

Happy Birthday – When Music Meets Computer Science

Meinard Müller

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

Conference: Configuration Spaces and
Moduli Spaces in Homotopy Theory
20.10.2016

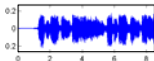


Happy Birthday

Sheet Music (Image)



CD / MP3 (Audio)



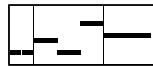
MusicXML (Text)

```
<musicxml>
  <score>
    <staff>
      <note>
        <pitch>
          <name>C4
        </pitch>
      </note>
    </staff>
  </score>
</musicxml>
```

Dance / Motion (Mocap)



MIDI



Singing / Voice (Audio)



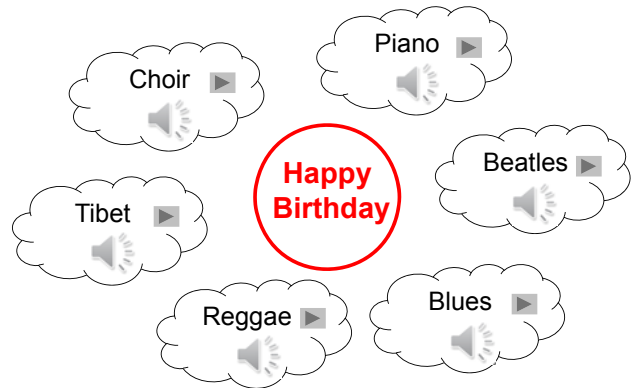
Music Film (Video)



Music Literature (Text)

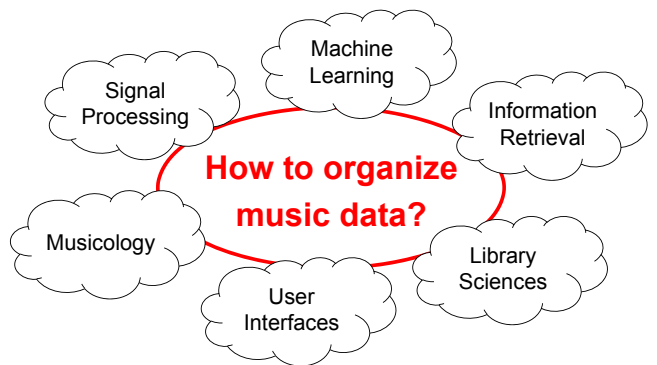


Happy Birthday



How to organize
music data?

Music Information Retrieval



Meinard Müller

- 1997 Diplom (Prof. Bödigheimer)
"Parallelschlitzgebiete"
- 2001 PhD (Prof. Clausen)
"Computer Algebra"
- 2007 Habilitation
"Multimedia Retrieval"
- 2007 – 2012 Senior Researcher
"Computer Graphics"
- Since 2012 Professor (W3)
"Semantic Audio Processing"



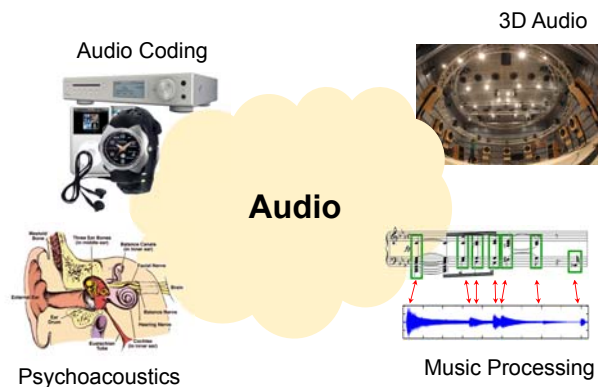
International Audio Laboratories Erlangen



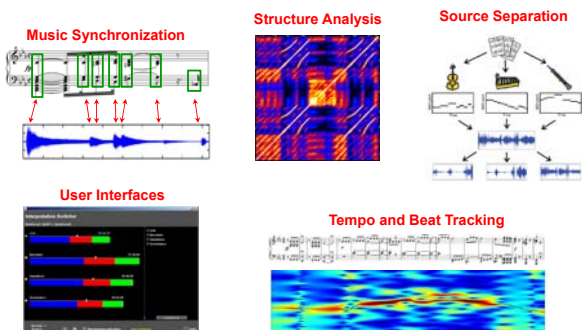
International Audio Laboratories Erlangen



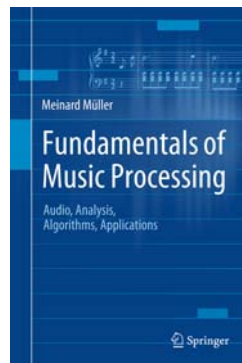
International Audio Laboratories Erlangen



Music Processing



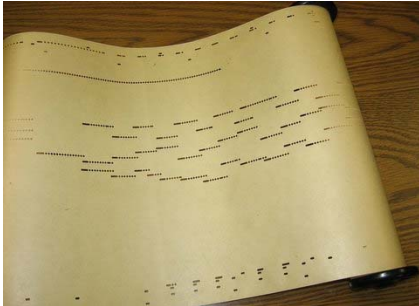
Book: Fundamentals of Music Processing



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

Accompanying website:
www.music-processing.de

Piano Roll Representation

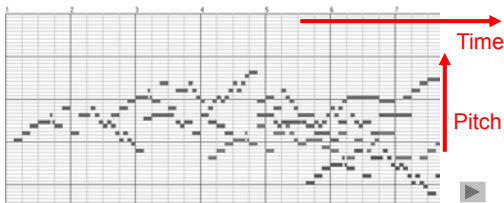


Player Piano (1900)



