# Music Encoding Conference 2025

Book of Abstracts

**London, UK**

MUSIC ENCODING INITIATIVE

CITY ST GEORGE'S UNIVERSITY OF LONDON

Goldsmiths UNIVERSITY OF LONDON

# Music Encoding Conference 2025

Book of Abstracts

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**Edited by**
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Cover image by David Lewis

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# Foreword

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We are pleased to present the Book of Abstracts of the Music Encoding Conference (MEC) 2025, held June 3-6 2025 at City, University of London in London, United Kingdom. The Music Encoding Conference has emerged as the foremost international forum where researchers and practitioners from varied fields can meet and explore new research built on digital music editions and, especially, research into music encoding itself. The Conference serves not only as the annual meeting of the Music Encoding Initiative (MEI) community but celebrates a multidisciplinary program, combining the latest advances from established music encodings, novel technical proposals and encoding extensions, and the presentation and evaluation of new practical applications of music encoding (e.g. in academic study, libraries, editions, pedagogy).

When using and manipulating digital music information, the properties and behaviours of its encoding are of fundamental importance. This applies equally for musicological study, music theory, production of digital editions, composition, performance, teaching and learning, cataloguing, symbolic music information retrieval and recommendation, or more general electronic presentation of musical material and associated narratives. The study of music encoding and its applications is therefore a critical foundation for the use of music information by scholars, librarians, publishers, and the wider music industry.

To highlight this foundational nature, we gave the conference an explicitly broad scope, welcoming contributions from those working on music encoding, but also those whose research builds on digital music resources or corpora. We are delighted at the breadth of musical repertories represented at the conference, and in this volume, including among others Jianpu Number-Based Notation, Ottoman art music, Mensural music, Lute tablatures, Chant, post-tonal and spectral music, as well as drum kit performances and film music. The topics regarding the application of Music Encoding cover a similar wide range, encompassing digital music editions, performance studies, automated music analysis, as well as dynamic interactive visualisation and generative computer improvisation.

We have many people to thank, including our keynote speakers Anja Volk and Tim Crawford. With their keynotes “Making sense of music: de- and encoding music information” and “A quarter-century of music encoding” they share their tremendous experience and insights.

Together, they help us see how to take the history and core of the field of Music Encoding into the future – in classrooms and applications around the world.

We thank the members of the programme committee for their thoughtful reviews of all submissions: Richard Freedman, Mark Gotham, Paul Gulewycz, Andrew Hankinson, Olja Janjuš, Anna E. Kijas, Elsa De Luca, Davide Andrea Mauro, Fabian C. Moss, Salome Obert, Kevin Page, Frankie Perry, David Rizo, Nevin Şahin, Martha E. Thomae, Sandra Tuppen, Mirjam Visscher, David M. Weigl. Considering the exceptional number of submissions we received this year, their dedication, efficiency, and the detailed, constructive nature of their reviews were remarkable.

We also thank the local organising committee for their work: Golnaz Badkobeh and the Department of Computer Science at City St George's, University of London for hosting the Music Encoding Conference, Jamie Ward and the School of Computing at Goldsmiths, University of London for sponsoring our keynotes, Tobias Bachmann for technical support, Jamie Forth, Tillman Weyde and Asif Nawaz for organisational help, along with Sarah Acs, Paola Amigo, Nikki Cheng, Alexus Deese, and Andreas Prohl-Plaksin for general support during the conference.

We thank Sophie Stremel for her exceptional work on the formatting and editing of this Book of Abstracts.

Finally, we would like to express our gratitude to the MEI Board for their generous support in making the Travel Bursaries possible, helping to ensure broader, more inclusive participation—particularly among early-career researchers and students.

# KEYNOTE PRESENTATIONS

# Making Sense of Music: de- and encoding music information

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## Introduction

In Matt Haigs popular sci-fi novel “How to stop time”, Tom Hazard, currently looking like a 41-year-old, has been playing music for four centuries, being 439 years old due to a rare condition of aging much slower than ordinary people. In attempting to make sense of his 400-years-old existence to find a path forward, he also seeks to make sense of the role of music in his long life.

Becoming a music researcher is often motivated by making sense of music one way or another, though we usually have much less than 400 years of personal experience we can draw upon. With the digital encodings we have at hand now, we process music information that spans way more than 400 years, as demonstrated at this year’s MEC conference, with papers addressing Gregorian tradition, polyphonic lute music, Schubert, Stravinsky, post-tonal music, Klezmer, or electroacoustic and film music. The diversity of research topics addressed, such as the study of melody, musical form, polyphony, repeated structures, performances or visualizations, demonstrate different aspects of our musical scholarship related to de- and encoding of music information. In attempting to make sense of music together, how do we connect these different perspectives on music?

To open a reflection on this question during the conference, I will discuss in my talk examples from 25 years of research at Utrecht University on de- and encoding of music information, connecting musicological inquiries on musical structures with applications of these structures in different interaction contexts. In our case, finding connections between musical structures and interactions is crucial for demonstrating why music research matters within the academic and societal context in which we work. It also became important in our education of students at the intersection of computer science and music, for making sense of music together in the classroom, which brings me back to Tom Hazard.

Tom’s wish to live an ordinary life after 400 years, leads to a decision to become a schoolteacher in contemporary London. When interacting with rather disinterested teenagers, he offers a (sometimes comical) stage for making sense of his long life while educating the next generation. I can relate to this experience. Making sense of music together with students in the classroom has provided a (sometimes comical) learning experience for me that also sharpens my mind on finding connections between different aspects of musical inquiries, and on staying connected to why music matters to us. I will discuss examples from teaching computer science students about the de- and encoding of music information, and from my colleague Peter van Kranenburg's experience of teaching machine learning to musicology students. In preparing a new inter-faculty course for both student groups, we now seek to find connections for both groups to make sense of music together. This community has given us inspirations for teaching in the past, and I welcome ideas and reflections on making sense of music in the classroom by engaging different aspects of our musical inquiry during MEC2025.

# A quarter-century of music encoding

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## Abstract

One way or another, I have been involved with ‘music encoding’ for well over 25 years now. It started in 1987 with my first Macintosh computer, on which I played with a program called Hypercard, which you could get to play tunes rather crudely; I was soon exploring how to make it play from lute tablature, for which I needed my own encoding format. Soon after, I met the late Donald Byrd, then working on his music-notation editor, Nightingale, a Macintosh program which never achieved the success it deserved. Don’s colleague, John Gibson, helped me to hack together, using bits of code from Nightingale, my own Tablature Processor for Mac, which soon died owing to my failure to keep up with successive OS upgrades. But I was able to use it in earnest in an exacting project, providing modern quasi-facsimile tablature for a pair of volumes of my own scholarly edition of lute music by Silvius Leopold Weiss (1687-1750).

Don and I worked on several projects together, including Online Music Recognition and Searching (OMRAS), which received joint US/UK funding for three years. It was at the suggestion of our US funders, the NSF Digital Libraries Initiative, that we hold an international workshop, which in fact became the first ISMIR conference (Plymouth, Massachusetts, 2000). Already, with Don and John Gibson, I had contributed a chapter to *Beyond MIDI* (1999) about the Nightingale Notelist, an ASCII-based encoding format for music which captured many of the features of Nightingale itself. But all was swept aside by the rapid domination of formats based on XML, which itself had only existed for a decade or so at that point. At the second ISMIR (Bloomington, Indiana, 2001), I was witness in a pub to what can best be described as a ‘lively discussion’ between Michael Good, whose MusicXML had just got going, and Perry Roland, about the relative merits of elements and attributes for certain features of music which I don’t need to go into here. Since the last time I was honoured to give an MEC keynote (at Charlottesville, Virginia, in 2014), Perry’s baby, MEI (amusingly, known to my email client as ‘Mei’), has grown up considerably.

My original intention had been to try to summarise briefly what has been achieved with MEI since 2001. However, I realised that would have been both tedious and at best incomplete, as (a) most of those present know the story at least as well as I do, and (b) I don’t pretend to keep up to date in every facet of MEI’s development; there may well also be things happening which none of us know about - such is the nature of Open Source. I thought

instead it might be more interesting to look back over the last quarter of a century in a non-technical and personal way at how progress in the the handling of music with computers has touched upon my own work as a music researcher.

## *Beyond MIDI* (ed. Selfridge-Field, MIT Press, 1997)

### *The Nightingale Notelist*

In my own efforts on coding and testing the development versions of Don Byrd's Macintosh program Nightingale, I got to know its internal structure sufficiently to author a chapter for *Beyond MIDI* on the Nightingale Notelist, a simple ASCII encoding of the basic information needed to define a score. The principal idea at the time was to allow exchange of the essential musical data between the program itself and other processing routines (e.g. for analysis, but also including other notation editors, of course). Although this experience taught me much about the problems of music-representation, the Notelist never caught on, as Nightingale - excellent though it was - never achieved much success in the market.

Despite the small number of the 30 or so music-encoding formats described in detail in *Beyond MIDI* that survive today (many more are listed and summarised in an appendix), it is still a highly useful and relevant text, which I recommend reading, most particularly for the ancillary chapters by Eleanor Selfridge-Field in which she raises several issues in music-representation which still have value today.

## Electronic Corpus of Lute Music (1999)

Having devised a simple coding scheme for lute tablature, which allowed me to create the modern tablature for the S.L. Weiss edition, it seemed obvious that I should gather as much lute music in encoded form and do corpus-based work on it. In order to marshal the critically-important metadata for the sources, composers and other information, we needed a programmer to set up a relational database; thus was born my long-term collaboration with today's chairman, David Lewis, and I'd like to thank him for the many years of knowledge sharing we've been able to enjoy ever since he joined the project. More on ECOLM later.

