Emerging Topics: Music Synthesis for Wind Music

Dr.-Ing. Stefan Balke

Bamberg, 02.02.2026

Friedrich-Alexander-Universität Erlangen-Nürnberg

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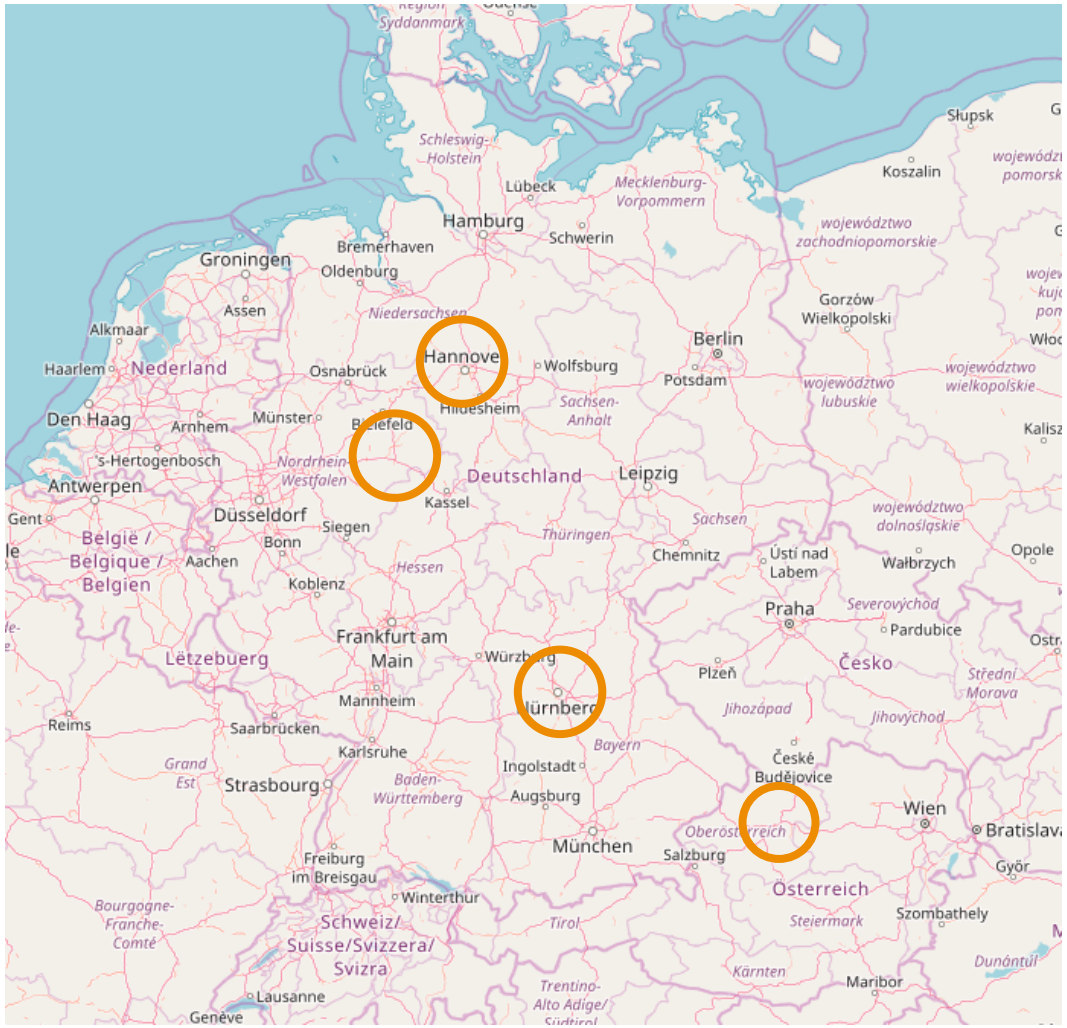
Professional Background



- Electrical Engineering (Dipl.-Ing.) @ Uni Hannover
- PhD in **Erlangen** @ AudioLabs
- PostDoc in **Linz** @ JKU
- Teamlead Data Science in **Paderborn** @ pmOne
- Professor at Hochschule Weserbergland, Hameln
- **Current:** PostDoc in Erlangen @ AudioLabs (Habilitation)

- **Teaching:**
  - TH OWL: Datenbanken (2020-23), Data Science Seminar (2025)
  - Hochschule Weserbergland
  - Hochschule Trier: Machine Learning (2020-23)
  - Controller Institut Wien: Data Science

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Community Work

- **1996:** Weserberglandorchester Bödexen (WBO)
- **Since 2008:** Sinfonischen Blasorchester Höxter (SBO)
- **Since 2019:** Organizing Committee SBO
- **2020-23:** Board member Stadtmusikverband Höxter
- **Since 2021:** Co-Conductor WBO (with Nicole Krois)
- **Since 2025:** Board member SBO HX e.V.
- **Since 2026:** Board member ISMIR (member-at-large)

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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

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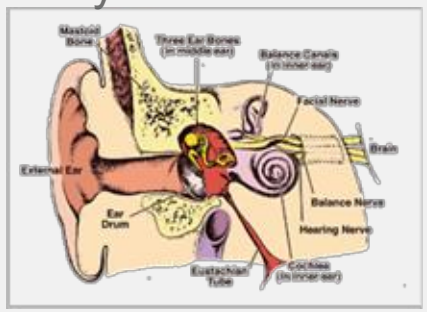
International Audio Laboratories Erlangen

Audio Coding

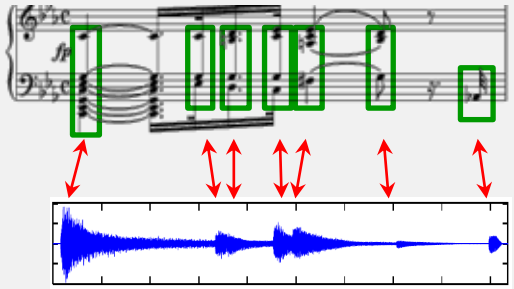
3D Audio

Psychoacoustics



AUDIO

Music Processing



Internet of Things

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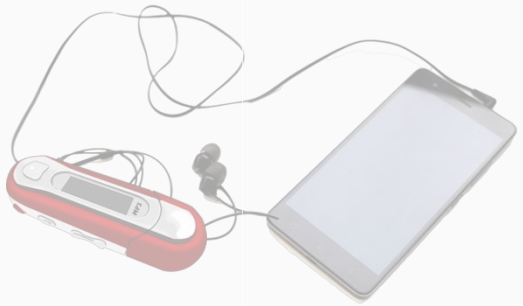
International Audio Laboratories Erlangen

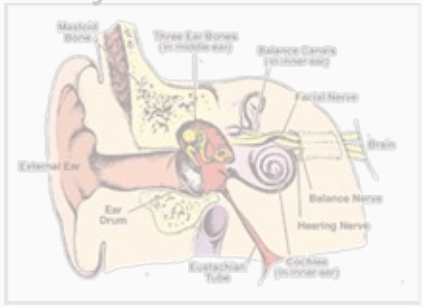
Prof. Meinard Müller

Audio Coding



3D Audio

Psychoacoustics



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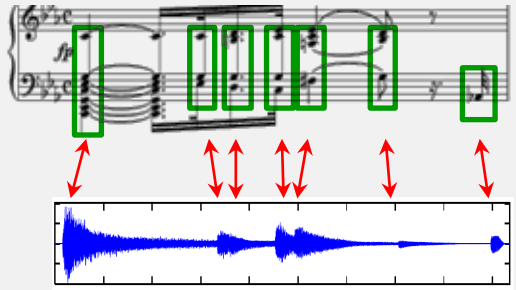
Music Processing



Internet of Things

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Meinard Müller: Research Group

- Ben Maman
- Simon Schwär
- Johannes Zeitler
- Abhirup Saha
- Sebastian Strahl
- Uli Berendes
- Vlora Arifi-Müller
- Stefan Balke
- Manuel Peters









- Ching-Yu Chiu (Sunny)
- Peter Meier
- Yigitcan Özer
- Michael Krause
- Christof Weiß
- Sebastian Rosenzweig
- Frank Zalkow
- Hendrik Schreiber
- Christian Dittmar
- Stefan Balke
- Jakob Abeßer
- Jonathan Driedger
- Thomas Prätzlich
- …












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Music Processing for Wind Music
Outline

Part 1: Datasets

- Introduction & Overview
- ChoraleBricks dataset
- ChoraleWind dataset

Part 2: Synthesis

- Introduction & Overview
- Pulsetable Synthesis
- Differentiable Pulsetable Synthesis

Thanks to my colleagues:


Meinard Müller


Simon Schwär


Christian Dittmar


Manuel Peters

And all the great contributions from the ISMIR and signal processing community.

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Part 1

DATASETS

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Datasets
Overview in the MIR Community

- Hundreds of datasets available in den MIR community
- Overview of existing datasets: https://github.com/ismir/mir-datasets
  (>200 entries…constantly growing)
- Datasets usually contain audio data (mono, stereo, multitrack) + annotations

- **Annotations:**
  Beats, structure, melody, fundamental frequency, harmony, metadata (artist, title, genre), …
- Not all audio data can be shared publicly → copyright restrictions

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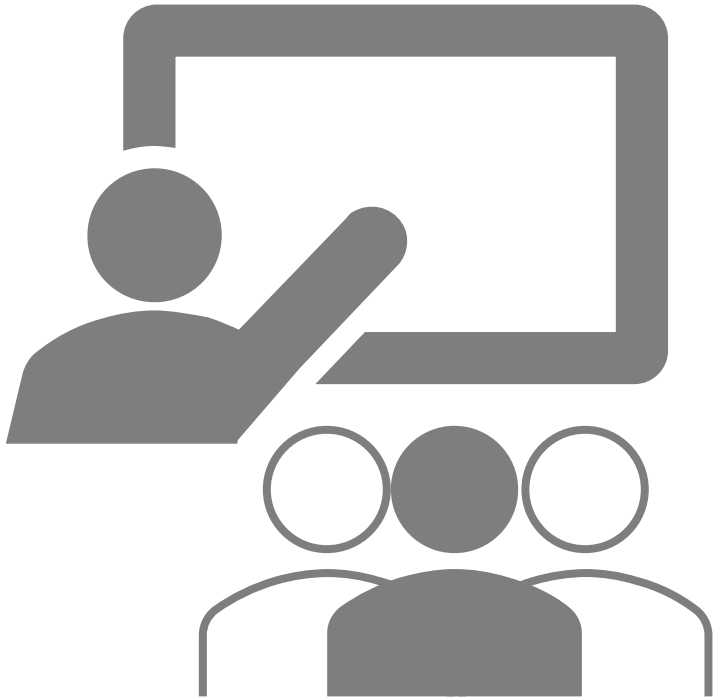
Datasets

Your opinion



Why are public datasets important (not only) in music research?

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Datasets

Why are datasets important in music research?

- Basis for experiments: validate or falsify research questions/theories
- Serve as training data: No data → no machine learning models
- Facilitate exchange between researchers
- Evaluation on public datasets can help to make works comparable
- Preservation of cultural heritage

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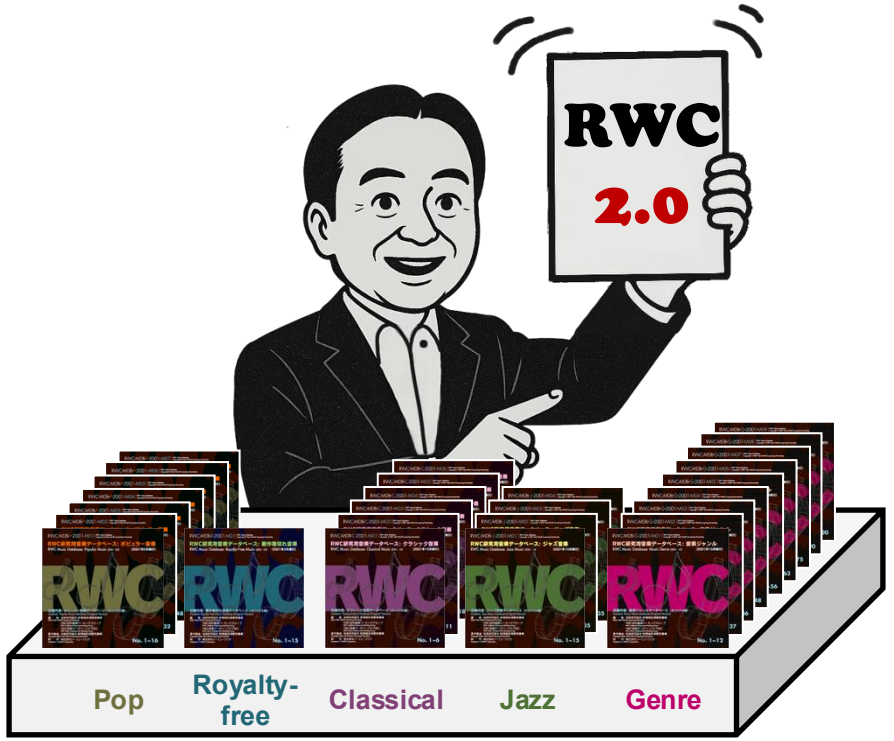
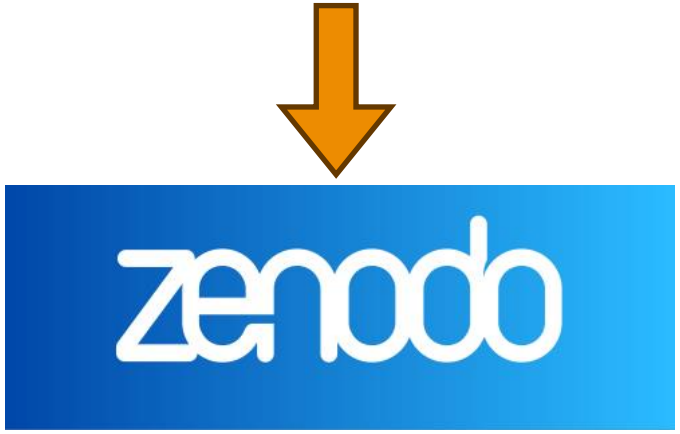
Datasets
Spotlight: RWC

- Released in 2002 by Masataka Goto
- First dataset with cleared licenses
- Most of the 315 pieces new compositions mimicing different styles
- **Annotations:** Beats, structure, lyrics, melody, sheet music (MIDI)





Stefan Balke, Johannes Zeitler, Vlora Arifi-Müller, Brian McFee, Tomoyasu Nakano, Masataka Goto, and Meinard Müller:
RWC Revisited: Toward a Community-Driven Music Information Retrieval Corpus
Accepted for TISMIR, 2026.

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Datasets

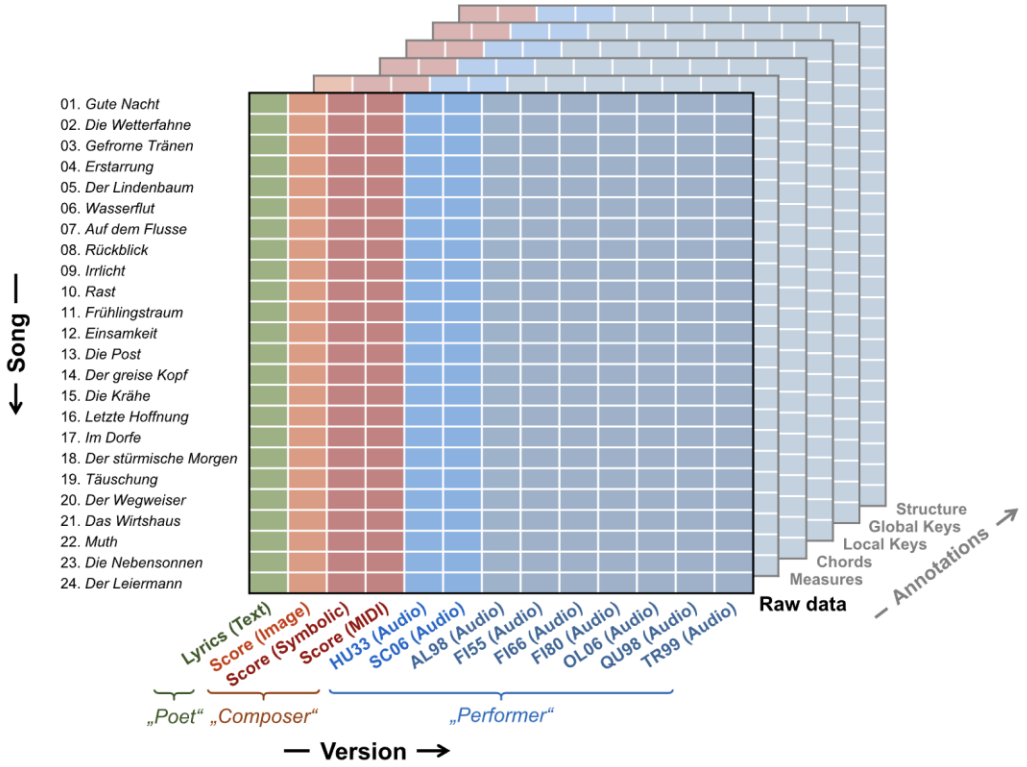
Spotlight: Schubert Winterreise

- Recordings of Franz Schubert‘s song cycle „Die Winterreise“ (1827)
- 24 songs, 9 performances
- 2 are open access
- **Annotations:** Sheet music, chords, structure, lyrics

Hüsch
1933

Fischer-Dieskau
1955

Quasthoff
1998
-2 semitones



Christof Weiß, Frank Zalkow, Vlora Arifi-Müller, Meinard Müller, Hendrik Vincent Koops, Anja Volk, and Harald Grohganz
Schubert Winterreise Dataset: A Multimodal Scenario for Music Analysis
ACM Journal on Computing and Cultural Heritage (JOCCH), 15(2): 1–18, 2021.