Piano Roll Representation (MIDI)

J.S. Bach, C-Major Fuge
(Well Tempered Piano, BWV 846)

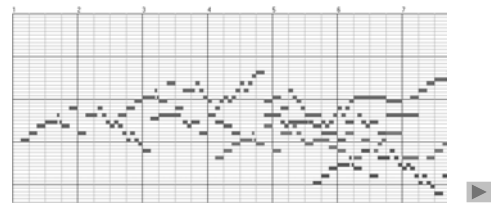


Piano Roll Representation (MIDI)

Query:

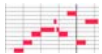


Goal: Find all occurrences of the query



Piano Roll Representation (MIDI)

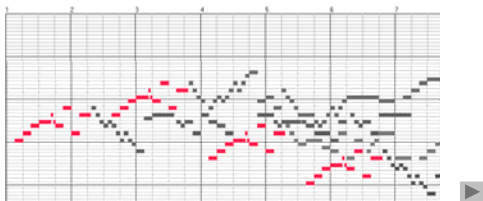
Query:



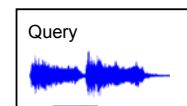
Goal: Find all occurrences of the query



Matches:



Music Retrieval



Audio-ID

Version-ID

Kategorie-ID

Database



Hit

Bernstein (1962)
Beethoven, Symphony No. 5

Beethoven, Symphony No. 5:

- Bernstein (1962)
- Karajan (1982)
- Gould (1992)

- Beethoven, Symphony No. 9
- Beethoven, Symphony No. 3
- Haydn Symphony No. 94



Music Synchronization: Audio-Audio

Beethoven's Fifth

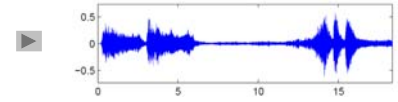


Music Synchronization: Audio-Audio

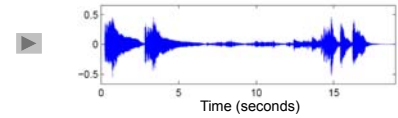
Beethoven's Fifth



Orchester
(Karajan)



Piano
(Scherbakov)

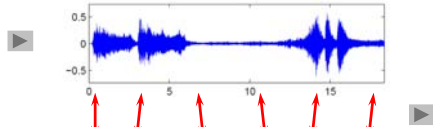


Music Synchronization: Audio-Audio

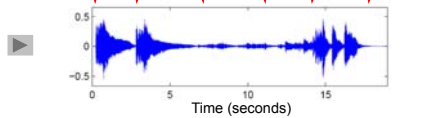
Beethoven's Fifth



Orchester
(Karajan)



Piano
(Scherbakov)



Application: Interpretation Switcher



The application interface shows a list of recordings for Beethoven's Fifth Symphony, Op. 67, Movement 1. It includes a progress bar for each recording and a 'Download all' button. The recordings listed are:

- mid: 00:44:18
- Bernstein: 01:00:44
- Sawallisch: 00:58:35
- Scherbakov: 00:52:45

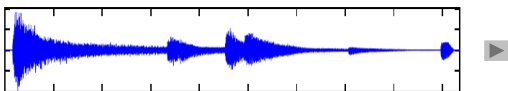
At the bottom, there are controls for 'Absolute', 'Relative', and 'Reference' views, a 'Movement selection' dropdown, an 'Interval Repeat' button, and an 'Info' icon.

Music Synchronization: Image-Audio

Image

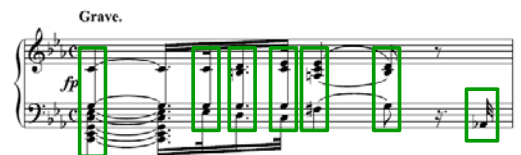


Audio

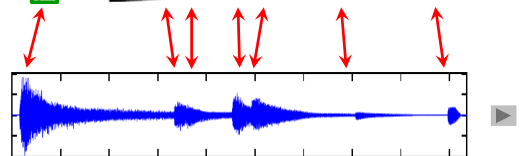


Music Synchronization: Image-Audio

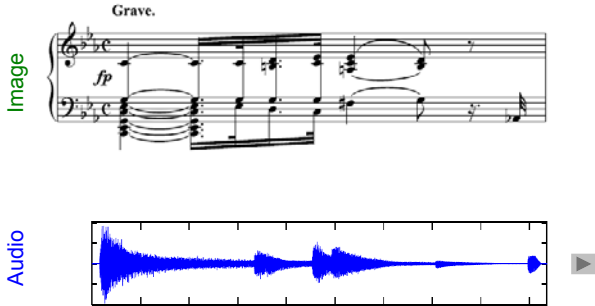
Image



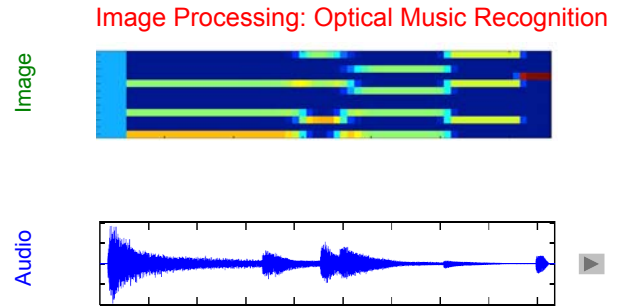
Audio



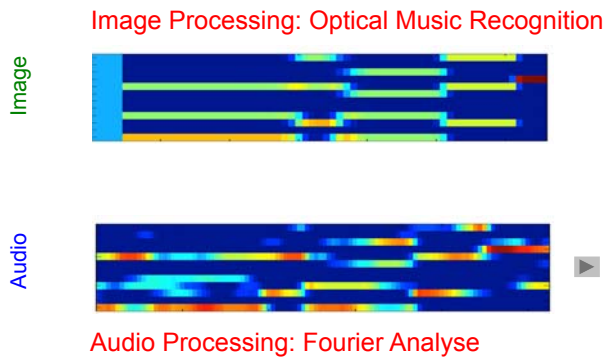
How to make the data comparable?



