INTERNATIONAL AUDIO LABORATORIES ERLANGEN
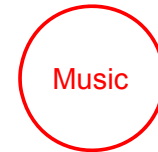
AUDIO
LABS

Lecture
Music Processing

Beethoven, Bach, and Billions of Bytes

New Alliances between Music and Computer Science

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

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
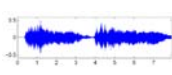
Fraunhofer
IIS

Music

Music Processing

Sheet Music (Image)

CD / MP3 (Audio)

MusicXML (Text)

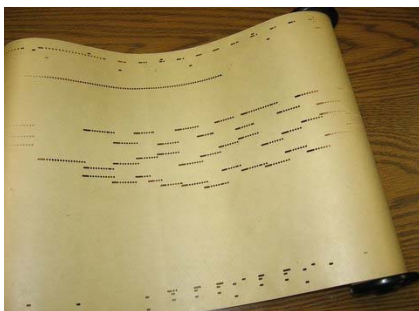Dance / Motion (Mocap)

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

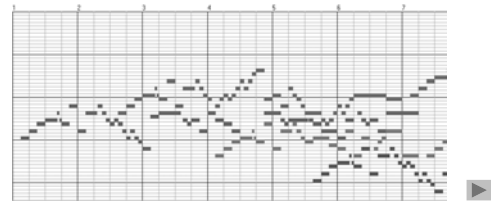(Well Tempered Piano, BWV 846)

Time

Pitch

Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

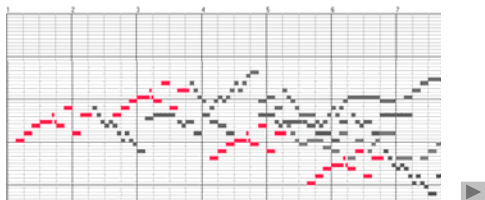## Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

Matches:

Audio Data

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)

Time (seconds)

Music Synchronization: Audio-Audio

Beethoven's Fifth

Orchester
(Karajan)
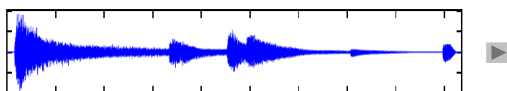
Piano
(Scherbakov)

Time (seconds)
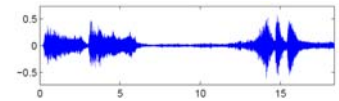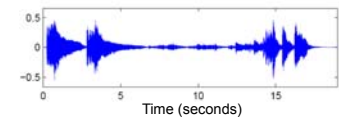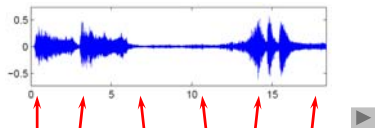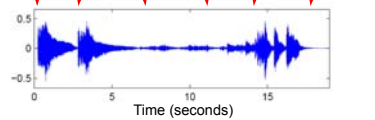
Application: Interpretation Switcher