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Datasets
A Task Perspective

Our goal: Automatic Music Transcription for Orchestral Music

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Datasets

A Task Perspective

Our goal: Automatic Music Transcription for Orchestral Music

Task Complexity

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Datasets

A Task Perspective

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Data Gap

Task Complexity

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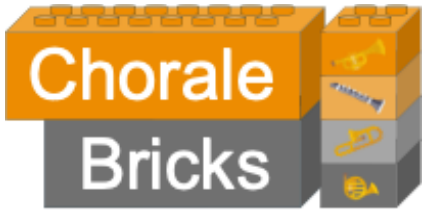
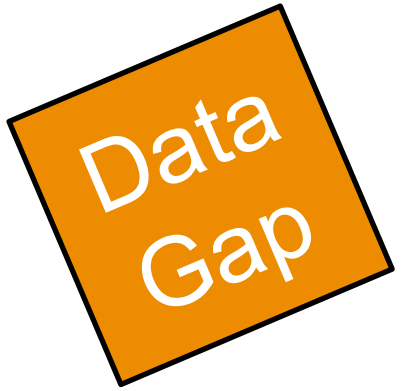
Datasets

A Task Perspective

Our goal: Automatic Music Transcription for Orchestral Music





MIR

Task Complexity

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Datasets

A Task Perspective

Our goal: Automatic Music Transcription for Orchestral Music

Data Gap

MIR

Task Complexity

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Concert Band

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Concert Band

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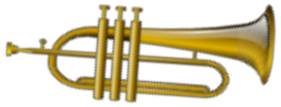
Four-Voice Choir (SATB)

Drese: Jesu geh voran

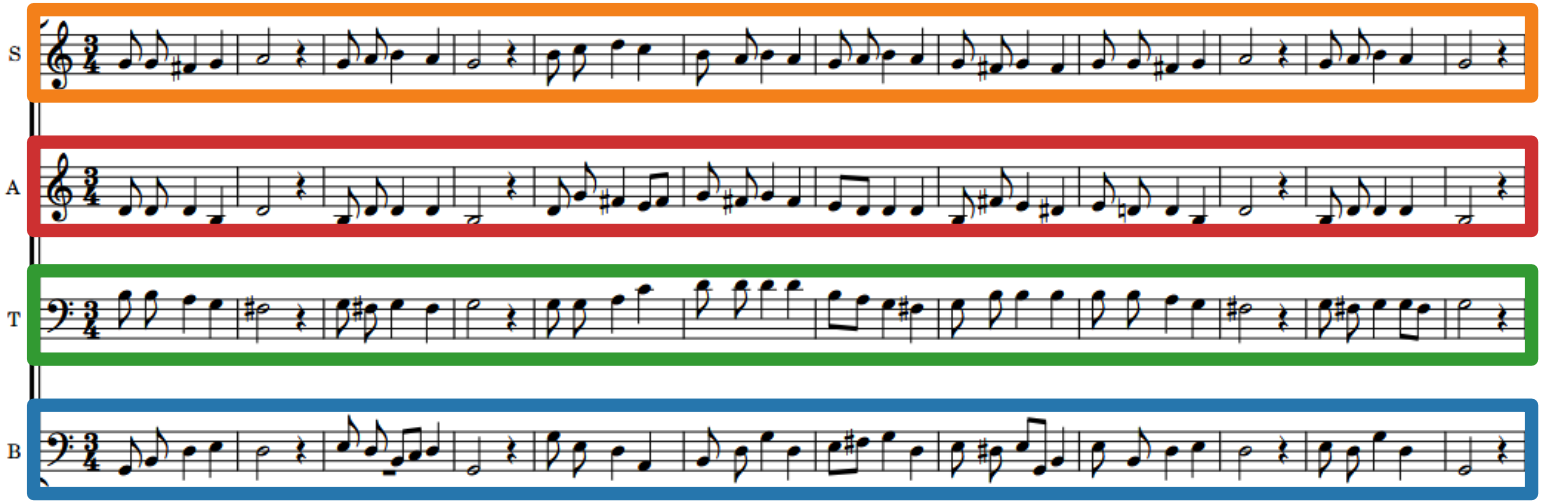
Soprano (S)

Alto (A)



Tenor (T)

Bass (B)



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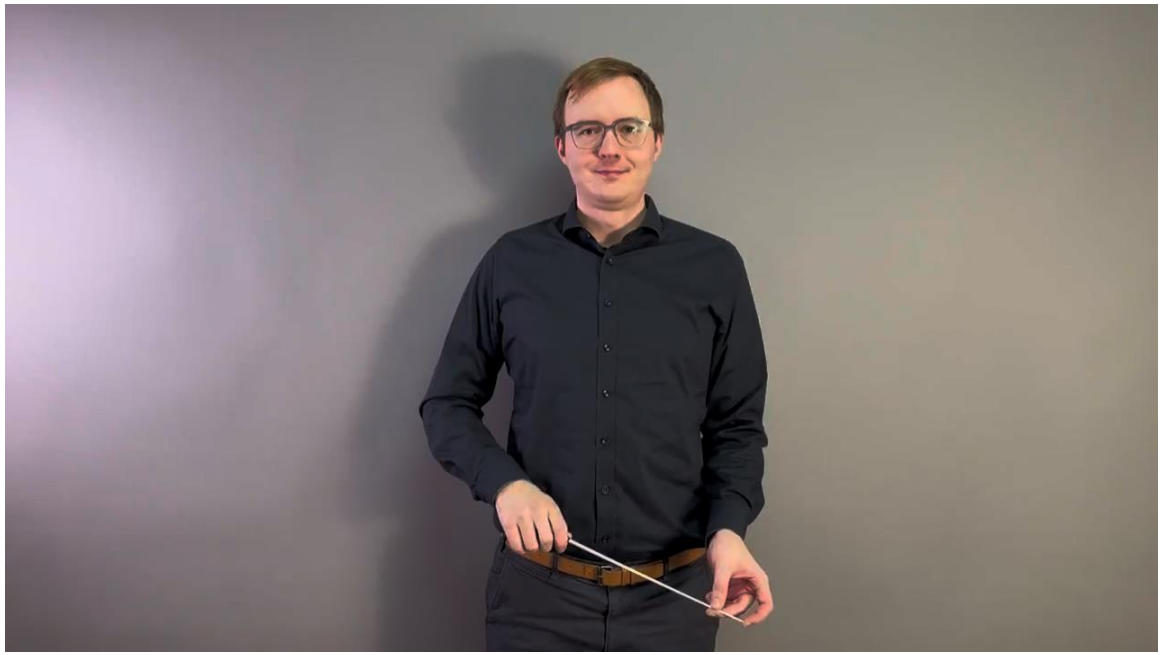
ChoraleBricks

Multitrack Dataset for Wind Music Research

- Dataset featuring 10 SATB chorales
- 193 isolated tracks with 13 instruments
- Recorded along conducting video for syncronization



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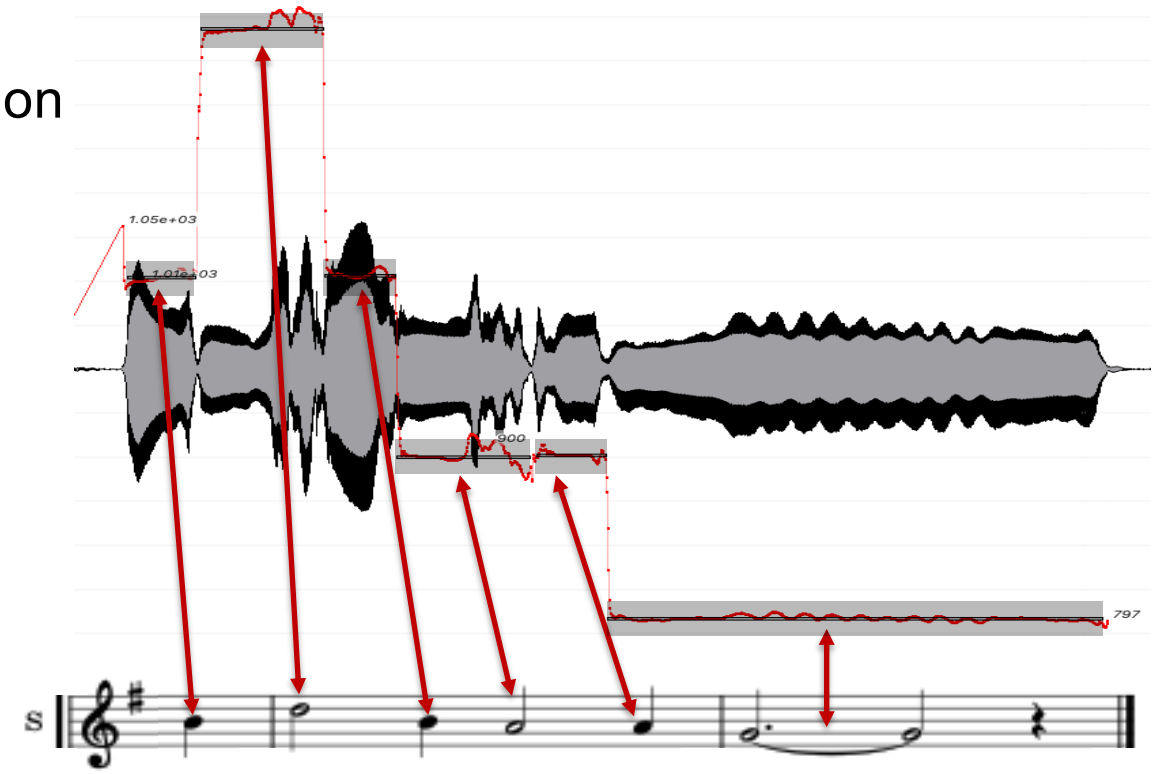
ChoraleBricks

Multitrack Dataset for Wind Music Research

- Dataset featuring 10 SATB chorales
- 193 isolated tracks with 13 instruments
- Recorded along conducting video for syncronization
- Annotations of signal properties
  - Notes
  - Pitch / F0
  - Onsets
  - Beat & measure positions
  - Instrumentation



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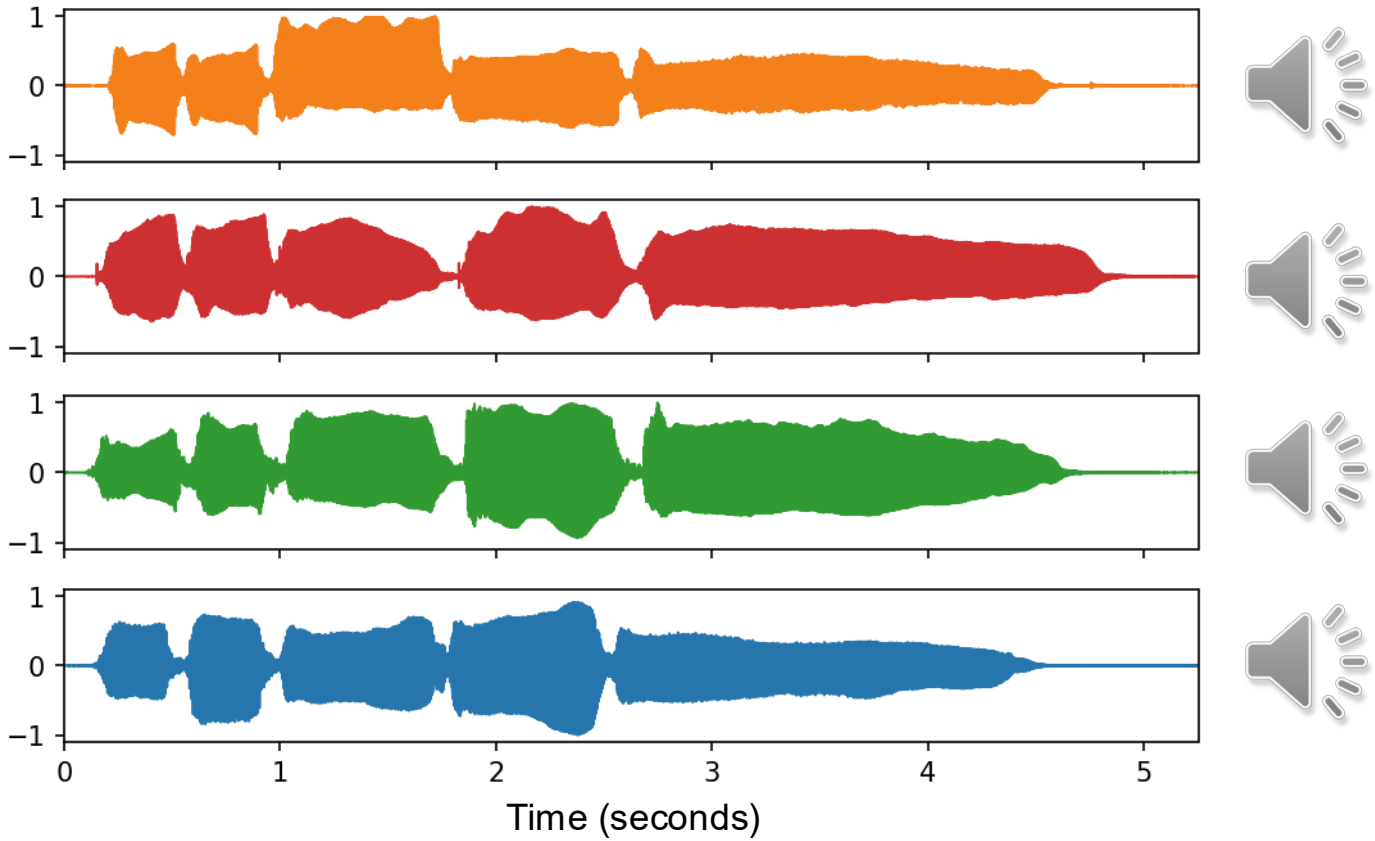
ChoraleBricks
Waveform



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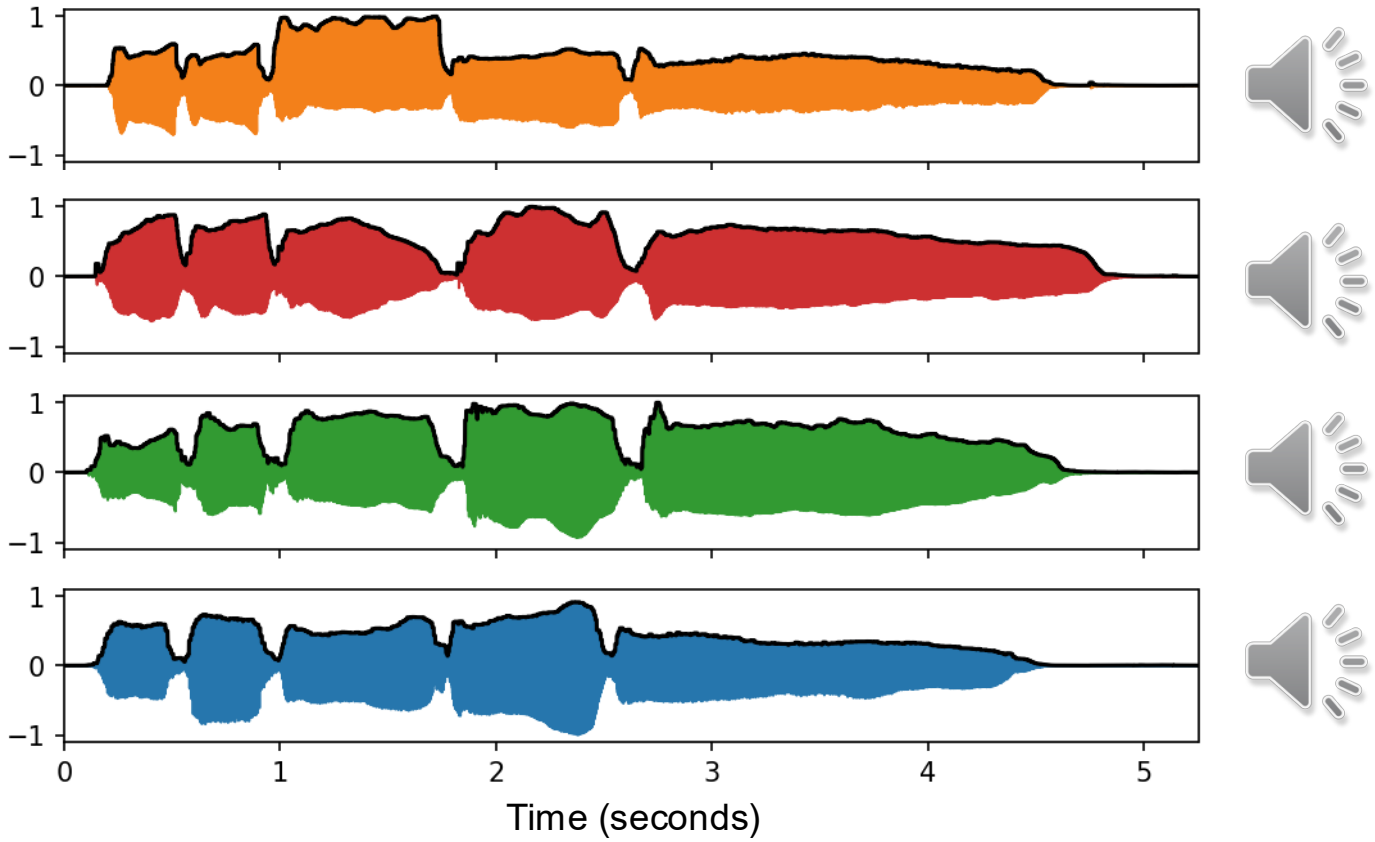
ChoraleBricks

Waveform with Temporal Energy Envelope



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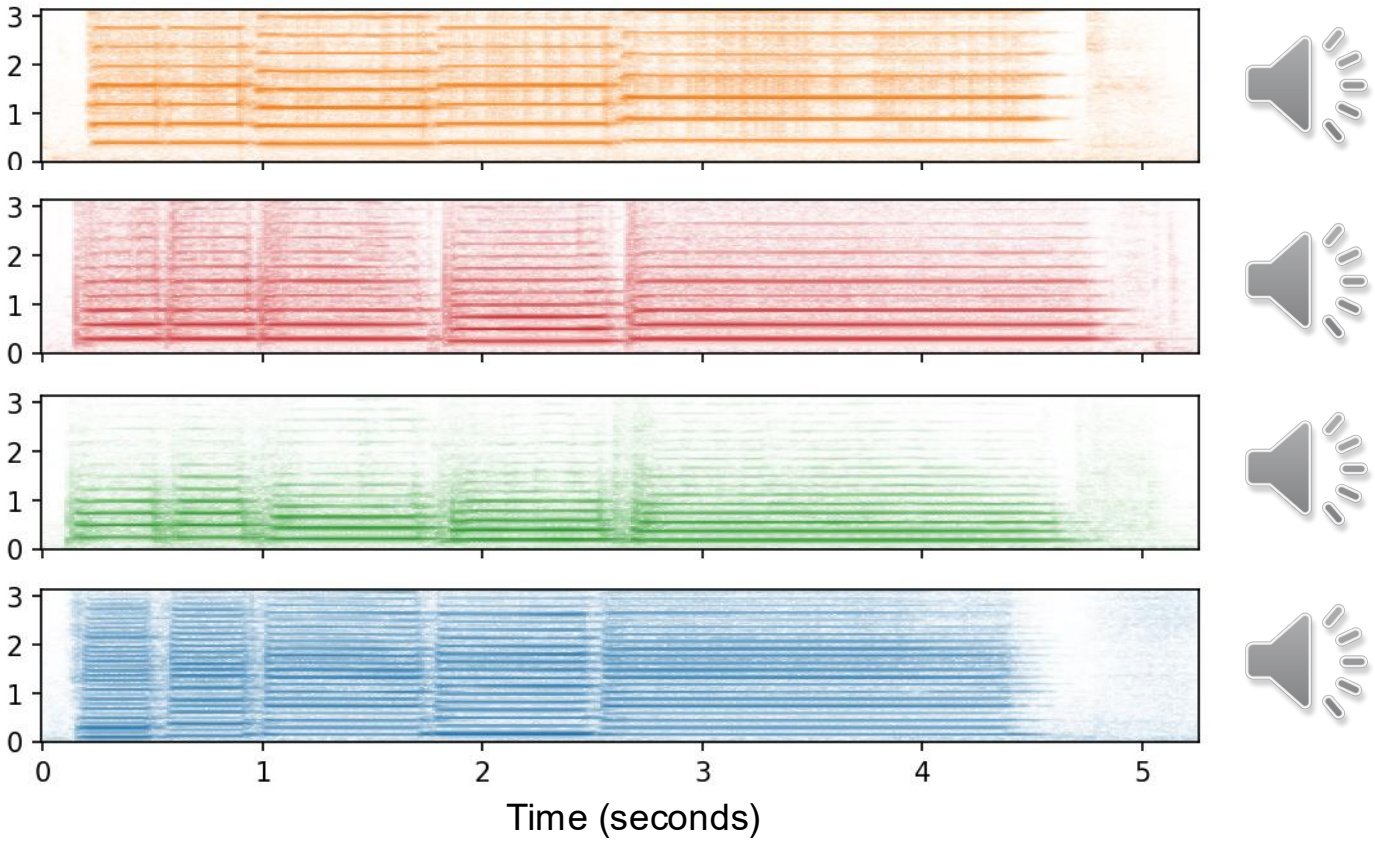
ChoraleBricks

