INTERNATIONAL AUDIO LABORATORIES ERLANGEN
A joint institution of Fraunhofer IIS and Universität Erlangen-Nürnberg

AUDIO LABS

Automatische Erschließung von Musikdaten

Meinard Müller

International Audio Laboratories Erlangen

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FAU Friedrich-Alexander-Universität Erlangen-Nürnberg

Fraunhofer IIS

Meinard Müller

- Mathematics (Diplom/Master, 1997)
  Computer Science (PhD, 2001)
  Information Retrieval (Habilitation, 2007)
- Senior Researcher (2007-2012)
- Professor Semantic Audio Processing (since 2012)
- Former President of the International Society for Music Information Retrieval (MIR)
- IEEE Fellow for contributions to Music Signal Processing

universitätbonn

max planck institut informatik

FAU

ISMIR

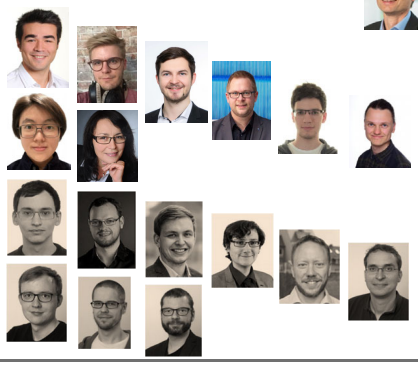
IEEE

Meinard Müller: Research Group

Semantic Audio Processing

- Yigitcan Özer
- Simon Schwär
- Johannes Zeitler
- Peter Meier
- Sebastian Strahl
- Uli Berendes
- Chiu Ching/Sunny
- Vlora Arifi-Müller

- Michael Krause
- Christof Weiß
- Sebastian Rosenzweig
- Frank Zalkow
- Hendrik Schreiber
- Christian Dittmar
- Stefan Balke
- Jonathan Driedger
- Thomas Prätzlich
- …



International Audio Laboratories Erlangen

Fraunhofer IIS

- Fraunhofer Institute for Integrated Circuits IIS
- Largest Fraunhofer institute with ≈ 1000 members
- Applied research for sensor, audio, and media technology

mp3

AUDIO LABS

FAU Friedrich-Alexander-Universität Erlangen-Nürnberg

- Friedrich-Alexander Universität Erlangen-Nürnberg (FAU)
- One of Germany's largest universities with ≈ 40,000 students
- Strong Technical Faculty

International Audio Laboratories Erlangen

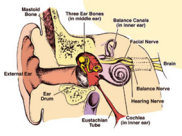
Audio

International Audio Laboratories Erlangen

Audio Coding

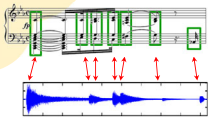
3D Audio

Audio



Psychoacoustics

Internet of Things

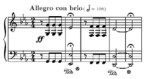


Music Processing

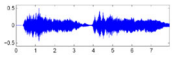
Music

Music Information Retrieval (MIR)

Sheet Music (Image)



CD / MP3 (Audio)



MusicXML (Text)

Dance / Motion (Mocap)

Music

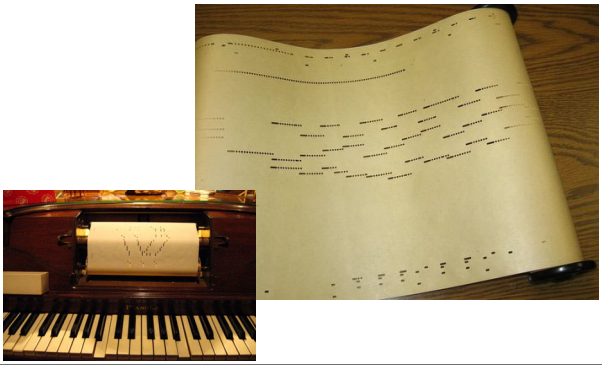
MIDI

Singing / Voice (Audio)

Music Film (Video)

Music Literature (Text)

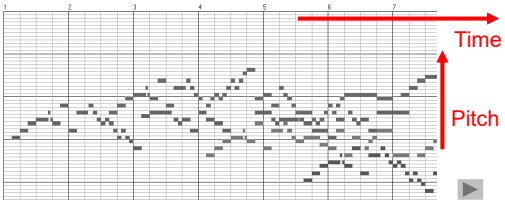
Piano Roll Representation (1900)



Piano Roll Representation

J.S. Bach, C-Major Fuge

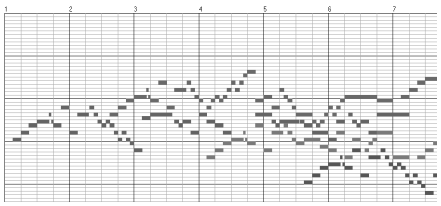
(Well Tempered Piano, BWV 846)



Piano Roll Representation

Query:

Goal: Find all occurrences of the query

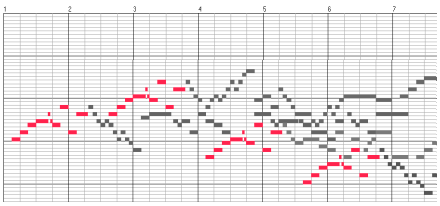


Piano Roll Representation

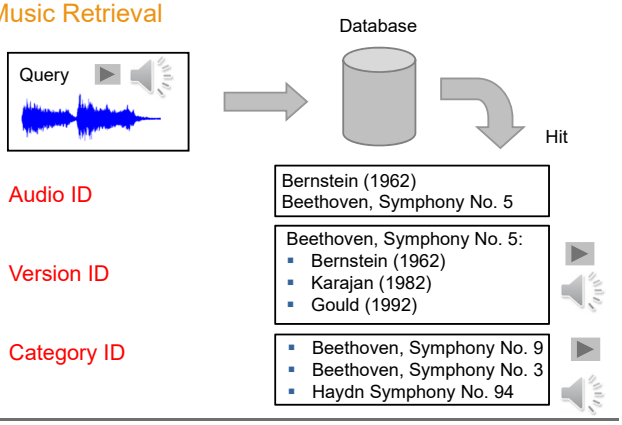
Query:

Goal: Find all occurrences of the query

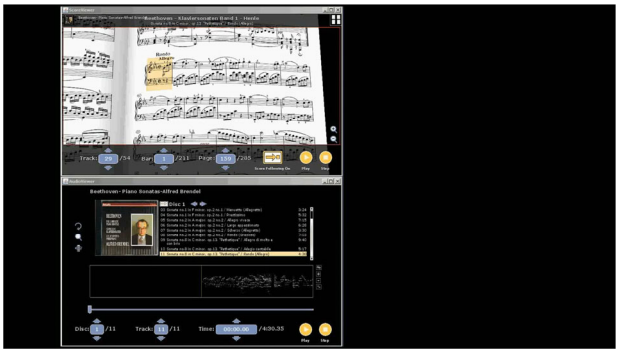
Matches:



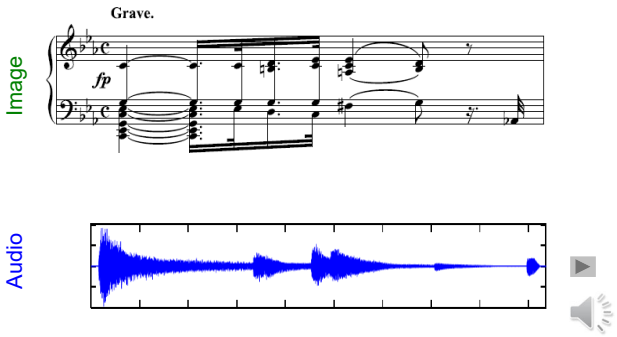
Music Retrieval



Music Synchronization

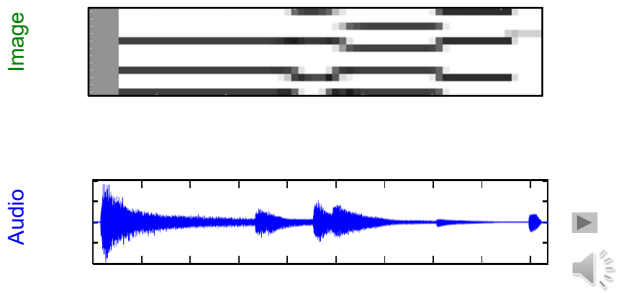


Music Synchronization: Image-Audio



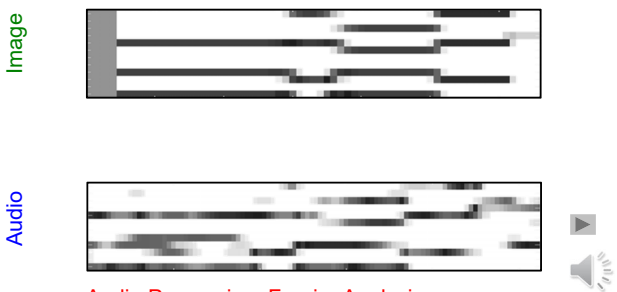
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition



Music Synchronization: Image-Audio

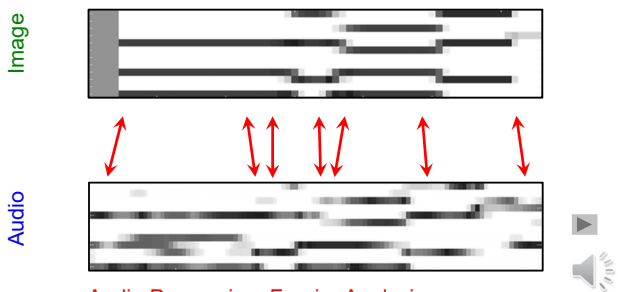
Image Processing: Optical Music Recognition



Audio Processing: Fourier Analysis

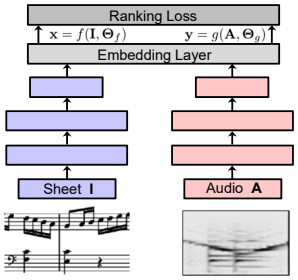
Music Synchronization: Image-Audio

Image Processing: Optical Music Recognition



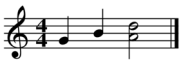
Audio Processing: Fourier Analysis

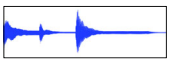
Music Synchronization: Image-Audio



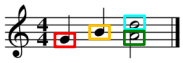
- Deep learning
- Embedding techniques
- Weak annotations
- Loss functions
- …