Music Synchronization: Image-Audio

Image

Audio

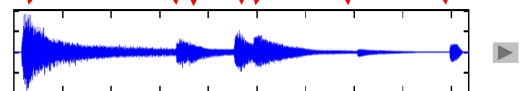## Music Synchronization: Image-Audio
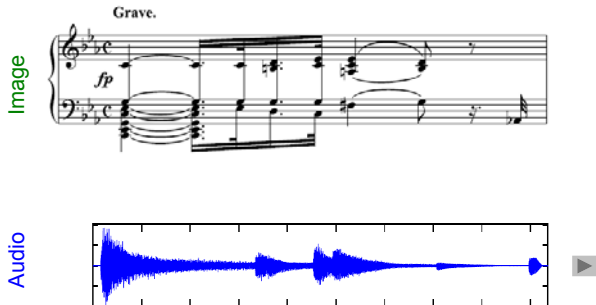
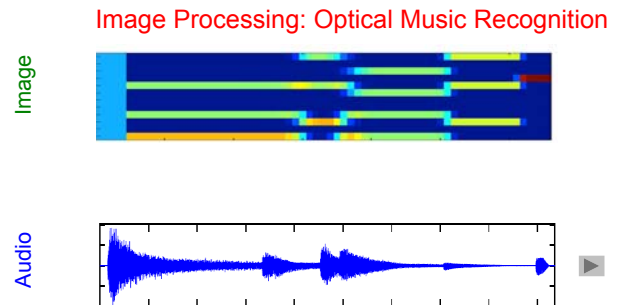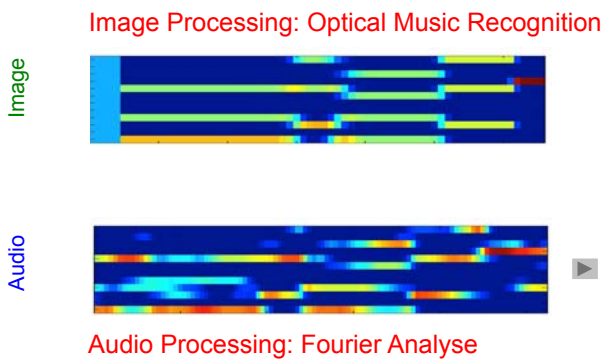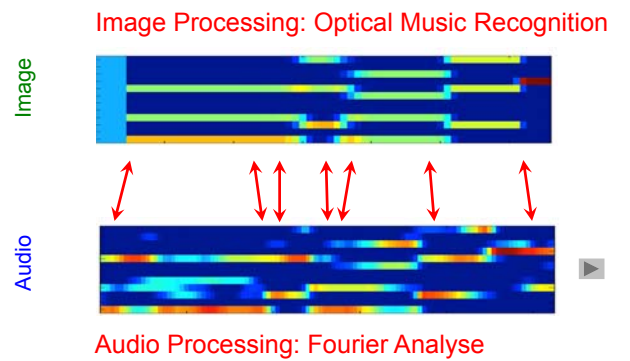Image

Audio

How to make the data comparable?

Image

Audio

How to make the data comparable?

Image Processing: Optical Music Recognition

Image

Audio

How to make the data comparable?

Image Processing: Optical Music Recognition

Image

Audio

Audio Processing: Fourier Analyse

How to make the data comparable?

Image Processing: Optical Music Recognition

Image

Audio

Audio Processing: Fourier Analyse

Application: Score Viewer
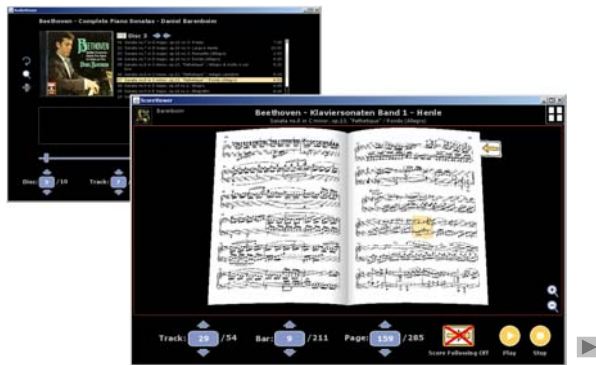
Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?

Music Processing

Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?

Music Processing

| Coarse Level	Fine Level
What do different versions have in common?	What are the characteristics of a specific version?
What makes up a piece of music?	What makes music come alive?
Identify despite of differences	Identify the differences

Music Processing

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

Performance Analysis
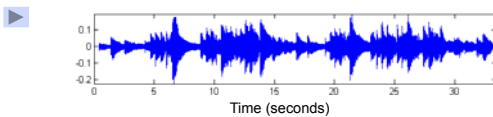
Schumann: Träumerei

Performance:
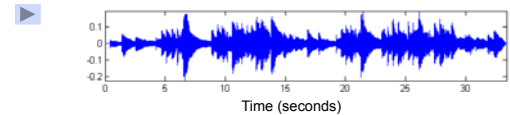
Performance Analysis

Schumann: Träumerei

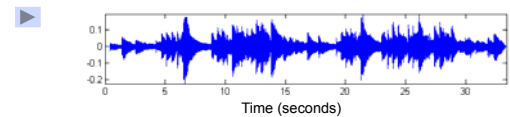Score (reference):

Performance:

Performance Analysis

Schumann: Träumerei

Score (reference):