Time-Frequency Fourier Representation



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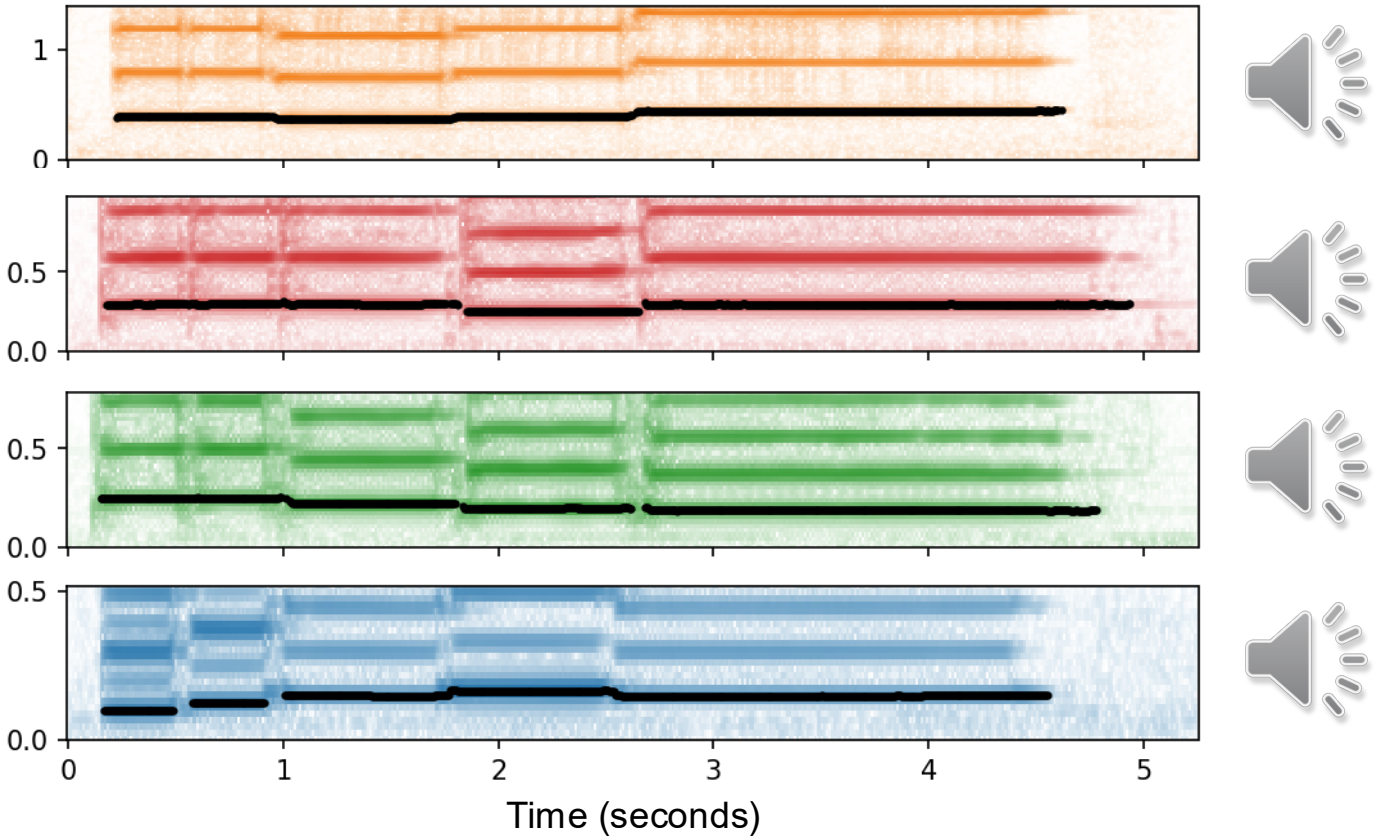
ChoraleBricks

Time-Frequency Fourier Representation with F0 Trajectory



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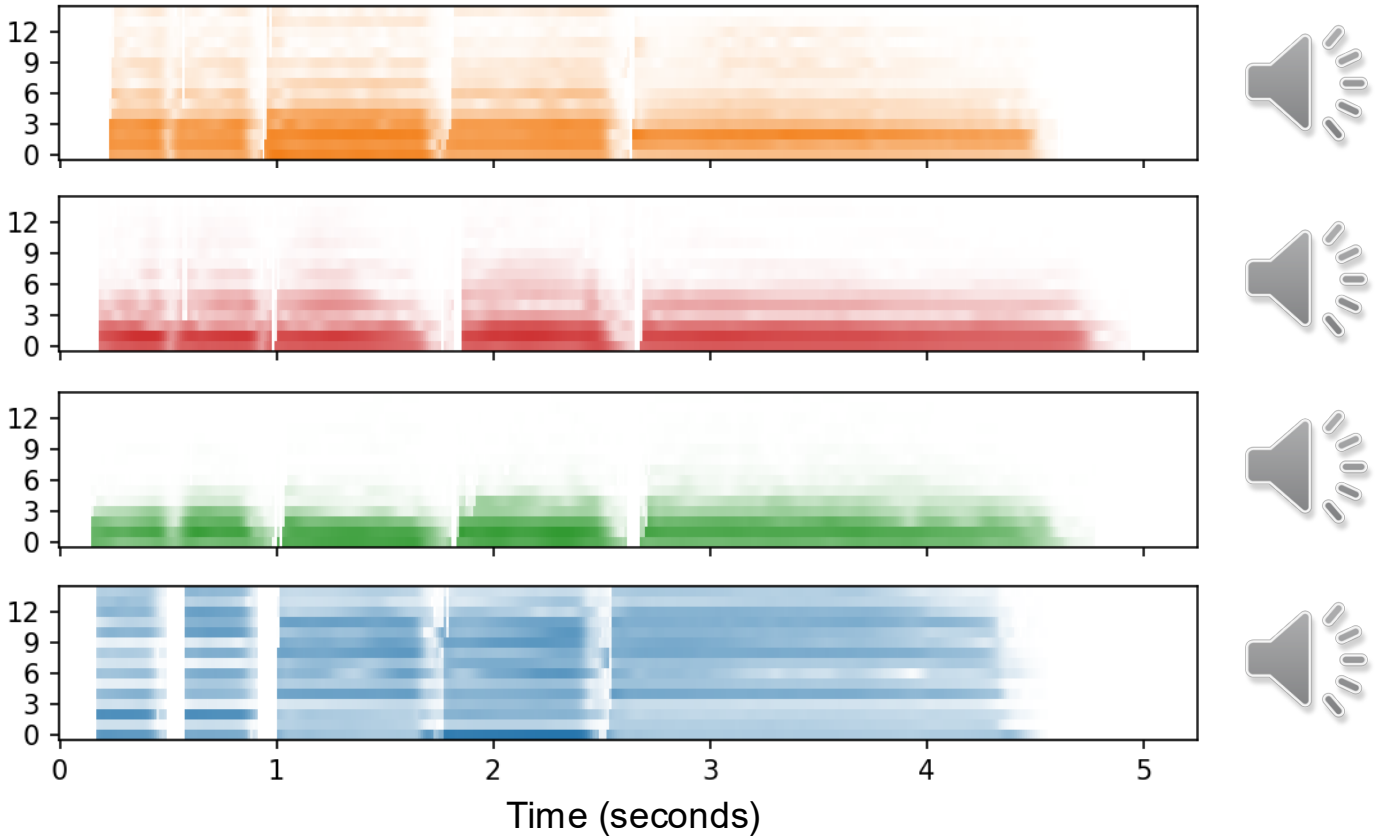
ChoraleBricks

Harmonic Peak Amplitudes (Timbre-Related Feature)



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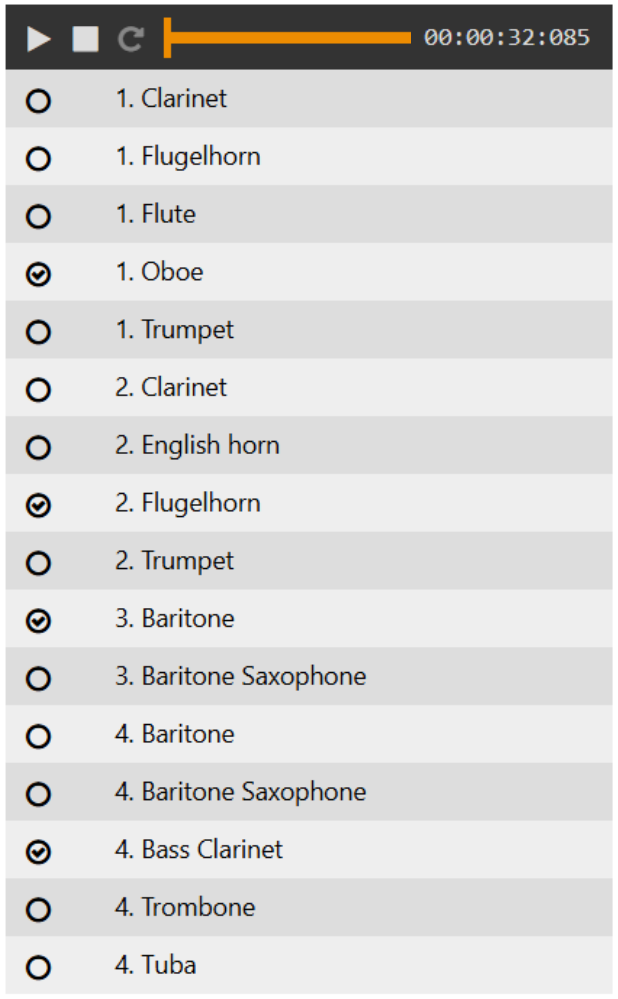
ChoraleBricks

A Modular Multitrack Dataset for Wind Music Research



5 × S

4 × A

2 × T

5 × B

5 × 4 × 2 × 5 = 200 combinations

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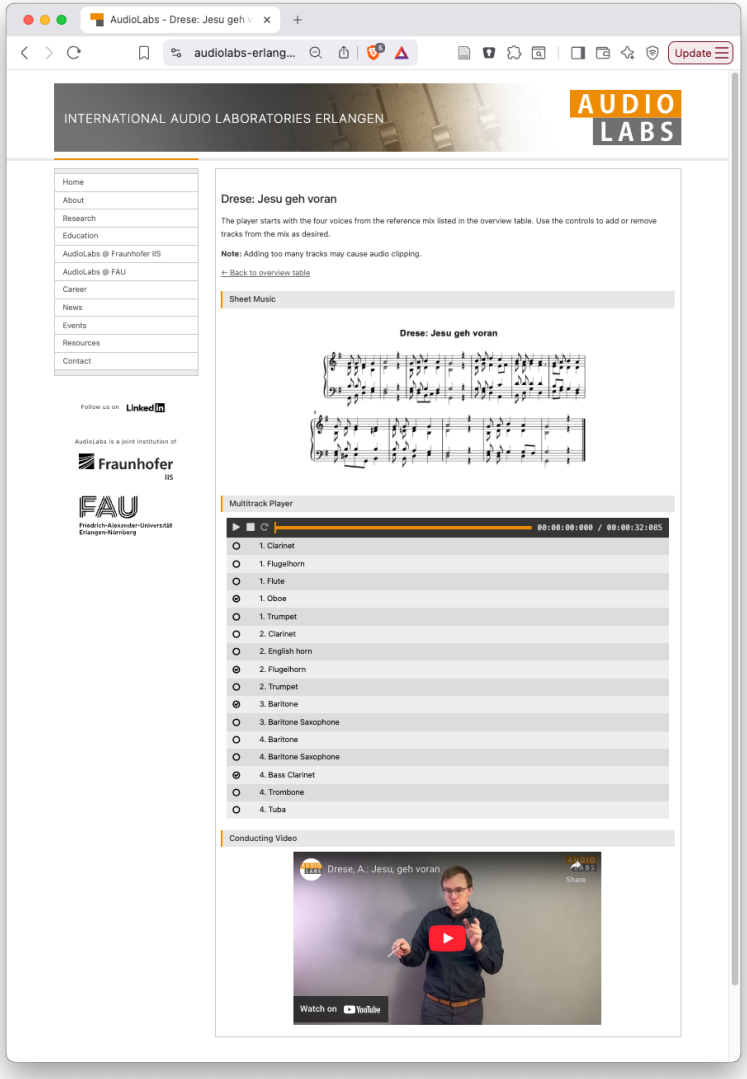
ChoraleBricks



- 193 isolated tracks with 13 instruments (2:10 h)
- 4582 possible SATB ensembles (~52 h)

- Dataset documentation and multitrack player: https://audiolabs-erlangen.de/resources/MIR/2025-ChoraleBricks
- Accompanying Python toolbox: https://github.com/stefan-balke/choralebricks
- Dataset download: https://doi.org/10.5281/zenodo.15081740

Stefan Balke, Axel Berndt, and Meinard Müller
ChoraleBricks: A Modular Multitrack Dataset for Wind Music Research
Transaction of the International Society for Music Information Retrieval (TISMIR), 8(1): 39–54, 2025.

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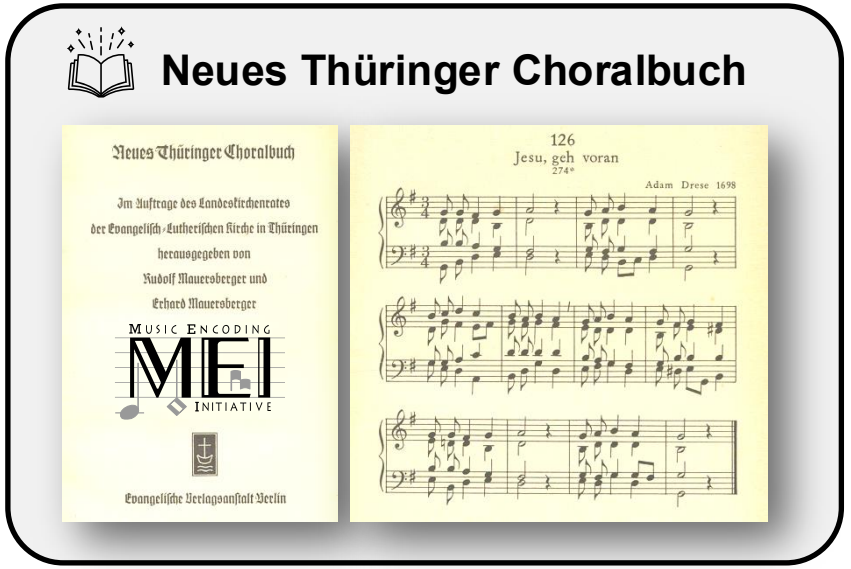
Datasets
ChoraleWind

- ChoraleBricks was a subset from the „Neues Thüringer Choralbuch“
- Contains 312 chorales
- We used it to render synthetic performances



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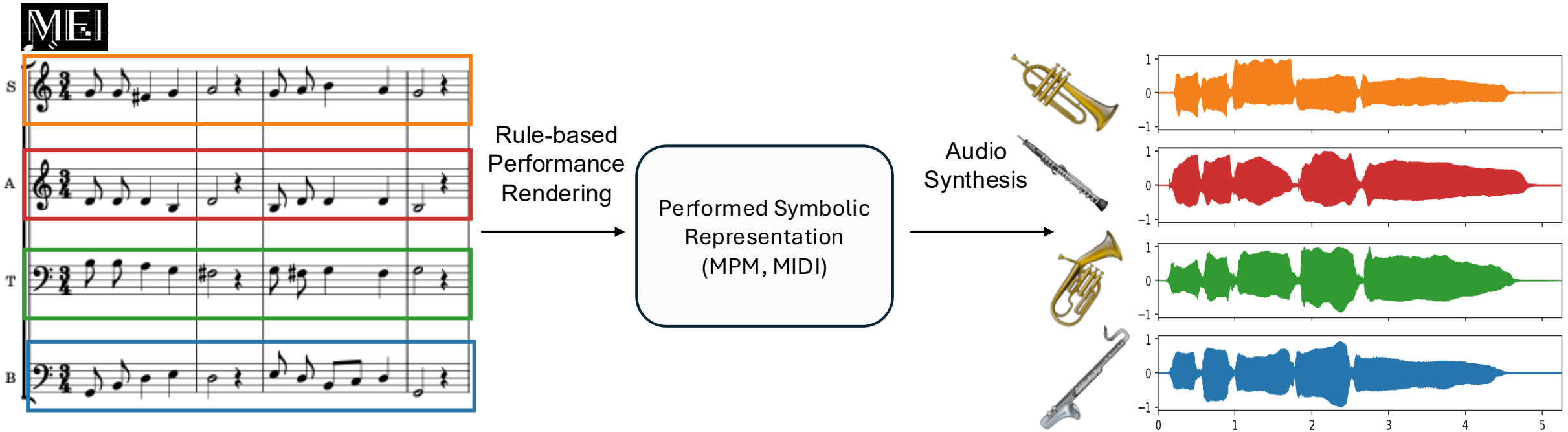
Datasets
Performance Rendering



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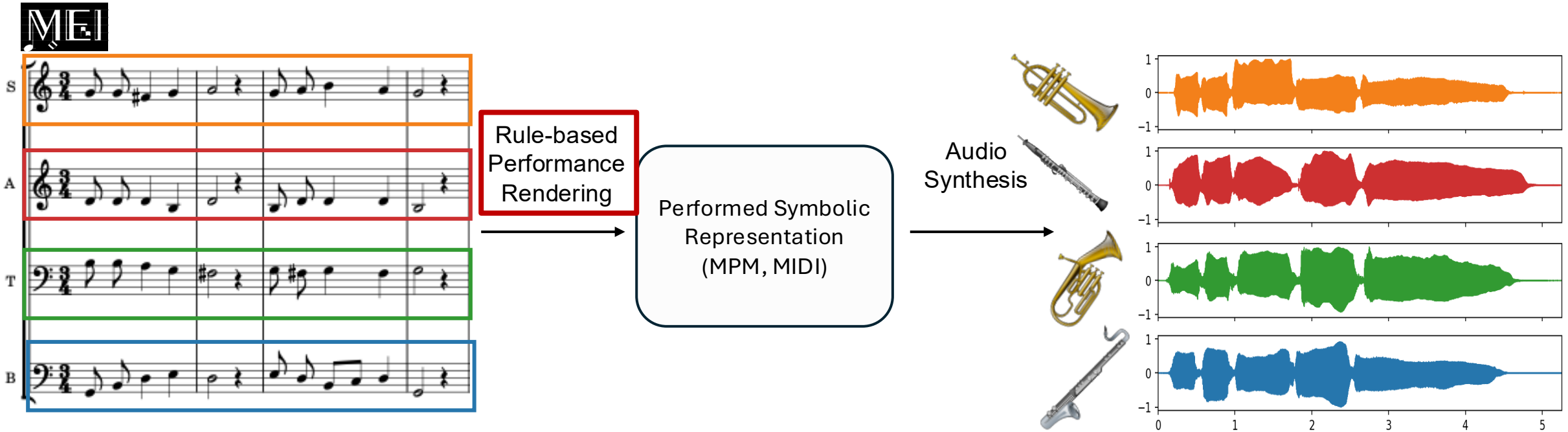
Datasets
Performance Rendering