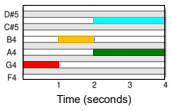
Score-Informed Audio Decomposition

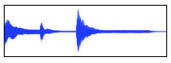




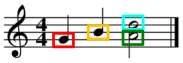
Score-Informed Audio Decomposition

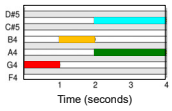


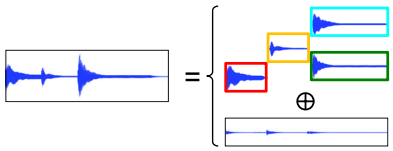




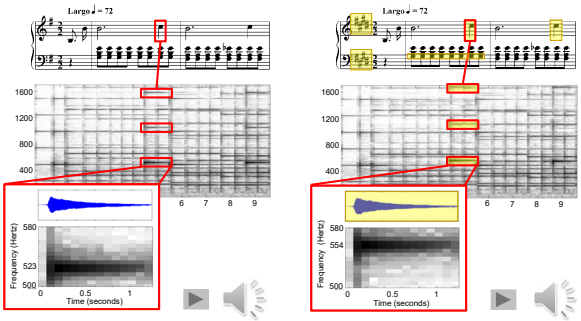
Score-Informed Audio Decomposition







Score-Informed Audio Decomposition



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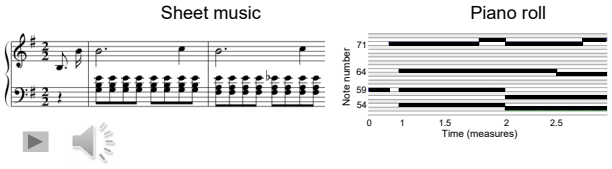
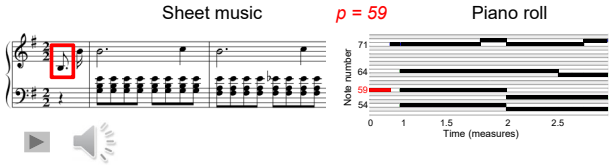


Score-Informed Audio Decomposition



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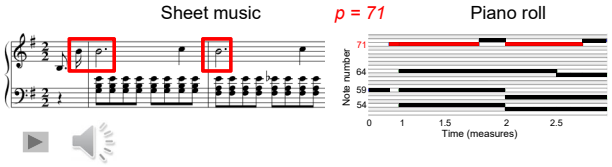

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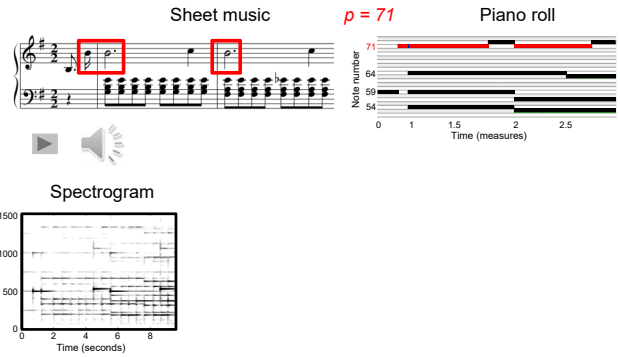
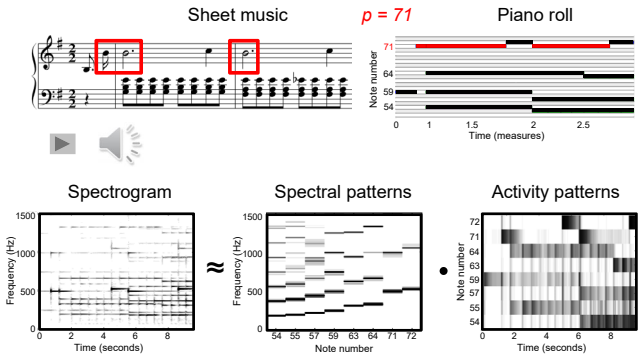
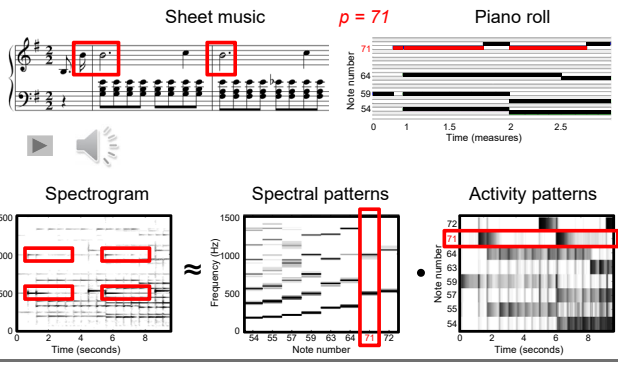


Score-Informed Audio Decomposition

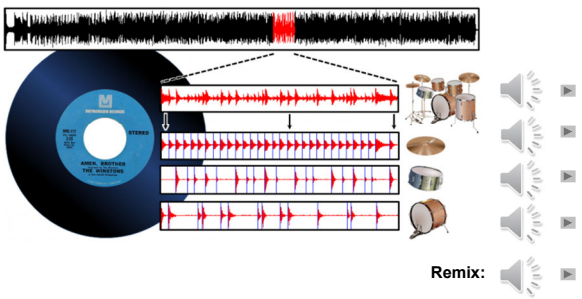


Score-Informed Audio Decomposition



Score-Informed Audio Decomposition

Informed Drum-Sound Decomposition

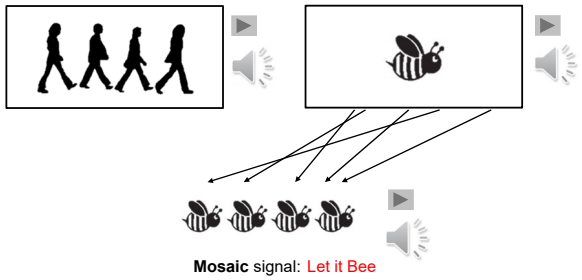


Score-Informed Audio Decomposition

Audio mosaicing (style transfer)

Target signal: Beatles–Let it be

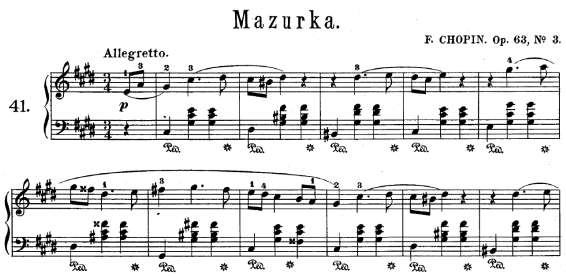
Source signal: Bees



Mosaic signal: Let it Bee

Why is Music Processing Challenging?

