

Advanced Course Computer Science

Music Processing

Summer Term 2010

Meinard Müller

Saarland University and MPI Informatik
meinard@mpi-inf.mpg.de

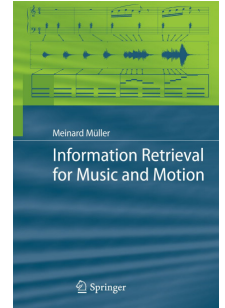
Beethoven, Bach, and Billions of Bytes

New Alliances between Music and Computer Science

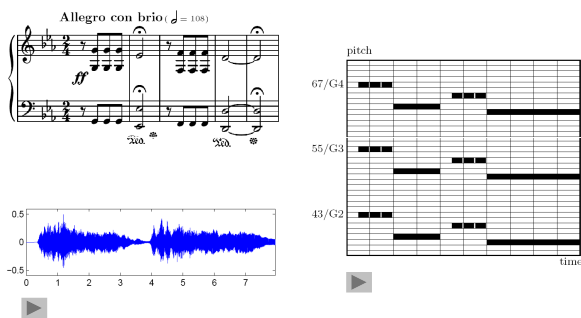


Priv.-Doz. Dr. Meinard Müller

- 2007 Habilitation, Bonn
- 2007 MPI Informatik, Saarland
- Cluster of Excellence
- 5 PhD Students (2 Cluster, 3 DFG)



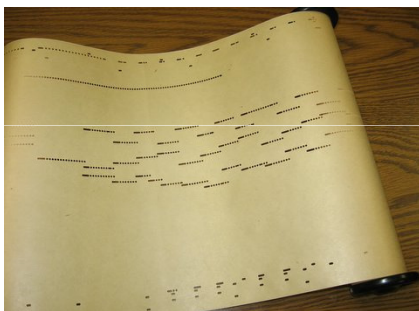
Music Data



Music Information Retrieval (MIR)

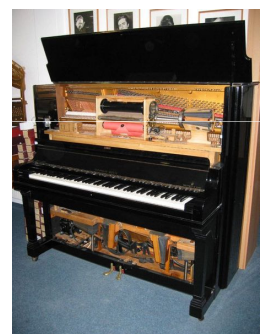
- Detection of semantic relations, e.g., harmonic, rhythmic, or motivic similarity
- Extraction of musical entities such as note events, instrumentation, or musical form
- Tools and methods for multimodal search, navigation, and interaction

Piano Roll Representation



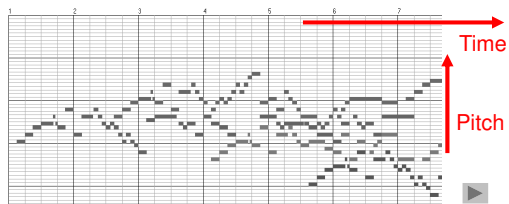
Piano Roll Representation

Player Piano (1900)



Piano Roll Representation (MIDI)

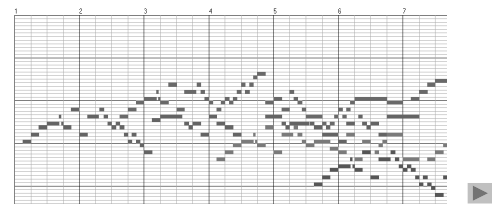
J.S. Bach, C-Major Fuge
(Well Tempered Piano, BWV 846)



Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

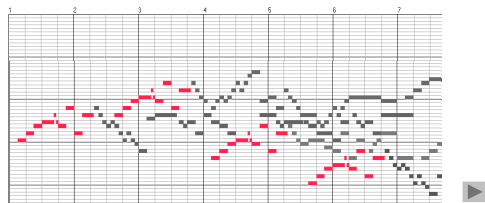


Piano Roll Representation (MIDI)

Query:

Goal: Find all occurrences of the query

Matches:



Audio Data

Various interpretations – Beethoven's Fifth

Bernstein

Karajan

Scherbakov (piano)

MIDI (piano)