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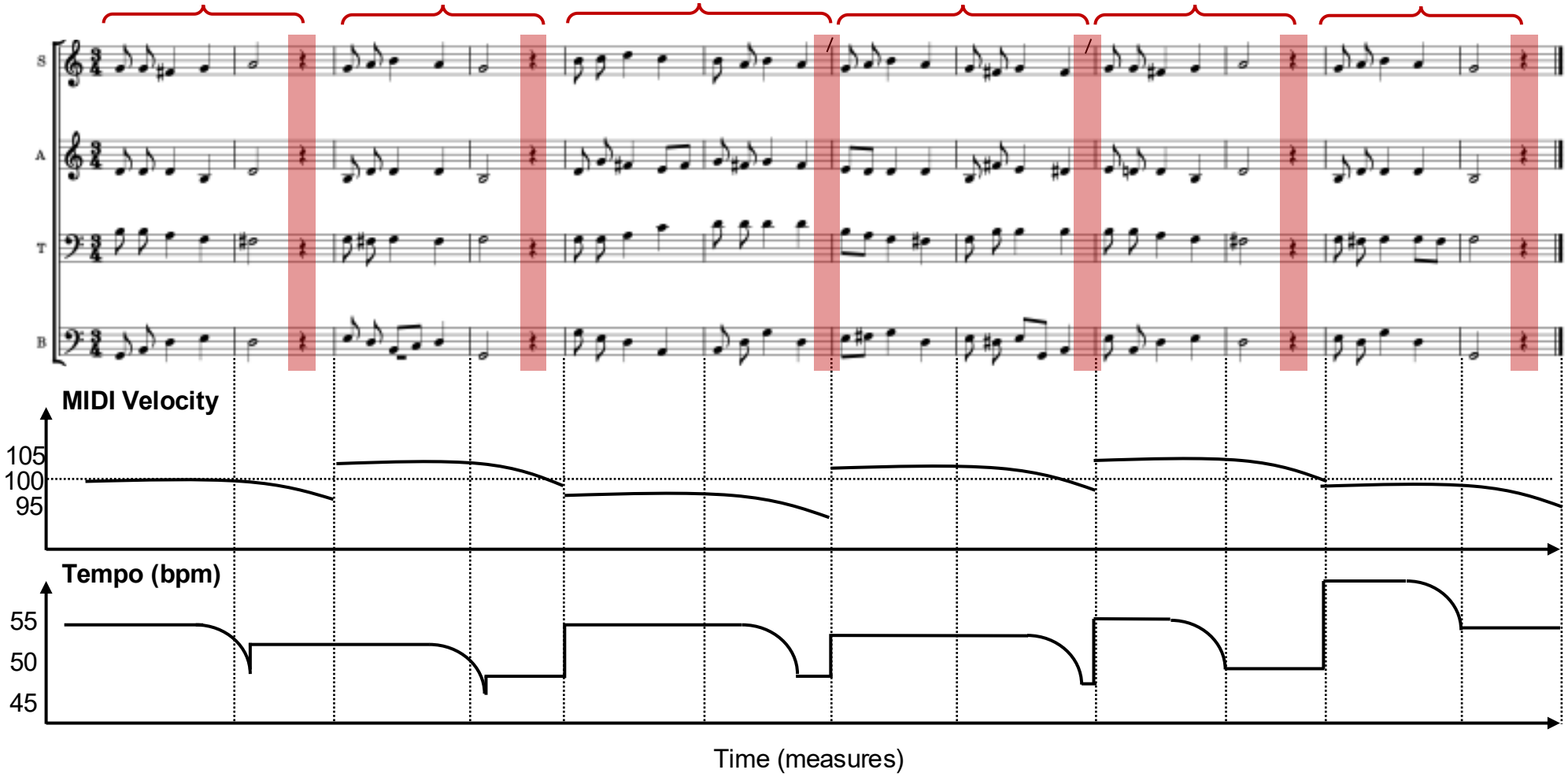
Datasets

Performance Rendering



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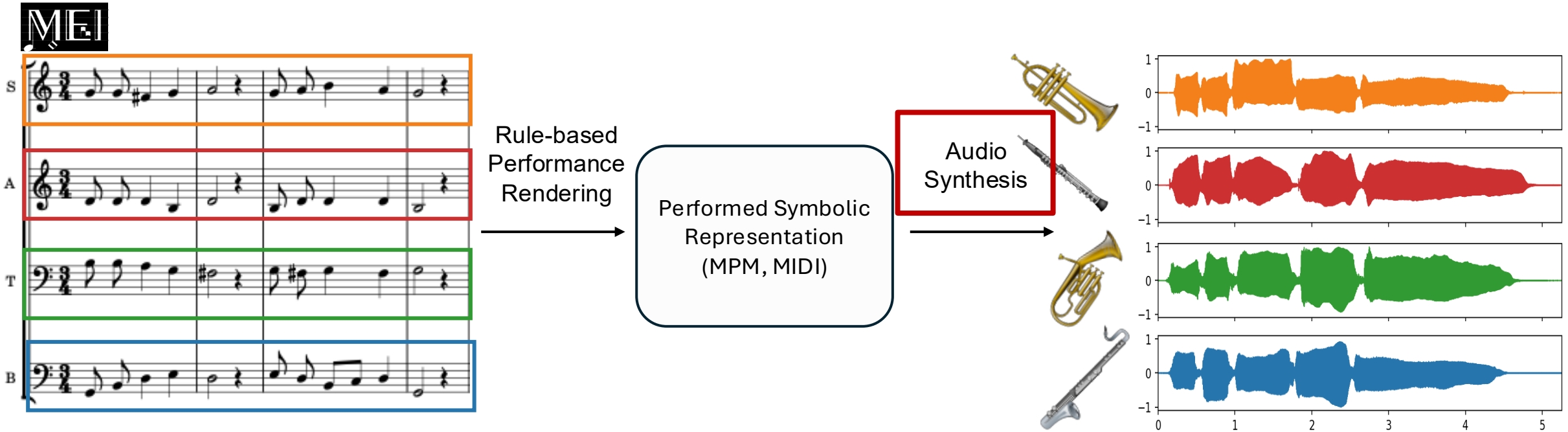
Datasets
Performance Rendering



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Datasets
Audio Synthesis

- **Commercial Synthesizer:**
  SWAM Engine from Audio Modeling
- Based on physical modelling
- Rendered 16 different instruments
- 85 hours of isolated tracks

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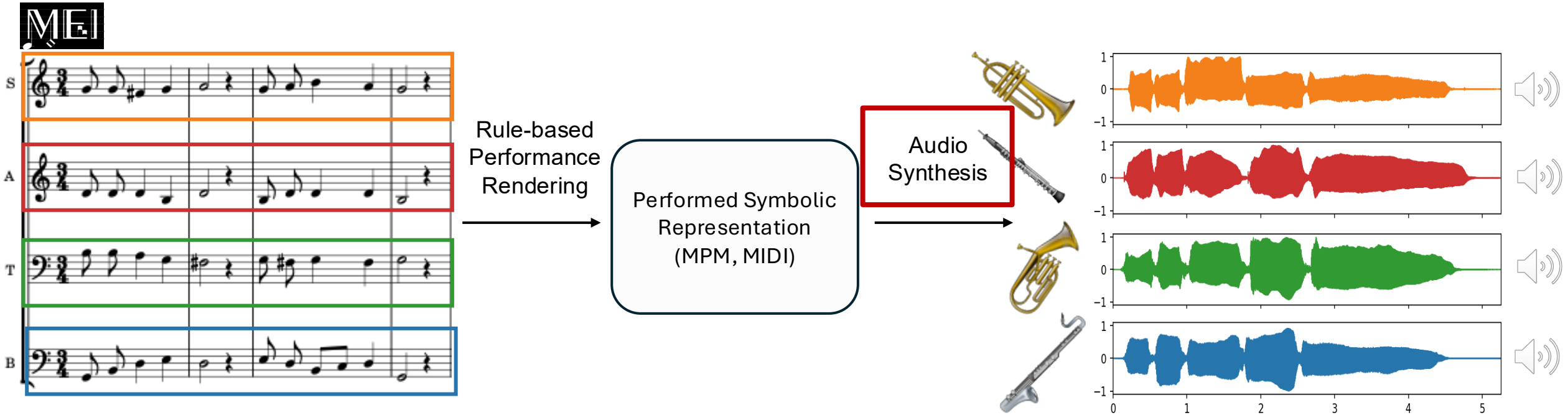
Datasets
Performance Rendering



Axel Berndt, Aida Amiryan-Stein, Manuel Peters, Meinard Müller, and Stefan Balke
ChoraleWind: An Expressive Wind-Quartet Dataset for End-to-End Rendering from the Neues Thüringer Choralbuch
Submitted, 2026.

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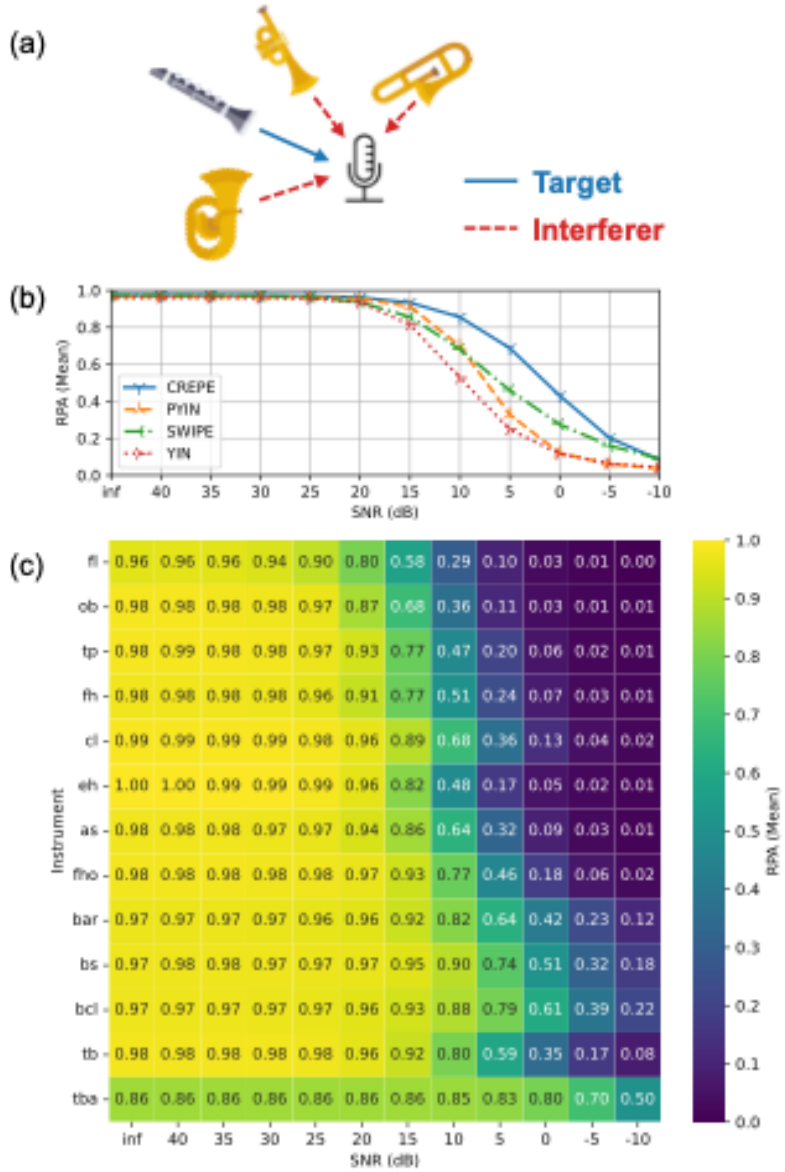
Robustness of Pitch Estimators

Or: When do pitch estimators break?

- Cross-talk always present in real-world ensemble recordings

- **Research question:** How robust are current pitch estimators to different cross-talk settings?



Peter Meier, Meinard Müller, and Stefan Balke: **Analyzing Pitch Estimation Accuracy in Cross-Talk Scenarios: A Study with Wind Instruments**, In Proceedings of the Sound and Music Computing Conference (SMC), Accepted, 2025.

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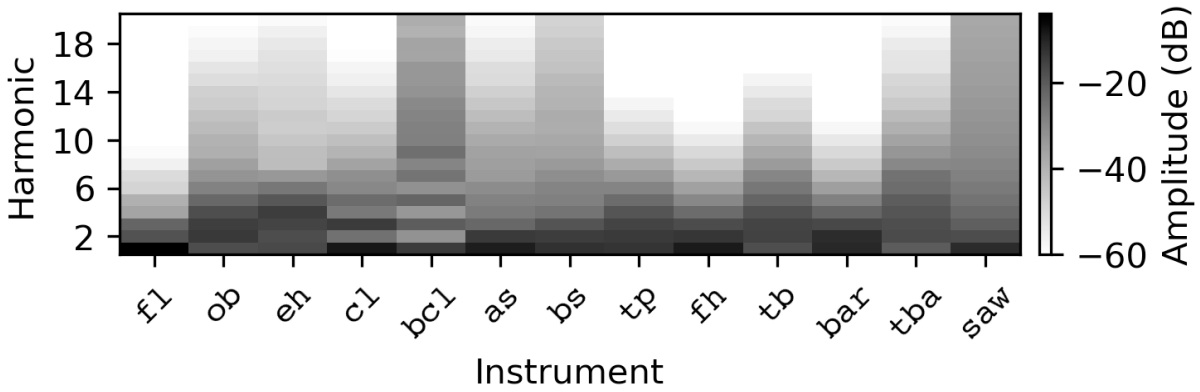
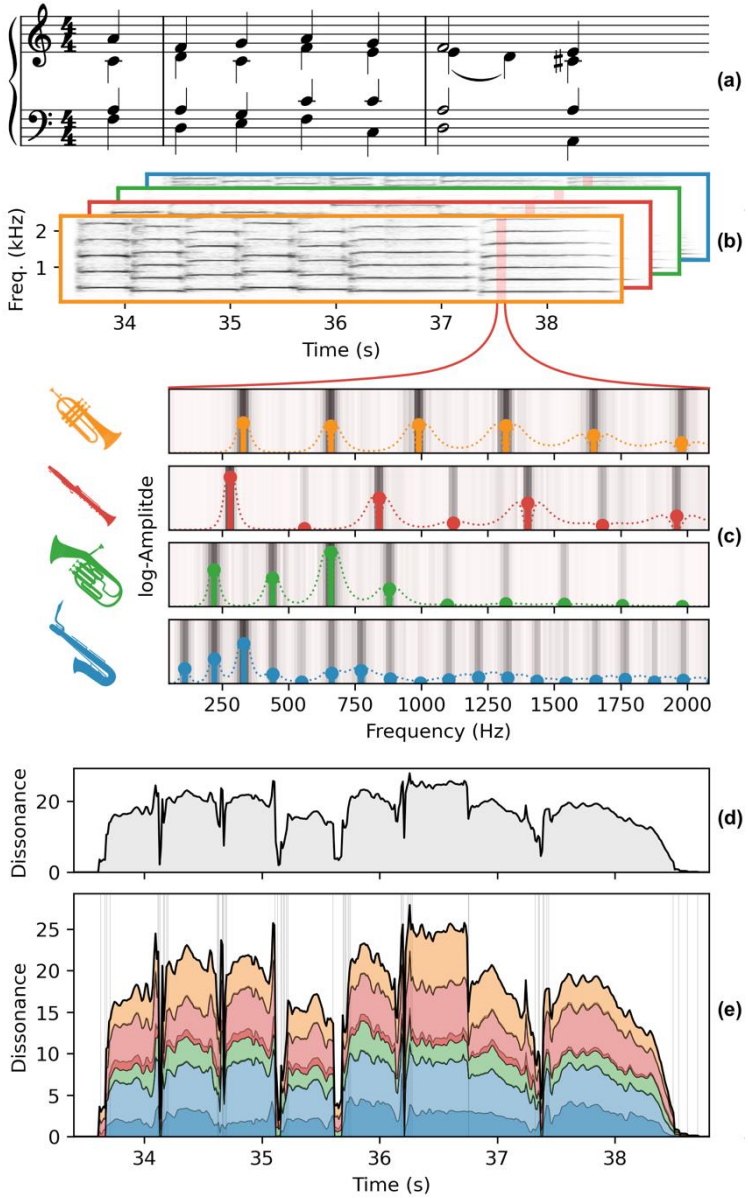
Dissonance Analysis

Or: Why does it sound unpleasant?

- Automatically measure Sensory (perceived) Dissonance
- **Reaserch question:** What are the impacts of timbre, tuning, and intonation?

Simon Schwär, Stefan Balke, and Meinard Müller:
Measuring Sensory Dissonance In Multi-Track Music Recordings: A Case Study with Wind Quartets, ISMIR, 2025.





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Part 2

MUSIC SYNTHESIS

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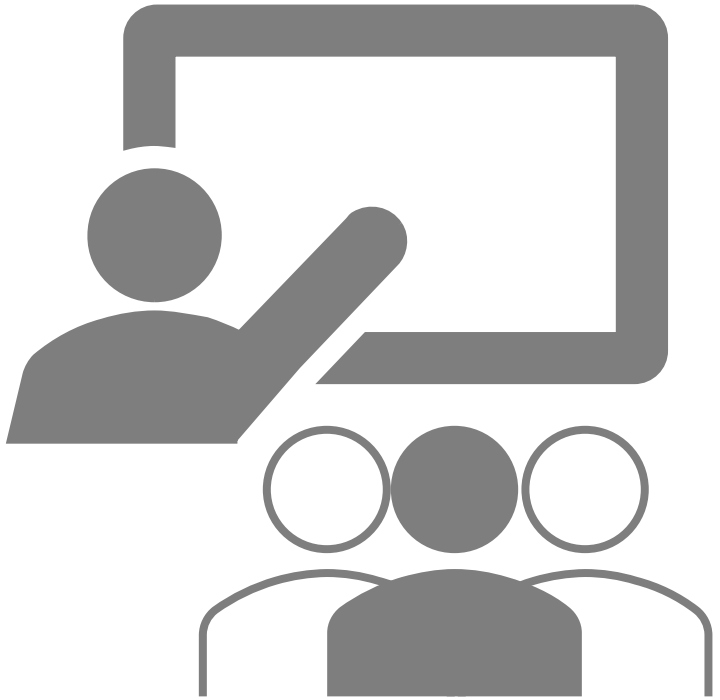
Datasets



Which synthesizers do you know?

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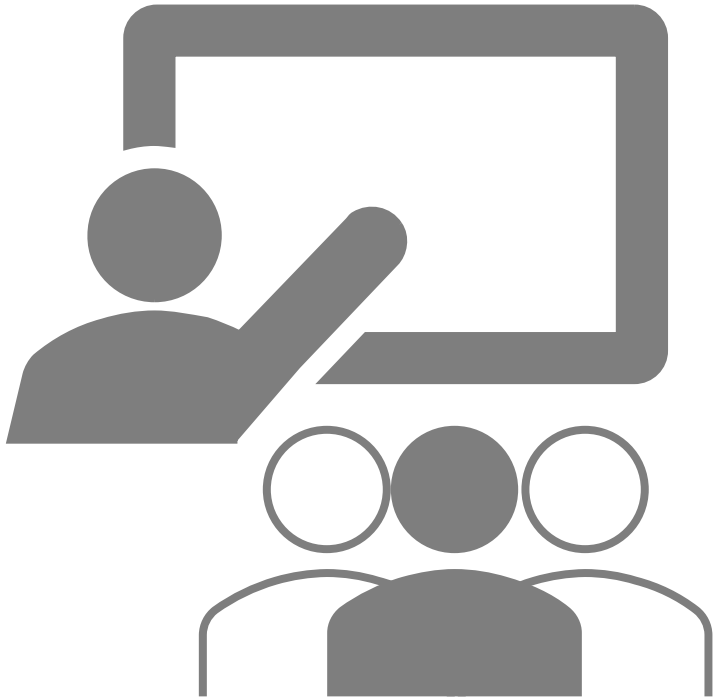
Datasets



Which synthesizers do you know?

Do you know how they work?