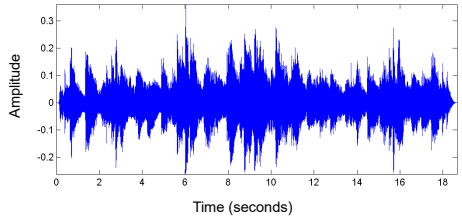
Example: Chopin, Mazurka Op. 63 No. 3



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

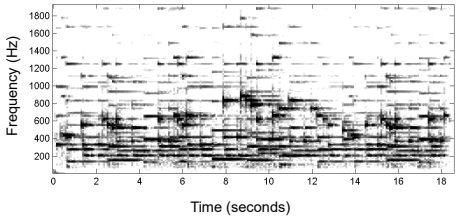
- Waveform



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

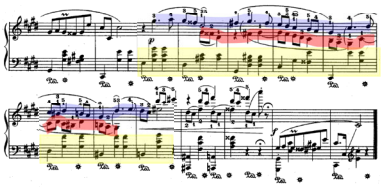
- Waveform / Spectrogram



Why is Music Processing Challenging?

Example: Chopin, Mazurka Op. 63 No. 3

- Waveform / Spectrogram
- Performance
  - Tempo
  - Dynamics
  - Note deviations
  - Sustain pedal
- Polyphony



Main Melody
Additional melody line
Accompaniment

Source Separation

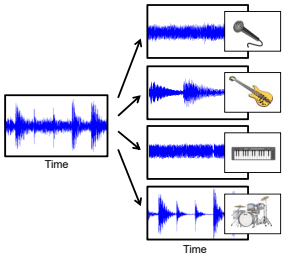
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”

Source Separation

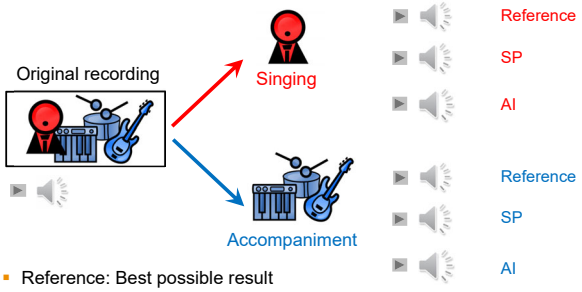
- Decomposition of audio stream into different sound sources
- Central task in digital signal processing
- “Cocktail party effect”
- Several input signals
- Sources are assumed to be statistically independent

Source Separation (Music)

- Main melody, accompaniment, drum track
- Instrumental voices
- Individual note events
- Only mono or stereo
- Sources are often highly dependent



AI-Based Source Separation



- Reference: Best possible result
- SP: Using traditional signal processing
- AI: Using data-driven approach

AI-Based Source Separation

- Yigitcan Özer
- PhD student in engineering
- Pianist

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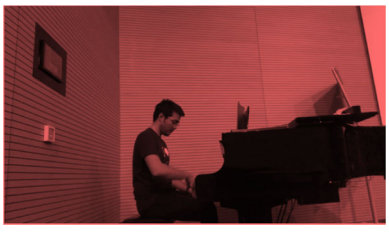
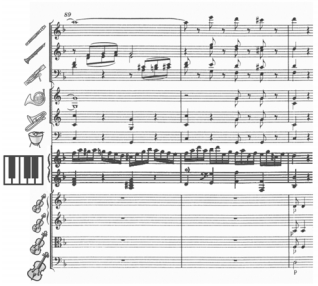
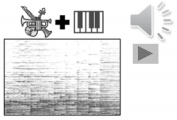


Only Piano!

Where is the orchestra?

AI-Based Source Separation





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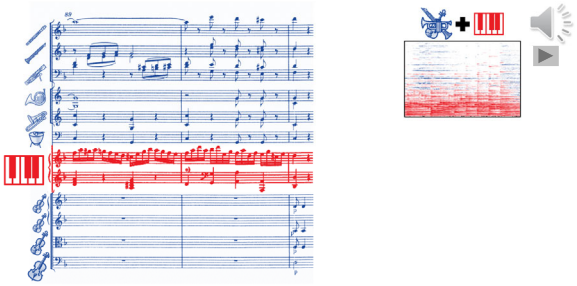

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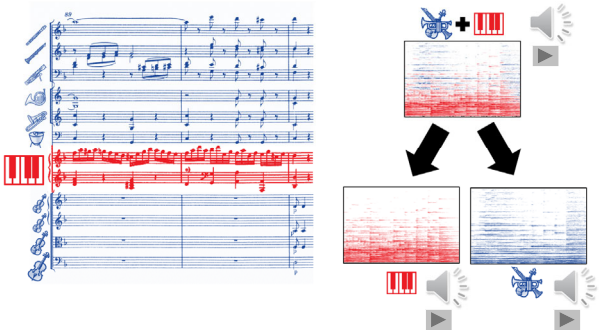

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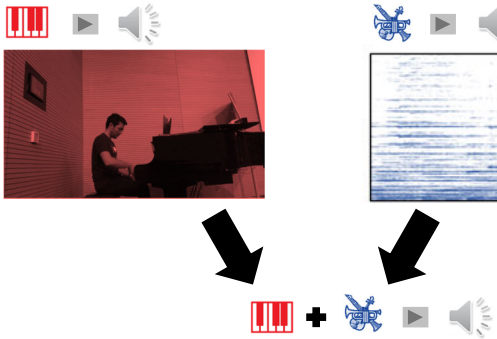


AI-Based Source Separation

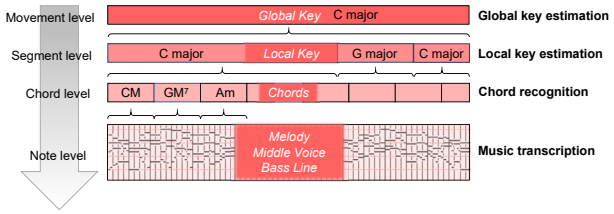
- Understanding modern machine learning techniques
- Critical questioning of artificial intelligence (AI) concepts
- Developing explainable AI models
- Educating next generation of scientists
- …