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 |

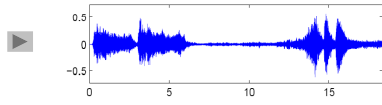
Memory Requirements

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

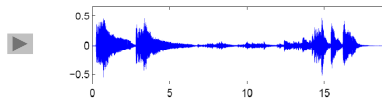
Music Synchronization: Audio-Audio

Beethoven's Fifth

Karajan



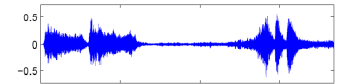
Scherbakov



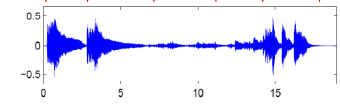
Music Synchronization: Audio-Audio

Beethoven's Fifth

Karajan



Scherbakov

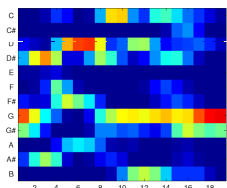


Synchronization: Karajan → Scherbakov

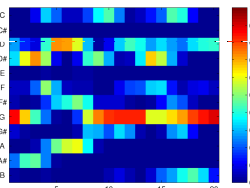
Music Synchronization: Audio-Audio

Feature extraction: chroma features

Karajan

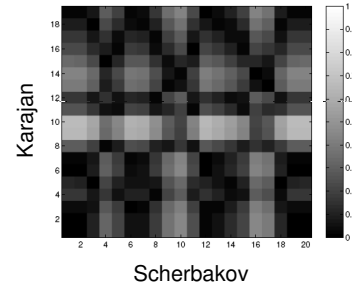


Scherbakov



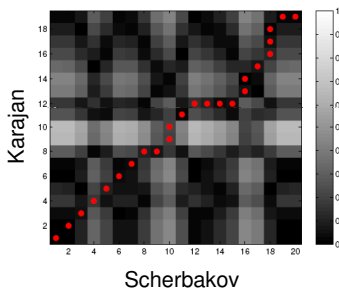
Music Synchronization: Audio-Audio

Cost matrix

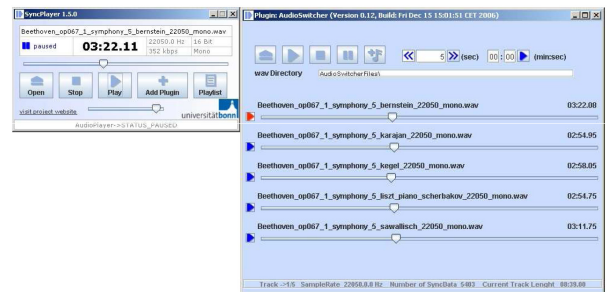


Music Synchronization: Audio-Audio

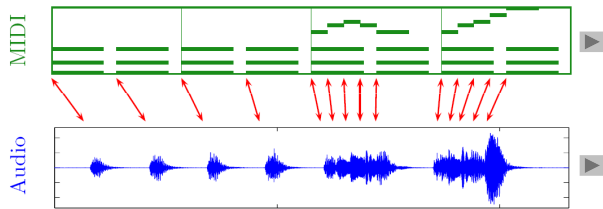
Cost-minimizing warping path



System: SyncPlayer/AudioSwitcher



Music Synchronization: MIDI-Audio



Music Synchronization: MIDI-Audio

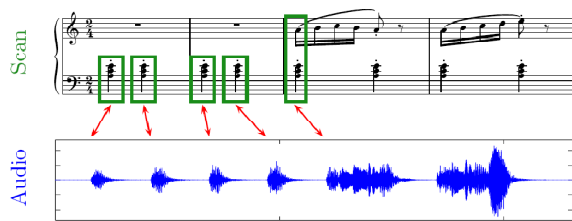
MIDI = meta data

Automated annotation

Audio recording

Sonification of annotations ▶ ▶