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Music Synthesis
Popular Approaches

Image Sources:
https://commons.wikimedia.org/wiki/File:Hammond_B3_Organ_at_Recording_Studios.jpg
https://commons.wikimedia.org/wiki/File:Minimoog,_Deutsches_Museum.jpg

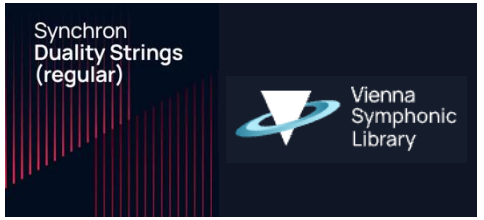
Audio Sources:
Procol Harum – A Whiter Shade of Pale
Herbie Hancock – Chameleon
Fabio Amurri – A New Prince

Additive Synthesis

- Represent sound as a sum of sinusoids (Fourier principle)
- Each sinusoid represents a partial
- Amplitude of each partial forms timbre

Subtractive Synthesis

- Sound starts with a spectrally rich source (e.g., sawtooth, square, noise)
- Filter partials to create sounds



Sample-based Synthesis

- Sound is generated with recorded samples
- Longer notes with looping
- Pitch changes by transposition or resampling

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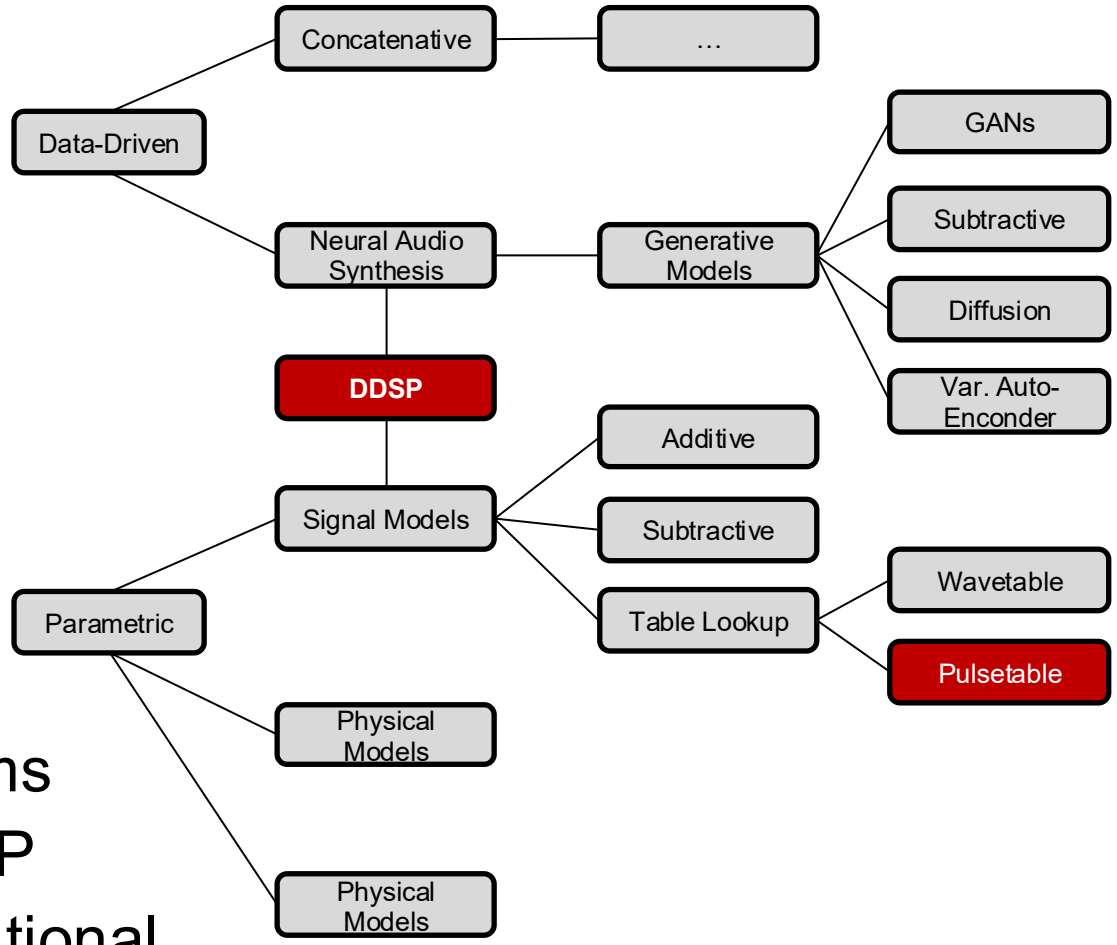
Music Synthesis
Recent Approaches

- **Neural Synthesis:**
  Use a neural network to generate audio
  → high flexibility, hard to control, high computational requirements

- **Differentiable Digital Signal Processing:**
  Use neural networks to control DSP systems
  → constrained to the capabilities of the DSP system, interpretable, much lower computational requirements



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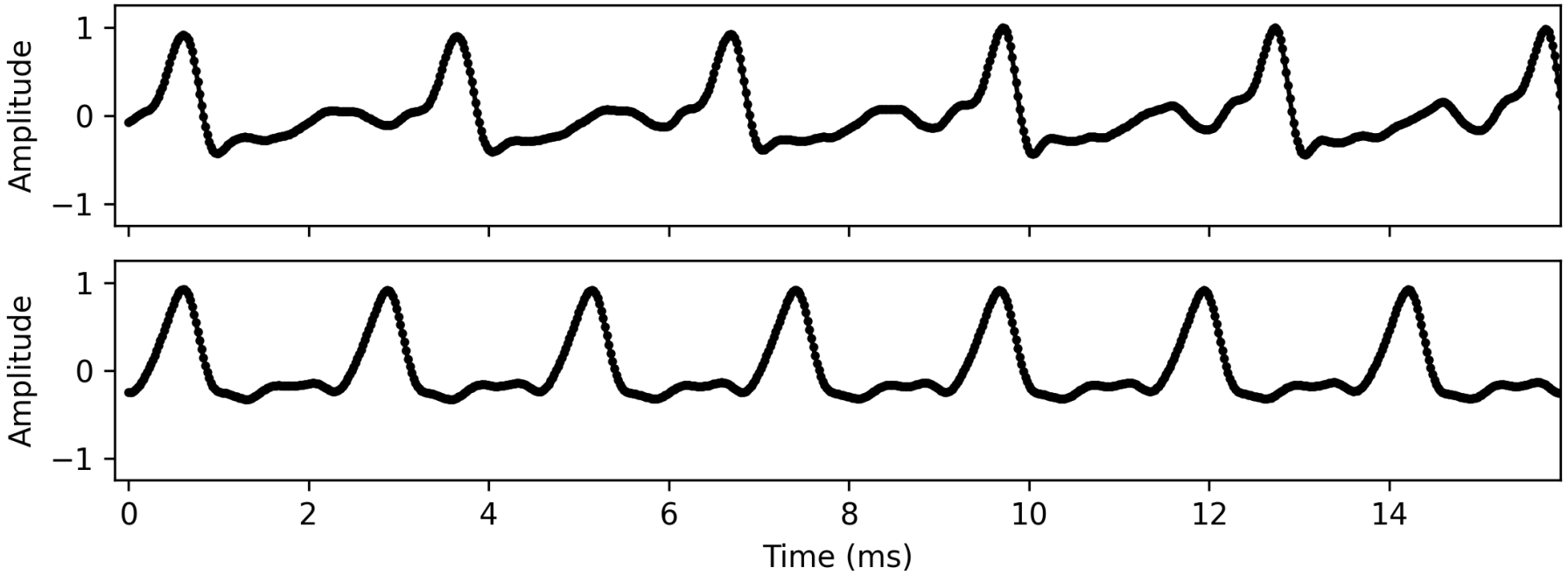
Music Synthesis
Pulsetable Synthesis



→ „Zoomed-In“ waveforms of an audio recording of a trumpet
→ Two different positions in the recording → pulses very similar

M. Oehler and C. Reuter, “Dynamic excitation impulse modification for a synthesis and analysis system for wind instrument sounds,” in MCM, 2009.

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Music Synthesis
Pulsetable Synthesis

Waveform:

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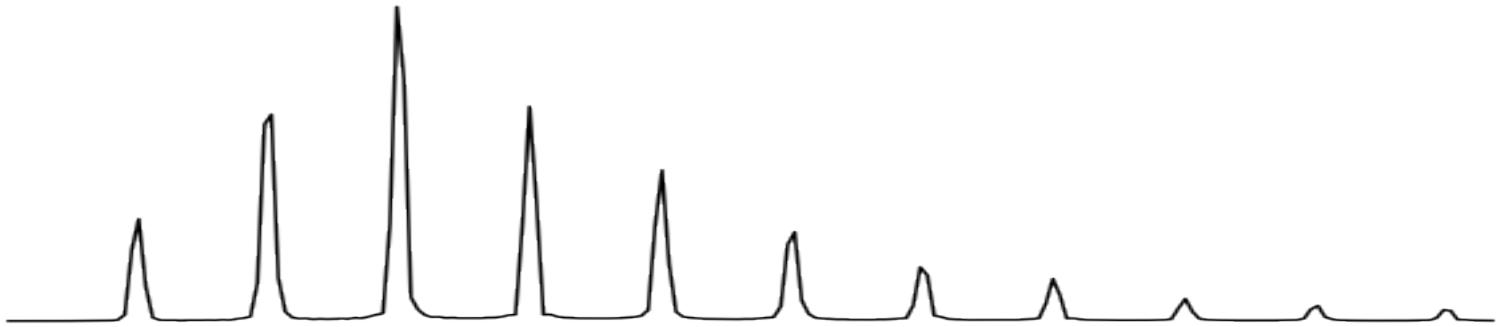
Music Synthesis

Pulsetable Synthesis (440 Hz)

Waveform:

Time

Frequency Spectrum:



Frequency

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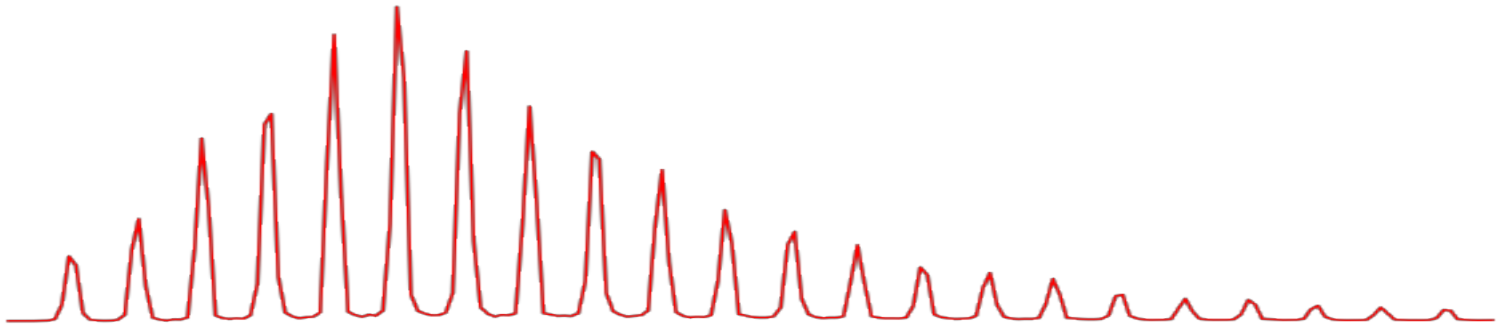
Music Synthesis

Pulsetable Synthesis (220 Hz)

Waveform:

Time

Frequency Spectrum:



Frequency

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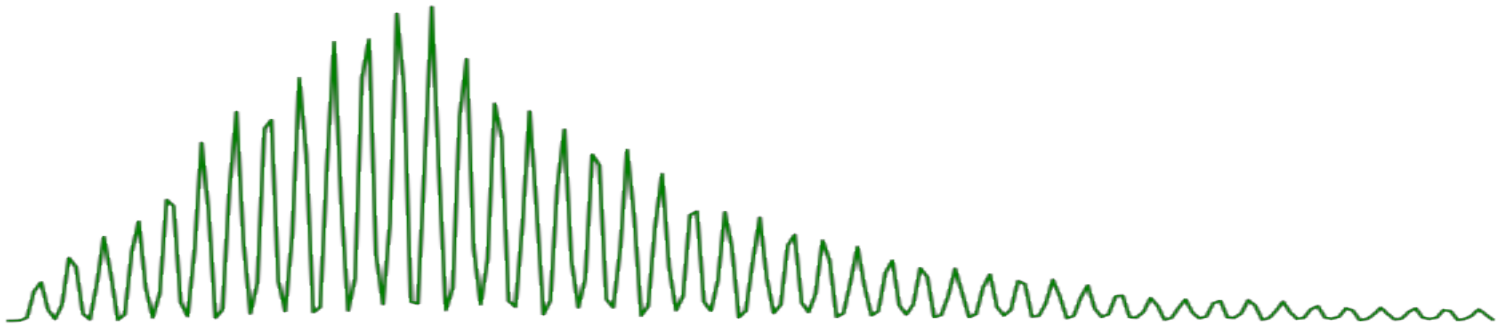
Music Synthesis

Pulsetable Synthesis (110 Hz)

Waveform:

Time

Frequency Spectrum:



Frequency

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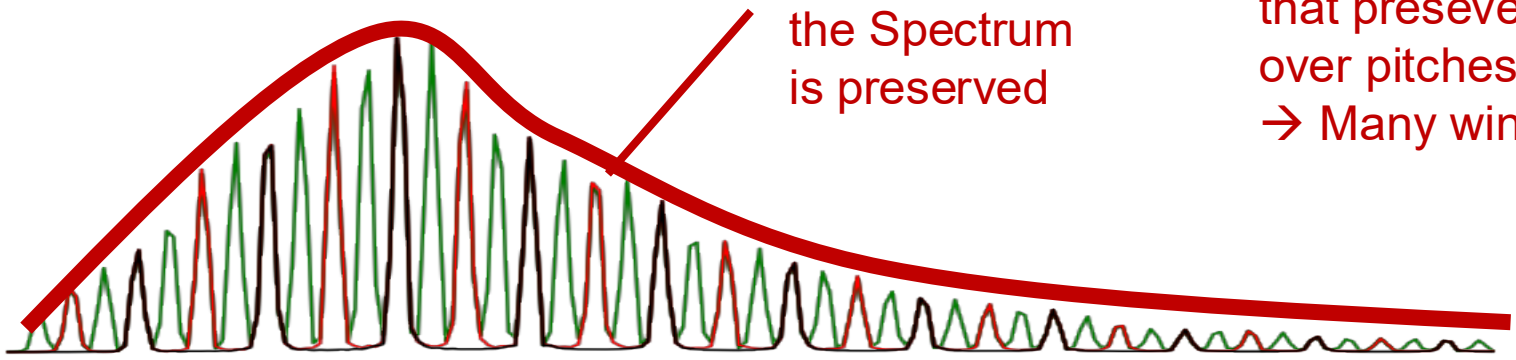
Music Synthesis
Pulsetable Synthesis

Waveform:

Time

Frequency Spectrum:



→ Suitable for instruments that preseve the envelope over pitches
→ Many wind instruments

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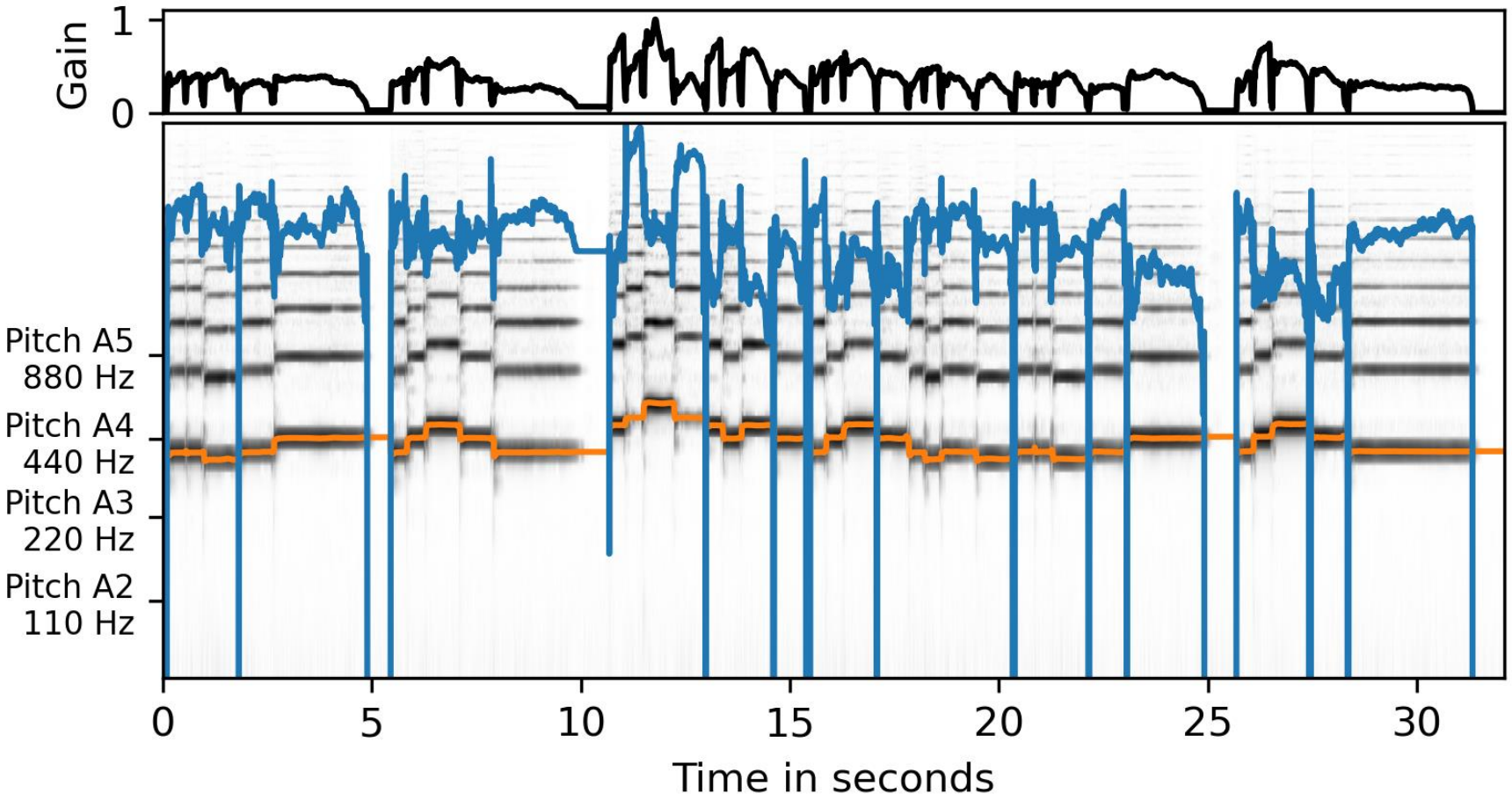
Music Synthesis
Pulsetable Synthesis

Christian Dittmar, Johannes Zeitler, Stefan Balke, Simon Schwär, and Meinard Müller
PULSE-IT: Lightweight and Expressive Synthesis of Wind Instrument Playing
In Late-Breaking Demos of the International Society for Music Information Retrieval Conference (ISMIR), 2025.
https://audiolabs-erlangen.de/resources/MIR/2025_DittmarZBSM_WindInstrumentSynth_ISMIR-LBD



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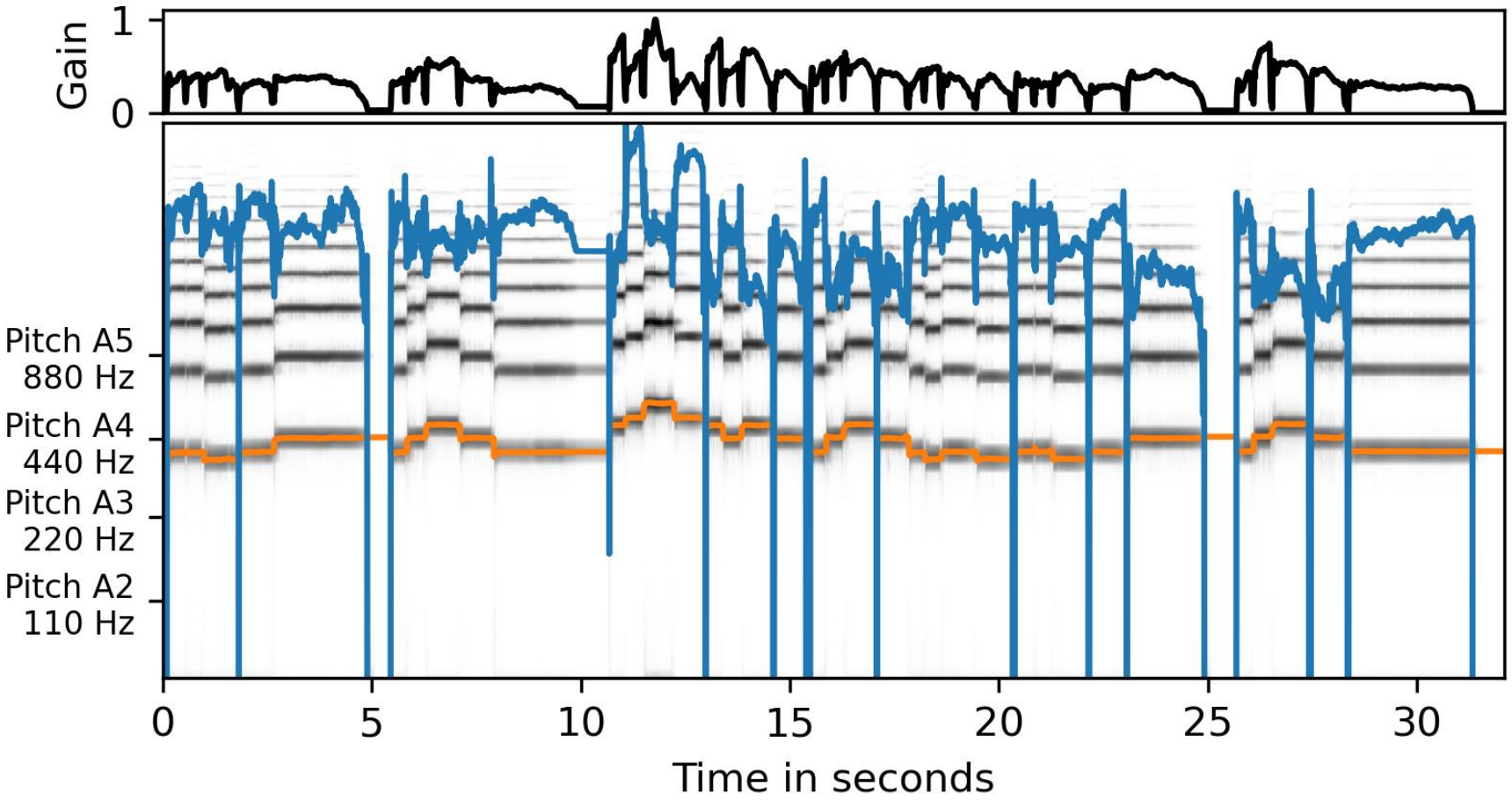