Computational Musicology

- Cooperation:
  - Rainer Kleinertz (Saarbrücken)
  - Stephanie Klauk (Saarbrücken)
  - Christof Weiß (Würzburg)
- Objectives
  - Harmony-based structural analysis
  - Beethoven Sonatas & Wagner's Ring
  - Interdisciplinary dialogue
- Since 2014: DFG-funded project

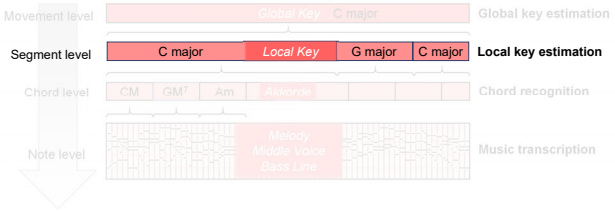
Computational Musicology: Harmony Analysis

- Different concepts
- Different temporal levels



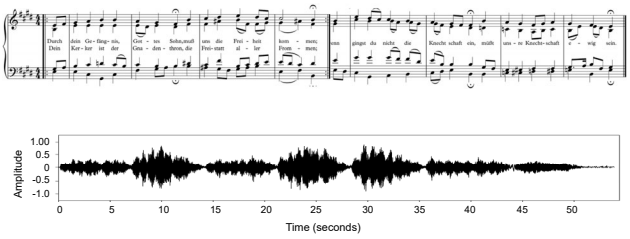
Computational Musicology: Harmony Analysis

- Different concepts
- Different temporal levels



Local Key Estimation

Example: J.S. Bach, Choral "Durch Dein Gefängnis" (*Johannespassion*)



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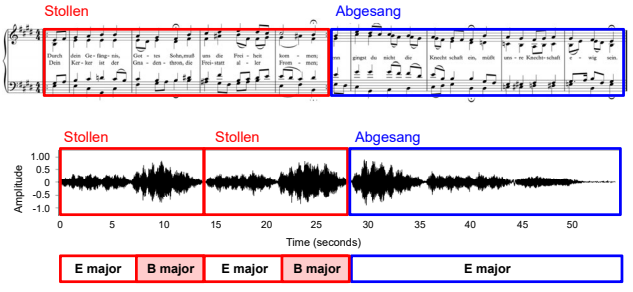
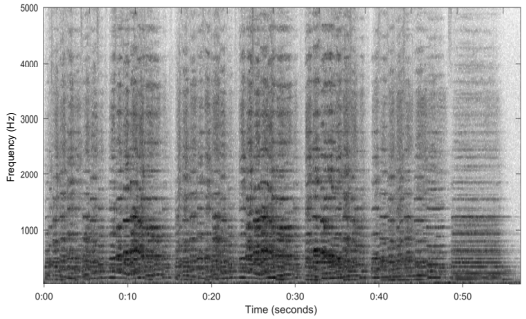