Music Synchronization: Scan-Audio

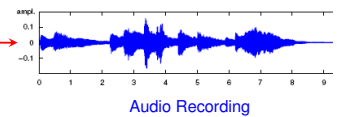


Music Synchronization: Scan-Audio

Scanned Sheet Music



Correspondence

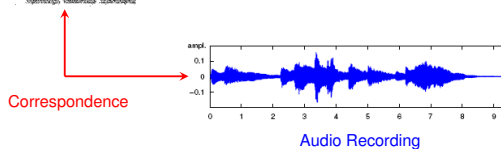


Music Synchronization: Scan-Audio

Scanned Sheet Music

Symbolic Note Events

OMR

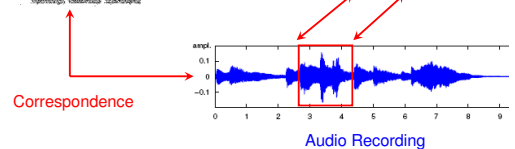


Music Synchronization: Scan-Audio

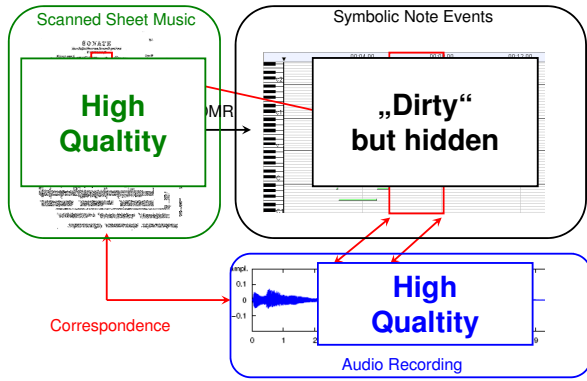
Scanned Sheet Music

Symbolic Note Events

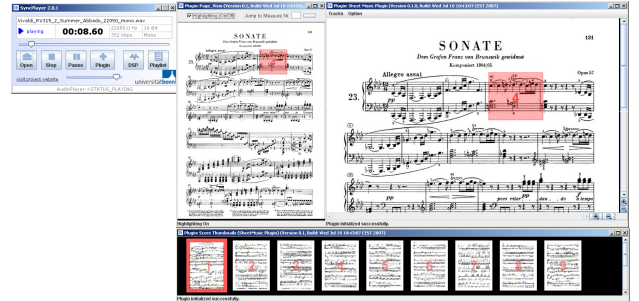
OMR



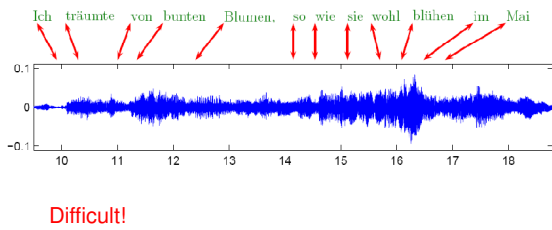
Music Synchronization: Scan-Audio



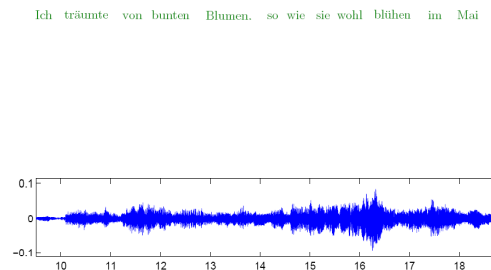
System: SyncPlayer/SheetMusic



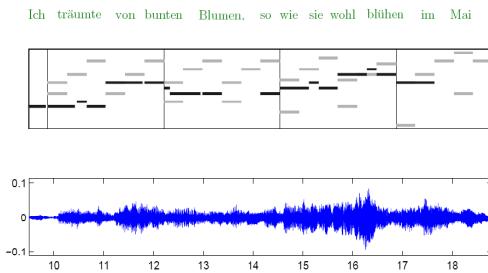
Music Synchronization: Lyrics-Audio



Music Synchronization: Lyrics-Audio

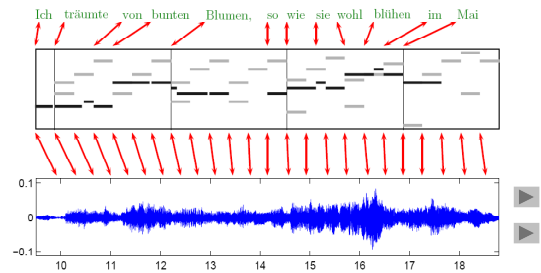


Music Synchronization: Lyrics-Audio



Music Synchronization: Lyrics-Audio

Lyrics-Audio → Lyrics-MIDI + MIDI-Audio

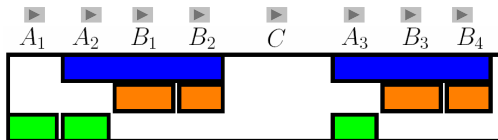


Audio Structure Analysis

Given: CD recording

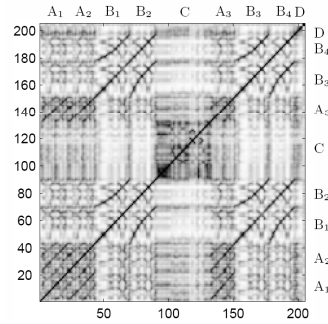
Goal: Automatic extraction of the **repetitive structure**
(or of the **musical form**)

Example: Brahms Hungarian Dance No. 5 (Ormandy)