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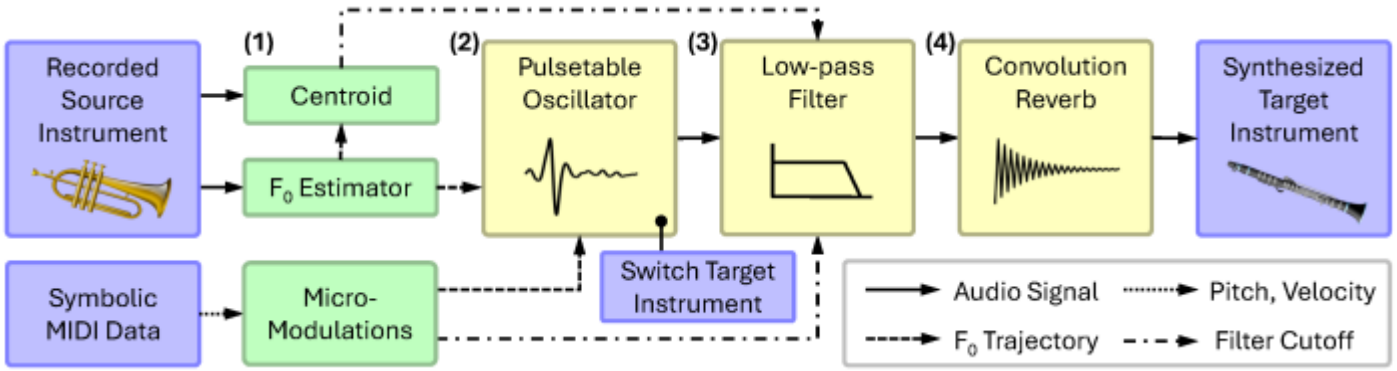
Music Synthesis
Pulsetable Synthesis

- Pulse extraction is tedious
- Post-processing involves manual „tweaking“
- Yielding sophisticated results is an art 🎨



Research Question:

Can we efficiently learn the parameters in a data-driven way?

Most important: Pitch, loudness, and timbre (pulses)

→ DDSP is one way!

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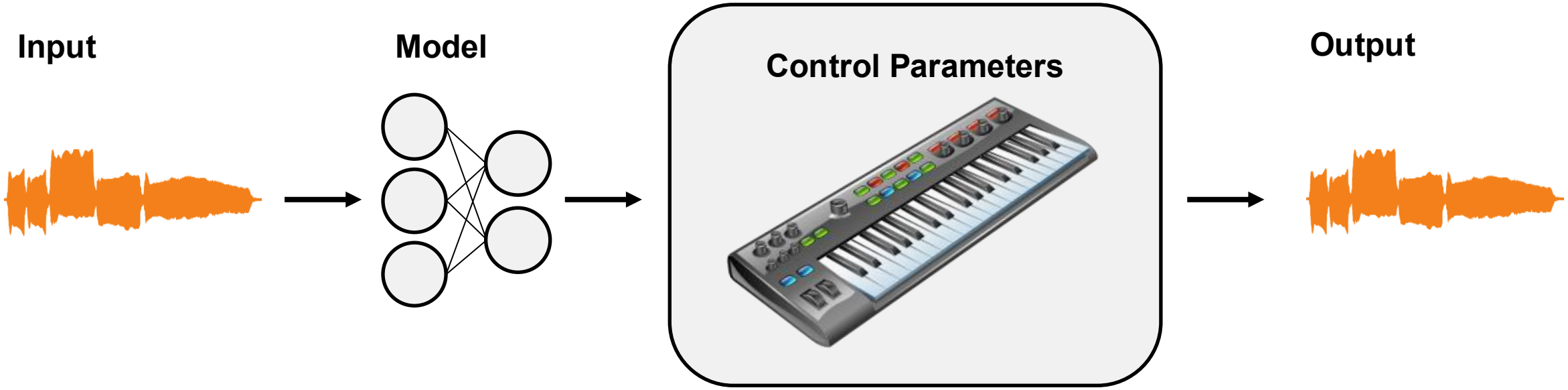
Music Synthesis
Differentiable Digital Signal Processing (DDSP)



Central Idea: Train a model that can „operate“ a DSP device (e.g., Synthesizer, Filter)

→ Solution space is constrained, models can be much smaller!

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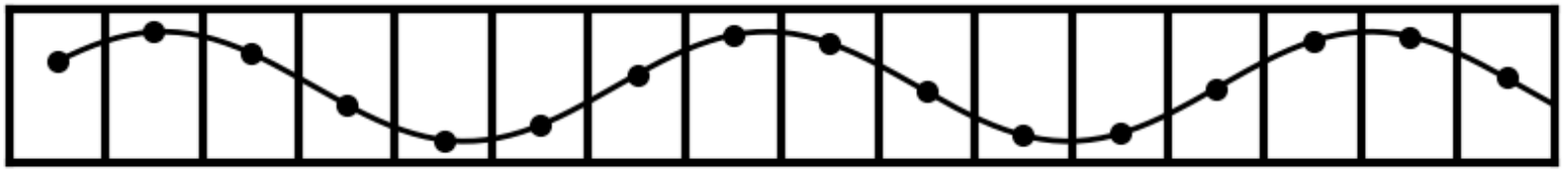
Music Synthesis

Differentiable Digital Signal Processing (DDSP)

Simon Schwär
Differentiable Models for Music Signal Reconstruction, Adaptation, and Synthesis
Dissertation, under review, 2026.

Target Signal



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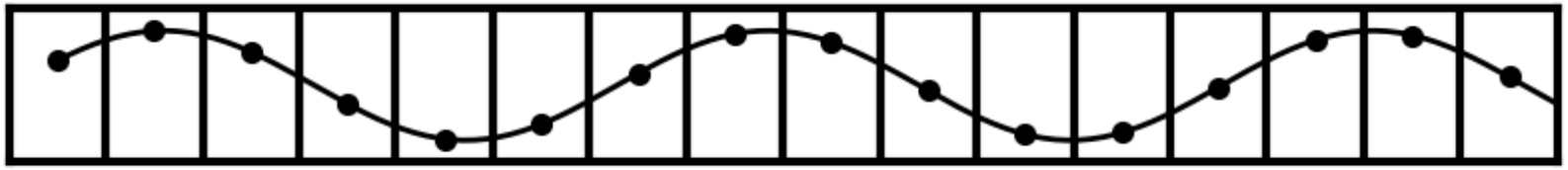
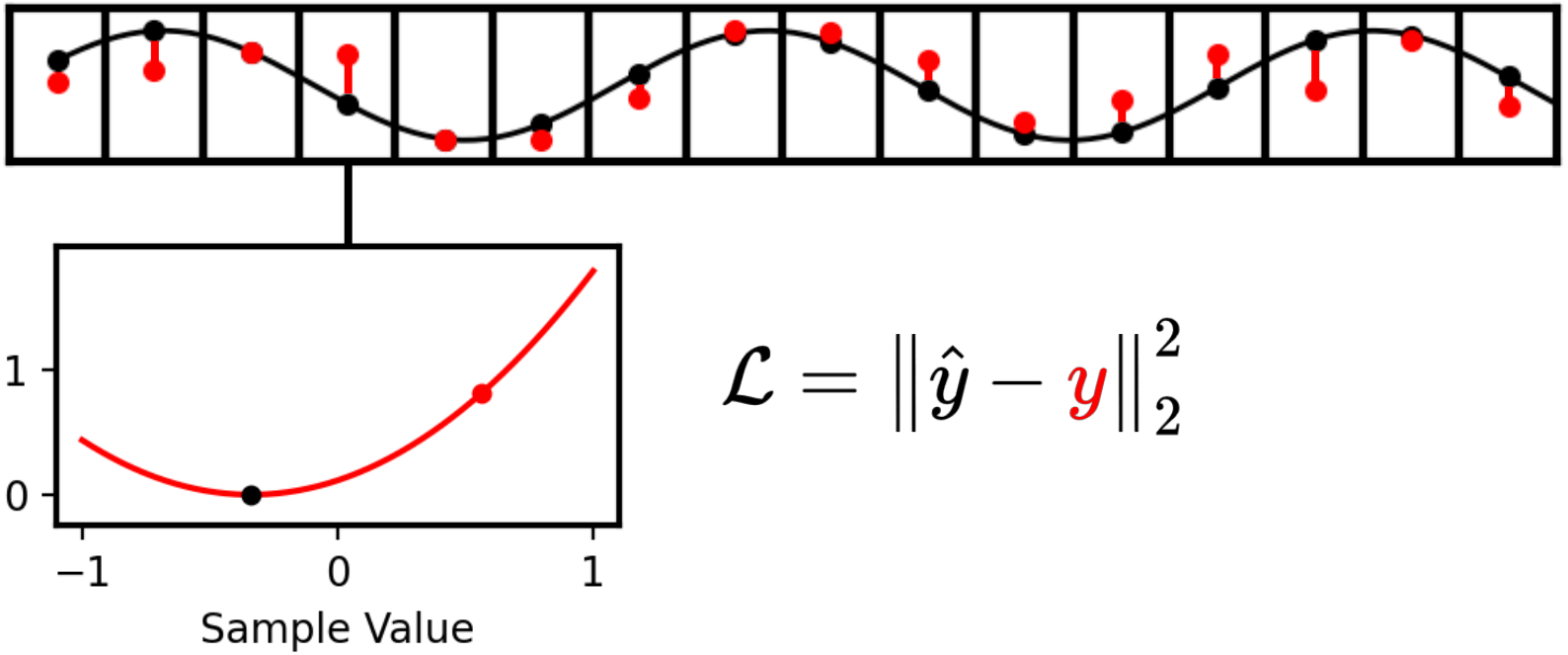


Estimation with 16 DoF



$$\mathcal{L} = \left\| \hat{y} - y \right\|_2^2$$

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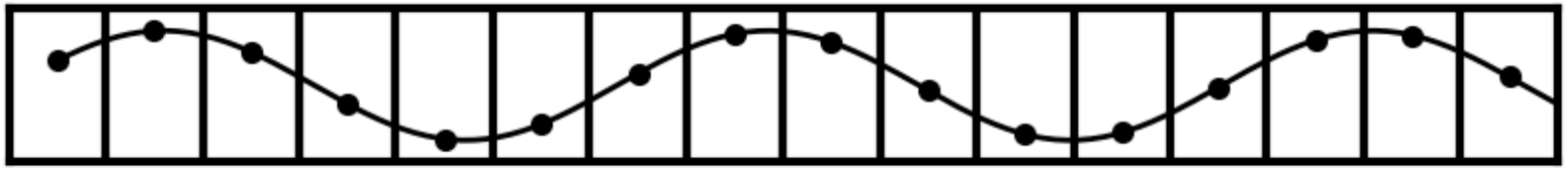
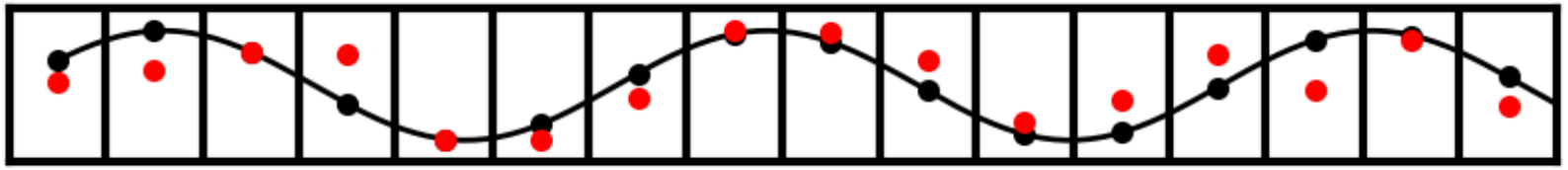
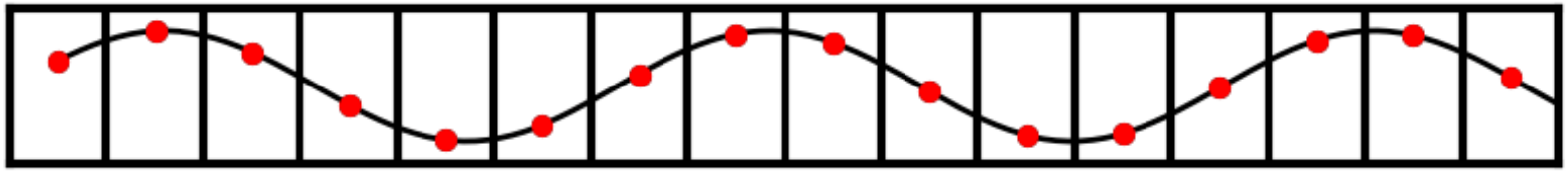


Estimation with 16 DoF



Estimation with one DoF (frequency)



$$\mathcal{L}_{\hat{y}}(z) = \sum_{n=0}^{N-1} \left(\hat{y}[n] - \sin(2\pi z n / f_s)\right)^2$$

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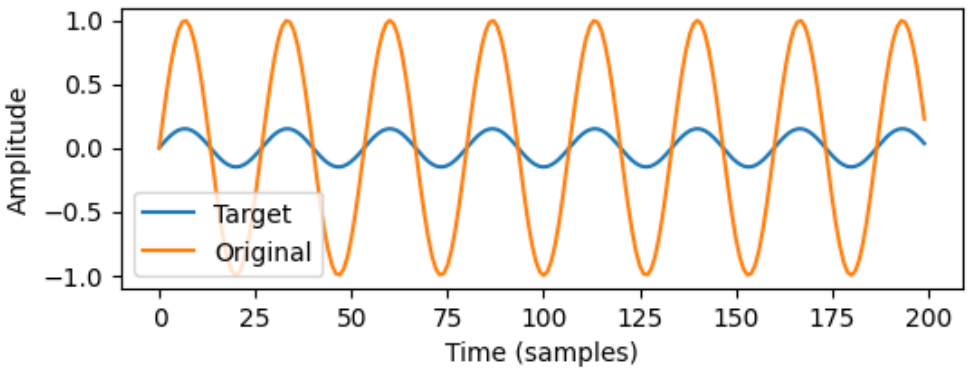
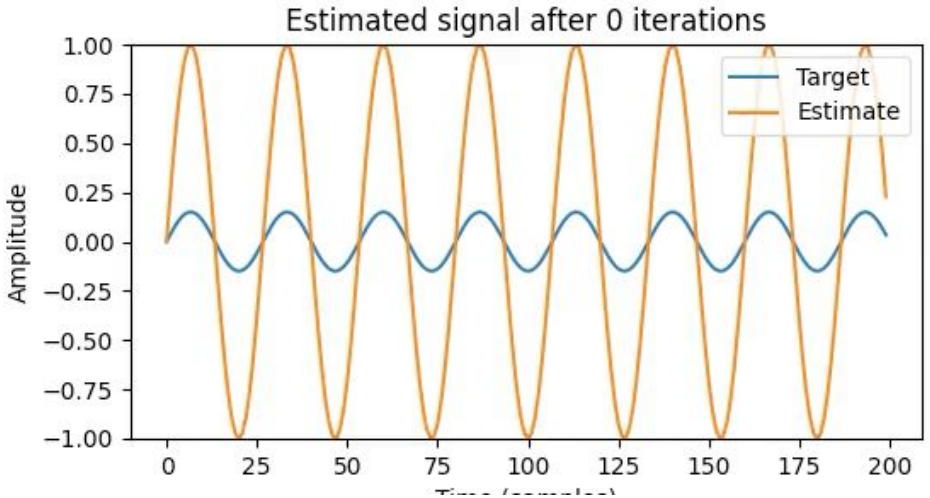
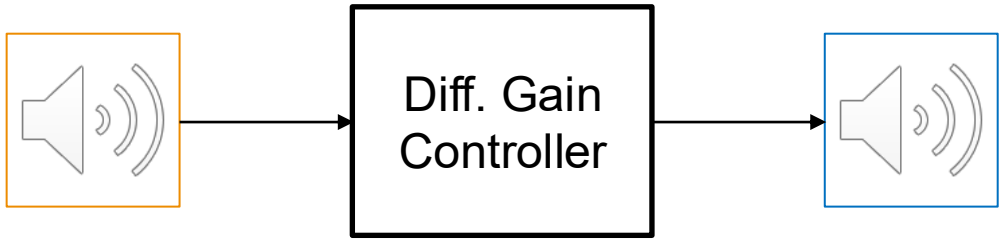
Music Synthesis
DDSP Example

Source: https://intro2ddsp.github.io/

- Differentiable Gain controller with a single parameter
- **Learning objective:** Estimate gain parameter via Stochastic Gradient Descent, L1-Loss







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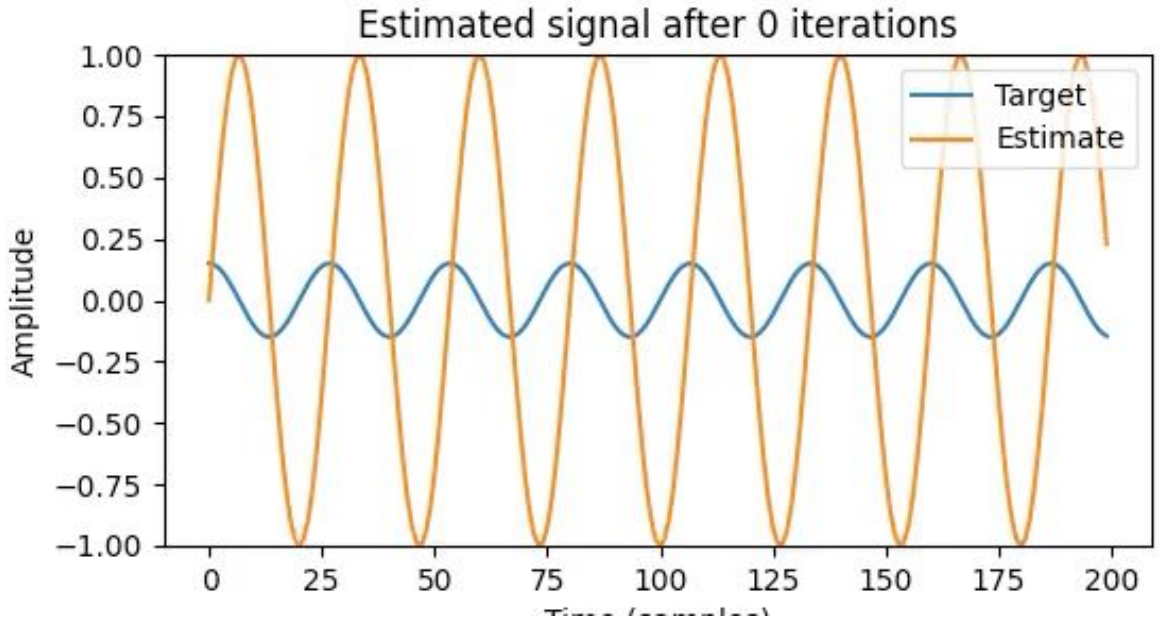
Music Synthesis
DDSP Example

