

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



Tutorial 5, ISMIR  
Milan, November 5, 2023

# Learning with Music Signals: Technology Meets Education

## Overview

**Meinard Müller**

International Audio Laboratories Erlangen  
[meinard.mueller@audiolabs-erlangen.de](mailto:meinard.mueller@audiolabs-erlangen.de)

# 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 (ISMIR)
- IEEE Fellow for contributions to Music Signal Processing



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



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

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# International Audio Laboratories Erlangen



**Audio**

# International Audio Laboratories Erlangen

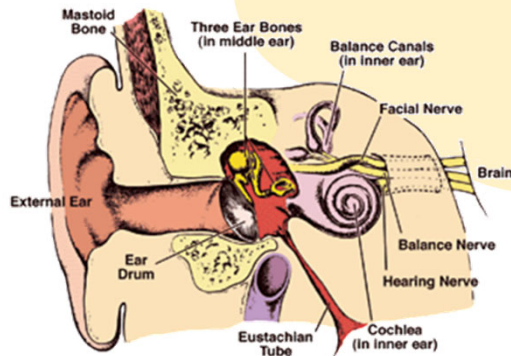
Audio Coding



3D Audio



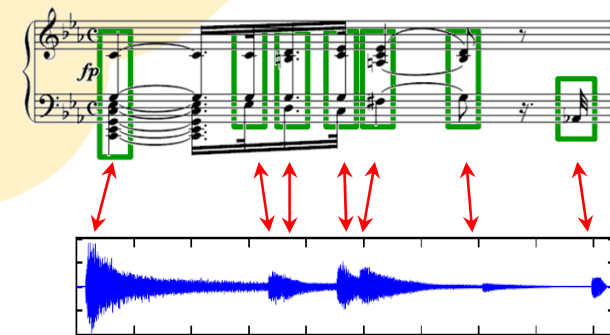
# Audio



Psychoacoustics



Internet of Things



Music Processing

# AudioLabs – FAU

- Prof. Dr. Jürgen Herre  
Audio Coding
- Prof. Dr. Bernd Edler  
Audio Signal Analysis
- Prof. Dr. Meinard Müller  
Semantic Audio Processing
- Prof. Dr. Emanuël Habets  
Spatial Audio Signal Processing
- Prof. Dr. Nils Peters  
Audio Signal Processing
- Dr. Stefan Turowski  
Coordinator AudioLabs-FAU



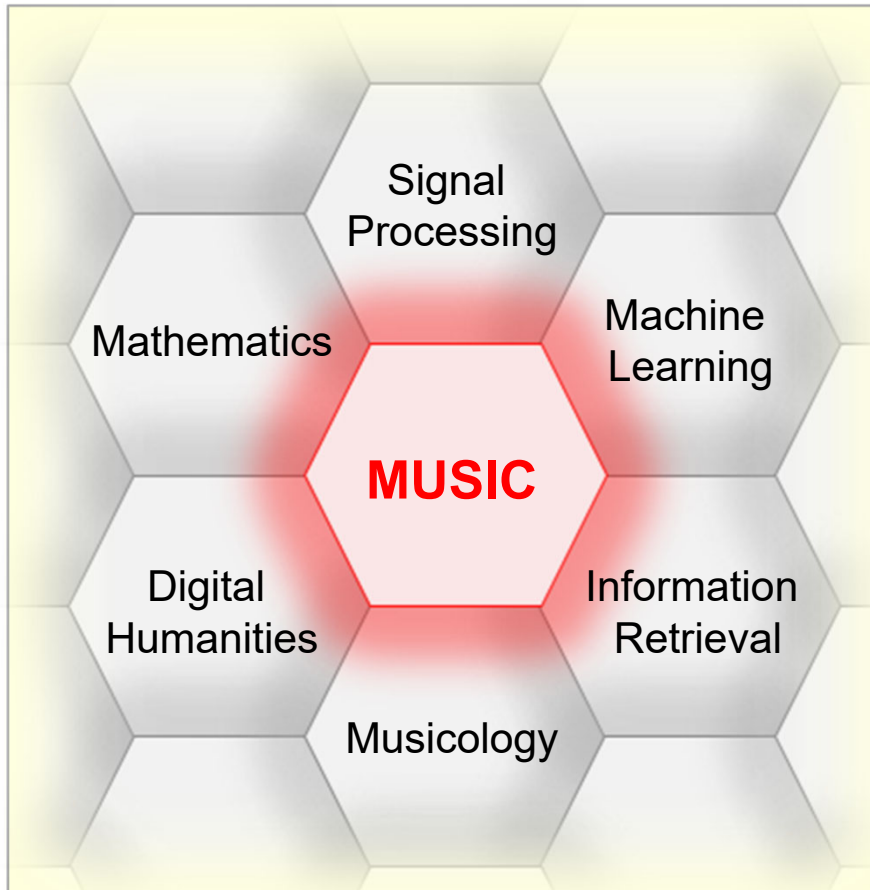
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# Music Processing





