

Beethoven, Bach und Billionen Bytes

Automatisierte Analyse von Musik und Klängen

Meinard Müller

Tutzing-Symposium
Oktober 2014



Meinard Müller



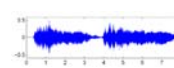
- 2001 PhD, Bonn University
- 2002/2003 Postdoc, Keio University, Japan
- 2007 Habilitation, Bonn University
"Information Retrieval for Music and Motion"
- 2007-2012 Senior Researcher
Max-Planck Institut für Informatik, Saarland
- 2012: Professor
Semantic Audio Processing
Universität Erlangen-Nürnberg

Music Processing

Sheet Music (Image)



CD / MP3 (Audio)



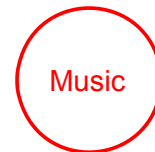
MusicXML (Text)

```

<musicxml>
  <score>
    <staff>
      <note>
        <pitch>
          <name>G4
        </pitch>
        <duration>4
      </note>
    </staff>
  </score>
</musicxml>

```

Dance / Motion (Mocap)



MIDI



Singing / Voice (Audio)



Music Film (Video)



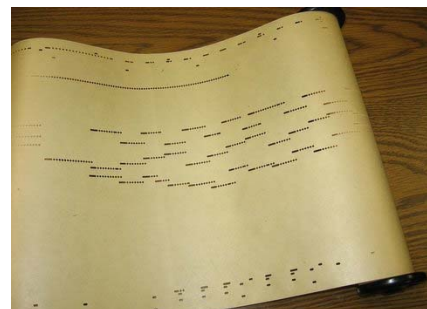
Music Literature (Text)



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)

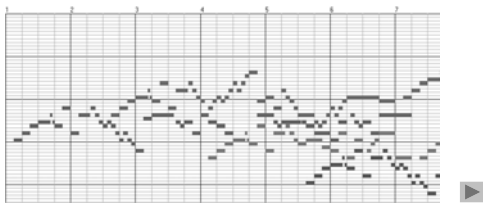


Piano Roll Representation (MIDI)



Query:

Goal: Find all occurrences of the query



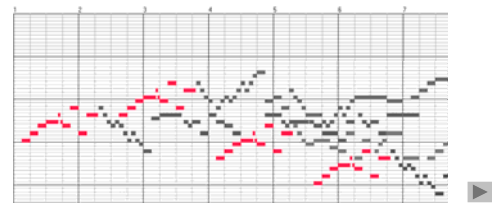
Piano Roll Representation (MIDI)



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

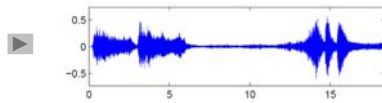


Music Synchronization: Audio-Audio

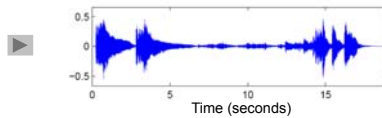
Beethoven's Fifth



Orchester
(Karajan)



Piano
(Scherbakov)



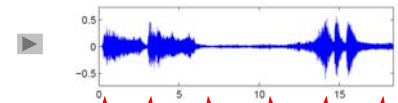
Time (seconds)

Music Synchronization: Audio-Audio

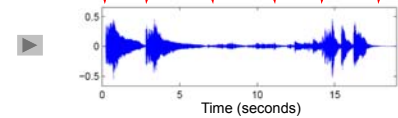
Beethoven's Fifth



Orchester
(Karajan)



Piano
(Scherbakov)

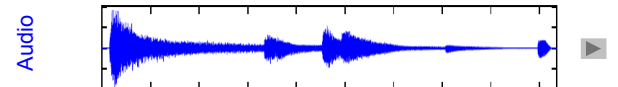


Time (seconds)