Source: https://intro2ddsp.github.io/



Signals are now phase-shifted (90°)

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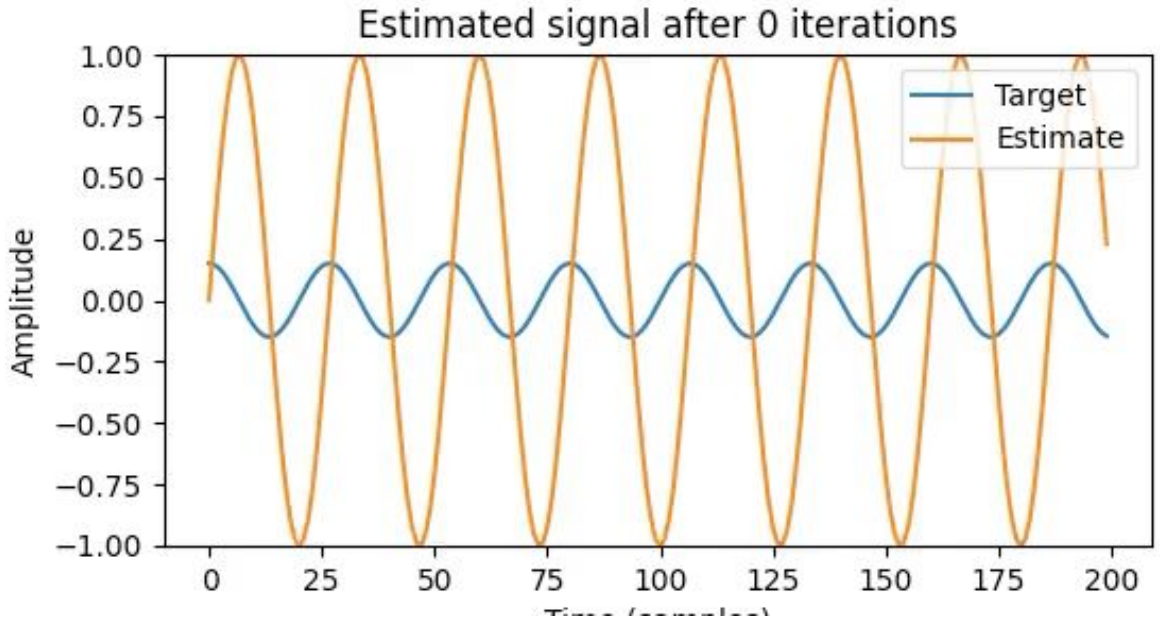
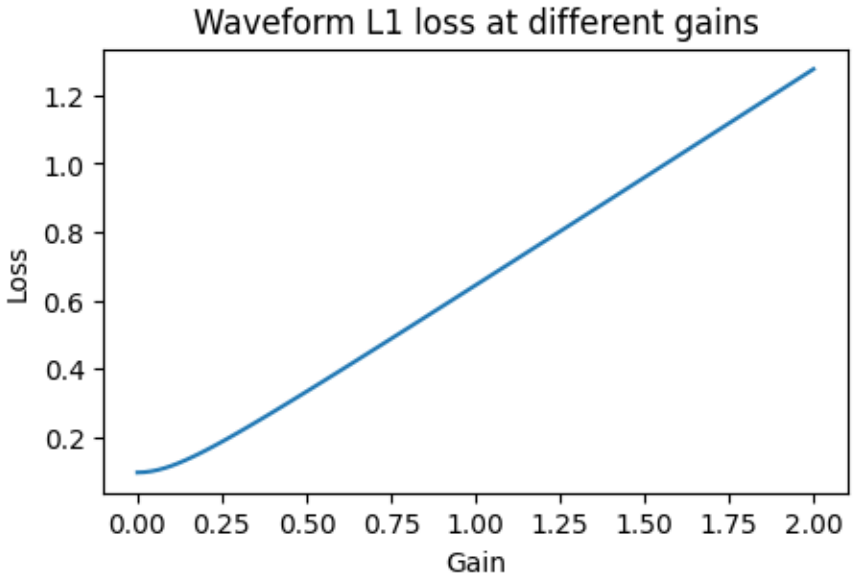
Music Synthesis
DDSP Example

Source: https://intro2ddsp.github.io/





Signals are now phase-shifted (90°)

→ No local minima with L1-Loss!

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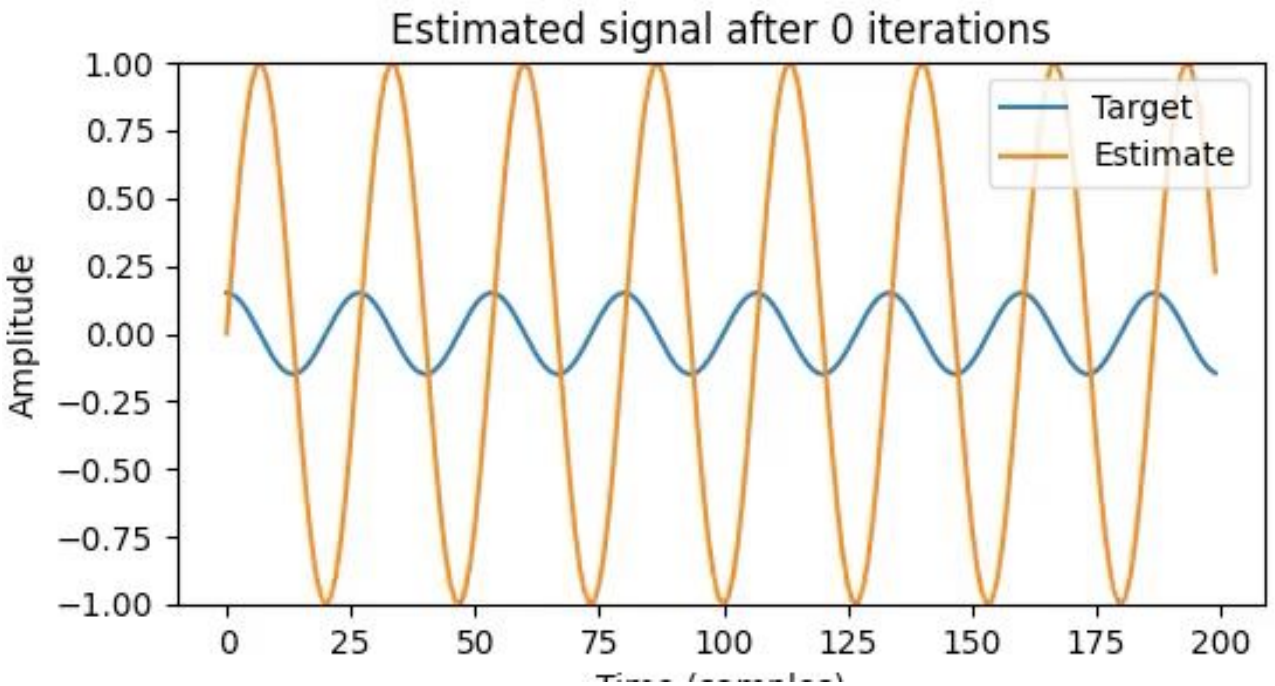
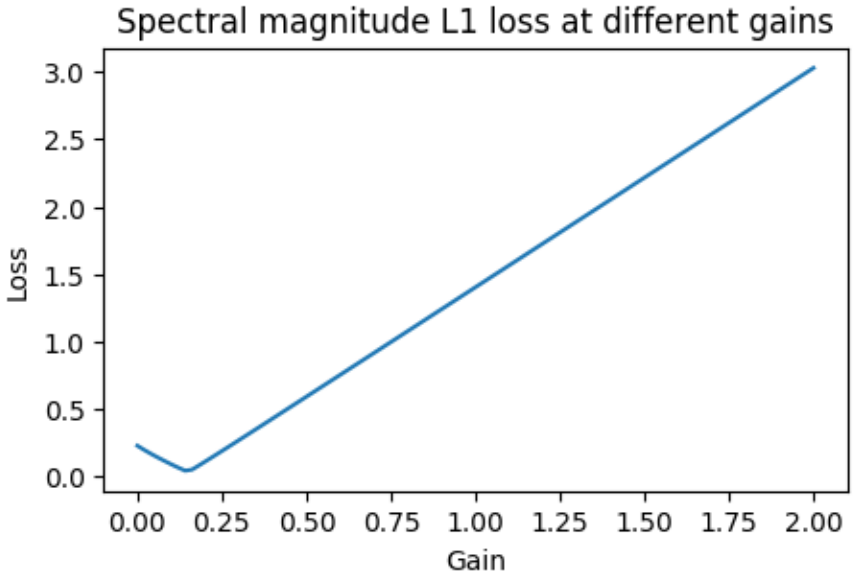
Music Synthesis
DDSP Example

Source: https://intro2ddsp.github.io/





→ Choice of foss function matters a lot!

Simon Schwär and Meinard Müller
Multi-Scale Spectral Loss Revisited
IEEE Signal Processing Letters, 30: 1712–1716, 2023.

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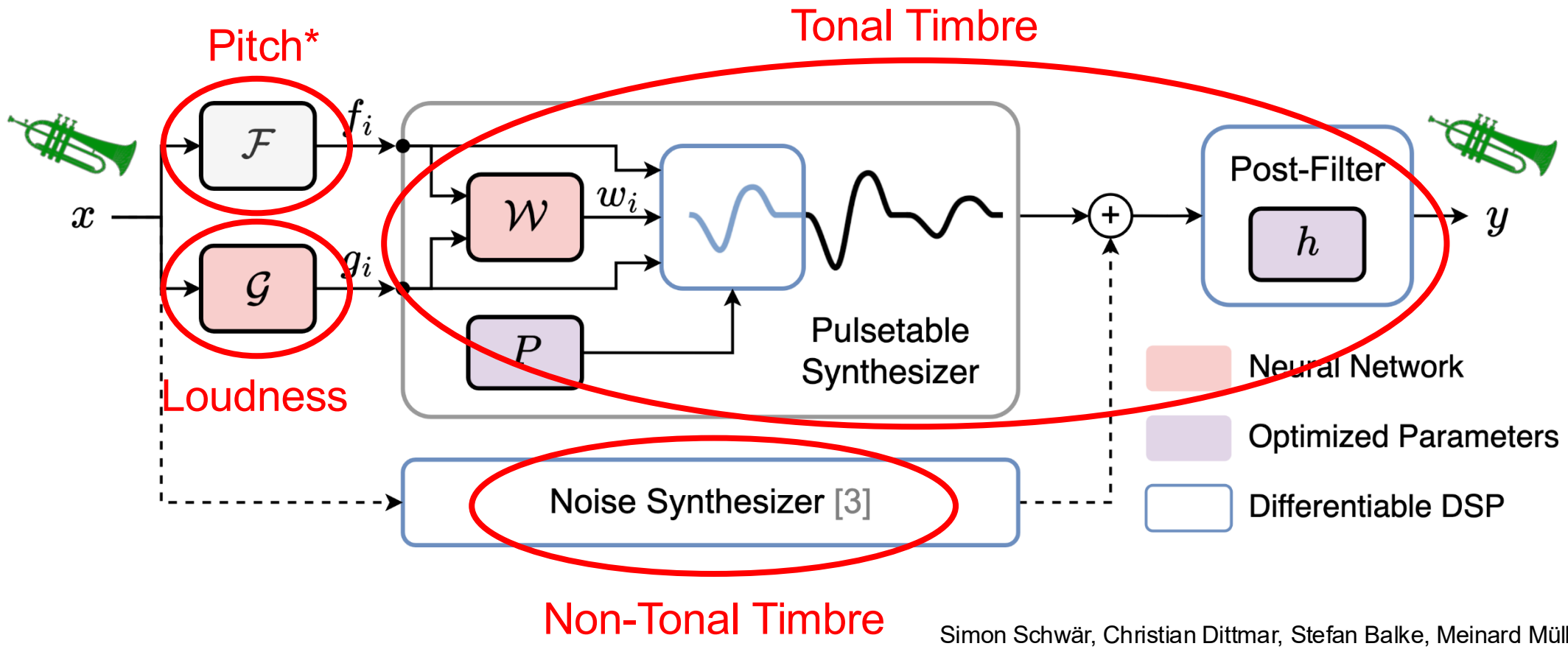
Music Synthesis

Differentiable Pulsetable Synthesis



*) Provided by existing systems/annotations.

Simon Schwär, Christian Dittmar, Stefan Balke, Meinard Müller
Differentiable Pulsetable Synthesis for Wind Instrument Modeling
accepted at IEEE ICASSP, Barcelona, Spain, 2026.

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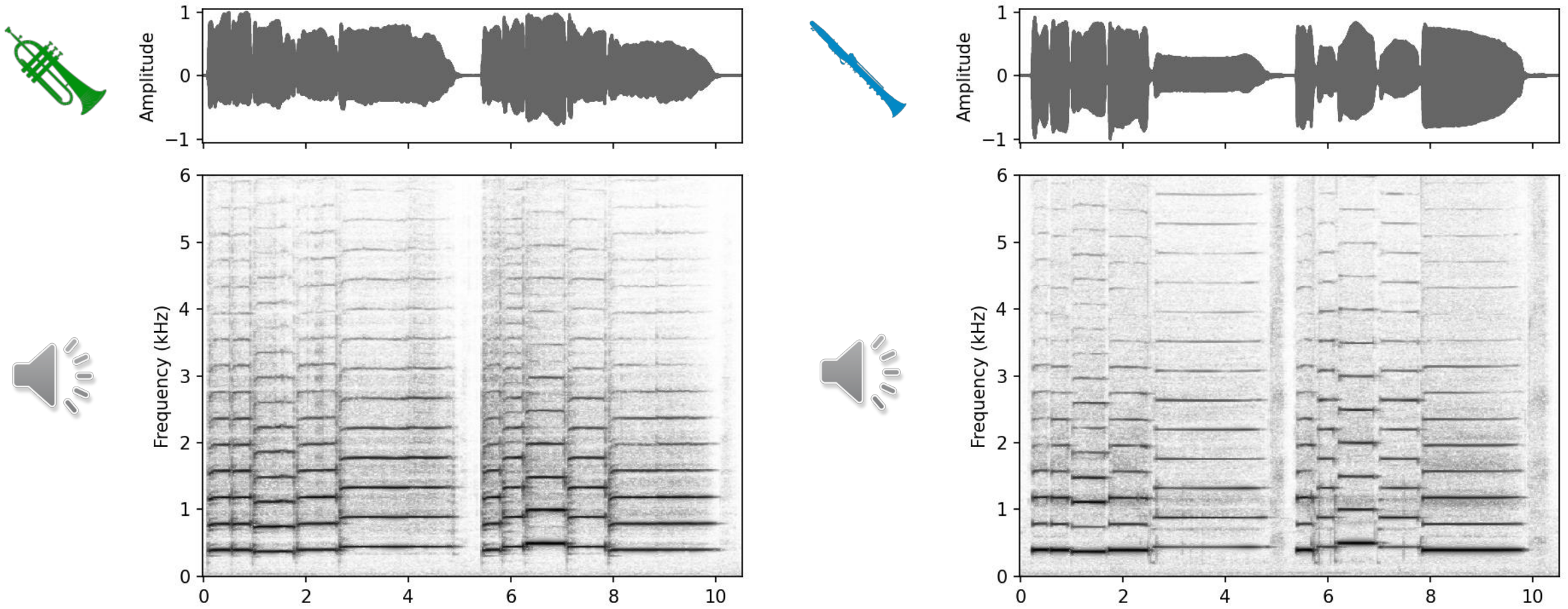
Tone Attributes: Pitch, Loudness, and Timbre



S. Balke et al., “ChoraleBricks: A Modular Multitrack Dataset for Wind Music Research,” TISMIR, 2025.

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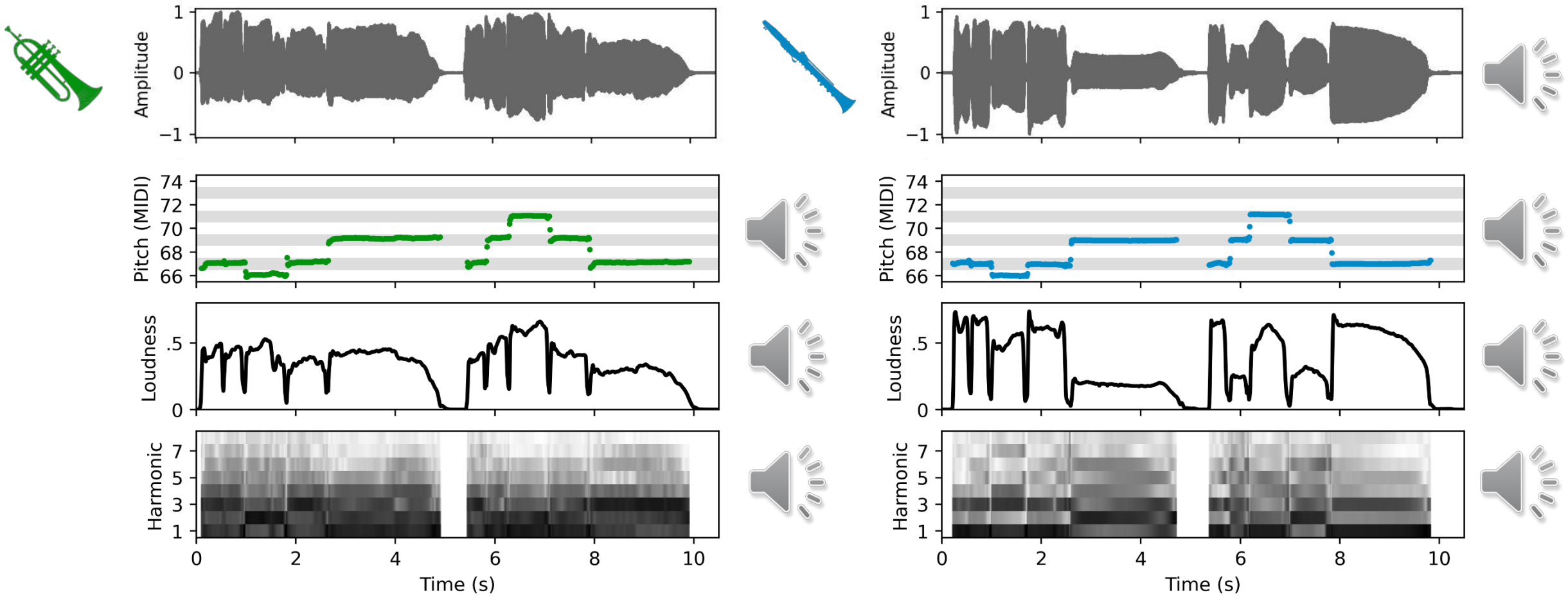
Tone Attributes: Pitch, Loudness, and Timbre