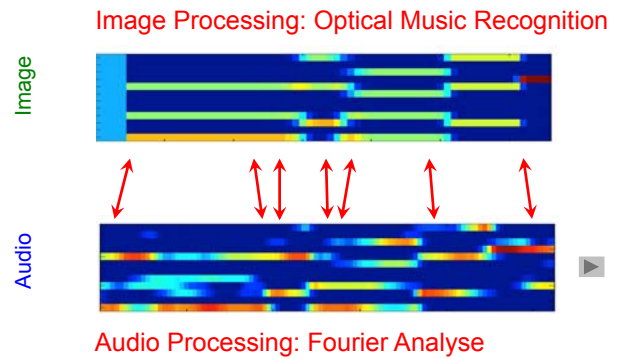
How to make the data comparable?



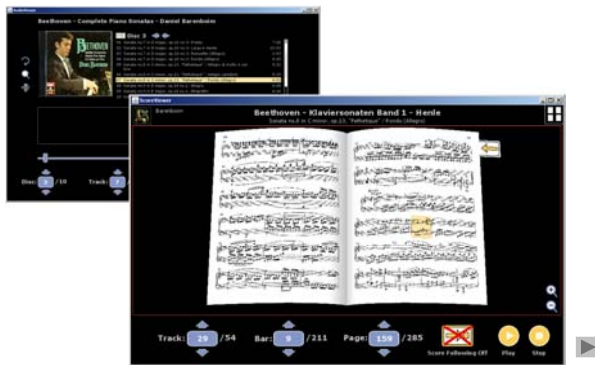
How to make the data comparable?



How to make the data comparable?



Application: Score Viewer



Why is Music Processing Challenging?

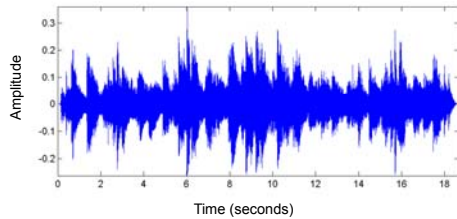
Example: Chopin, Mazurka Op. 63 No. 3



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3 ▶

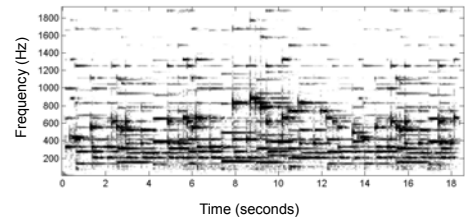
- Waveform



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3 ▶

- Waveform / Spectrogram



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3 ▶

- Waveform / Spectrogram

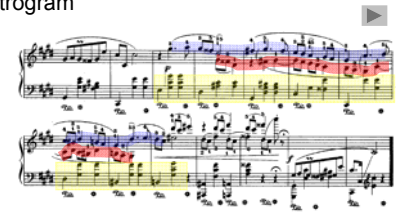
- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal

Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3 ▶

- Waveform / Spectrogram

- Performance
 - Tempo
 - Dynamics
 - Note deviations
 - Sustain pedal



- Polyphony

- Main Melody
- Additional melody line
- Accompaniment

Source Separation

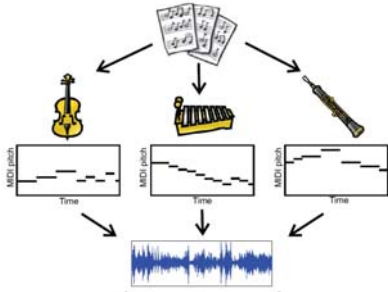
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”
- Sources are often assumed to be statistically independent
- This is often not the case in music

Strategy: Exploit additional information (e.g. musical score) to support the separation process