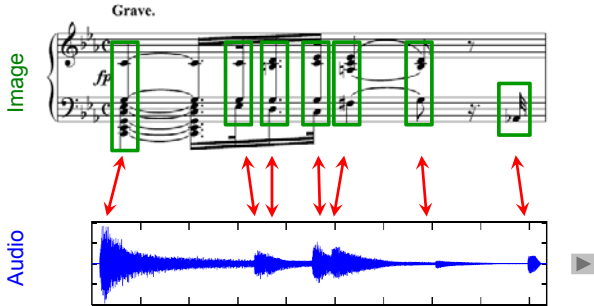
Application: Interpretation Switcher



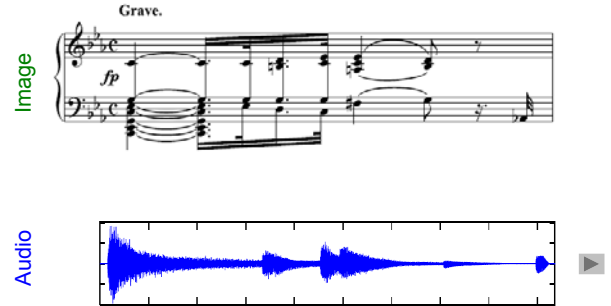
Music Synchronization: Image-Audio



Music Synchronization: Image-Audio

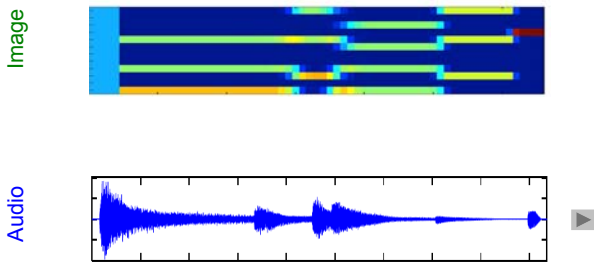


How to make the data comparable?



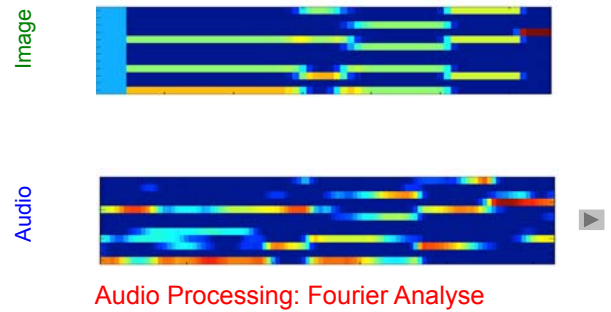
How to make the data comparable?

Image Processing: Optical Music Recognition



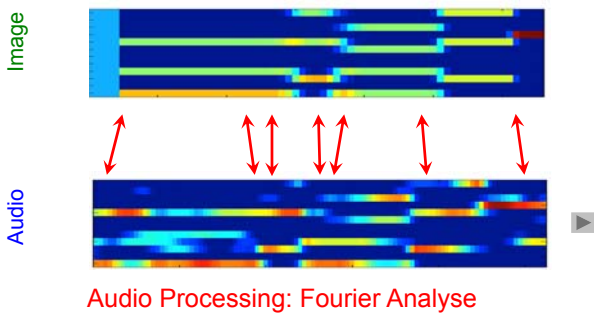
How to make the data comparable?

Image Processing: Optical Music Recognition

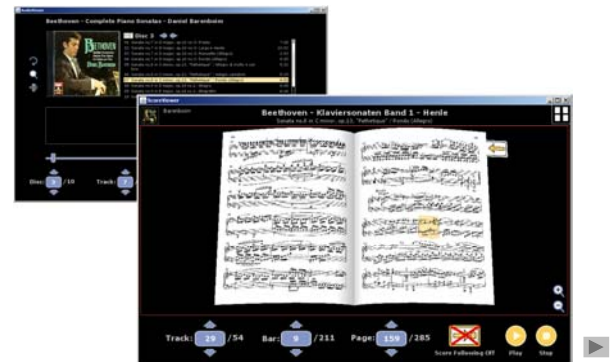


How to make the data comparable?

Image Processing: Optical Music Recognition



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

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What makes up a piece of music?	What makes music come alive?
Identify despite of differences	Identify the differences

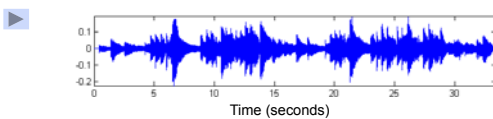
Music Processing

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:



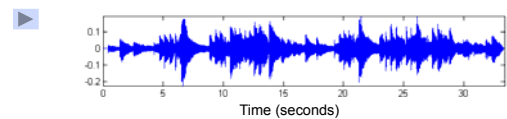
Performance Analysis

Schumann: Träumerei

Score (reference):



Performance:



Performance Analysis

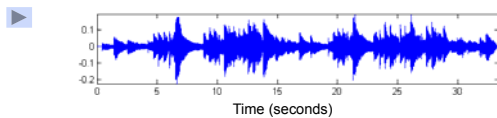
Schumann: Träumerei

Score (reference):



Strategy: Compute score-audio synchronization and derive tempo curve

Performance:



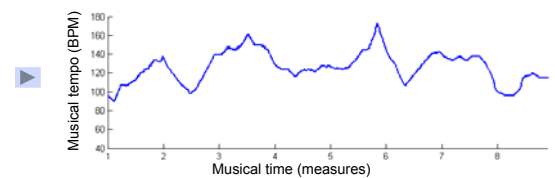
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curve:



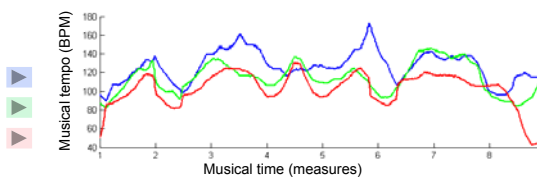
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:



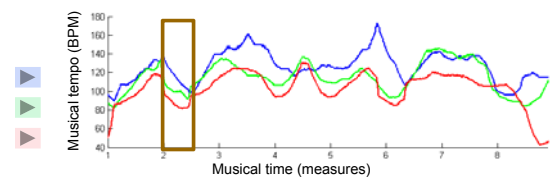
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:



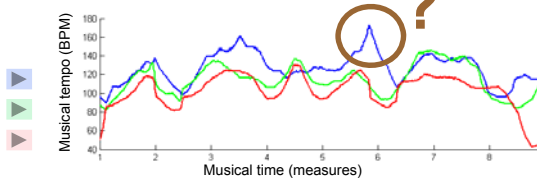
Performance Analysis

Schumann: Träumerei

Score (reference):



Tempo Curves:

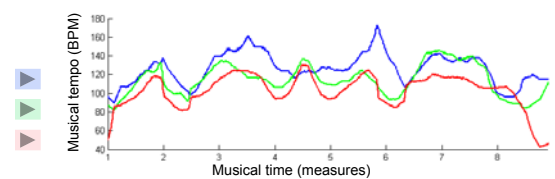


Performance Analysis

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

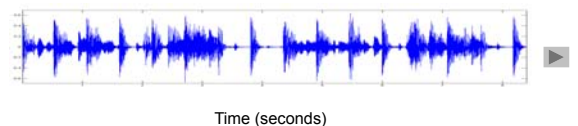
Tempo Estimation and Beat Tracking

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

Tempo Estimation and Beat Tracking

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

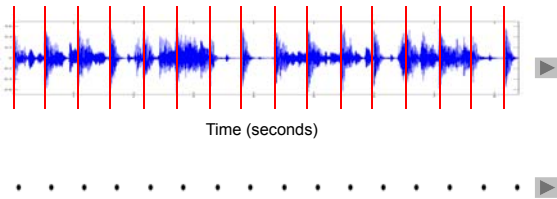
Example: Queen – Another One Bites The Dust



Tempo Estimation and Beat Tracking

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

Example: Queen – Another One Bites The Dust



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: ??? ▶

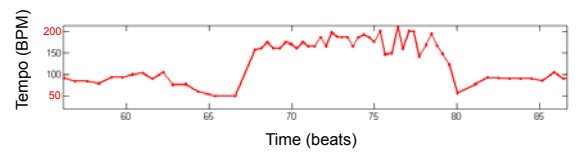
Tempo Estimation and Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: **50-200 BPM** ▶

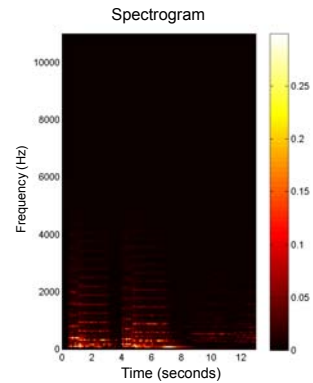
Tempo curve



Tempo Estimation and Beat Tracking

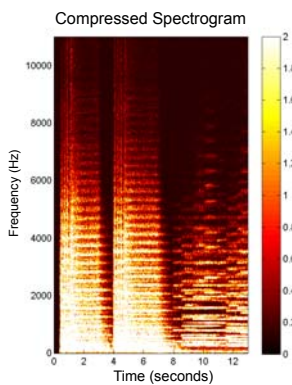
- Which temporal level?
- Local tempo deviations
- Sparse information (e.g., only note onsets available)
- Vague information (e.g., extracted note onsets corrupt)