## Online Music Retrieval And Searching (OMRAS, 1999)

While writing the Notelist chapter I was working with various colleagues in the Computer Science and Electronic Engineering departments at King'.s College, London, with the aim of achieving a workable music information retrieval program which would allow search across both audio and symbolic domains. Needless to say, this is still something of a dream. But we made a good start with OMRAS, a project with Don Byrd at UMass, which was enabled by joint UK and US funding.

As a Digital Library project, OMRAS was funded by NSF Digital Libraries (US) & JISC (UK). From the start, we worked on audio and score, so a priority was to find a way to cross-match between intermediate features derived from the two domains which expressed common perceptual patterns. Building on early work on monophonic pitch-extraction, we eventually were able to represent parallel harmonic profiles from audio and scores in a language model which was encouragingly robust to the amount of error in processing the music in these two forms.

At the suggestion of (and separately funded by) the NSF Digital Libraries Initiative, we were able to hold the first International Symposium on Music Information Retrieval at Plymouth, Mass, in 2000. Since then, the annual ISMIR conferences, attended by delegates from all over the world, have been a showcase for the technology around music streaming, discovery and recommendation, building on the simultaneous rise of the World Wide Web as a medium for entertainment and business.

In my MEC 2014 Keynote presentation I mentioned that we were “working on an ‘MEI-compliant’ lute-tablature encoding schema … [which] could be extended to other tablatures – e.g. guitar (both historical and modern) and keyboard – with large and important repertories.” That has now developed into a fairly complete MEI historical lute tablature module, with Verovio support sufficient to be of real use to musicologists, such as those involved in the eLaute project. Keyboard (and other) tablatures have had to wait so far.

I also mentioned some issues with the state of MEI at that time (2014), including ornament-signs (and their meaning), fingering-symbols and instrument-descriptions. At that time, a good way forward seemed to be to incorporate Linked Data URIs to point to ‘canonical’ (and persistent) examples of graphical appearance and/or performed interpretations. I am not sure what progress has yet been made on this.

## F-TEMPO (2018)

In 2018 we received a modest amount of funding for a project on full-text searching of large collections of historical printed music. F-TEMPO (Full-Text Search of Early Music Prints Online) was inspired by an online search program for Japanese prints, Ukiyo-e.org, developed by John Resig (the originator of jQuery). We ran Aruspix, Laurent Pugin’s excellent OMR program for 16c music prints, over about 500,000 pages of early printed music, most of which are single (monophonic) vocal parts, producing MEI representations of each page (with inevitable OMR errors). At the suggestion of the host of this conference, Golnaz Badkobeh, we indexed them using Minimal Absent Words, a method which immediately gave excellent - and quick! - retrieval results despite the high degree of error in the indexed data.

## TROMPA (2018)

In the EU Horizon 2020 project, TROMPA (Towards Richer Online Music Public-domain Archives), I led a group working on ways to assist music scholars in their online work. Thanks to my strenuous efforts to involve David Weigl in the TROMPA team, we were quickly able to persuade the project to adopt MEI from the start, and to incorporate much of the technology he’d helped to develop at Oxford in other projects, most significantly the MELD (Music Encoding and Linked Data) framework. This enabled the development of interfaces for interactive score-display, annotation and external linking; it also allowed us to demonstrate how selected musical features in a displayed score could be used as a query-by-example to an instance of F-TEMPO running externally.

However, the most significant outcome of TROMPA for the MEC community is probably MEIfriend, which was developed by Werner Goebl and David Weigl to make all our lives easier.

## Lute tablature as ‘music’

In my MEC presentation, I shall end by making some observations about Encoding and Decoding lute music, which I hope will expose some issues about music in general.

# LONG PAPER

# Music with Numbers: *Jianpu* Number-Based Music Notation in Cultural Heritage and Digital Humanities

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## Introduction

Number-based music notation (NMN) offers an intuitive way to represent music, using numbers to denote pitches. Widely used in Chinese music education, it serves both as an accessible entry point for learners and a comprehensive system for expressing and conceptualising music. NMN's versatility and adaptability stem from and are influenced by musical education systems across various cultures, helping students engage with music straightforwardly and effectively.

We examine NMN’s historical and modern usage in both Eastern and Western contexts, highlighting the extensive adoption of Jianpu in 20th and 21st-century China (Sections 1, 2, and 3). We also explore its integration into computer music software, databases, and encodings. We discuss how NMN can represent both simple and complex musical structures, emphasising its potential for broader incorporation into digital humanities initiatives, including encoding systems such as MEI. We propose reframing the perception of Jianpu — not as merely “simplified“ notation, but as a legitimate and effective system for teaching, learning, and practising music (Sections 4 and 5).

# 1 NMN across Cultures and History

As reported by Picard (1990), earliest examples of Number-based Music Notation (NMN) in Europe are found in Spain, in the 16th century on organ tablatures, in particular with Juan Bermudo (1555) and L. Venegas de Henestrosa (1557) (Figure 0). The system that Rousseau later invented in his *Dissertation sur la musique moderne* (1743) was updated and used by Galin (1818). What is called the *Galin-Paris-Chevé* system was particularly developed by Nanine Paris. In her *Méthode élémentaire de musique vocale* (1844), which she published with her husband, she gave more than 1000 exercises designed to learn music through NMN (Figure 1a), and only later introduced staff notation as an extension of NMN-based learning.

However, NMN was not really successful in the Western world. It's really in Asia that the system has developed and flourished. During the Meiji Restoration, Japan adopted Western educational reforms, including music education based on Paris’s system (Chang, 2022). NMN was then brought to China, influencing public school singing classes (学堂乐歌, Xuetang *Yuege*) and becoming an integral part of music education (ibid) (Figure 1b). The next sections will detail how the *Jianpu* NMN is popular in Chinese music. Meanwhile, a similar number notation system, *Nut Angka*, has been used widely in Indonesian traditional music since the 19th century (Figure 1c) (Andono et al., 2022). NMN was also used in European and American vocal education and religious contexts (Figure 2a, Alonen & Forment, 2023). More recent variants of NMN include proposals to encode chord progressions or other scales (Figure 2b, 2c).

Our focus on NMN as defined by numeric pitch encoding necessarily excludes certain culturally significant but symbolically distinct systems (Silpayamanant, 2023). For example, Indian sargam and Byzantine neumes both represent relative pitch through non-numeric symbols, while Chinese Gongchepu uses characters as pitch names (Pearson & Ramanujacharyulu, 2023; Troelsgård, 2011; Wang & Chen, 2024). The choice to center numeric systems stems from their shared technological affordances in digital encoding: Numbers provide a natural bridge between human-readable notation and machine-processable data structures. This computational universality underpins NMN's unique value in digital humanities initiatives.

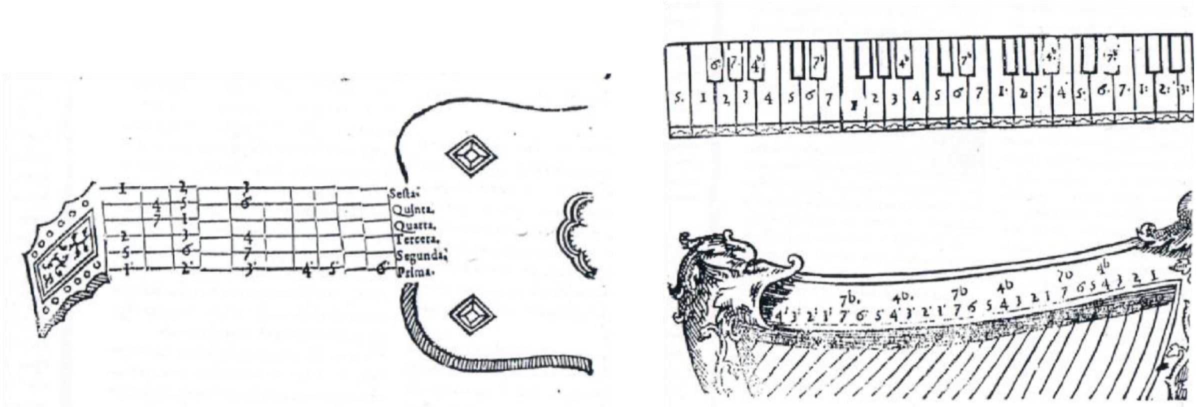



**Figure 0**. Number-based Music Notation reported by L. Venegas de Henestrosa (1557), on vihuela, keyboard, and harp.

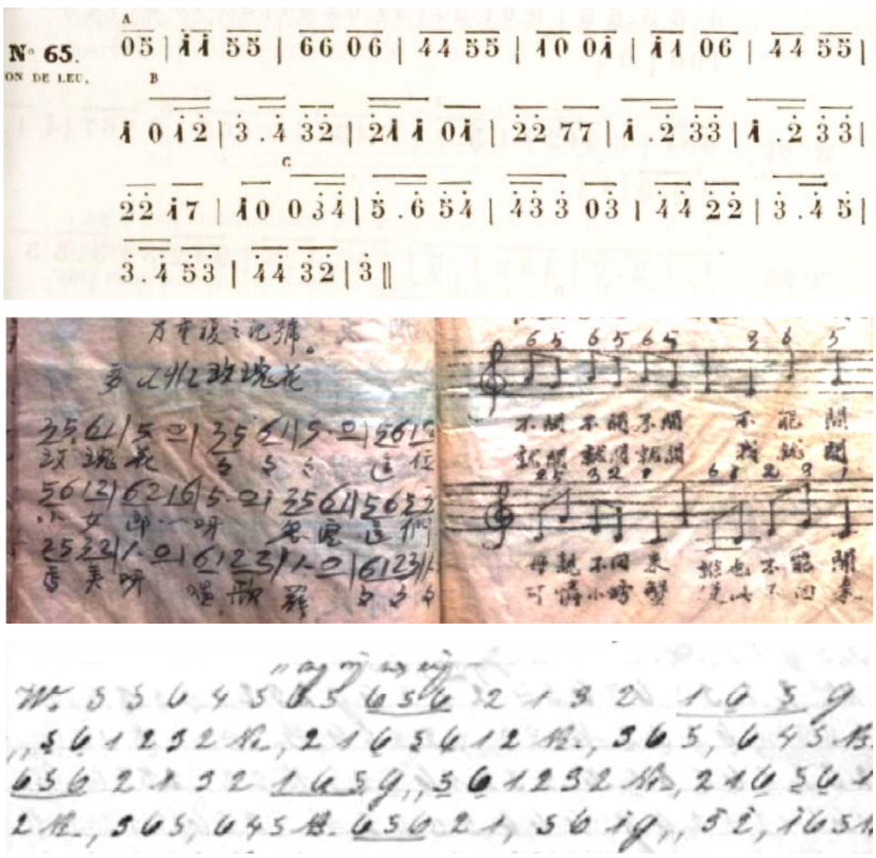



**Figure 1:** a) Canon with three voices as notated by Paris (1844). b) Kunming Normal School Songbook, combining numbered and staff notation, in Chinese traditional singing classes around the early 20th century. c) Indonesian *nut angka* (Ishida, 2010).