# Music Processing: A Multifaceted Research Area

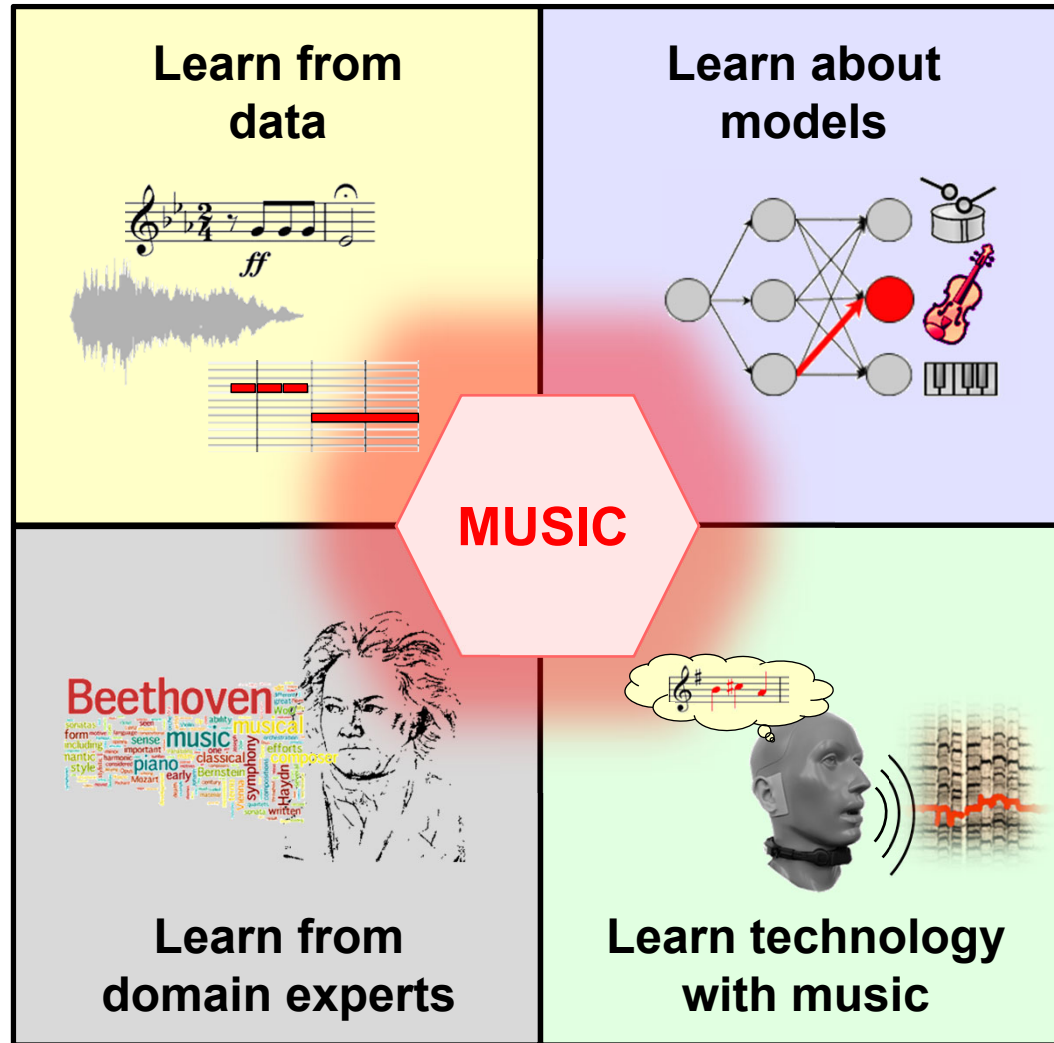


## Music ...

- important part of our lives ...
- ... Spotify, Pandora, iTunes, ...
- interdisciplinary research
- intuitive entry point to education

# Learning with Music Signals

## Technology Meets Education



- Machine learning for music signal processing