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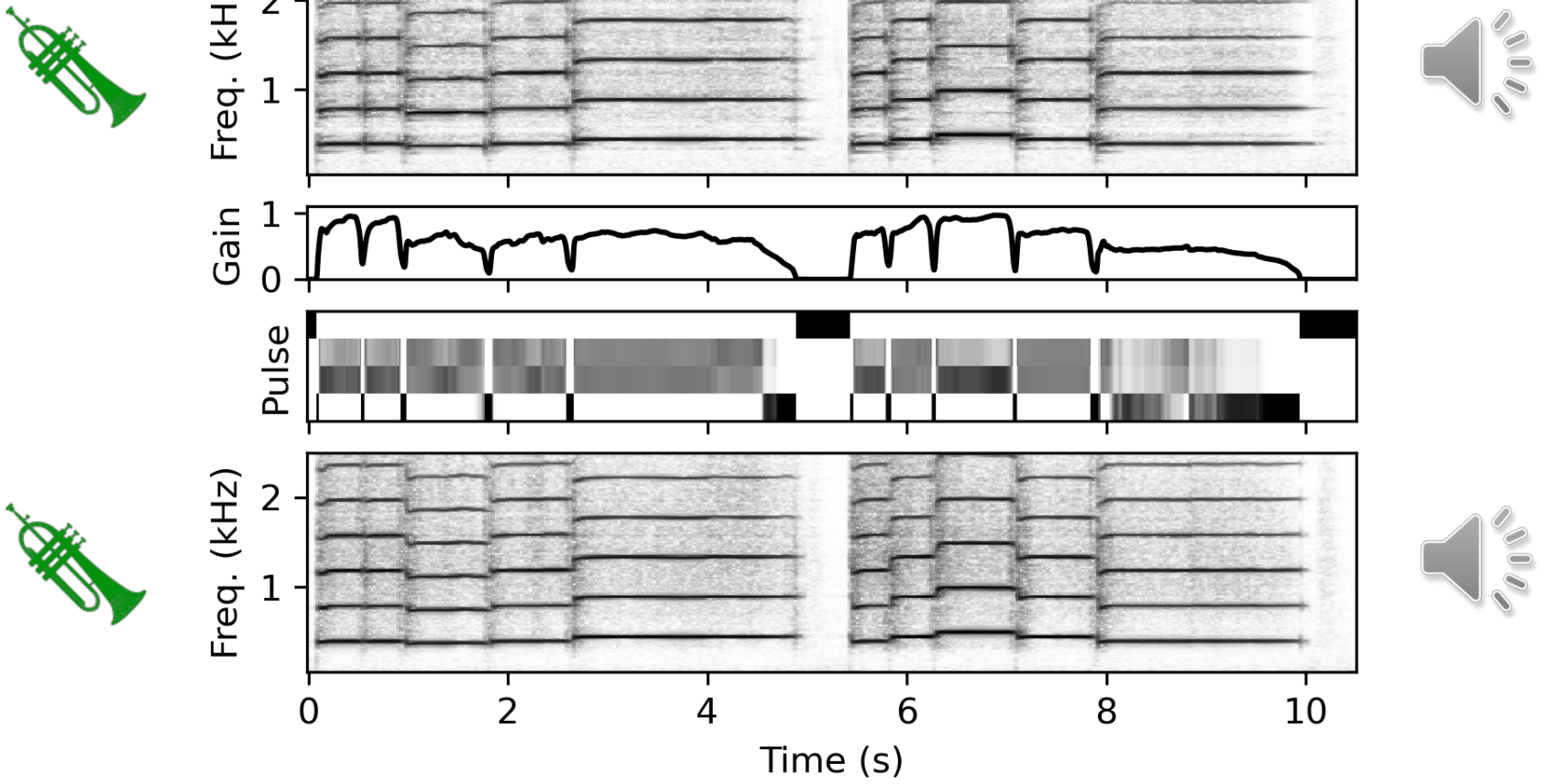
Differentiable Pulsetable Synthesis

Results



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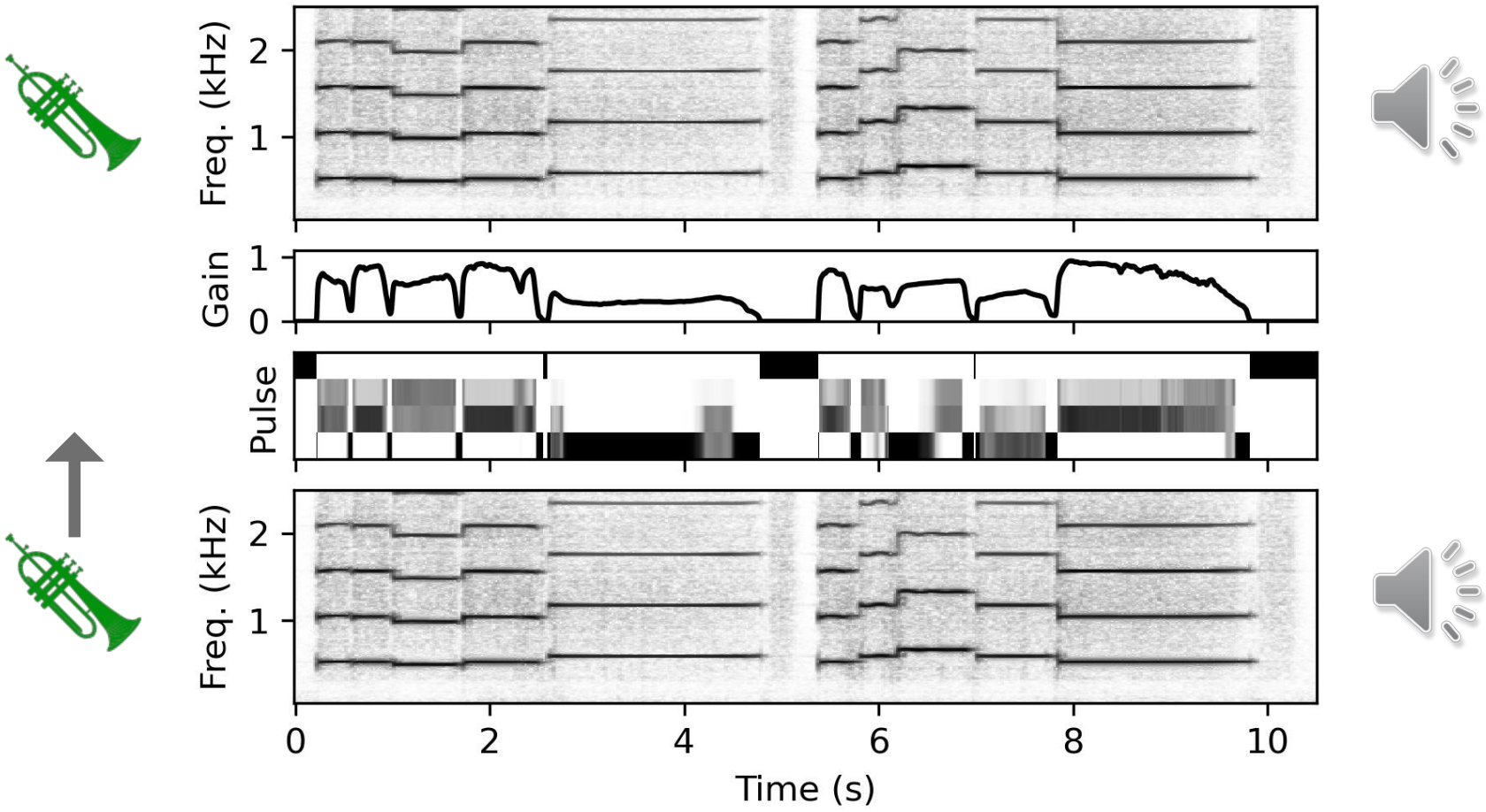
Differentiable Pulsetable Synthesis

Results



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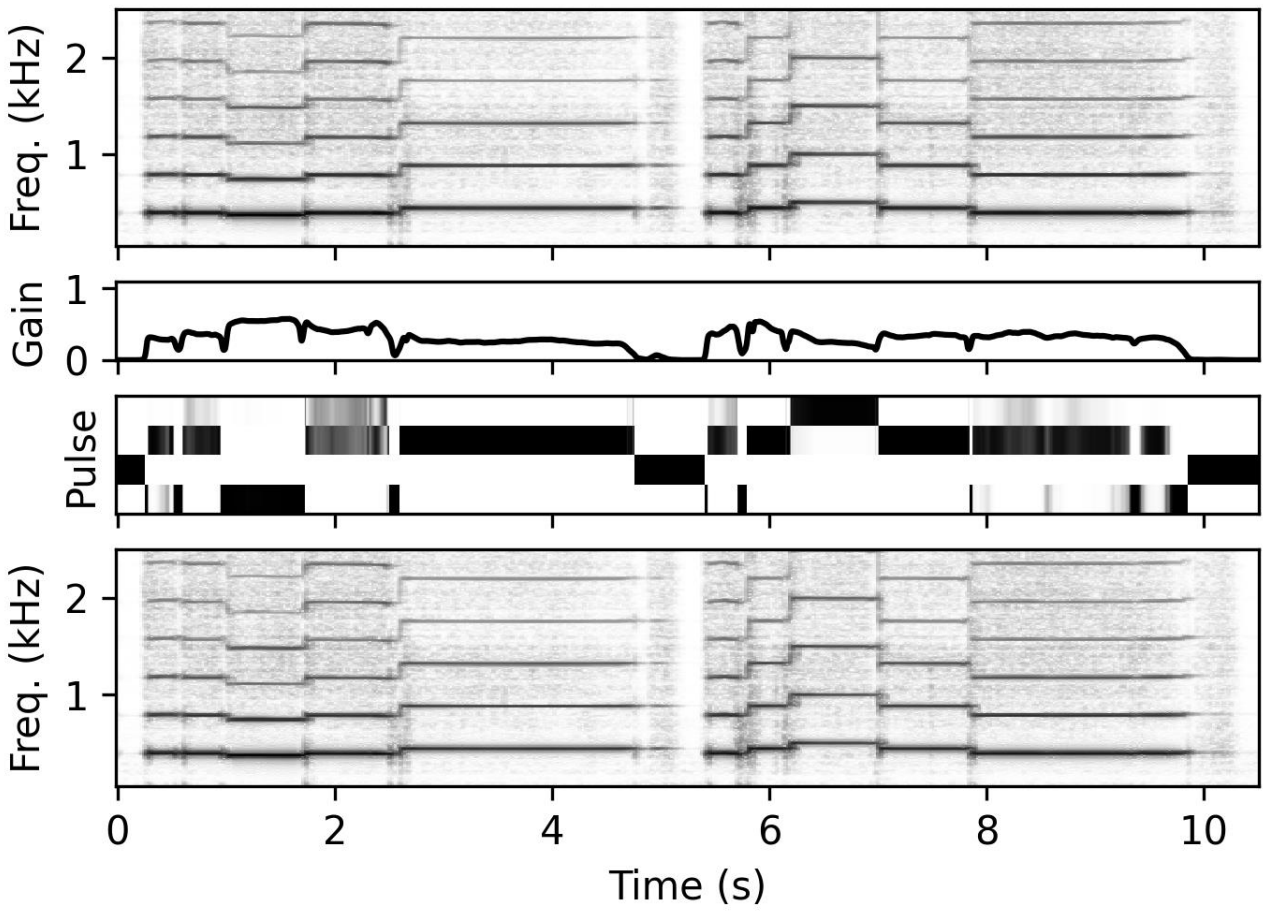
Differentiable Pulsetable Synthesis

Results



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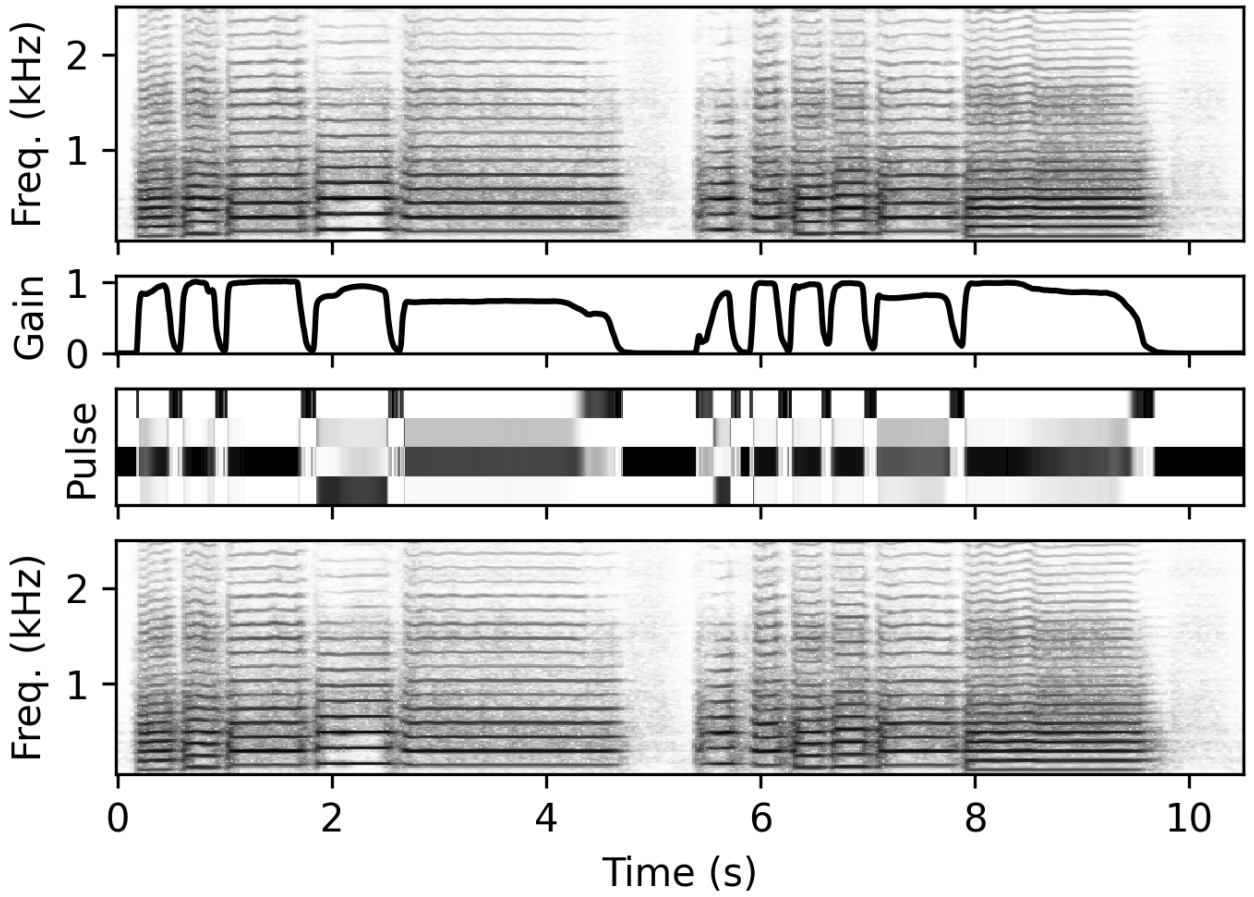
Differentiable Pulsetable Synthesis

Results



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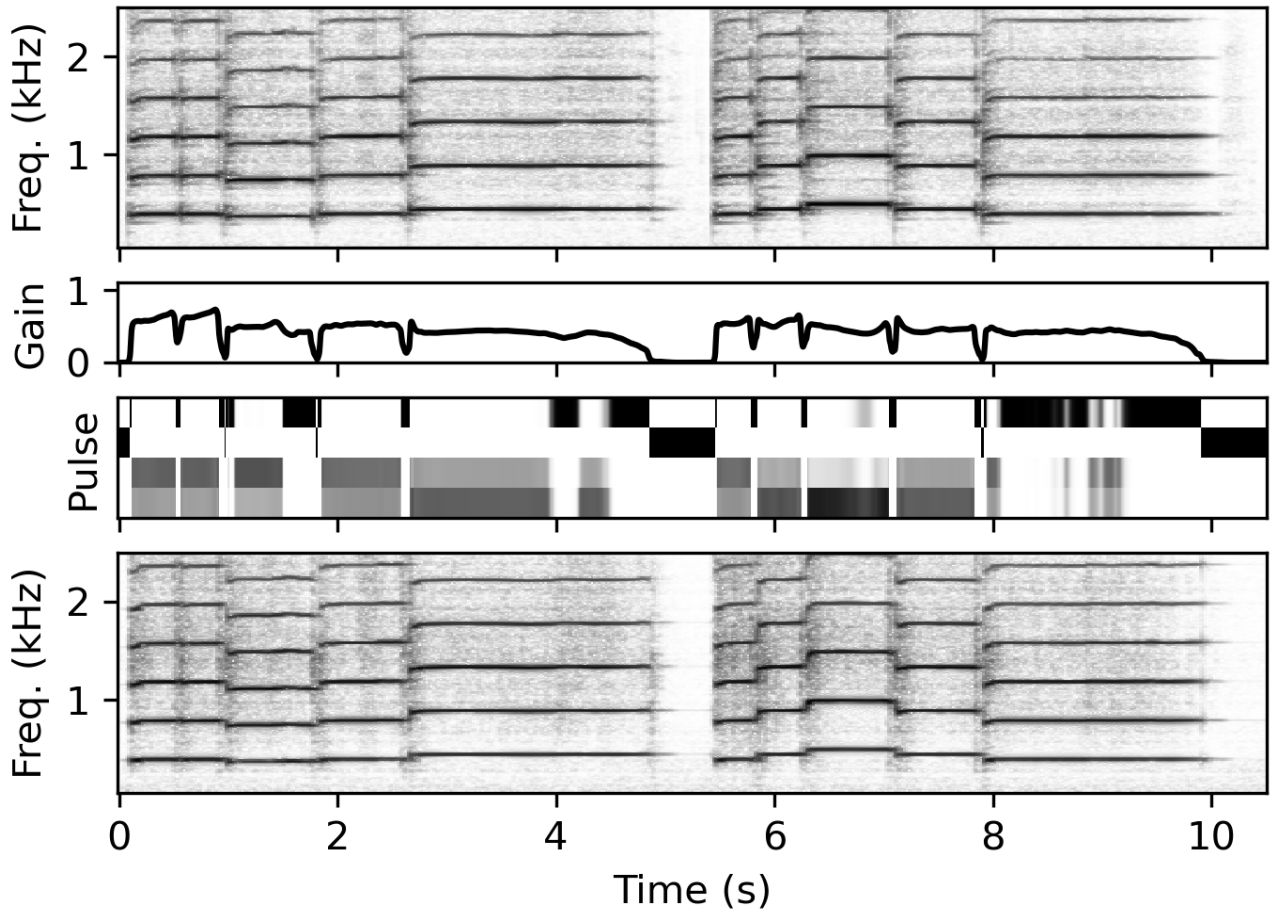
Differentiable Pulsetable Synthesis

Results



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Summary
Emerging Topics: Music Synthesis for Wind Music

- Brief overview on datasets in Music Information Retrieval
- Deep Dive on datasets for wind music (ChoraleBricks, ChoraleWind)
- **Take home message:**
  Developing an intuition for your data is very important → leads to new ideas!

- Brief overview on popular synthesis approaches
- Deep dive on Pulsetable Synthesis
- Fundamental concept of Differentiable DSP
- **Take home message:**
  Potential for efficient, interpretable models → combination of AI & DSP

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DAGA 2026
23.-26.03.2026 in Dresden

- Annual meeting of the german-speaking acoustic community
- We (Meinard Müller, Jakob Abeßer, and myself) organize a special session

Music Information Retrieval
26.03.2026
14 presentations, whole day

Also very interesting:
Musikklanganalyse und AI
Challenges in AI-based Environmental and Industrial Sound Analysis

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1. Stefan Balke, Axel Berndt, and Meinard Müller
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   Schubert Winterreise Dataset: A Multimodal Scenario for Music Analysis
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   ChoraleWind: An Expressive Wind-Quartet Dataset for End-to-End Rendering from the Neues Thüringer Choralbuch
   Submitted, 2026.
5. Peter Meier, Meinard Müller, and Stefan Balke:
   Analyzing Pitch Estimation Accuracy in Cross-Talk Scenarios: A Study with Wind Instruments, In Proceedings of the Sound and Music Computing Conference (SMC), Accepted, 2025.
7. Simon Schwär, Stefan Balke, and Meinard Müller:
   Measuring Sensory Dissonance In Multi-Track Music Recordings: A Case Study with Wind Quartets, ISMIR, 2025.
8. Christian Dittmar, Johannes Zeitler, Stefan Balke, Simon Schwär, and Meinard Müller
   PULSE-IT: Lightweight and Expressive Synthesis of Wind Instrument Playing
   In Late-Breaking Demos of the International Society for Music Information Retrieval Conference (ISMIR), 2025.
9. Ben Hayes, Jordie Shier, György Fazekas, Andrew McPherson, and Charalampos Saitis
   A review of differentiable digital signal processing for music and speech synthesis.
   Frontiers of Signal Processing, 2024.
10. Simon Schwär and Meinard Müller
    Multi-Scale Spectral Loss Revisited
    IEEE Signal Processing Letters, 30: 1712–1716, 2023.
11. Simon Schwär, Christian Dittmar, Stefan Balke, Meinard Müller
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12. Meinard Müller
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