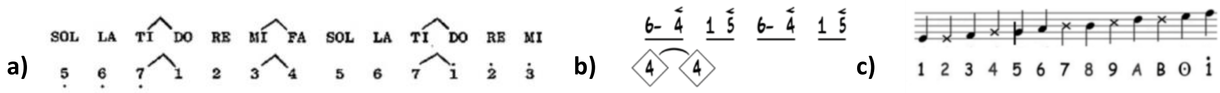



**Figure 2**: Western recent uses and variants of NMN. a) Ward method. b) End of the chorus from “Peace of Mind“ in Nashville Number System (NNS) (Clercq, 2019). c) Hamburg Music Notation (Robert 2014).

# 2 The Jianpu NMN

NMN here refers to a broad family of notation systems that use numbers to denote pitch, typically within a movable-*do* system, with 1 corresponding to *do* and 7 to *si*. *Jianpu* has unique notational conventions, such as octave dots and rhythmic dashes, which enhance its usability and make it prominent in China. The term 简谱 (*Jianpu*) could be translated to “simplified notation,“ where 简 (Jian) means “simple“ or “accessible“ and 谱 (*Pu*) means “notation“ or “score“. *Jianpu* is recognised for its accessibility and ease of learning, making it a popular choice for everyone. In this paper, we use the English term “score” as 谱 (*Pu*) to encompass all forms of musical notation.

Jianpu can represent melodic lines or chords, but unlike (five-line) staff notation, within a key-centric context, it focuses on scale degrees rather than fixed pitches (Figures 3, 4). This may seem challenging for those accustomed to staff notation, but this helps performers internalise tonal relationships, encourages musicians to focus on intervals and tonal hierarchies, and facilitates experimentation with modulation, transposition, and scales. Jianpu can also describe complex scores, for example, with Guzheng techniques (Figure 4).

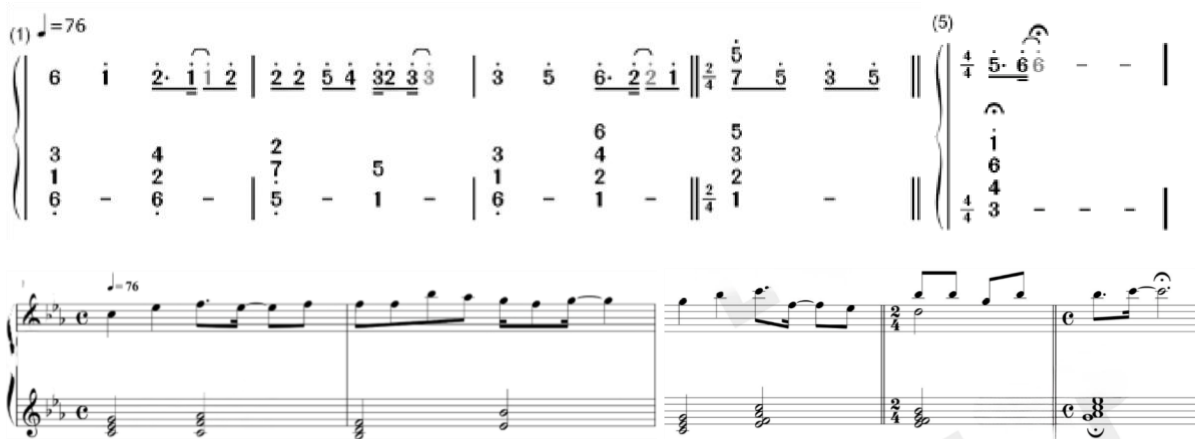



**Figure 3**: First five bars of the Japanese anime EVA song in *Jianpu* Cruel Angel's Thesis, as transcribed by (Everyone Piano). a) (top) Jianpu, C minor is notated using “1“ for E flat, with “6“ showing its minor quality. b) (bottom) Staff notation transcription.

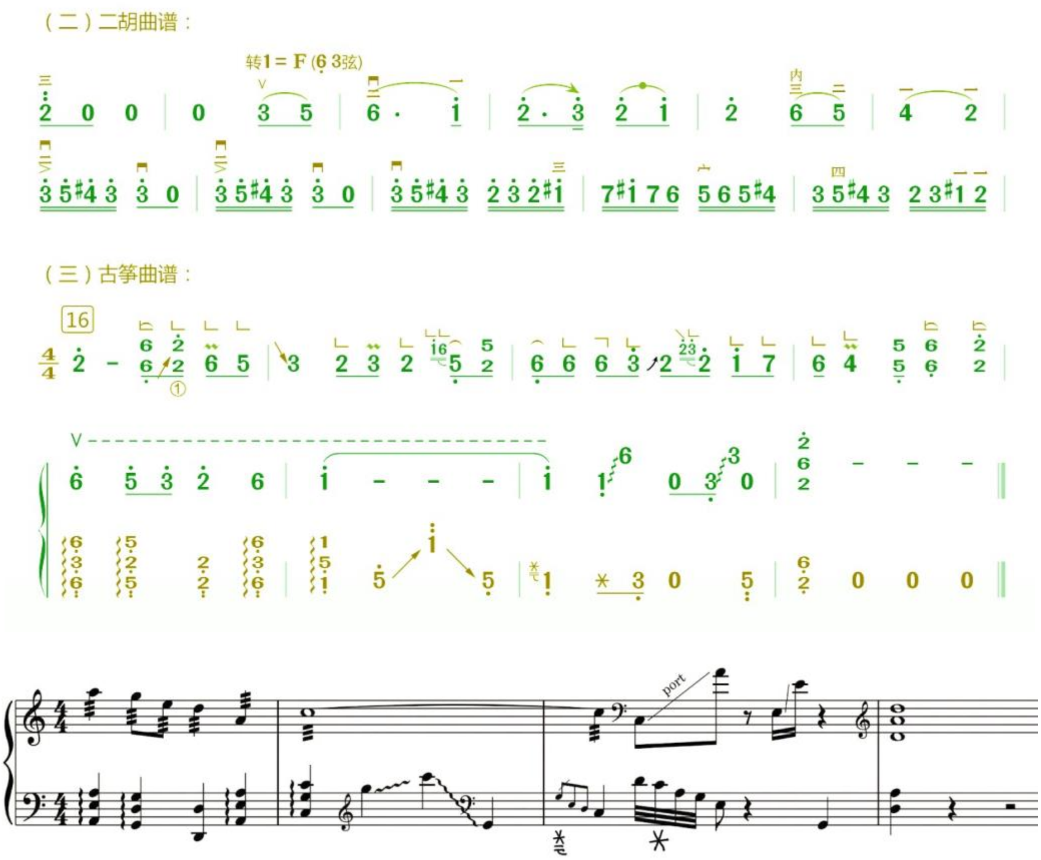



**Figure 4**: (top) The Jianpu score for Chinese instruments Erhu and Guzheng (demonstration file for JP-Word). The *flower note* * denotes plucking the strings with the thumb by feel. (bottom) Staff notation transcription of the last four bars (own work). All glissando and portamento are pentatonic. The first * is acciaccatura played before the beat. The second * has a longer duration (within a quaver).

# 3 Contemporary Use of Jianpu NMN in China: Pedagogy and Beyond

Jianpu NMN is deeply integrated into Chinese musical education and practice, and is particularly beneficial for Chinese learners struggling to find an appropriate music-learning approach (Xue Ya, 2020). Historically, character-based notations like *Gongche* were challenging to learn without formal training, limiting access to music education (Chang, 2022). In the early 20th century, Chinese educators and politicians like Cai Yuanpei (1868-1940) advocated the popularisation of music education, and Jianpu became an important tool for the "musification of the national education" movement (Ho, 2010; Ju, 2014). It is recommended in official teaching guidelines (Department of Education, 2006) and in music textbooks (Primary Music Lesson Plans, 2023), predominant in early childhood education (Yang, 2020), and used in combination with staff notation as students progress to elementary school (Figure 5).


**Figure 5**: Chinese adaptation of Schubert's *Die Forelle* (鳟鱼) in music textbooks for year 9 children, with both melody and lyrics (People's Education Press Music textbook, 2013).

For children, starting music education with Jianpu before introducing staff notation aligns better with their developmental abilities and makes learning easier (Tian, 2011).

Beyond formal education, Jianpu is deeply embedded in both private and community music practices, such as bands or choirs (Figures 6, 7, and 8). When paired with Jianpu, the combination of numbers and characters is extremely efficient. Many Chinese folk artists compose music using Jianpu without studying staff notation. An example, Sun (2004) transitioned from being a folk artist to a professional musician, relying on his Jianpu education and only began reading staff notation when learning the flute. Jianpu forms thus a part of Chinese musical identity, and Kaminski (2022) examines how it helps sustain this identity in New York's Chinatown.