Tempo Estimation and Beat Tracking



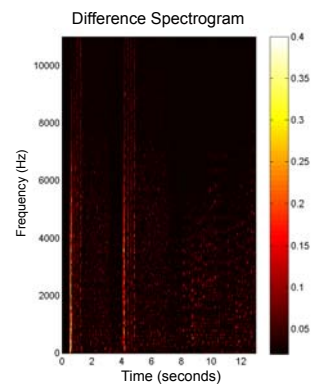
- Steps:**
1. Spectrogram

Tempo Estimation and Beat Tracking



- Steps:**
1. Spectrogram
 2. Log Compression

Tempo Estimation and Beat Tracking

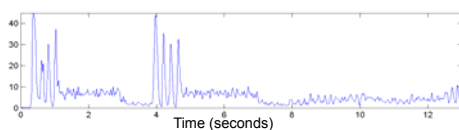


- Steps:**
1. Spectrogram
 2. Log Compression
 3. Differentiation

Tempo Estimation and Beat Tracking

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

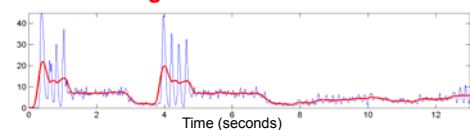
Novelty Curve



Tempo Estimation and Beat Tracking

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

Novelty Curve Local Average

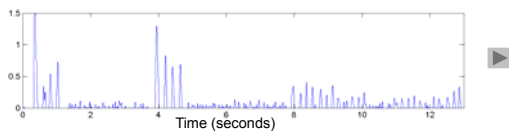


Tempo Estimation and Beat Tracking

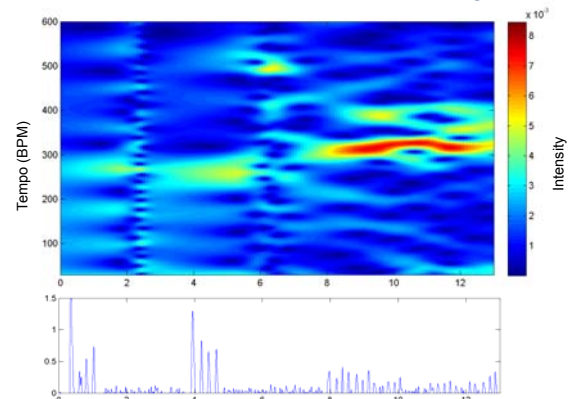
Steps:

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

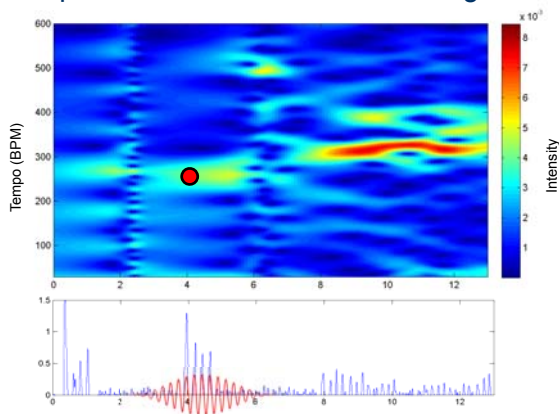
Novelty Curve



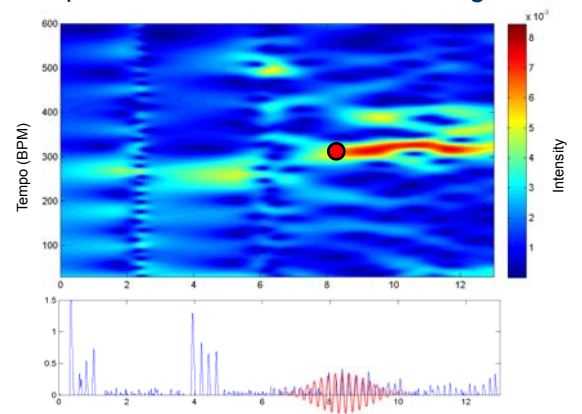
Tempo Estimation and Beat Tracking



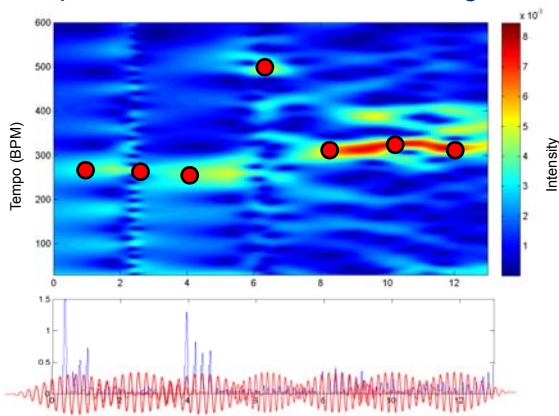
Tempo Estimation and Beat Tracking



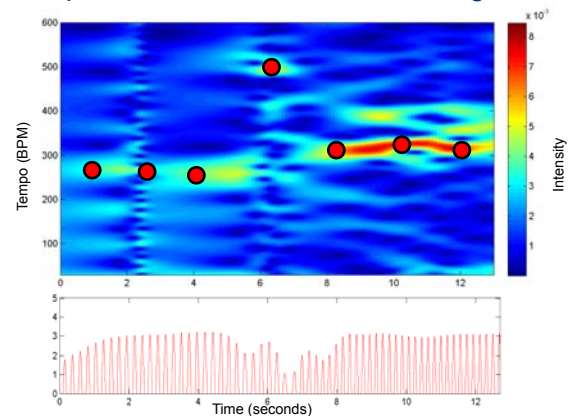
Tempo Estimation and Beat Tracking



Tempo Estimation and Beat Tracking



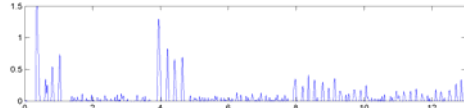
Tempo Estimation and Beat Tracking



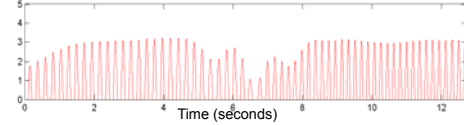
Tempo Estimation and Beat Tracking



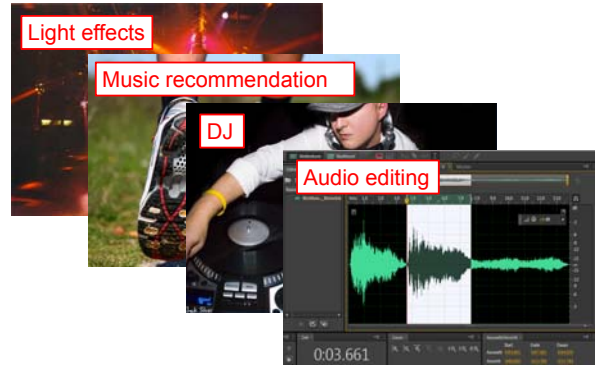
Novelty Curve



Predominant Local Pulse (PLP)



Tempo Estimation and Beat Tracking



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

The image shows a musical score with a vocal line (Soprano, Alto, Tenor, Bass) and piano accompaniment. A red box highlights a specific melodic motif in the vocal line, which corresponds to the letters 'B A C H' written below it. The motif consists of a sequence of notes: B (flat), A, C, and H (natural).

Thanks

- Thomas Prätzlich (AudioLabs Erlangen)
- Peter Grosche (Saarland University)
- Sebastian Ewert (Queen Mary University of London)
- Michael Clausen (Bonn University)
- 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 Recognition
6. Tempo and Beat Tracking
7. Content-based Audio Retrieval
8. Music Transcription

To appear (plan):
End of 2015

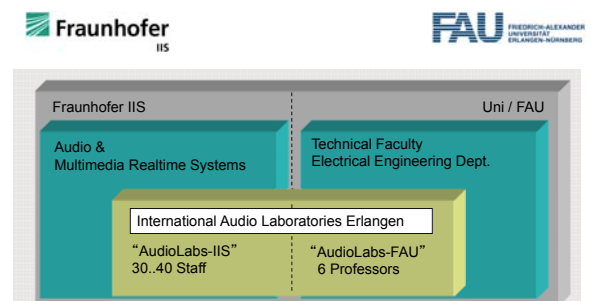
Project & Cooperations

- 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

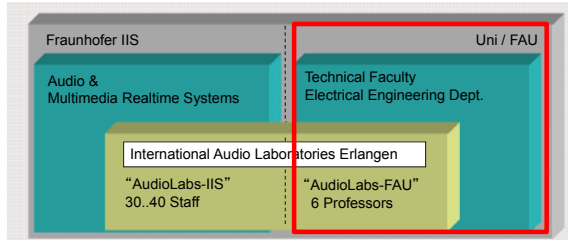
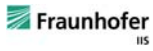
International Audio Laboratories Erlangen

The image displays the logos for Fraunhofer IIS, the mp3 format, and FAU (Friedrich-Alexander-Universität Erlangen-Nürnberg). Below these logos is a stack of gold coins with a downward-pointing arrow, leading to the 'AUDIO LABS' logo.

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Audio

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