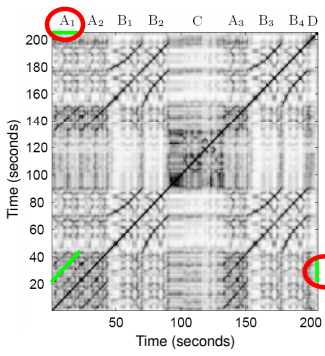
Basic Procedure

Self-similarity matrix

Similarity structure

Basic Procedure

Self-similarity matrix

Similarity structure

Basic Procedure

Self-similarity matrix

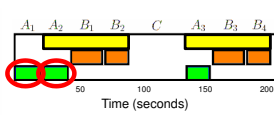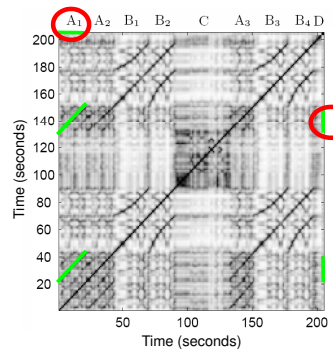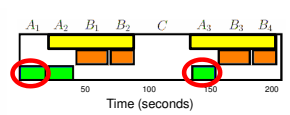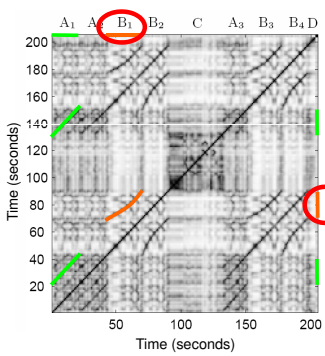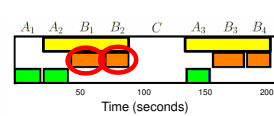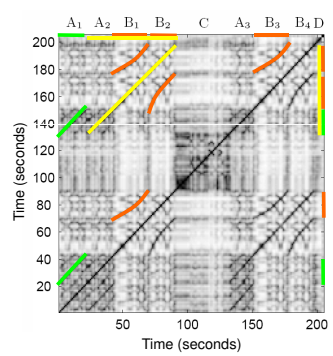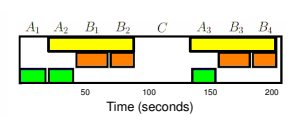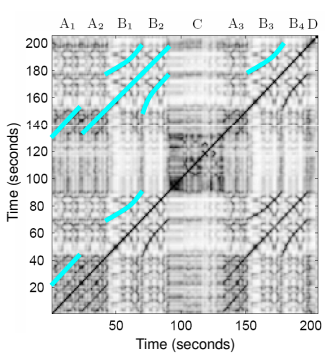Similarity structure

Basic Procedure
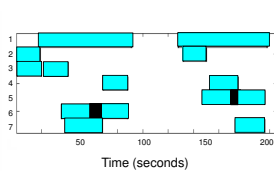
Self-similarity matrix

Similarity structure

Basic Procedure

Self-similarity matrix
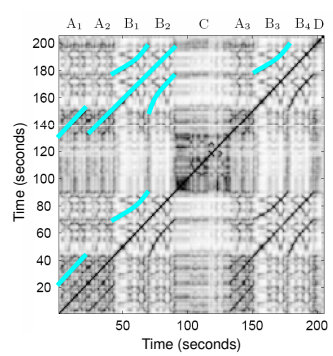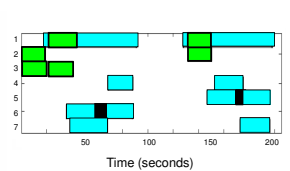
Path relations