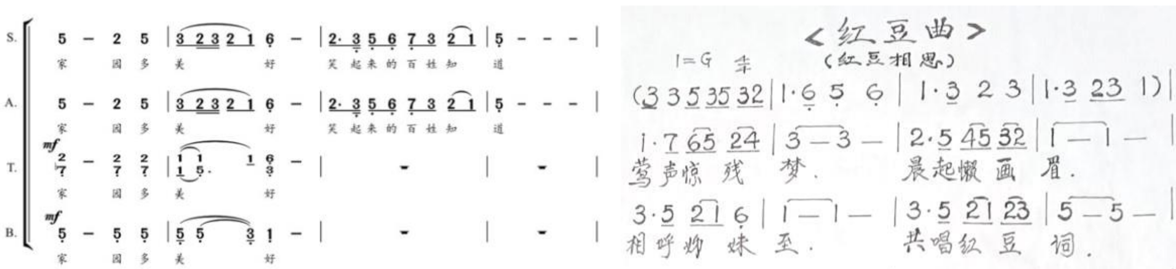



**Figure 6**: *Jianpu* used by a) the semi-professional Chinese choir of the Central Conservatory of Music (Jin Zhao, 2023). b) the amateur Guangzhou Senior Choir.

**Figure 7**: Teaching, playing, and reading Jianpu. a) Xiaolu Qiu (primary school teacher) with parents. b) Ru Xie (kindergarten teacher) with her pupils.  c) Guihe Pan (member of Guangzhou Senior Choir). d) & e) & f) Xiaolu Qiu's and Min Xie's students. g) 木木大魔王 (zhongruan learner). Pictures reproduced with the owners' authorization.

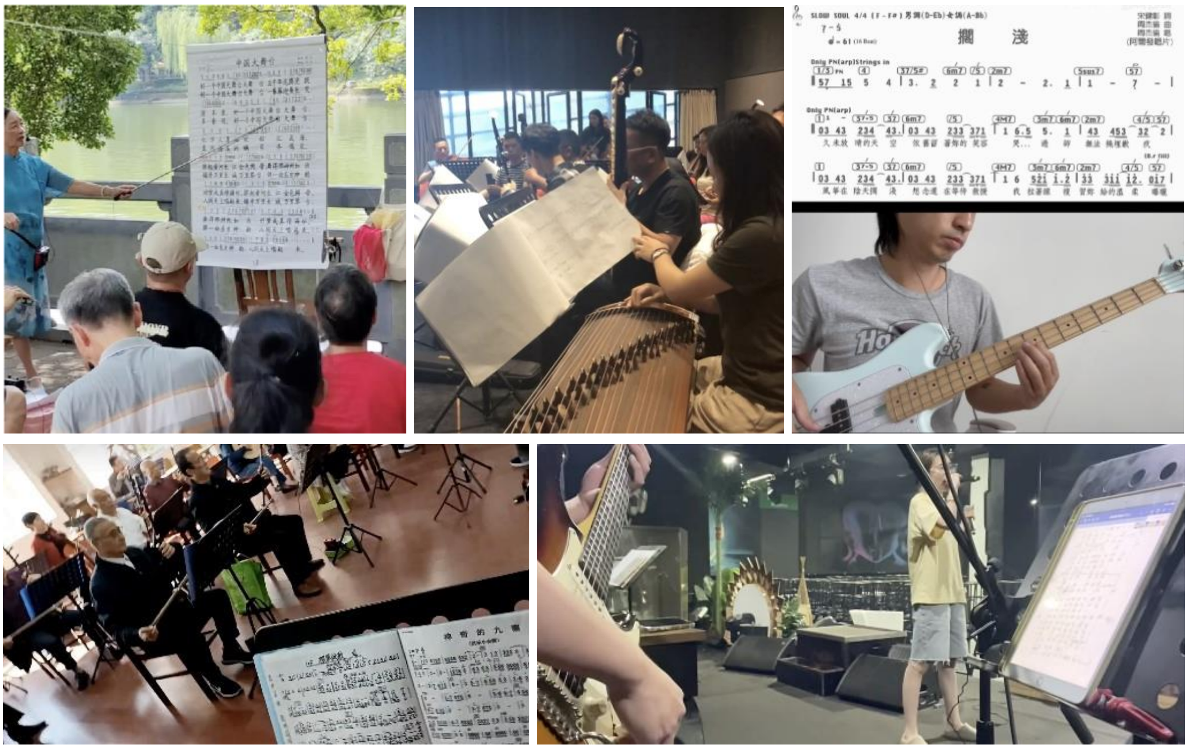



**Figure 8:** Videos posted on the "Bilibili" social network between 2020 and 2024. Screenshots under fair use (Top) a) The choir under the banyan tree in Guangzhou's Dongshan Lake Park is my ideal retirement life. Posted by 马路牙子唱支歌. b) Zhejiang Little Hundred Flowers Yueju Opera Troupe Band Rehearsal. Posted by -梅子茶泡饭 c) [Bass Teaching] Stranded by Jay Chou. Posted by 贝斯手刘弘霆小 G. (Bottom) d) Rehearsal of folk music 'Magical Jiuzhai'. Posted by 竹林 673. e) How much fun is it to be a musician in a bar in Dabian? Posted by 夏季八煮. Screenshots used under fair use for academic and commentary purposes.

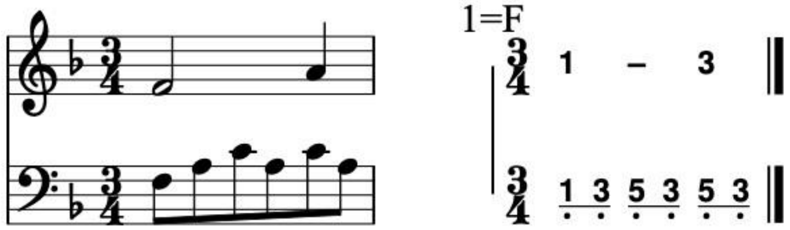
| | | |
|---|---|---|
| **China Music Score Network** 中国曲谱网 | Over 300,000 scores (mostly Jianpu), Over 880,000 users | https://www.qupu123.com/ http://qupu123.com/Mobile-lists-type-hot.html |
| **Jianpu Home** 简谱之家 | Over 100,000 Jianpu scores | https://www.jianpu.net/ |
| **AiQupu** 爱曲谱网 | Mostly Jianpu scores | https://www.2qupu.com/ |

**Table 1.** The major Chinese music score websites have hundreds of thousands of Jianpu scores.

# 4 Jianpu NMN & Computer Music: Software, Databases, Towards Better Integration in Music Encodings

The widespread adaptation of Jianpu NMN in China is evident in digital music archives (Table 1) and software (Table 2, in Appendix; Yuan, 2024), mainly using proprietary formats. Some Music Information Retrieval (MIR) studies worked on Optical Music Recognition of *Jianpu* (Wu & Jang, 2014; Wu, 2017). The *Jingju* collection (Repetto et al., 2017) serves as an example of transcribing *Jianpu* into machine-readable Western staff notation formats. Many music encodings (such as MIDI or base-40) and music notation encodings (SCORE) already use integers to represent pitches (Hewlett 1992; Sapp, 2015). However, the lack of a standardised file format for native *Jianpu* notation poses a significant challenge for preservation and research (Yuan, 2024).

MEI's ability to encode diverse musical traditions supports cultural preservation (Hankinson et al., 2011). It has successfully incorporated several non-standard notation practices, like Black and Mensural notation (Zitellini & Pugin, 2016; Elías, 2021). Building on these examples, expanding MEI to support additional notational systems like NMN could further enhance its inclusivity and capacity for preserving underrepresented musical traditions. Extending MEI to support NMN is feasible (Figure 9), though it would require further development to determine what flavours of NMN to consider and the best encoding solutions for more complex scenarios, such as those illustrated in Figures 3 and 4. MEI and *Verovio* (Elías, 2021) could offer capabilities that go beyond those of existing NMN software. MEI's modular tags enable flexible definitions of pitches, such as <clef>, useful to notate relative pitches when the tonality is unclear (Kepper & Roland). Harmony symbols <harm> could encode chords or NNS. Version notes <app> could ensure historical variations are documented and retained. Finally, articulation attributes could be extended to encode *Guzheng* techniques (Figure 4).




```xml
<measure n="1">
    <staff n="1">
    <layer>
        <note nmn.n="1" dur="2" octave="4"/>
        <note nmn.n="3" dur="4" octave="4"/>
    </layer>
    </staff>
    <staff n="2">
    <layer>
        <note nmn.n="1" dur="8" octave="3"/>
        <note nmn.n="3" dur="8" octave="3"/>
        <note nmn.n="5" dur="8" octave="3"/>
        <note nmn.n="3" dur="8" octave="3"/>
        <note nmn.n="5" dur="8" octave="3"/>
        <note nmn.n="3" dur="8" octave="3"/>
    </layer>
    </staff>
</measure>
```

**Figure 9**: Mozart's Sonata No.12 in F major, K.332, staff notation (generated with Llilypond), *Jianpu* NMN (generated with txt-lilypond) and possible encoding within MEI.

# 5 Recognising the Global Significance of Jianpu NMN and Promoting it in Digital Humanities

We explained the popularity and accessibility of Jianpu, as well as its potential to serve as a gateway for Western audiences to understand Chinese music. Certainly, Jianpu is less suited for large ensemble music due to its linear and melody-focused structure, whereas Western staff notation offers flexibility and detail. Jianpu NMN design prioritises simplicity and clarity, making it ideal for melodic lines, vocal music, and smaller ensembles.

However, is Jianpu NMN *simple*? The dominance of Western white male theorists in shaping global music theory frameworks has been critiqued (Ewell, 2021). The Chinese term “simplified notation“ (简谱) may reflect an unconscious alignment with the Western-centric perspective that assumes staff notation is the “golden standard“. Framing Jianpu as a “simplified“ notation can undermine its legitimacy and potential for deeper academic recognition. Jianpu NMN offers legitimate musical training, developing ear training, melodic recognition, performance skills, and an understanding of tonal relationships and structure, independent of traditional Western notation. When Rousseau (1743) introduced his system, he was not merely simplifying music but proposing a new way of conceptualising it. The vibrant contemporary Chinese music scene built around Jianpu demonstrates that NMN is a fully realised system of musical representation.