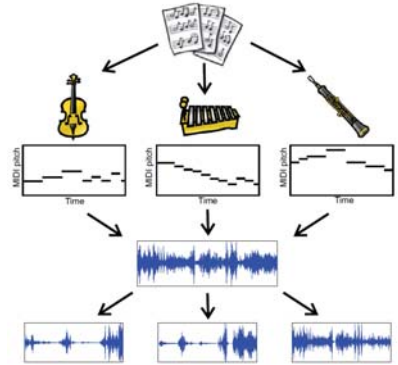
Score-Informed Source Separation



Score-Informed Source Separation

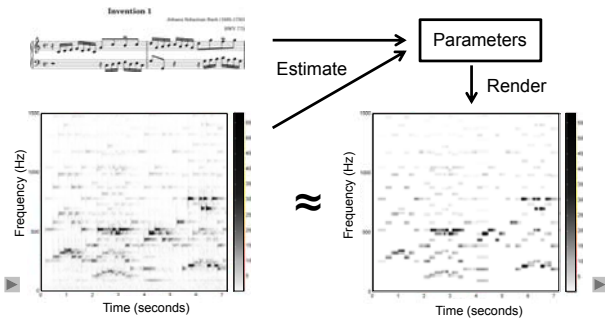


Score-Informed Source Separation

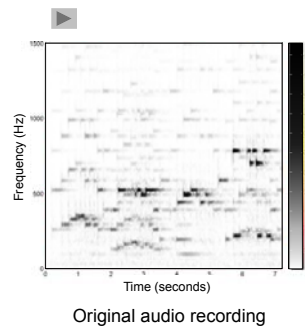


Score-Informed Source Separation

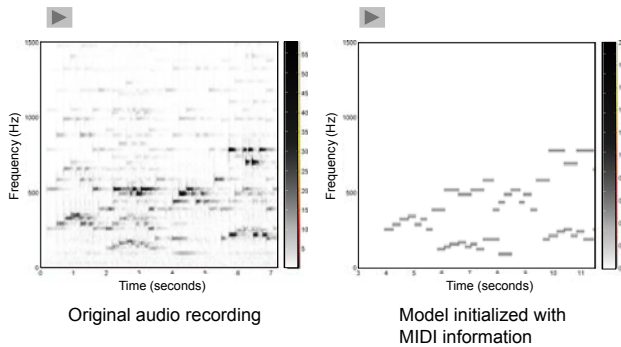
Goal: Approximate spectrogram using a parametric model exploiting availability of score information



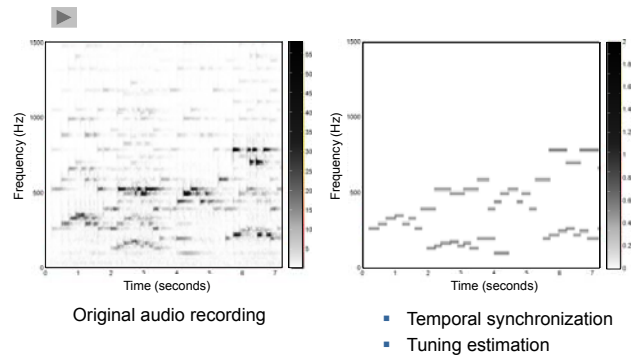
Score-Informed Source Separation



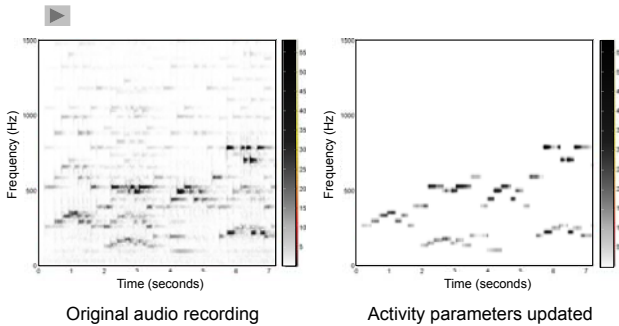
Score-Informed Source Separation



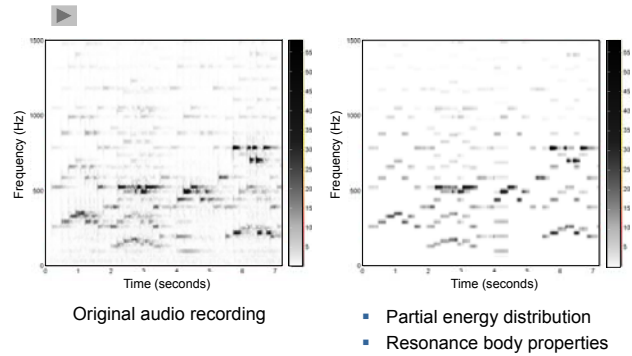
Score-Informed Source Separation



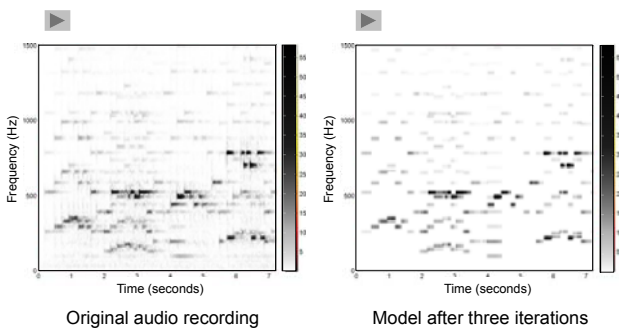
Score-Informed Source Separation



Score-Informed Source Separation



Score-Informed Source Separation



Note: Each note specified by the score parameterizes a portion of the spectrogram

Score-Informed Source Separation

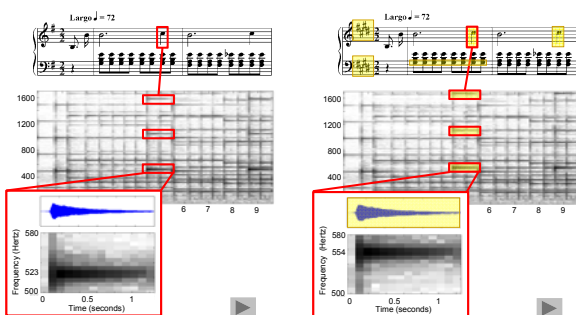
Experimental results for separating left and right hands for piano recordings:



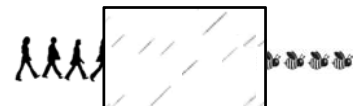
Composer	Piece	Database	Results			
			L	R	Eq	Org
Bach	BWV 875, Prelude	SMD	▶▶▶▶	▶▶▶▶	▶▶▶▶	▶▶▶▶
Chopin	Op. 28, No. 15	SMD	▶▶▶▶	▶▶▶▶	▶▶▶▶	▶▶▶▶
Chopin	Op. 64, No. 1	European Archive	▶▶▶▶	▶▶▶▶	▶▶▶▶	▶▶▶▶

Score-Informed Source Separation

Audio editing

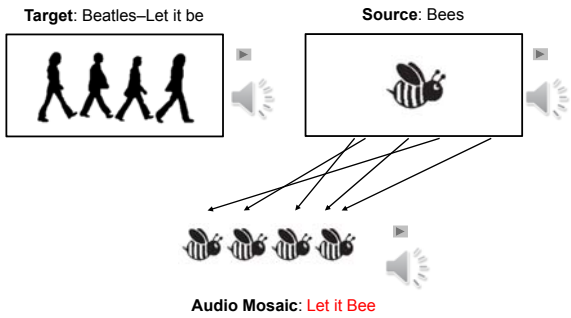


Audio Mosaicing



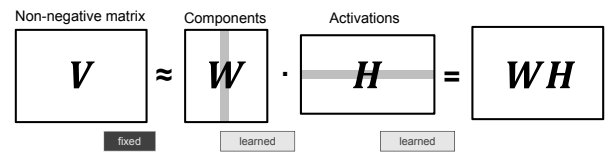
Jonathan Driedger, PhD 2016

Audio Mosaicing

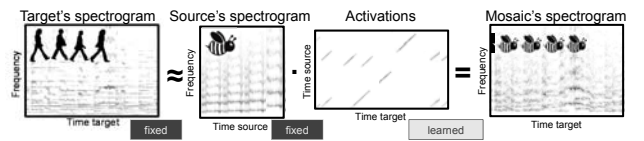


Audio Mosaicing

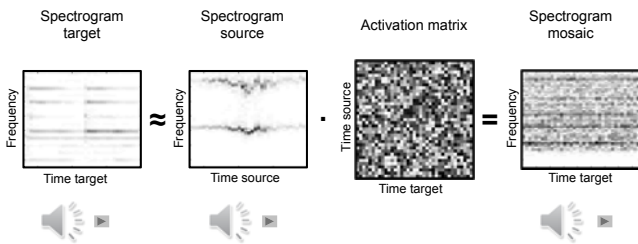
Non-negative matrix factorization (NMF)