- Interpretable models and knowledge integration
- Music understanding and applications
- Interactive learning in engineering through music

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# Schedule

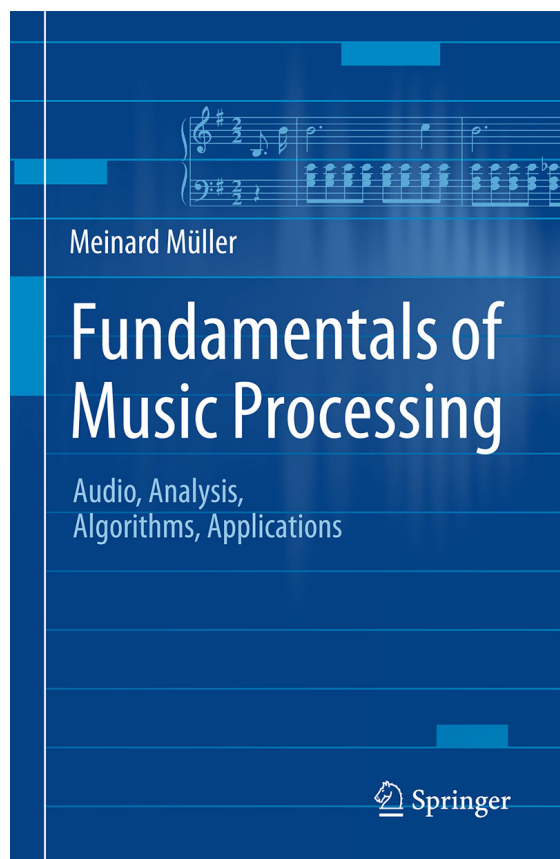
- Part 0: Overview
- Part I: Music Retrieval
- **Coffee Break**
- Part II: Audio Decomposition
- Part III: FMP Notebooks