In conclusion, NMN, particularly Jianpu, deserves greater academic attention and recognition and should be more effectively integrated into the field of digital humanities**.** While incorporating NMN into encoding systems like MEI would require further development, acknowledging its potential to represent diverse global music practices is an essential first step. This recognition could promote cultural preservation, inclusivity, and broader access to music education, fostering a more diverse and representative musical landscape for future generations.

# Acknowledgements

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## Statement

Figures used under fair use for academic and commentary purposes. All rights to the original videos remain with their respective copyright holders. Large Language Models such as ChatGPT-4o were used to assist with writing, translating, and correcting. The human authors fully controlled and endorsed every aspect of this article.

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# Appendix

| **Software Developer** | **Platform** | **Score** | **Licence Price** | **Link to software (or to Jianpu feature)** |
|---|---|---|---|---|
| **JP-Word 简谱编辑** HappyEO (China) | Win | Jianpu (native) | Proprietary Free to ¥598 | http://www.happyeo.com/intro_jpw.htm |

| | | | | |
|---|---|---|---|---|
| **Yale Jianpu1.1**<br>Yale Software Studio<br>(China) | Win | Jianpu (native) | Proprietary<br>Free | https://www.qupu123.c om/soft/q69.html |
| **Tomato Jianpu**<br>(China) | Web<br>(Chrome, IE, Firefox) | Jianpu (native) | Proprietary<br>Free | http://jianpu99.net |
| **QuickMake**<br>(China) | Win | Jianpu (native) | Proprietary<br>Free | https://www.2qupu.co m/soft/20160625/6.ht ml |
| **Mupa**<br>(China) | Win | Jianpu (native) | Proprietary<br>Free | https://www.2qupu.co m/soft/20160625/3.ht ml |
| **EOP**<br>(China) | Win | Jianpu (native)<br>Staff scores | Proprietary<br>Free | https://www.everyonep iano.cn/Software-7.htm l |
| **Lite**<br>(China) | iOS | Jianpu (native) | Proprietary<br>Free | https://cn.chartoo.com /itunes/app/127255977 0 |
| **Pizzicato**<br>Arpege Music<br>(Belgium) | Win, macOS | Staff scores (native)<br>HMN, Jianpu<br>Tablatures | Proprietary<br>€15-€195 | http://www.arpegemus ic.com |
| **TextMusic**<br>Supertintin Co<br>(UK) | macOS | Jianpu (native) | Proprietary<br>£4.99 | https://apps.apple.com/ us/app/textmusic-music- notation/id1486434332 |
| **TablEdit**<br>M. Leschemelle<br>(France) | Win, macOS<br>Android, iOS | Staff scores,<br>Tablatures (native)<br>Jianpu | Proprietary $44-$59 | https://tabledit.com/he lp/english/jianpu.shtml |
| **Crescendo**<br>NCH Software<br>(Australia) | Win, macOS<br>Android, iOS | Staff scores (native)<br>Tablatures<br>Jianpu | Proprietary $49-$99 | https://help.nchsoftwar e.com/help/en/crescen do/win/numbered.html |
| **Open Sheet Music**<br>PhonicScore<br>(Austria) | Rendering engine<br>(TypeScript) | Staff scores (native)<br>Jianpu | Open source<br>BSD-3 | https://opensheetmusic display.org/blog/jianpumode/ |
| **MuseScore**<br>Hiroshi Tachibana<br>-Jianpu (Japan) | Win, macOS<br>Android, iOS, Linux | Staff scores (native)<br>Tablatures<br>Jianpu (plugin) | Open-source<br>GPL v2 | https://musescore.org/ en/project/jianpu-num bered-notation-0 |
| **Jianpu-ly**<br>ssb22<br>(UK) | Plugin for Lilypond<br>(Win, macOS, Linux) | Jianpu (plugin) | Open-source<br>Apache 2.0 | https://ssb22.user.srcf.n et/mwrhome/jianpu-ly. html |

**Table 2.** Several NMN Chinese software handle natively Jianpu NMN. Other software handles Jianpu as plugins or options.

# Encoding non-Western Music Notation and Tonal Correspondences: A Case Study for Ottoman Music Sources

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## Introduction

Historically, numerous cultures and music traditions worldwide have developed their own notation systems, before Western staff notation became the de facto standard in notating music. There is evidence as ancient as Sumerian cuneiform to be used (Wulstan, 1971), and often, pitch signs were derived from a culture-specific writing system. The pitches themselves likewise depend on specific theories on harmony that led to the use of different scales. When working with historic, discontinued, or non-European notational systems, the emic concept of pitches and their corresponding signs must be correlated to Western staff notation in a critical edition. There is currently only native support of eurogenetic notations in MEI. The present paper showcases a solution of mapping emic pitch signs, pitch names, and Western staff notation, discussing Hampartsum notation used in the context of Ottoman music sources.

# 1 Hampartsum Notation

## *1.1 Invention and Characteristics of Hampartsum Notation*

Hampartsum notation (Figure 1) was invented around 1812 by a group of Catholic Armenians in Istanbul, of whom Hampartsum Limonciyan became the name giver of the notation system. Manuscripts were initially written by Armenians before the notation spread among Muslim scribes. The notations presumably functioned more as mnemonic aids than as prescriptive scores and the transmission of music was still primarily based on oral practices.

While early notation was characterised by a minimal stock of durational signs with relative values but more precisely differentiated pitch signs, the system subsequently underwent a specification of the durational values and a reduction in the number of pitch signs.

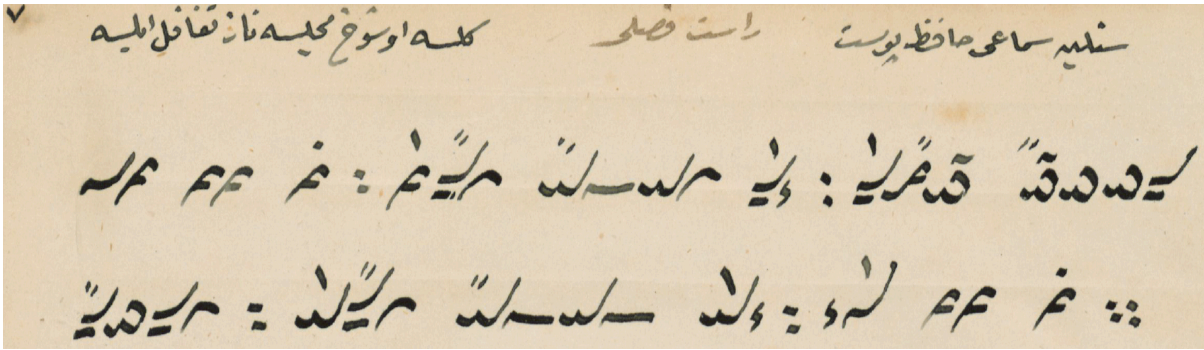

**Figure 1**: Example of Hampartsum notation. First division of “Sengīn semāʿī Ḥāfıẓ Post“ from TR-Iüne 208-6, p. 7. Courtesy of İstanbul Üniversitesi Nadir Eserler Kütüphanesi.

Essentially, the notation operates with three categories of signs: pitch, durational and structural signs. Pitch and durational signs are borrowed from medieval Armenian *khaz* notation and are reinterpreted. The fundamental pitch set consists of seven discrete signs (primary degrees), which represent the range of pitches within an octave based on a diatonic scale (Figure 2).

| Sign | Armenian name | Ottoman degree (perde) |
|---|---|---|
| | pʿuş | yegâh |
| | ēgōrc | aşîrân |
| | vēmaẖaz | ırâk |
| | pēngōrc | râst |
| | ẖōsrōvayin | dügâh |
| | nērkʿnaẖaz | segâh |
| | baruyg | çârgâh |

**Figure 2**: Basic pitch signs with their Armenian name and corresponding Ottoman degree.

The basic signs are modified to indicate octaves (Figure 3) and can also be added with a tilde (*kisver*) for further degrees (Figure 4). Adding the *kisver* above the basic sign forms secondary degrees between two consecutive basic signs. For a further gradation of intonation, the *kisver* is positioned below a basic sign, indicating tertiary degrees between a primary and a secondary degree.

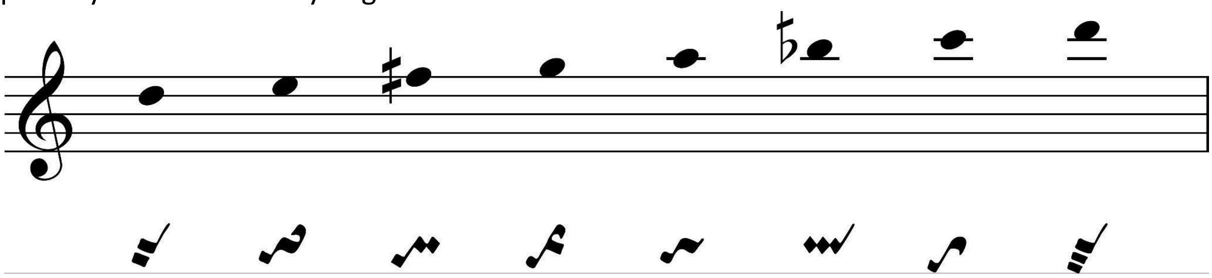

**Figure 3**: Higher octave of the basic pitch signs and their equivalent in Western staff notation.

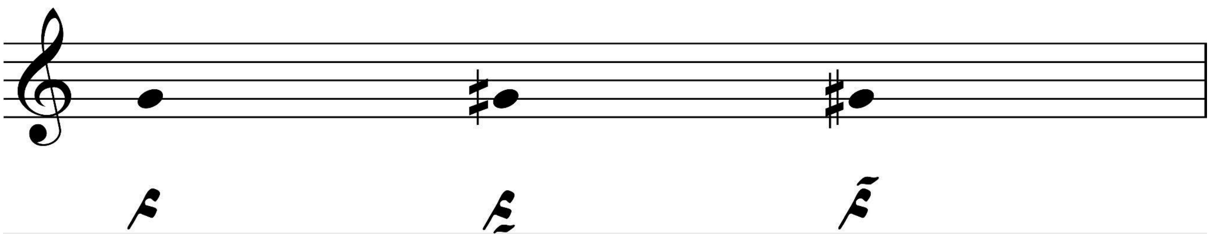

**Figure 4**: Primary degree (basic pitch sign) without *kisver*, tertiary degree with *kisver* below and secondary degree with *kisver* above.