Basic Procedure
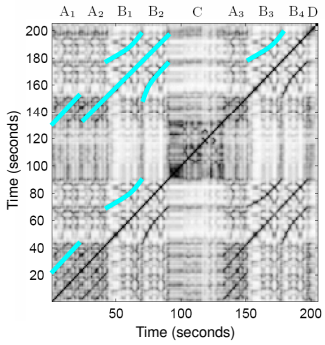
Self-similarity matrix

Path relations
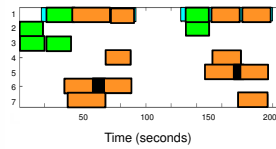
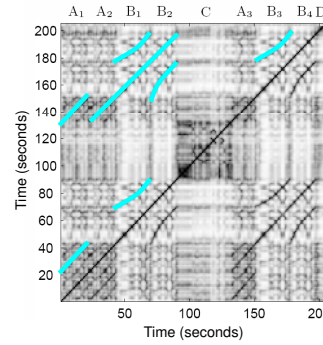Grouping / Transitivity

Basic Procedure

Self-similarity matrix

Path relations

Grouping / Transitivity

Basic Procedure

Self-similarity matrix

Path relations
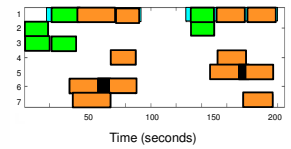
Grouping / Transitivity
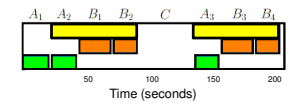
Music Processing

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:
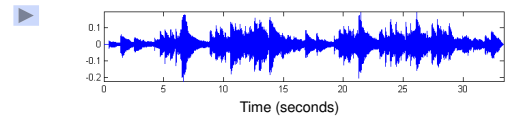
Performance Analysis: Tempo Curves

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):

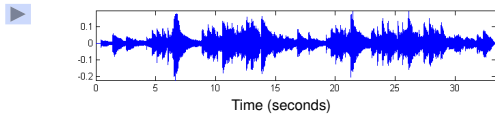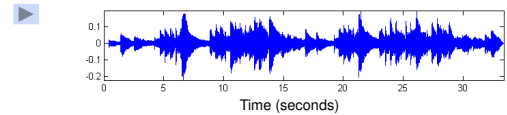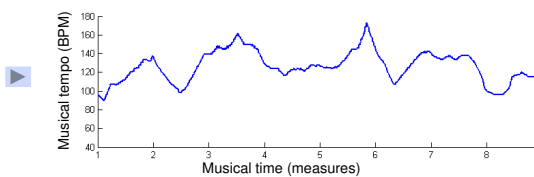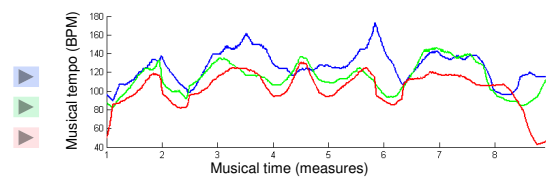Tempo Curve:

Performance Analysis: Tempo Curves

Schumann: Träumerei

Score (reference):

Tempo Curves:

Performance Analysis: Tempo Curves

Schumann: Träumerei
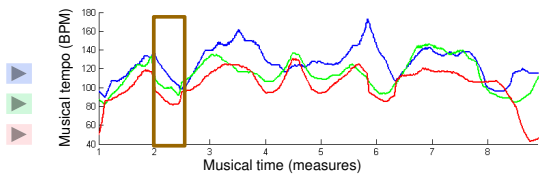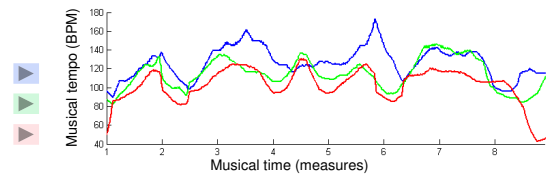
Score (reference):

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
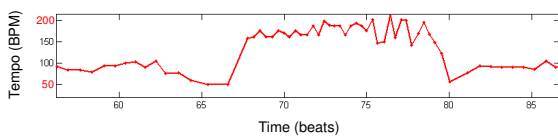
Tempo: ???

Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: 50-200 BPM
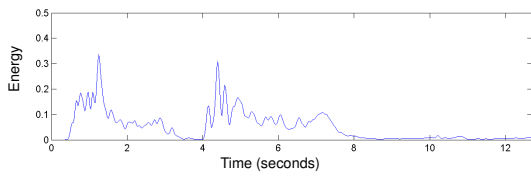
Tempo curve

Tempo Estimation

- Which temporal level?

- Local tempo deviations

- Sparse information
  (e.g., only note onsets available)

- Vague information
  (e.g., extracted note onsets corrupt)
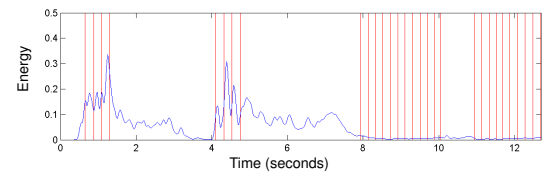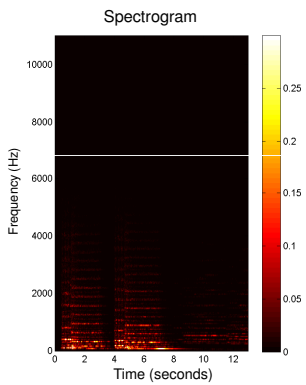
Tempo Estimation and Beat Tracking

Local Energy Curve:

Tempo Estimation and Beat Tracking
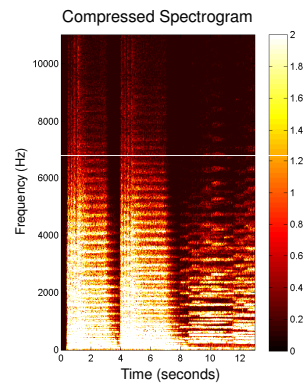
Local Energy Curve: Note Onset Positions

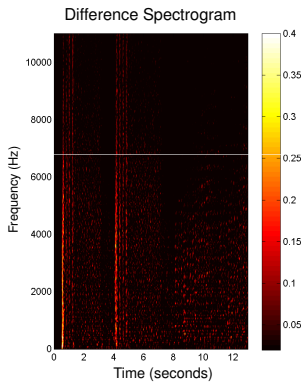## Tempo Estimation and Beat Tracking

Spectrogram

Steps:

1. Spectrogram

Tempo Estimation and Beat Tracking

Compressed Spectrogram

Steps:

1. Spectrogram
2. Log Compression

Tempo Estimation and Beat Tracking
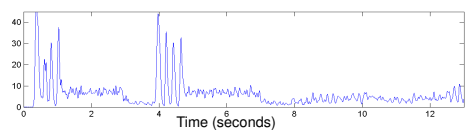
Difference Spectrogram

Steps:

1. Spectrogram
2. Log Compression
3. Differentiation

Tempo Estimation and Beat Tracking

Steps:

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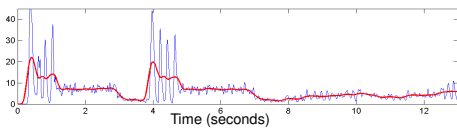3. Differentiation
4. Accumulation