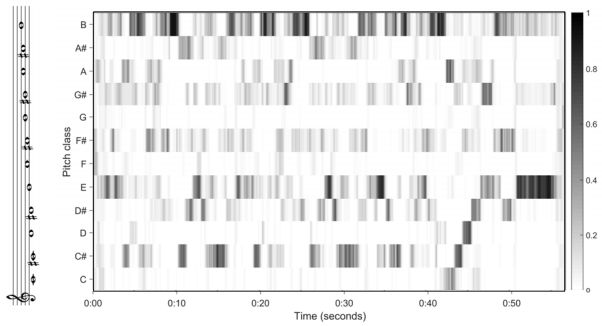
Local Key Estimation

Spectrogram



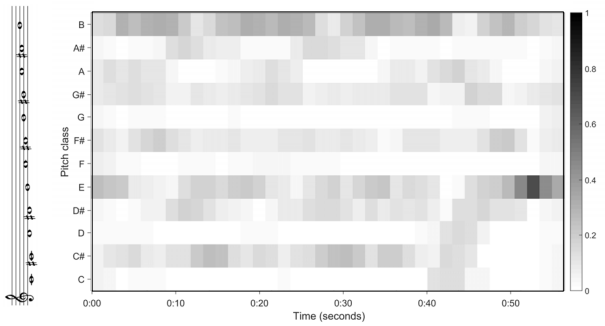
Local Key Estimation

Chromagram



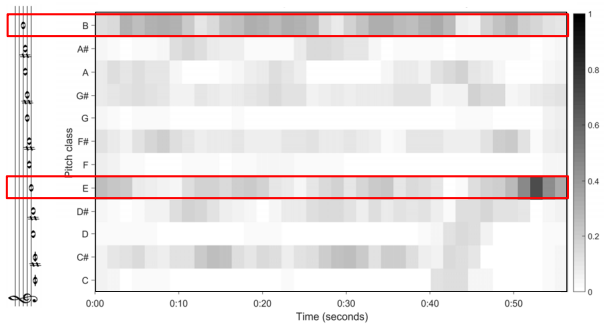
Local Key Estimation

Chromagram after smoothing



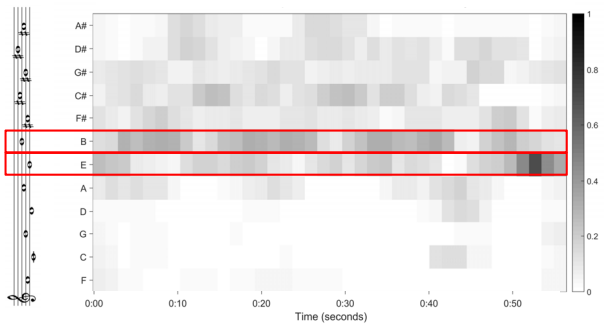
Local Key Estimation

Arrange pitch classes according to **perfect fifth** series



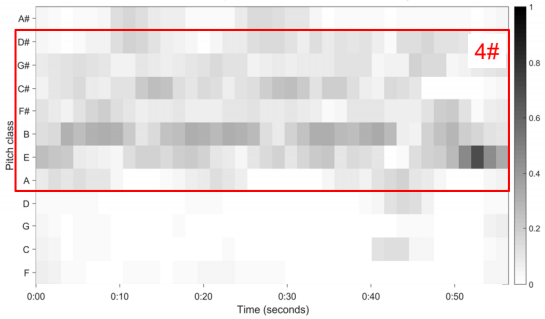
Local Key Estimation

Arrange pitch classes according to **perfect fifth** series



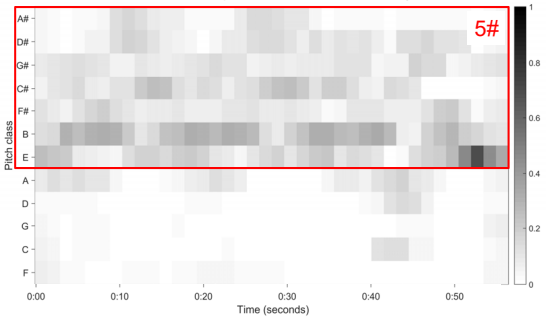
Local Key Estimation

Summarize pitch class content according to **diatonic scales**



Local Key Estimation

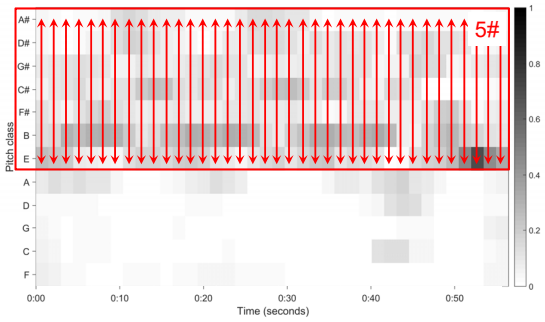
Summarize pitch class content according to **diatonic scales**



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

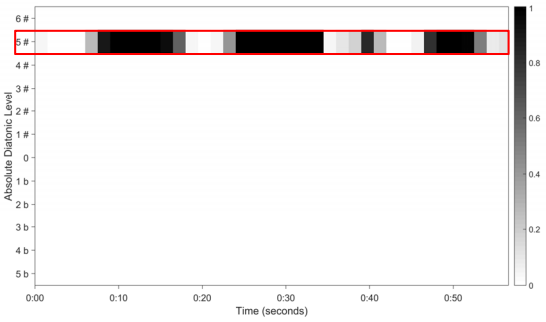
Multiply chroma values (in each column)



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

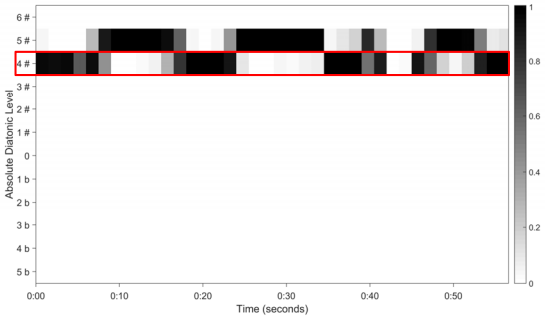
Multiply chroma values



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

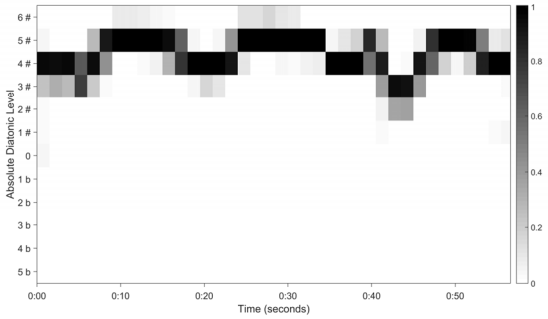
Multiply chroma values



Local Key Estimation

Summarize pitch class content according to **diatonic scales**

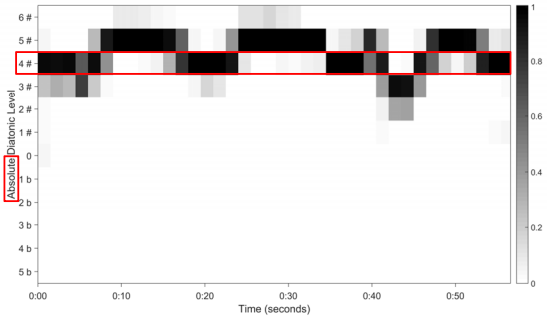
Multiply chroma values



Local Key Estimation

Normalize representation relative to global key

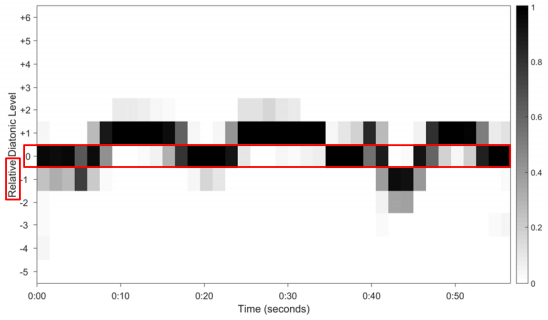
4 #
(E major)



Local Key Estimation

Normalize representation relative to global key

4 #
(E major)