The symbols of the basic pitch signs have an Armenian name which denotes the form. At the same time, the pitch signs of Hampartsum notation refer to pitch names in the theoretical system of Ottoman art music (*perde*), which correspond to a relative pitch in relation to an initial pitch that is not necessarily absolute. Historically, primary and secondary degrees were named, while no overarching nomenclature has been established for tertiary degrees.

### *1.2 Ottoman Music Theory and Tonal Systems*

The rich pitch scale and melodic diversity inherent in Ottoman music led to the existence of a gap between theory and performance, and this constituted the greatest handicap in notating this music. Although the theory of *makâm* music, was first systematically inscribed in books by Safiyüddîn el-Urmevî and his successors even before the Ottoman period, no notation system employed to date has been sufficient for the standardized and accurate representation of a musical composition as in the European musical system. In other words, notation has always been used as a mediator with limitations within this musical tradition.

The increasing adoption of Hampartsum notation from the 19th century on, does not indicate a change in the role of notation, but rather a change in the needs and behaviors of the modernizing society. In the 20th century, leading musicologists such as Raûf Yektâ and Hüseyin Saʾdeddîn Arel, tried to create pitch systems that could represent Ottoman music in the most rational and efficient way. Arel's activities led to the adoption of the pitch system created by him and his friends (Suphi Ezgi, Salih Murat Uzdilek) by a wider number of people. This Arel-Ezgi-Uzdilek (AEU) system divides an octave into 24 unequal intervals and is widely used in Turkey today. The system includes accidentals with values of 1, 4, 5, and 8 commas.

However, a new pitch system had to be created for the edition of the early Hampartsum notebooks. It was deemed appropriate by assigning different intervallic values to the same accidentals in the AEU system. The main reason for this endeavour is that some of the tertiary degrees cannot be represented by the AEU system.

## 2 Encoding non-Western Music Notation in MEI

### *2.1 Preliminaries*

To represent the multi-layered relationship between a pitch and its graphic representation in MEI and to enable a precise correlation between the emic tonal and notational system and the pitches in Western staff notation, an ontology inspired by the semiotic triangle (Ogden & Richards, 1923: fig. 11) was created, comprising of three relationships:

1. the sign with its Armenian name (the primary degree, Figure 2);
2. the Ottoman name of the *perde* associated with it (all degrees, Figures 2-4);
3. and the reference systems in which sign and pitch have a specific 1:n correlation (i.e. in the AEU system or others).

Parallel to the semiotic triangle, we have a symbol (the named sign) that symbolises specific tonal expressions (the *perde*) part of a correlational set between original and Western music notation.

### *2.2 Sign Name - Pitch Name Relations with mei:symbolTable*

The basic relationships, i.e. the overarching pitch systems, can be modelled with the mei:symbolTable element. Contained are a number of mei:symbolDef elements according to the set of the basic signs, each identified by @xml:id and a value corresponding to the sign name. Within the mei:symName element, it is represented as text and by @type identified as "armenian".

Each sign has multiple mei:symProp elements to describe the tonal properties or pitches associated with the sign. The mei:propName element contains the name of the *perde*, and is identified by @xml:id and a value corresponding to the pitch name plus a number, so a single *perde* name can be associated with multiple pitches in the reference system. In mei:propValue, a textual description of the pitch and its reference system is given. The pitch itself is represented by a standardised system in @type (e.g. “ks_f” for “pitch F with koma sharp”), @n provides a value for the reference system, e.g. “SPS” for the shared pitch system representing primary degrees, or “AEU” for other degrees in the Arel-Ezgi-Uzdilek system.

If applicable, the mei:symbol element can be used to reference the sign with a prototypical, graphic representation. This is either achieved by @glyph.auth and @glyph.num attributes (e.g. pointing to a Unicode code point and SMuFL) or by adding mei:line elements. A sample code is provided in Figure 5.

It should be stressed that the application of this modelling in the Ottoman context is solely based on the original Armenian names for the base signs. The alteration of these to represent different octaves (Figure 3) were also referred to by the basic sign names, although representing a different *perde*. What first appears to be a flaw in the modelling is in fact a true representation of the emic perception of the notational system. A graphic modification of the base sign can be recorded by a sibling mei:symbolDef element with a different @xml:id value, e.g. “vernaxal” and “vernaxal_oct5”.

```xml
<symbolTable>
   <symbolDef xml:id="vernaxal">
      <symName type="armenian">vernaxal</symName>
      <symProp>
         <propName xml:id="irak1" type="local">ırâk</propName>
         <propValue n="CPS" type="ks_f">Pitch F with koma (sharp)</propValue>
      </symProp>
      <symProp>
         <propName xml:id="irak2" type="local">ırâk</propName>
         <propValue n="AEU" type="bs_f">Pitch F with bakiye (sharp)</propValue>
      </symProp>
      <symProp>
         <propName xml:id="dik_acem_asiran1" type="local">dik acem aşîrân</propName>
         <propValue n="AEU" type="bmf_f">Pitch F with büyük mücenneb (flat) for post-1880 sources</propValue>
      </symProp>
      <symProp>
         <propName xml:id="gevest1" type="local">geveşt</propName>
         <propValue n="AEU" type="kms_f">Pitch F with küçük mücenneb (sharp) for post-1880 sources</propValue>
      </symProp>
      <symProp>
         <propName xml:id="gevest2" type="local">geveşt</propName>
         <propValue n="AEU" type="bf_g">Pitch G with bakiye (flat) for post-1880 sources</propValue>
      </symProp>
      <symbol startid="#p1" glyph.auth="smufl" glyph.num="#xE112"/>
   </symbolDef>
</symbolTable>
```

**Figure 5**: A sample encoding for the pitch sign *vernaxał* and its four *perde* associated with it.

## *2.3. Pitch Correspondances in the Pitch Set with mei:measure*

To correlate the description of the Ottoman sign and pitch system with Western staff notation in general and with a specific musical piece in a critical edition, a pitch set concordance (Figure 6) can be encoded within a proper mei:mdiv element.

**Figure 6**: An example of a pitch set. Concordance for the piece “Beste çenber İsaḳ” from TR-Iüne 204-2 (piece 49).

In Figure 6, the first sign is *vernaxał*, corresponding to the *perde* named *ırâk*. While in the earlier system it correlates with pitch F marked with *koma* sharp, in the post-1880 AEU system, it is marked with *bakiye* sharp. In MEI (Figure 5), we would relate this pitch with the *perde* of mei:propName@xml:id="irak2" and mei:propName@n="AEU".

Within the mei:note element (Figure 7), @corresp relates the note with the Ottoman *perde*, @altsym connects it to the original Hampartsum sign. In case there is a definition available in SMuFL, and granted a musical font supports it, a prototypical graph of the sign can be displayed as well.

```
<note xml:id="p1" dur="4" oct="4" pname="f" stem.visible="false" altsym="#vernaxal" corresp="#irak2">
   <accid accid="bs"/>
   <syl wordpos="s"><rend glyph.auth="smufl">&#xE112;</rend> (ırâk)</syl>
</note>
```

**Figure 7**: A sample encoding of a note F marked with *bakiye* sharp, relating it to the properties described in mei:symbolTable.

All layers in the correspondences between Hampartsum notation, the pitch system of Ottoman music and Western staff notation can be maintained one to one. Any note element within the edition of a piece can therefore always be traced back to the original not only (and not necessarily) by a graphic representation.

## Conclusion

The separation between a notational grapheme and its designation, the name(s) of its associated tones, and the correlating pitch(es) in Western staff notation makes the data modelling introduced for Hampartsum notation very versatile. It is therefore sustainable for other music cultures and traditions.

Hindustani *bandish* music, for example, shares traits similar to Ottoman art music (Saraf, 2011), like relative note positions (*svara*), a melodic mode (*raga*), and a rhythmic cycle (*taal*). It is written in Bhatkhande notation which is based on the Devanagari script. Another use-case is Japanese *gagaku*, where *kanji*-derived signs (*shōga*) represent pitches. Especially notational systems without a Unicode block (e.g. Hampartsum, Pipa, Súzìpǔ, Jiànzi, etc.) can be described with the present modelling, representing their autochthonous concepts.

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# A new XML conversion process for mensural music encoding : CMME_to_MEI (via Verovio)

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## Introduction

In 2020, the Ricercar Lab—the musicological research team at the Center for Advanced Studies in the Renaissance, University of Tours—took new steps managing its digital resources accumulated since the 1990s. Its first objective was to create a centralised online database, the Ricercar Data Lab (RDL), ready to launch publicly in June 2025 (Vendrix 2024).

While designing RDL, the team collaborated with two French Digital Humanities infrastructures, Biblissima and Huma-Num, shaping the concept of digital musicology in the wider context of the latest interoperable tools and practices for studying heritage and humanities. These activities produced, for example, reflections and developments on the alignment of music books' digitisations with musicological metadata (Fiala & Roger 2023) and led to the search for specific solutions for the production and open-access publication of encoded early music.