Strategy: Compute score-audio synchronization and derive tempo curve

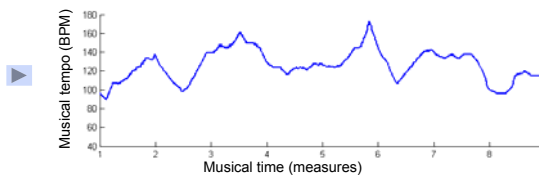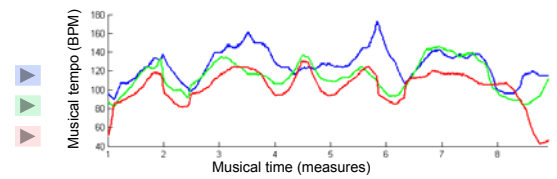Performance:

Performance Analysis

Schumann: Träumerei

Score (reference):

Tempo Curve:

Performance Analysis

Schumann: Träumerei

Score (reference):

Tempo Curves:

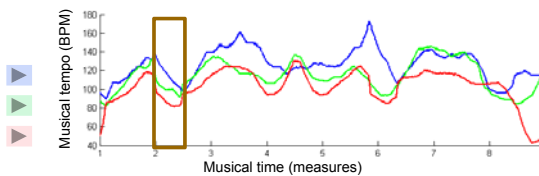## Performance Analysis

Schumann: Träumerei

Score (reference):

Tempo Curves:

Performance Analysis

Schumann: Träumerei

Score (reference):

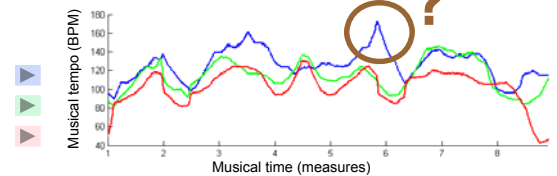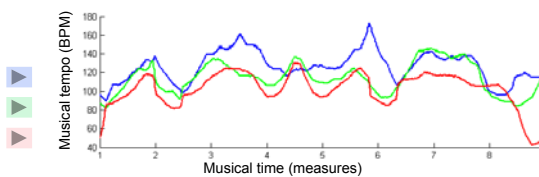
Tempo Curves:

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

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 and Beat Tracking

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

Tempo Estimation and Beat Tracking
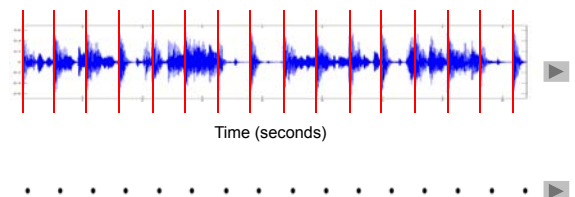
Basic task: "Tapping the foot when listening to music"

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)
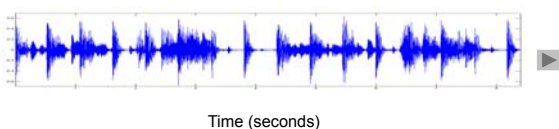
Tempo Estimation and Beat Tracking

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
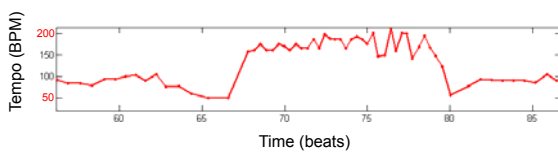
Tempo: ??? ▶

Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note
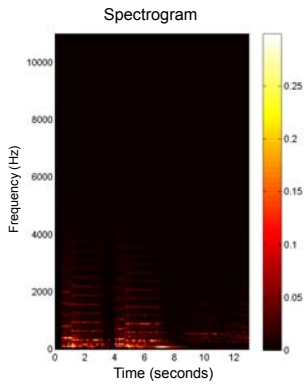
Tempo: 50-200 BPM ▶

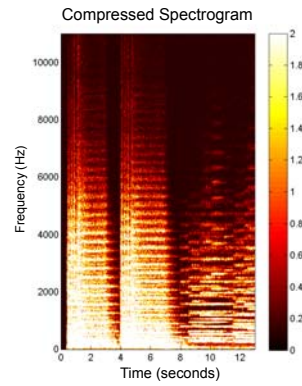Tempo curve

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)
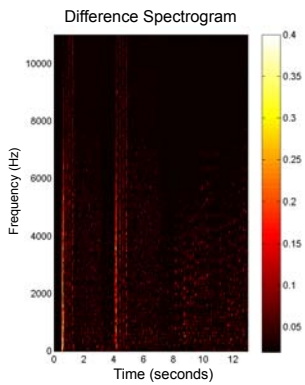
Tempo Estimation and Beat Tracking