## Slides/Material:

<https://www.audiolabs-erlangen.de/meinard>

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

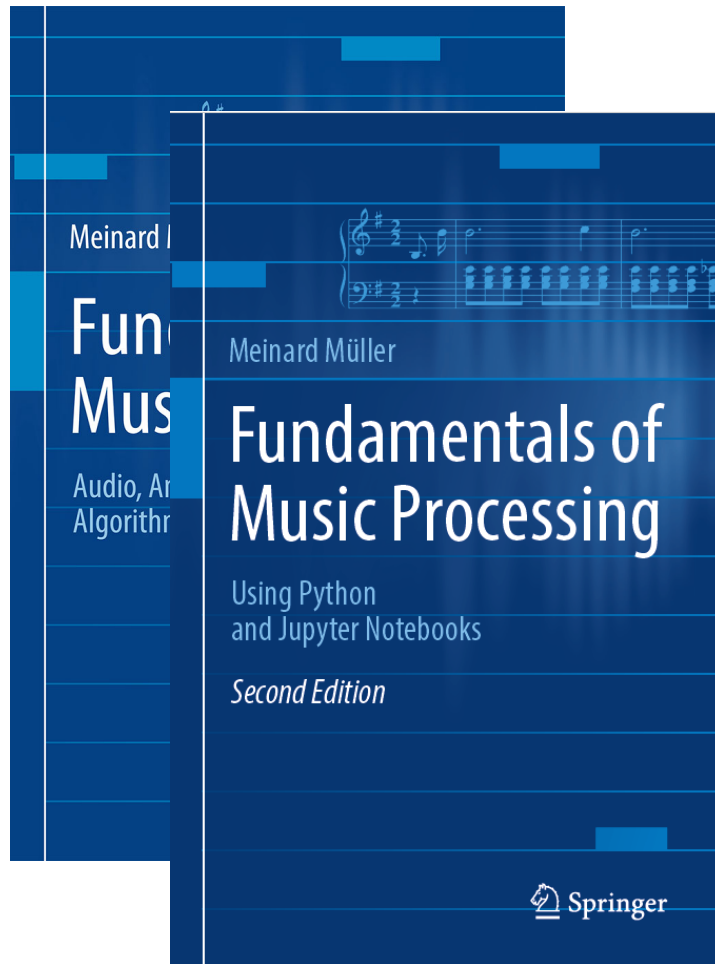
# Fundamentals of Music Processing (FMP)



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

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

# Fundamentals of Music Processing (FMP)

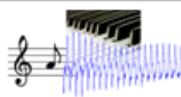

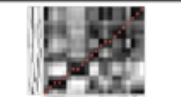
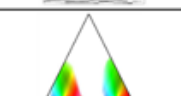

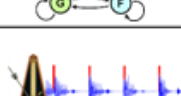




Meinard Müller  
Fundamentals of Music Processing  
Audio, Analysis, Algorithms, Applications  
Springer, 2015