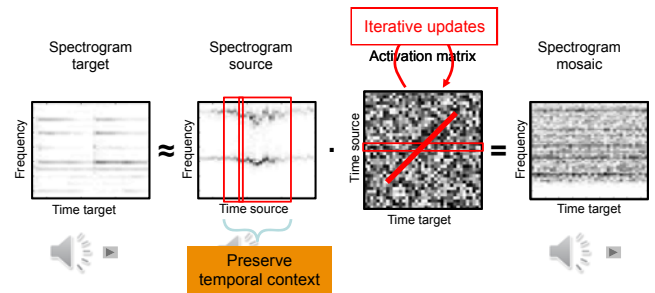
Proposed audio mosaicing approach



Audio Mosaicing

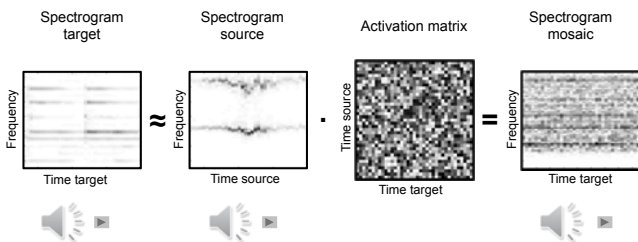


Audio Mosaicing

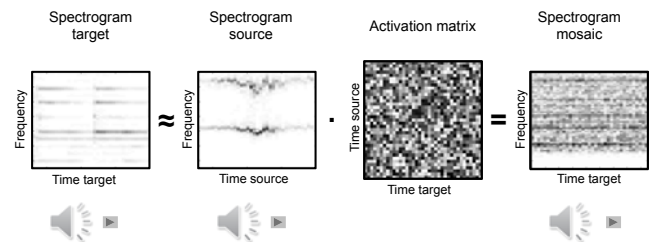


Core idea: support the development of sparse diagonal activation structures

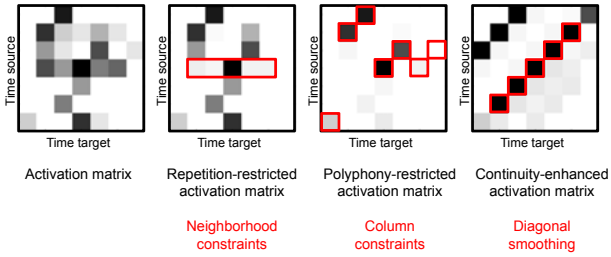
Audio Mosaicing



Audio Mosaicing

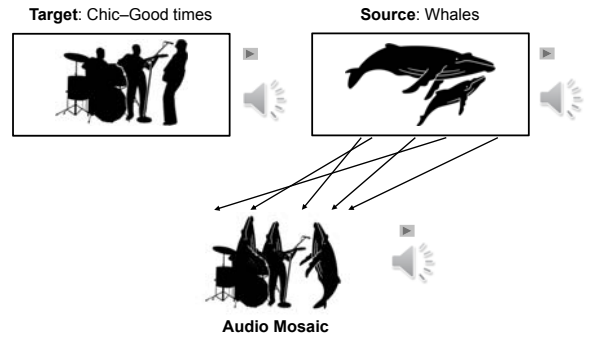


Audio Mosaicing

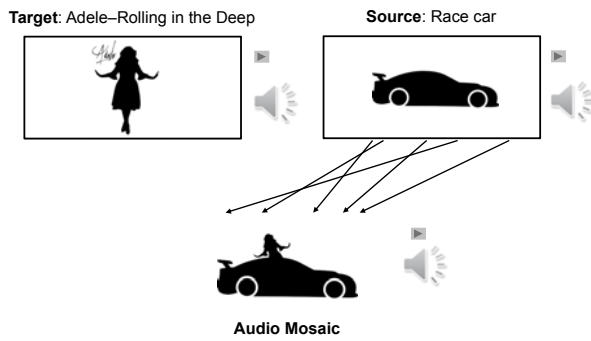


- Constraints are enforced by additional update rules
- Additional rules are interleaved with standard NMF update rules
- Soft alternative to NMF

Audio Mosaicing



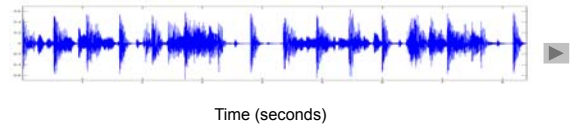
Audio Mosaicing



Beat Tracking

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

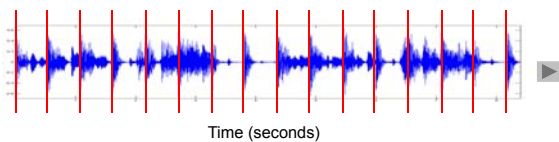
Example: Queen – Another One Bites The Dust



Beat Tracking

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

Example: Queen – Another One Bites The Dust



Beat Tracking

Example: Happy Birthday to you

Pulse level: **Measure**



Beat Tracking

Example: Happy Birthday to you

Pulse level: **Tactus (beat)**



Beat Tracking

Example: Happy Birthday to you

Pulse level: **Tatum (temporal atom)**



Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: ???

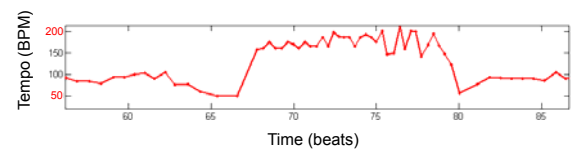
Beat Tracking

Example: Chopin – Mazurka Op. 68-3

Pulse level: Quarter note

Tempo: **50-200 BPM**

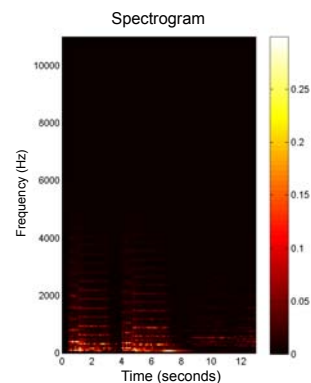
Tempo curve



Beat Tracking

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

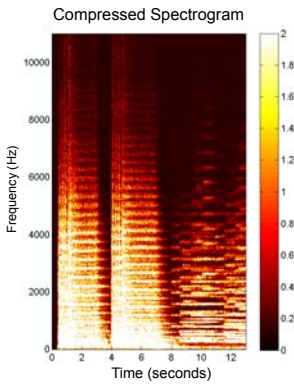
Beat Tracking



Steps:

1. Spectrogram

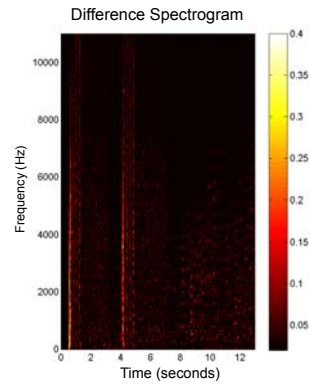
Beat Tracking



Steps:

1. Spectrogram
2. Log Compression

Beat Tracking



Steps:

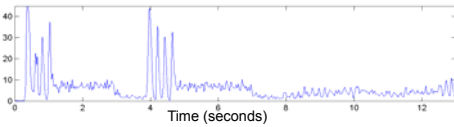
1. Spectrogram
2. Log Compression
3. Differentiation

Beat Tracking

Steps:

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

Novelty Curve

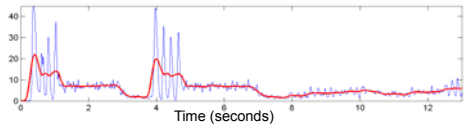


Beat Tracking

Steps:

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

**Novelty Curve
Local Average**

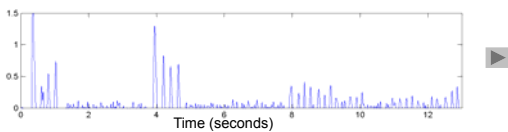


Beat Tracking

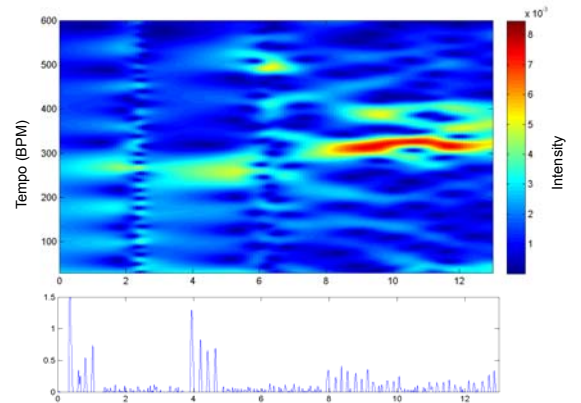
Steps:

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

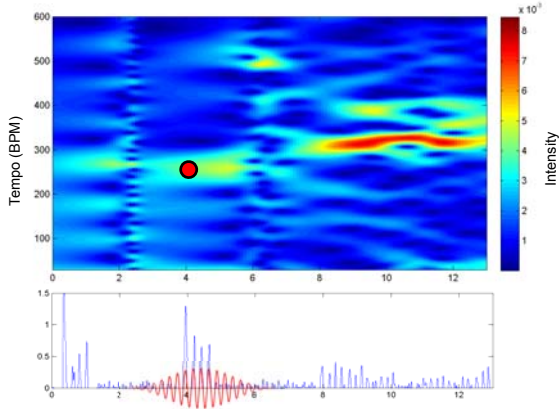
Novelty Curve



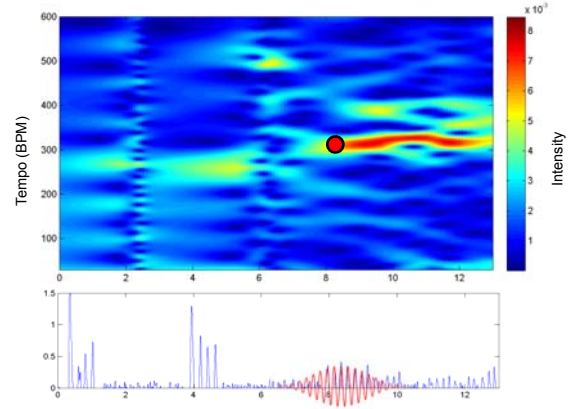
Beat Tracking



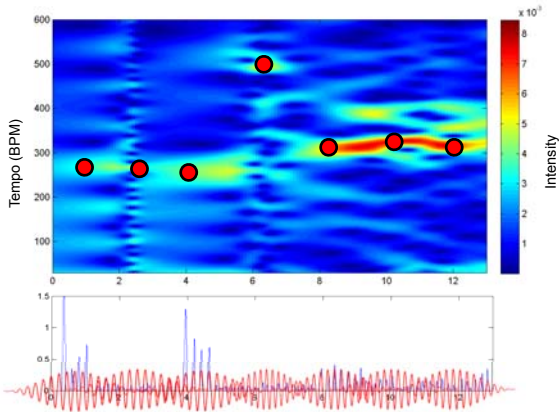
Beat Tracking



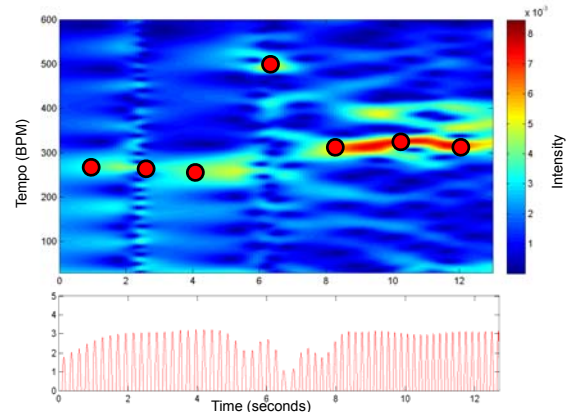
Beat Tracking



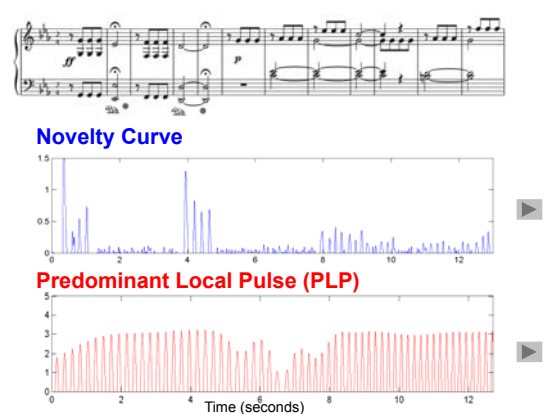
Beat Tracking



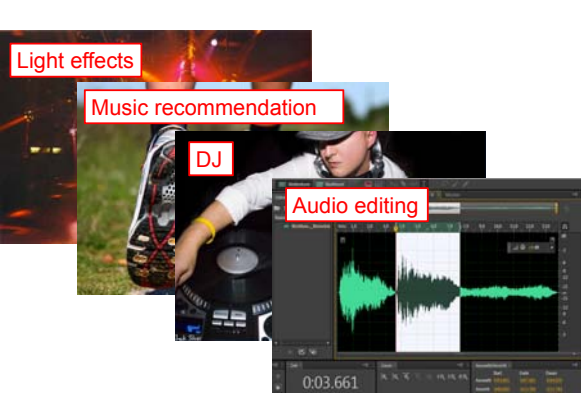
Beat Tracking



Beat Tracking



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

Var. 4: Vivace



Fêtes - Variations on Happy Birthday

Ivan Tcherepnin (1943 – 1998)



- American composer
- Russian father, Chinese mother
- Kirchner, Stockhausen, Boulez

Fêtes - Variations on Happy Birthday

Ivan Tcherepnin (1943 – 1998)



Prof. Elaine Chew, QMUL
Researcher and pianist

Fêtes - Variations on Happy Birthday

Ivan Tcherepnin (1943 – 1998)



Musical score for the first variation of 'Fêtes - Variations on Happy Birthday'. It features piano accompaniment with dynamic markings such as *mp*, *pp*, *cresc.*, *poco a poco*, *f*, *marcato*, *diminuendo*, and *poco rit.* Pedal markings are also present.