Spectrogram

Steps:
1. Spectrogram

Tempo Estimation and Beat Tracking

Compressed Spectrogram

Steps:
1. Spectrogram
2. Log Compression

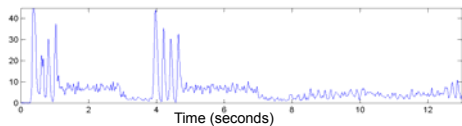## Tempo Estimation and Beat Tracking

Difference Spectrogram

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

Tempo Estimation and Beat Tracking

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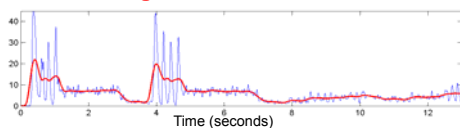2. Log Compression
3. Differentiation
4. Accumulation

Novelty Curve

Tempo Estimation and Beat Tracking

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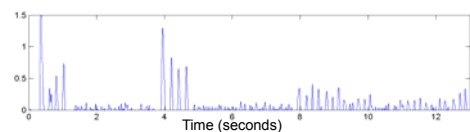3. Differentiation
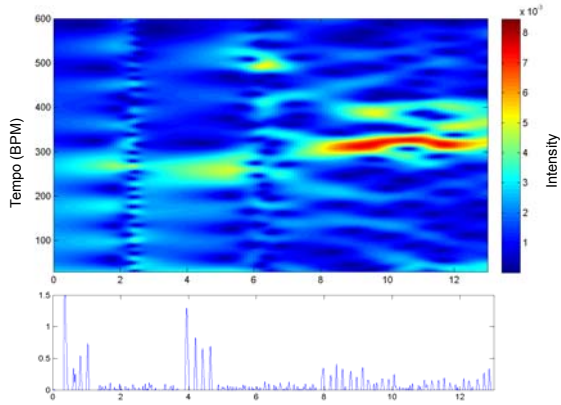4. Accumulation