Past projects of the Ricercar Lab (CRIM, Gesualdo Online) have repeatedly shown that digital music editions were very costly to produce (Vendrix 2023) but also the crucial foundation for any ambitious realisation in digital musicology. It is in this context that an essential corpus was identified: the editions published by Clemens Goldberg on his foundation's website from the early 2010s onwards (Goldberg Online).

## 1. The Golberg Stiftung online Editions

A specialist of 15th-c. French music, Goldberg encoded the full content of 34 major music sources of this time, totaling 3356 files. Another 260 complementary files allowed him to offer series of complete collections, such as the complete works of Okeghem, the complete chansons of all contemporaneous major composers (Du Fay, Binchois, Caron, Busnoys, Ghizeghem, Compère, Agricola…), and the complete reworkings of most famous chansons (*De tous biens plaine*, *D'un aultre amer*…). Such a corpus is of major interest in itself, but all the more so for a research institution located a few blocks from Okeghem's house, with specific interests in the French chanson and the musical life in the Loire valley.

Yet another feature of Goldberg's editions was of particular interest to the Ricercar Lab. Although the Goldberg Foundation website only offers the option to download PDF files of its series of collections, these editions have been encoded in an XML format named CMME, which the Ricercar Lab had contributed to develop 20 years ago. The lab itself used it for encoding 5000 musical incipits for its catalogue of 16th c. chansons[1].

All these elements led the Ricercar Lab, with Biblissima's support, to organise and fund 1. the purchase of the original CMME files owned by the Goldberg foundation and 2. the development of a set of conversion tools for CMME files to meet more up-to-date standards of music encoding, namely MEI. This article focuses on this last development which opens new perspectives for the encoding of early music.

## 2. The  CMME project and its components

CMME (Computerized Mensural Music Editing) was conceived by Theodor Dumitrescu as an undergraduate project at Princeton University in 1999. After one year at the CESR, Tours (2005-2006)—where the basics for the XML format, the transcribing/editing/viewing

[1] See first item of this catalogue (older interface).

software and web environment were laid—the project moved to Utrecht University with a three-year funding by NWO (Dumitrescu & Berchum 2009). In the years at Utrecht, the project team worked on a first collaborative editorial project of the Occo Codex. In 2011, CMME received a small grant (SURF) to work on the new editorial project “The Other Josquin” and prepare the CMME environment for the emerging semantic web. After 2011, the project received no further funding and entered a dormant state.

At the end of its funded period, CMME made all of the developed software, editions and metadata available as open access. The ‘stack’ consist of a custom CMME-XML format, tailored to mensural notation; software for transcribing/editing mensural music (the ‘Editor’) and viewing the scores (the ‘Viewer’); and an online environment for publishing the Editorial Projects, individual scores and the related metadata.[2] Due to changing web policies, the online version of the viewer software, integrated into the editorial projects, became unsupported by browsers. This made the usage of the online material far from ideal and demonstrated the urgency of moving to, or at the least enabling the conversion to, other music encoding standards.

## 3. Bringing CMME back into the MEI environment

With Biblissima’s support, a workshop was organised in September 2024 at the Campus Condorcet in Paris, gathering a small team of experts with a wide range of knowledge: CMME, mensural notation, MEI mensural module, general MEI ecosystem, programming skills. Their goal was to put in place a set of tools for converting CMME files to MEI.

As the project progressed, the decision was made to integrate the converter directly into Verovio. Indeed, this open-source rendering library for MEI developed by the RISM Digital Center in Bern (Pugin, Roland & Zitellini 2014) supports both mensural notation and CMN rendering and acts as a converter to MEI for other important music notation formats (e.g., Humdrum and MusicXML). Furthermore, Verovio is available in different bindings, including JavaScript and Python, which means offering out-of-the-box a whole range of environments in which the converter can be used or embedded. An additional argument was the use of LibMEI, which directly ties the tool with the MEI Schema, facilitating the implementation and maintenance of the tool. The conversion from CMME to MEI mensural was implemented during the workshop, while the conversion to MEI CMN was implemented afterwards by the RISM Digital Center.

Implementing the converter confirmed that MEI for mensural notation is already quite mature and can represent almost everything that CMME does. However, the mapping from CMME to MEI is not always straightforward and the conversion cannot always rely on a one-to-one correspondence. Not surprisingly, durations are the most difficult to handle. A new option had to be introduced to Verovio for replicating the CMME equivalence duration on the minima. For proportions, a well-known complexity of mensural music, CMME makes the distinction between actual proportions, and proportions representing tempo changes. Since there is no such distinction in MEI, typing the proportion with a generic attribute (@type) was necessary. Also, not all cases would be precisely disentangled semantically even though the converter always produces the same voice alignment.

[2] The source code, including the xsd-file of the CMME-XML format, is available at https://github.com/tdumitrescu/cmme-editor; the website is www.cmme.org; all CMME-XML scores produced by the project are available at https://github.com/tdumitrescu/cmme-music.

Using a generic typing attribute was used in quite a few places in the conversion to MEI (notes marked as *signa congruentiae*, gaps marked as ellipsis, and variants marked as lacuna). For all these cases, the use of the generic typing attribute allows for the information to be preserved, although not in a fully satisfactory manner. These will eventually be considered on a case-by-case basis by the MEI mensural-ig to improve the semantic structure for the conversion project. Along the same lines, a few missing features in MEI were identified (e.g., support for accidentals within ligatures) and will be potentially proposed as additions for the next version of MEI by the mensural-ig.

The conversion to CMN in Verovio is triggered with a new option, available not only for CMME files but also for mensural MEI files. In the conversion to CMN, the editorial markup is dropped. However, using the editorial markup selection option in Verovio, it is possible for a particular reading to be selected for the conversion to CMN. Mensural-specific features such as ligatures and coloration are also dropped during the conversion process, but preserved as brackets and bracket angles, following standard practices. Clefs are normalised to G2, G2 with *ottava bassa*, and F4. All note durations are preserved with a mapping of a *minima* to a half-note and with the longest duration being the *breve*—tied notes are then used to represent longer durations. In the barring process and when generating measures, meter signatures are selected to best accommodate the mensur signs. More precisely, mensur signs are converted into CMN meter signatures 3/2, 4/2 and 6/2. The meter signature is arbitrarily determined by the top voice when voices have conflicting meter signatures. Also, a meter signature change is introduced when all voices have a mensur sign at the position and the resulting meter signature is actually different from the previous one. The mensur signs are not preserved as such. However, a MEI dir (directive) is inserted with a textual transcription representing the mensur sign. Finally, proportions are converted into tuplets. A tuplet that matches the proportion can be used when notes do not need to be cut across several bars. Otherwise, the tuplet proportion needs to be adjusted according to the proportion of the note part that goes in one bar and the other. The result is more or less legible but mathematically correct.

Overall, the result of the conversion to CMN is meant to be as simple as possible. The conversion supports the MEI-Basic option, which makes the data widely reusable. The files produced by the converter with the MEI-Basic option enabled can thus be loaded into MuseScore, opening up a wide range of use-case scenarios for the CMME data.[3]

## Conclusion

With the availability of a direct import of CMME-XML into Verovio, the corpus of existing CMME files gets a new life. Furthermore, since the stand-alone CMME software still works fine and no alternative is available for native MEI, one can imagine a pipeline for encoding and editing mensural notated music. A first transcription, including variant readings, can be made with CMME, after which the MEI software components take care of conversion, further edition (e.g. in mei-friend) and publication (Verovio).

[3] The only exception are complex proportions that can, in some cases, produce tuplets that are appropriately represented in MEI but not supported by MuseScore, but that is only for a very small portion of the files the converter has been tested with.

## Acknowledgements

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# Plainchant Analyser for MEI Neumes: A Tool for Understanding Chant Transmission

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## Introduction

In this paper, we present the **Plainchant Analyser for MEI Neumes (Plainchant Analyser, or PAM)**,[1] a prototype web application designed to assist musicologists in the search and analysis of historical chants encoded in the Music Encoding Initiative (MEI) Neumes format (Roland et al., 2014).

Plainchant was transmitted orally for centuries, with its compositional principles grounded in formulaic structures that reused melodic segments across varying texts. From the eleventh century onwards, transmission gradually shifted from orality to writing. The plainchant repertory – comprising thousands of melodies sung over many centuries and across various regions – was preserved in a wide range of notational styles. Regarded as sacred, this body of texts and melodies was generally not subject to significant voluntary alteration. The stability of plainchant enables tracing melodic material across time and space. Due to the repertory's vastness and the complexity of notations, scholars have typically focused on small subsets, rarely engaging in large-scale comparative analysis. PAM addresses these limitations by using computational methods to find and analyse melodies across different scripts within a broader comparative framework.

PAM enables analysis of plainchant melodies found in manuscripts (books and fragments) in the archives of Braga and Guimarães (Portugal), written between the twelfth and the seventeenth centuries.[2] PAM currently comprises approximately fifty melodies across over one hundred sources, with half of the repertoire written in Aquitanian neumes and the other half in square notation, all encoded in MEI Neumes. Each notational style conveys different levels of complexity and types of musical information.[3] Designed for scalability, PAM can be expanded to include more melodies and notational styles, including Eastern neumes and modern staff notation. This paper shows the current status of the PAM and outlines its functionalities.

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[1] The tool is available online: https://echoes-from-the-past.github.io/PAM/. PAM is part of the research project "Echoes from the Past: Unveiling a Lost Soundscape with Digital Analysis" (2022.01957.PTDC) https://doi.org/10.54499/2022.01957.PTDC.

[2] The melodies were first encoded with GABC, then transformed into MEI files (Thomae et al., 2024).

[3] Aquitanian neumes were written around a line whose meaning could change according to the mode of the chant, but information on the location of the semitone was not always provided (De Luca, 2020). Iberian square notation was written on a staff with four or five lines and it always provided clear information on the pitches (Ferreira, 1995, pp. 58–60).