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

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

# Fundamentals of Music Processing (FMP)

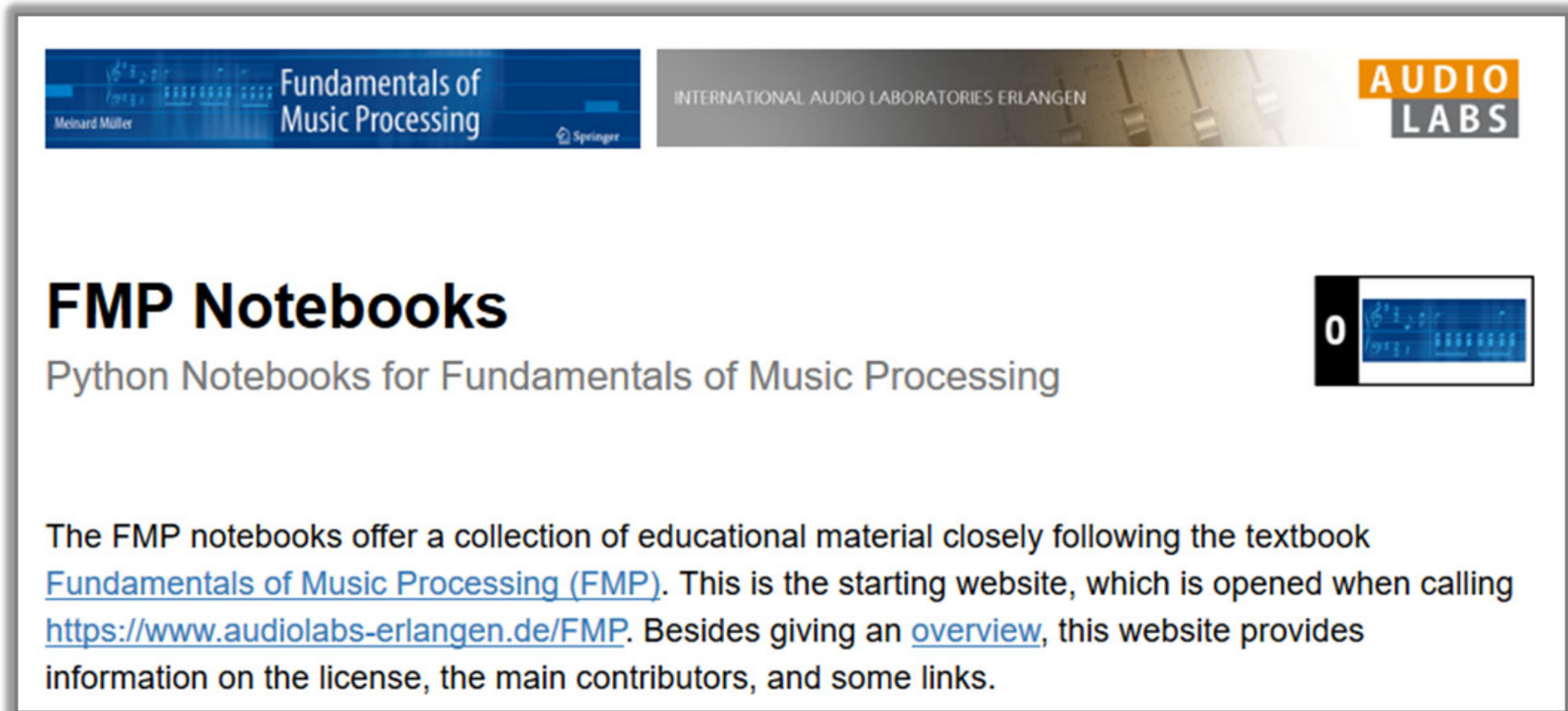
Chapter		Music Processing Scenario
1		Music Representations
2		Fourier Analysis of Signals
3		Music Synchronization
4		Music Structure Analysis
5		Chord Recognition
6		Tempo and Beat Tracking
7		Content-Based Audio Retrieval
8		Musically Informed Audio Decomposition

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

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

2nd edition  
Meinard Müller  
Fundamentals of Music Processing  
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Springer, 2021

# FMP Notebooks: Education & Research



The screenshot shows the header of the FMP Notebooks website. On the left, there is a blue banner for the book 'Fundamentals of Music Processing' by Meinard Müller, published by Springer. To the right of this banner is the text 'INTERNATIONAL AUDIO LABORATORIES ERLANGEN' and the 'AUDIO LABS' logo. Below the banner, the main heading reads 'FMP Notebooks' in a large, bold, black font, followed by the subtitle 'Python Notebooks for Fundamentals of Music Processing' in a smaller, grey font. To the right of the subtitle is a small thumbnail image of a notebook page with a black bar on the left containing the number '0'. Below the heading and subtitle, a paragraph of text describes the notebooks: 'The FMP notebooks offer a collection of educational material closely following the textbook [Fundamentals of Music Processing \(FMP\)](#). This is the starting website, which is opened when calling <https://www.audiolabs-erlangen.de/FMP>. Besides giving an [overview](#), this website provides information on the license, the main contributors, and some links.'

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

# References (FMP Textbook & 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>

# Resources

- librosa:  
<https://librosa.org/>
- madmom:  
<https://github.com/CPJKU/madmom>
- Essentia Python tutorial:  
[https://essentia.upf.edu/essentia\\_python\\_tutorial.html](https://essentia.upf.edu/essentia_python_tutorial.html)
- mirdata:  
<https://github.com/mir-dataset-loaders/mirdata>
- open-unmix:  
<https://github.com/sigsep/open-unmix-pytorch>
- Open Source Tools & Data for Music Source Separation:  
<https://source-separation.github.io/tutorial/landing.html>