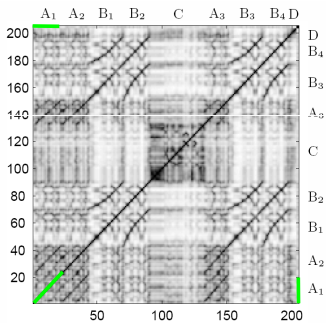
Audio Structure Analysis

Self-similarity matrix



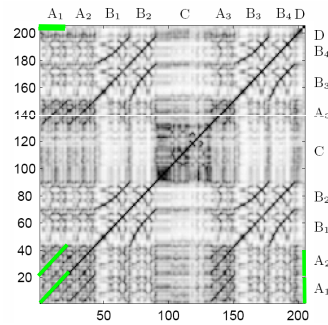
Audio Structure Analysis

Self-similarity matrix



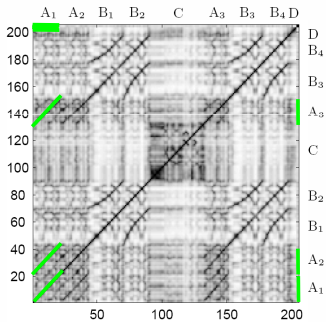
Audio Structure Analysis

Self-similarity matrix



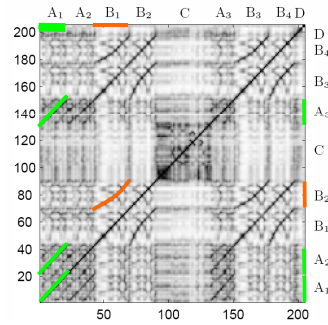
Audio Structure Analysis

Self-similarity matrix



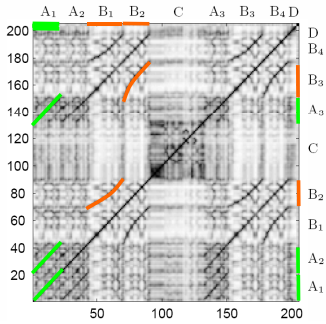
Audio Structure Analysis

Self-similarity matrix



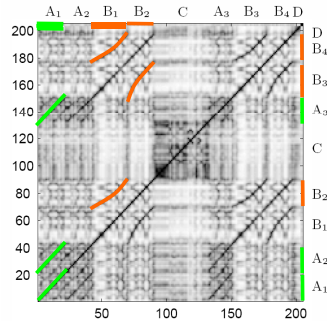
Audio Structure Analysis

Self-similarity matrix



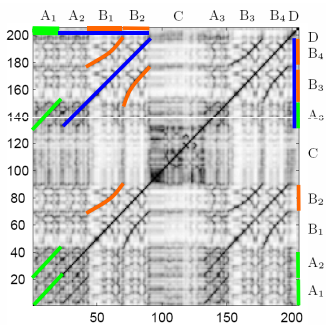
Audio Structure Analysis

Self-similarity matrix



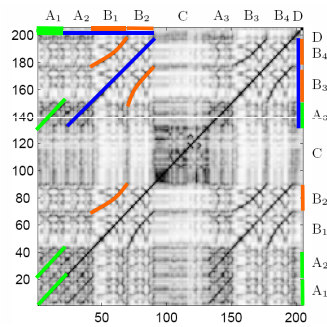
Audio Structure Analysis

Self-similarity matrix

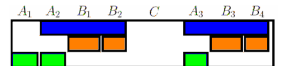


Audio Structure Analysis

Self-similarity matrix



Similarity cluster



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 |

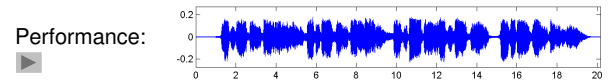
Music Processing

| 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 |

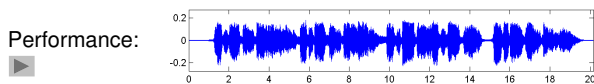
Performance Analysis

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')

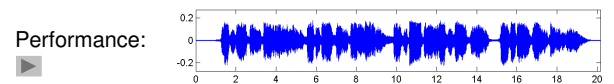
Performance Analysis



Performance Analysis



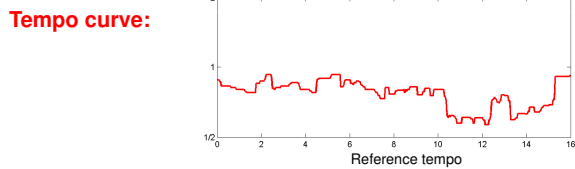
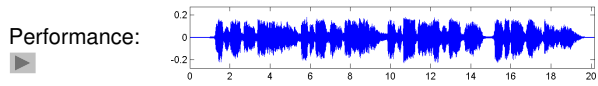
Performance Analysis



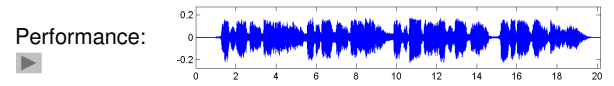
Strategy: Compute score-audio synchronization and derive tempo curve



Performance Analysis



Performance Analysis



What can be done if no reference is available?