Prof. Elaine Chew, QMUL
Researcher and pianist

Fêtes - Variations on Happy Birthday

Ivan Tcherepnin (1943 – 1998)



Continuation of the musical score for the first variation. It includes dynamic markings like *mp*, *pp*, *dim*, *p*, and *ppp*. Performance instructions include *a tempo*, *poco allargando*, *poco più mosso*, and *poco rit.* Pedal markings are also included.



Prof. Elaine Chew, QMUL
Researcher and pianist

Fêtes - Variations on Happy Birthday

Ivan Tcherepnin (1943 – 1998)



Musical score for the first variation with red chord diagrams overlaid on the notes. The diagrams are labeled with letters: C, B, and F, representing specific chords used in the piece.

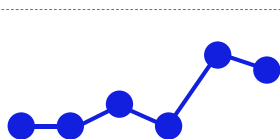


Prof. Elaine Chew, QMUL
Researcher and pianist

Motivic Transformations: Original



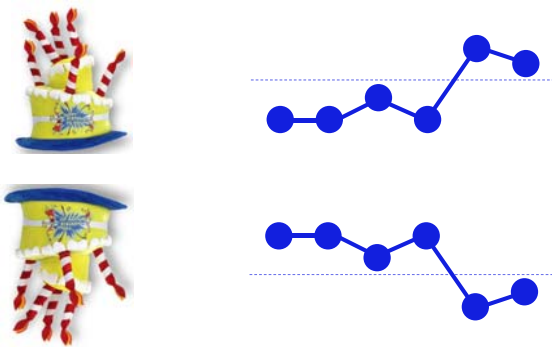
Motivic Transformations: Transposition



Motivic Transformations: Original



Motivic Transformations: Inverse



Motivic Transformations: Stretto

8 poco allargando poco

dim. pp

* senza Ped

Motivic Transformations: Stretto

8 poco allargando poco

dim. pp

* senza Ped

Motivic Transformations: Stretto

8 poco allargando poco

dim. pp

* senza Ped

Motivic Transformations: Original



Motivic Transformations: Inverse



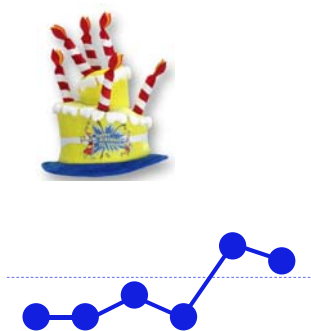
Motivic Transformations: Inverse in Stretto



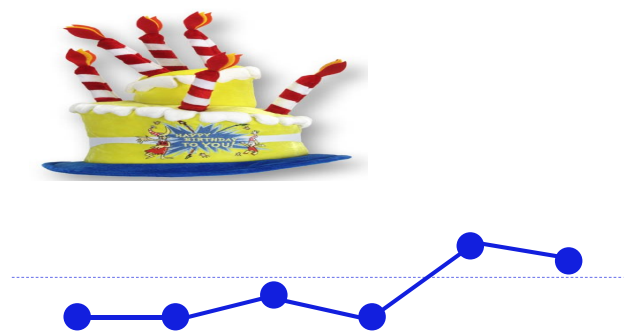
Motivic Transformations: Inverse in Stretto

Musical notation for the 'Inverse in Stretto' transformation. It shows two staves of music. The top staff has a melody with notes highlighted in yellow and red. The bottom staff shows the inverted melody, also with notes highlighted in yellow and red. Dynamics markings include *mf*, *pp*, *mp*, and *f*. A 'Ped.' marking is also present.

Motivic Transformations: Original



Motivic Transformations: Augmentation



Motivic Transformations: Diminution



Motivic Transformations: Diminution

Musical notation for the 'Diminution' transformation. It shows four staves of music. The top two staves show the original melody with notes highlighted in yellow and red. The bottom two staves show the diminished melody, also with notes highlighted in yellow and red. A play button icon is visible at the bottom right.

Motivic Transformations: Diminution



The image shows a musical score with four systems. The first system is the original melody. The second system shows the melody transposed up an octave. The third and fourth systems show the melody further transposed up, with some notes highlighted in red and yellow to show the transformation.

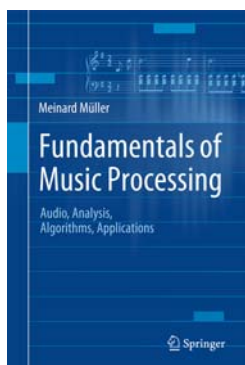
Motivic Similarity

B A C H

S
auf - ge - raff,
und nie - mand ach - tet
A
und nie - mand ach - tet drauf
T
und nie - mand ach - tet drauf
B
auf - ge - raff.

The image shows a musical score for a vocal line with lyrics. A red box highlights a specific motif in the vocal line, which is a sequence of notes that corresponds to the letters B, A, C, H.

Book: Fundamentals of Music Processing



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

Accompanying website:
www.music-processing.de

Book: Fundamentals of Music Processing

Chapter	Music Processing Scenario
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	Musically Informed Audio Decomposition

Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

Accompanying website:
www.music-processing.de