Novelty Curve
Local Average

Tempo Estimation and Beat Tracking

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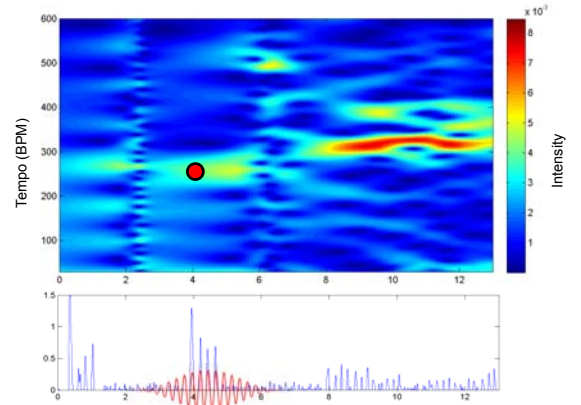3. Differentiation
4. Accumulation
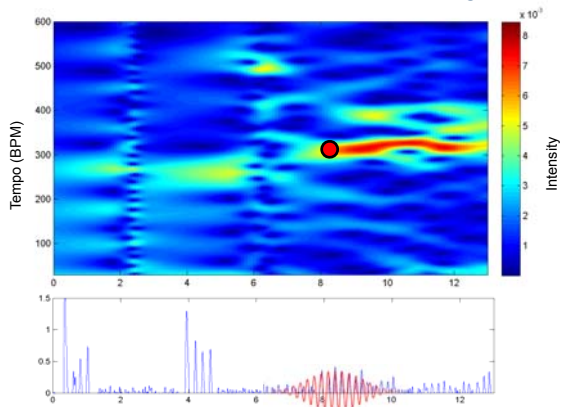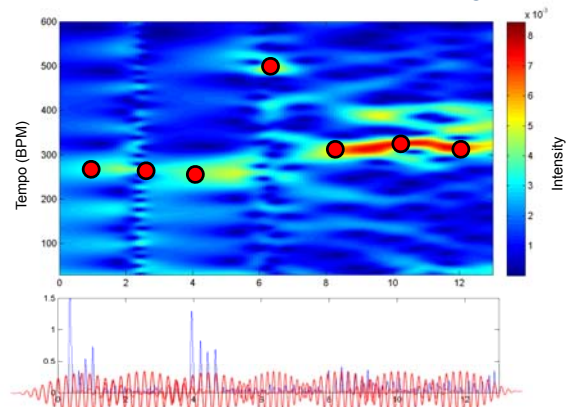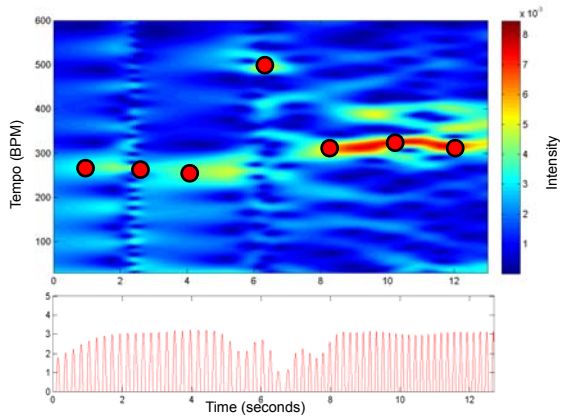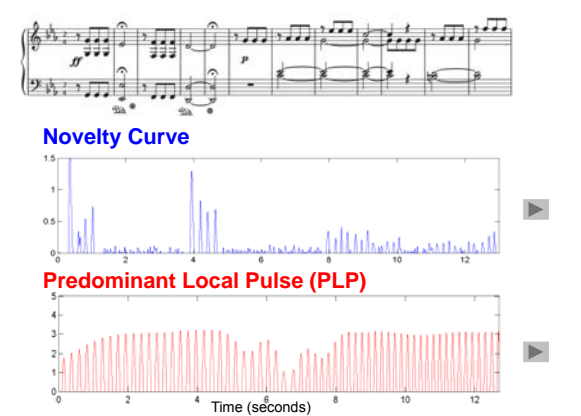5. Normalization

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

Tempo Estimation and Beat Tracking

Novelty Curve

Predominant Local Pulse (PLP)

Tempo Estimation and Beat Tracking

Light effects

Music recommendation

DJ

Audio editing

0:03.661

Motivic Similarity

Allegro con brio ($\bullet = 108$)

ff
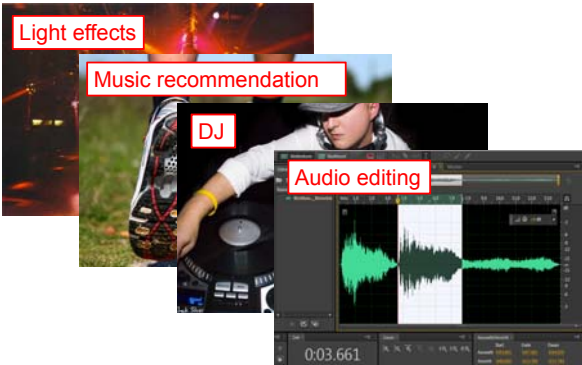
Beethoven's Fifth (1st Mov.) ▶

Motivic Similarity

Allegro con brio ($\bullet = 108$)

ff

Beethoven's Fifth (1st Mov.) ▶

Beethoven's Fifth (3rd Mov.) ▶

Motivic Similarity

Allegro con brio ($\bullet = 108$)

ff

Beethoven's Fifth (1st Mov.) ▶

Beethoven's Fifth (3rd Mov.) ▶

Beethoven's Appassionata ▶

Motivic Similarity

Var. 4: Vivace

f

▶

Motivic Similarity

B   A   C   H

▶

S   auf - - ge - rafft,   und nie - mand ach - - tet

A   b   a   e   h   und nie - mand ach - - tet drauf

T   und nie - mand ach -

B   auf - - ge - rafft,

▶

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. Temo and Beat Tracking
7. Content-based Audio Retrieval
8. Music Transcription

Springer

To appear (plan):
End of 2015