Novelty Curve

Tempo Estimation and Beat Tracking

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

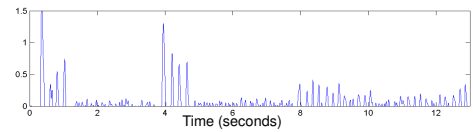**Novelty Curve**
Local Average

Tempo Estimation and Beat Tracking
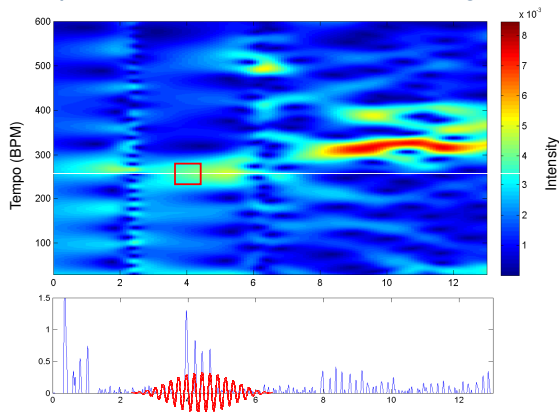
Steps:
1. Spectrogram
2. Log Compression
3. Differentiation
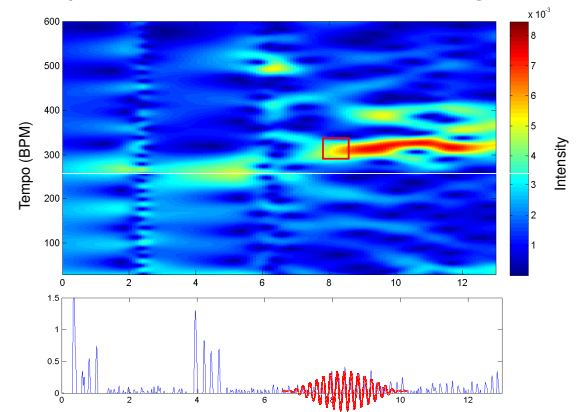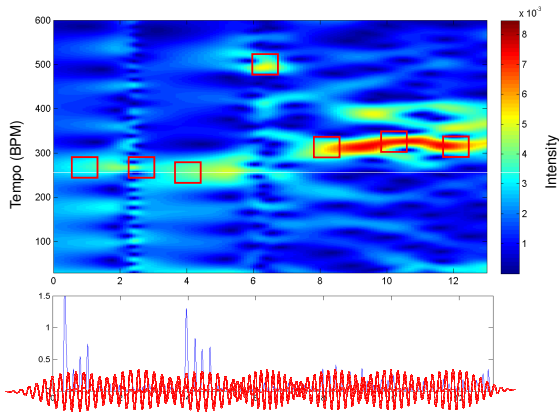4. Accumulation
5. Normalization

Novelty Curve

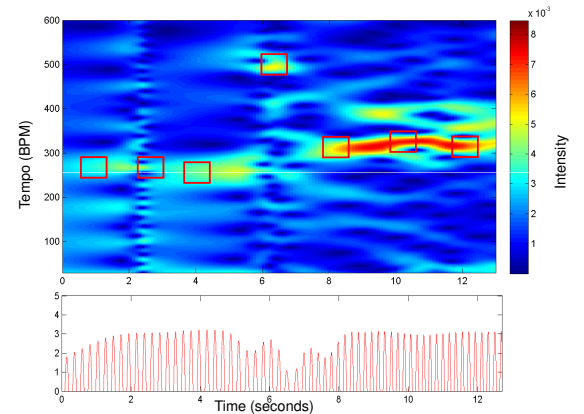---

Tempo Estimation and Beat Tracking

Tempo Estimation and Beat Tracking

Tempo Estimation and Beat Tracking

Tempo Estimation and Beat Tracking
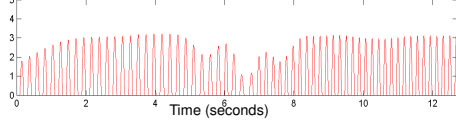
Tempo Estimation and Beat Tracking

Novelty Curve
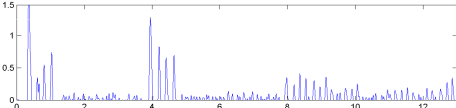
Predominant Local Pulse (PLP)

Time (seconds)

Motivic Similarity

Var. 4: Vivace

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
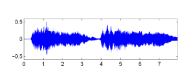
Multimodal Computing and Interaction

Sheet Music (Image)   MIDI   CD / MP3 (Audio)
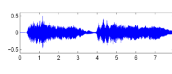
Music

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Sheet Music (Image)

MIDI

CD / MP3 (Audio)

MusicXML (Text)

Music

Singing / Voice (Audio)

Music Literature (Text)

Music Film (Video)

Dance / Motion (Mocap)