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

Birth - day dear _____, Hap - py Birth - day to you!

Tempo Estimation

Tactus (beat)

Birth - day dear _____, Hap - py Birth - day to you!

Tempo Estimation

Tatum (temporal atom)

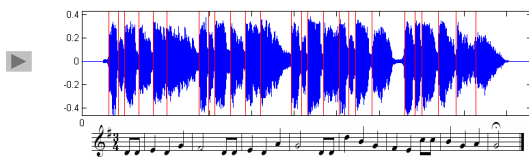
Birth - day dear _____, Hap - py Birth - day to you!

Tempo Estimation

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

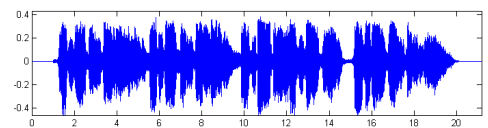
Tempo Estimation

Performance



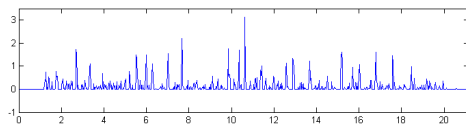
Tempo Estimation

Performance



Tempo Estimation

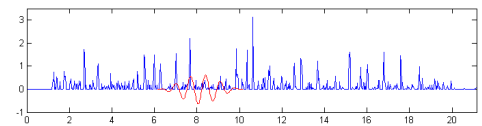
Novelty Curve



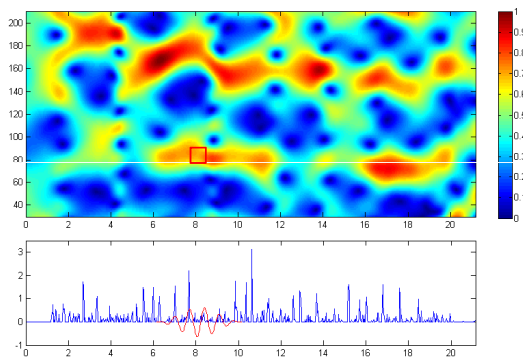
Tempo Estimation

Novelty Curve

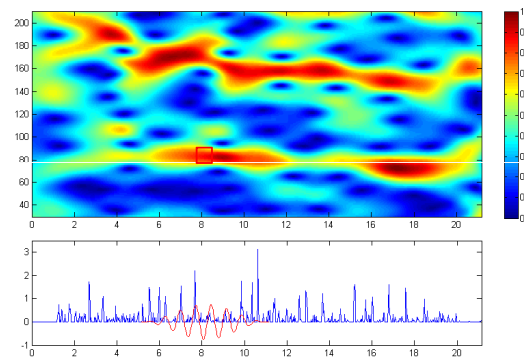
Periodicity Analysis



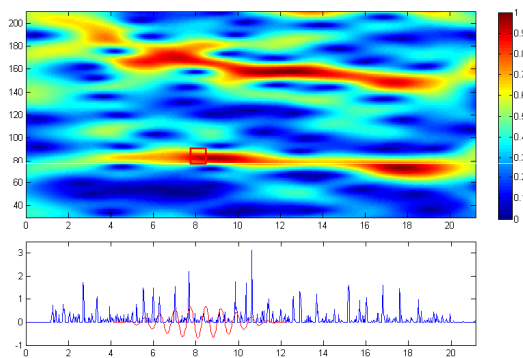
Tempo Estimation: Tempogram



Tempo Estimation: Tempogram



Tempo Estimation: Tempogram



Motivic Similarity

Var. 4: Vivace

A musical score for a piece titled "Var. 4: Vivace". The score is written in bass clef with a 2/4 time signature. It consists of four staves of music. The first staff starts with a forte (*f*) dynamic. The second and third staves continue the melodic line. The fourth staff includes piano (*p*) and forte (*f*) dynamics. A play button icon is located below the score.

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

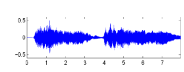
Sheet Music (Image)



MIDI



CD / MP3 (Audio)



Music

Multimodal Computing and Interaction

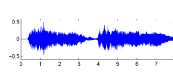
Sheet Music (Image)



MIDI



CD / MP3 (Audio)



MusicXML (Text)

```
<?xml version="1.0" encoding="UTF-8" ?>
<musicxml>
  <score>
    <part id="1" name="Violin I" type="string">
      <measure>
        <note>
          <pitch>
            <name>G4
          </pitch>
          <duration>4
        </note>
      </measure>
    </part>
  </score>
</musicxml>
```

Music

Singing / Voice (Audio)



Music Literature (Text)



Music Film (Video)



Dance / Motion (Mocap)