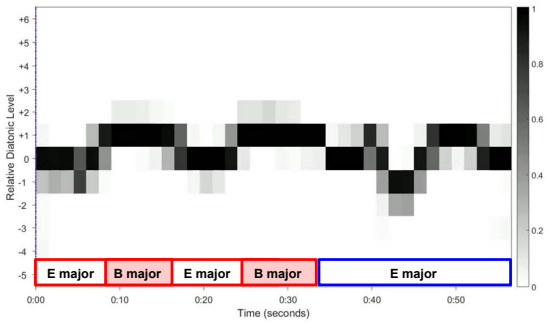


Local Key Estimation

J.S. Bach: Choral "Durch Dein Gefängnis" (*Johannespassion*)

Recording: Scholars Baroque Ensemble, Naxos 1994

4 #
(E major)

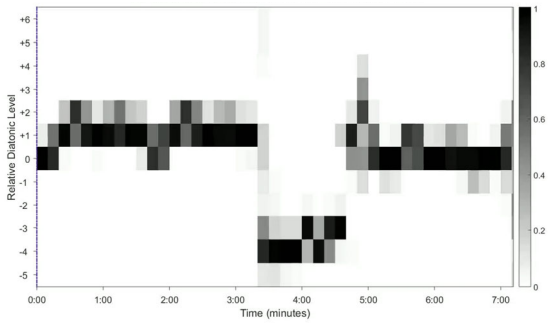


Local Key Estimation

L. v. Beethoven: Piano Sonata No. 10 (Op. 14 Nr. 2), 1. Allegro

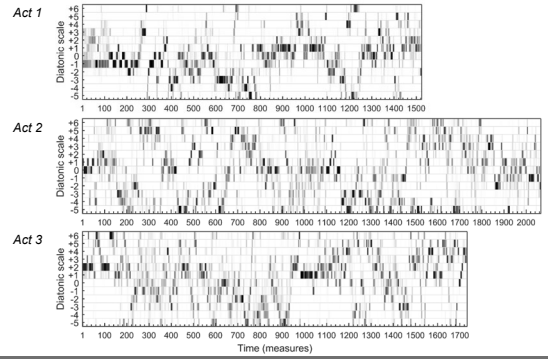
Recording: Barenboim, EMI 1998

1 #
(G major)



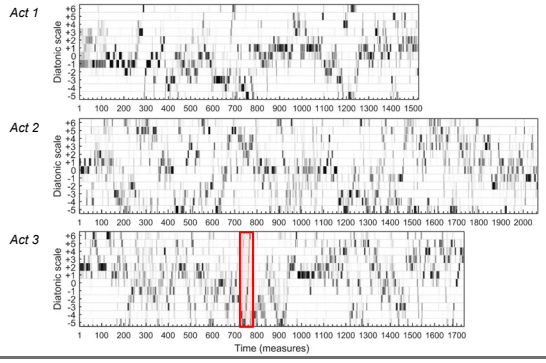
Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



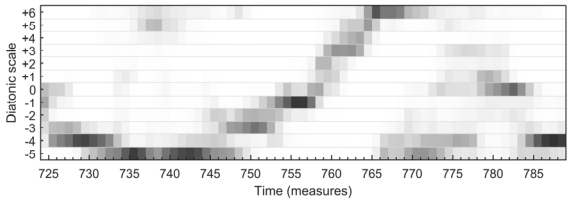
Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)



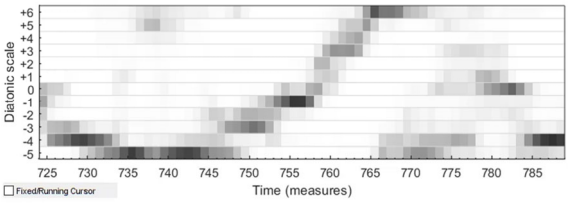
Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)
Act 3, measure 724–789 (*Wotan's punishment*)



Local Key Estimation

R. Wagner: WWV 86 B (*Die Walküre*)
Act 3, measure 724–789 (*Wotan's punishment*)



Computational Ethnomusicology: Traditional Georgian Vocal Music

- Interdisciplinary research project
  - Prof. Dr. Frank Scherbaum (Potsdam)
  - Dr. Nana Mzhavanadze (Tbilisi)
  - Sebastian Rosenzweig (FAU)
- Objective: Tonal analysis
- 2018 – 2022: DFG-funded project

Universität Potsdam

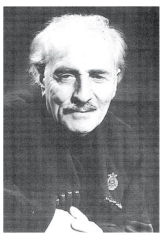
FAU Friedrich-Alexander-Universität Erlangen-Nürnberg

DFG

Traditional Georgian Vocal Music

Example: Erkomaishvili corpus

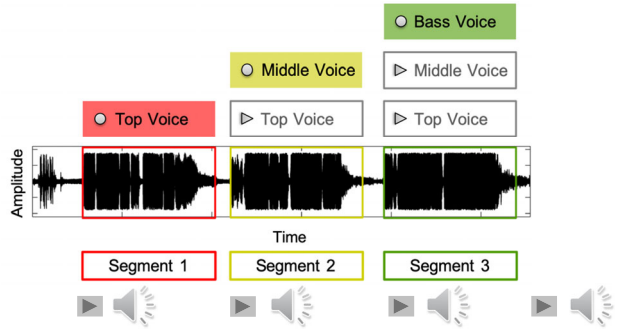
- Collection of traditional three-voice Georgian songs
- Performed by the former Georgian master chanter Artem Erkomaishvili (1887-1967)
- Recordings of 100 songs using tape recorders (1966)



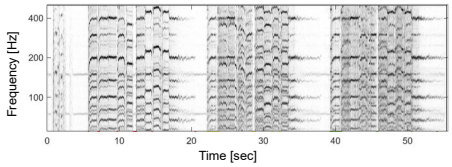
"*Original masterpieces of Georgian musical thinking.*" (Shugliashvili, 2014)

Traditional Georgian Vocal Music

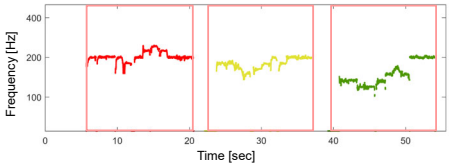
Example: Erkomaishvili corpus



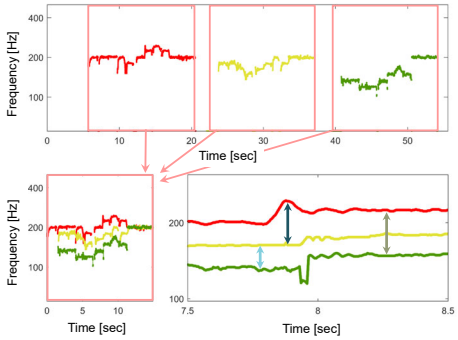
Traditional Georgian Vocal Music



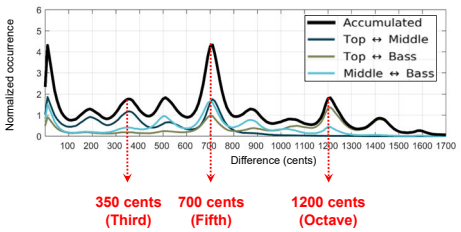
Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



Traditional Georgian Vocal Music



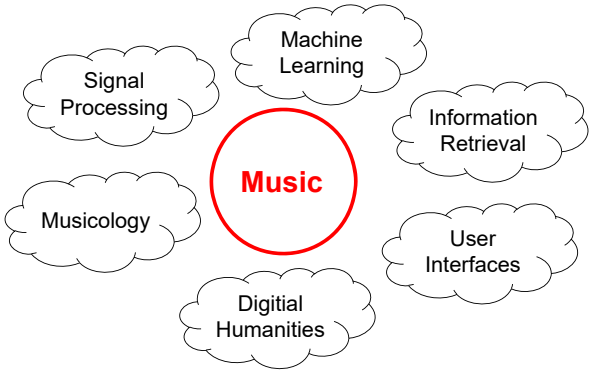
- Peak at 350 cents (between minor and major third)
- **Non-western temperament**

Traditional Georgian Vocal Music

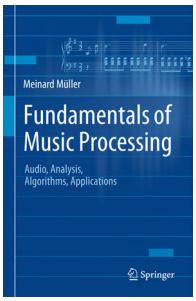
- Recordings from field expedition in 2016
- 216 performances
- Multitrack audio + video
  - Room, HSM, LRX
- Total duration: 6 h

Room Microphone

Music Information Retrieval (MIR)



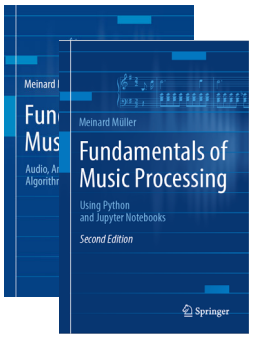
Fundamentals of Music Processing (FMP)



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
Springer, 2015

Accompanying website:
www.music-processing.de

Fundamentals of Music Processing (FMP)



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Fundamentals of Music Processing
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2nd edition
Meinard Müller
Fundamentals of Music Processing
Using Python and Jupyter Notebooks
Springer, 2021

Fundamentals of Music Processing (FMP)

Chapter	Music Processing Scenario
1	Music Represenations
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

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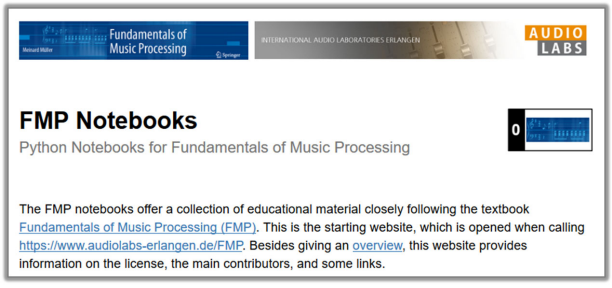
FMP Notebooks: Education & Research



https://www.audiolabs-erlangen.de/FMP

References (FMP Notebooks)

- Meinard Müller: Fundamentals of Music Processing – Using Python and Jupyter Notebooks. 2nd Edition, Springer, 2021. https://www.springer.com/gp/book/9783030698072
- Meinard Müller and Frank Zalkow: libfmp: A Python Package for Fundamentals of Music Processing. Journal of Open Source Software (JOSS), 6(63): 1–5, 2021. https://joss.theoj.org/papers/10.21105/joss.03326
- Meinard Müller: An Educational Guide Through the FMP Notebooks for Teaching and Learning Fundamentals of Music Processing. Signals, 2(2): 245–285, 2021. https://www.mdpi.com/2624-6120/2/2/18
- Meinard Müller and Frank Zalkow: FMP Notebooks: Educational Material for Teaching and Learning Fundamentals of Music Processing. Proc. International Society for Music Information Retrieval Conference (ISMIR): 573–580, 2019. https://zenodo.org/record/3527872#.YOhEQOgzaUk
- Meinard Müller, Brian McFee, and Katherine Kinnaird: Interactive Learning of Signal Processing Through Music: Making Fourier Analysis Concrete for Students. IEEE Signal Processing Magazine, 38(3): 73–84, 2021. https://ieeexplore.ieee.org/document/9418542

Resources (Group Meinard Müller)

- FMP Notebooks:
  https://www.audiolabs-erlangen.de/FMP
- libfmp:
  https://github.com/meinardmueller/libfmp
- synctoolbox:
  https://github.com/meinardmueller/synctoolbox
- libtsm:
  https://github.com/meinardmueller/libtsm
- Preparation Course Python (PCP) Notebooks:
  https://www.audiolabs-erlangen.de/resources/MIR/PCP/PCP.html
  https://github.com/meinardmueller/PCP