# 1 Search filters & analysis functionalities

PAM offers numerous search filters and analysis tools, enabling users to sort through the corpus and highlight various features of chants in the search result table (Figure 1). Search options include filtering by metadata, text, finalis, melodic pattern (sequence of pitches), and contour (sequence of melodic intervals), as presented in Sections 1.1 and 1.2. Users can further refine their search results by ornamental neumes and notation type (Section 1.3).

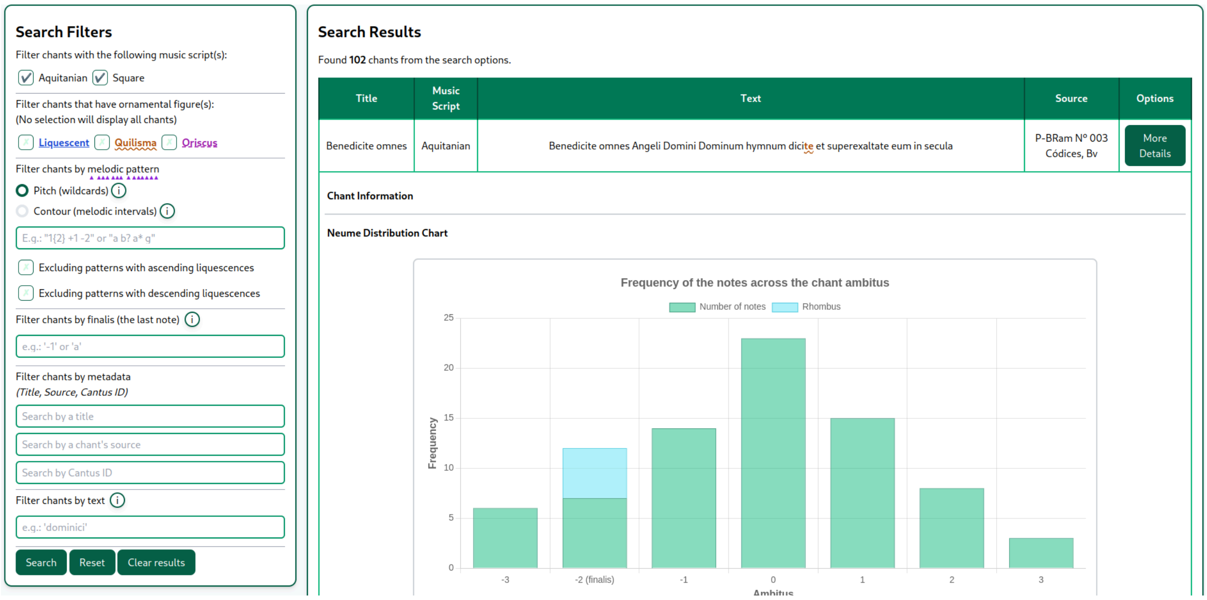


**Figure 1:** Graphical user interface (GUI) of the Plainchant Analyser.

## *1.1 Metadata & text search*

Users can search the corpus by entering a chant's metadata (Figure 2):

- **Title:** Typically derived from the first two or three words of the chant (Figure 3).
- **Source:** Identified by its siglum in the *Portuguese Early Music* (*PEM*) database,[4] which combines the RISM[5] sigla with the manuscript shelfmark.[6] (Figure 4)
- **Cantus ID**: A unique identifier assigned to chants within the Cantus Index cataloguing system, linking multiple online early music databases[7] and allowing users to retrieve all versions of a chant for analysis and comparison. (Figure 3)

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[4] https://pemdatabase.eu/

[5] https://rism.info/

[6] For example, *P-BRam N° 003 Códices* refers to a fragment housed in the *Arquivo Municipal of Braga*, identified by the shelfmark "N° 003 Códices" (see https://pemdatabase.eu/source/82438).

[7] https://cantusindex.org/

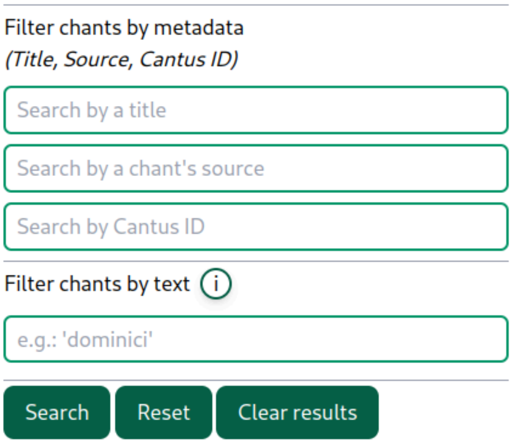


**Figure 2**: Input fields for filtering chants by metadata and text.

**Search Results**

Found **3** chants from the search options.

| Title | Music Script | Text | Source | Options |
|---|---|---|---|---|
| O lux | Square | O lux et decus hispaniae sanctissime Jacobe qui inter apostolos primatum tenes primus eorum martyrio laureatus o singulare praesidium qui meruisti videre redemptorem nostrum adhuc mortalem in deitatem transformatum exaudi preces servorum tuorum et intercede pro nostra salute omnium que populorum aleluia | P-BRs Ms. 028, 18r | More Details |
| O lux | Square | O lux et decus hispaniae sanctissime Jacobe qui inter apostolos primatum tenes primus eorum martyrio laureatus o singulare praesidium qui meruisti videre redemptorem nostrum adhuc mortalem in deitatem transformatum exaudi preces servorum tuorum et intercede pro nostra salute omnium que populorum aleluia | P-BRs Ms. 028, 105v | More Details |
| O lux | Square | O lux et decus hispaniae sanctissime Jacobe qui inter apostolos primatum tenes primus eorum martyrio laureatus o singulare praesidium qui meruisti videre redemptorem nostrum adhuc mortalem in deitatem transformatum exaudi preces servorum tuorum et intercede pro nostra salute omnium que populorum aleluia | P-BRs Ms. 034, 278 | More Details |

**Figure 3:** Search results when searching for the title “O Lux” or Cantus ID “a00193”.

| Title | Music Script | Text | Source |
|---|---|---|---|
| Benedicite omnes | Square | Benedicite omnes angeli domini dominum hymnum dicite et superexaltate eum in secula | P-BRs Ms. 034, 330 |
| De fructu operum | Square | De fructu operum tuorum domine faciabitur terra ut educat panem de terra et vinum laetificet cor hominis ut exhilaret faciem in oleo et panis cor hominis confirmet | P-BRs Ms. 034, 123 |
| Dicit dominus | Square | Dicit dominus implete hydrias aqua et ferte architriclino dum gustasset architriclinus aquam vinum factum dicit sponsus servasti vinum bonum usque adhuc hoc signum fecit Jesus primum coram discipulis suis | P-BRs Ms. 034, 027 |
| Ecce virgo | Square | Ecce Virgo concipiet et pariet Filium et vocabitur nomen ejus hemanuel | P-BRs Ms. 034, 012 |
| Jerusalem surge | Square | Iherusalem surge et sta in excelso et vide jucunditatem quae veniet tibi a Deo tuo | P-BRs Ms. 034, 006 |

**Figure 4:** Different chants from manuscript “P-BRs Ms. 034”.

The "Search by text" functionality is useful to analyse a text segment that appears in multiple chants, enabling users to discover and assess any differences between the chants, such as their original sources, music script, and the text-music correlation (Figure 5).

**Search Results**

Found **3** chants from the search options.

| Title | Music Script | Text | Source | Options |
|---|---|---|---|---|
| Mitte manum | Aquitanian | Mitte manum tuam et cognosce loca clavorum alleluia et noli esse incredulus sed fidelis alleluia alleluia | P-BRad Pastas 028, Bv | More Details |
| Mitte manum | Aquitanian | Mitte manum tuam et cognosce loca clavorum alleluia et noli esse incredulus sed fidelis alleluia alleluia | P-BRad Pastas 176, r | More Details |
| Mitte manum | Square | Mitte manum tuam et cognosce loca clavorum alleluia et nolii esse incredulus sed fidelis alleluia alleluia | P-BRs Ms. 034, 066 | More Details |

**Figure 5:** Result table when searching for the text "clavorum alleluia".

## *1.2 Melodic pattern search*

### 1.2.1 Pitch/Location pattern with wildcards

Users can input a sequence of notes in a textbox. In square notation, notes are represented by letters; while in Aquitanian script, they are represented by numerical values based on their relative position with respect to the line, as this neumatic script only indicates the interval size between two notes, but not their exact pitches. The line is at location 0; notes above it are represented by positive integers, whereas notes below it by negative integers. Matching melodic patterns are highlighted with purple triangular markings on the corresponding syllables in the "Text" column of the table (Figure 6). In Section 2, users can view a modern rendition of the chant, where the matching notes are highlighted in purple (Figure 20).

Found **3** chants from the search options.

| Title | Music Script | Text |
|---|---|---|
| Factus est repente | Square | Factus est repente de caelo sonus advenientis spiritus vehementis ubi erant sedentes alleluia et repleti sunt omnes spiritu sancto loquentes magnalia dei alleluia alleluia |
| Tunc invocabis | Square | Tunc invocabis et dominus exaudiet clamabis et dicet ecce adsum |
| In sanctitate serviamus | Square | In sanctitate serviamus domino et liberabit nos ab inimicis nostris |

**Figure 6:** Result table with triangular markings highlighting the syllables where the melodic pattern was found.

The melodic pattern search supports the use of **wildcards**, offering users flexibility and aiding the analysis of fragmentary, poorly preserved, or sometimes partially unreadable sources. Wildcards help detect and compare minor melodic variations, contributing to a deeper understanding of chant transmission. Following the conventional Regular Expression standard,[8] the wildcards are:

- **Dot**: an arbitrary note.
- **Question mark** (quantifier): an optional note (zero or one occurrences).
- **Asterisk** (quantifier): repetition of a note (zero or more occurrences).
- **Curly brackets** (quantifier): specify the number of occurrences as a specific number or a range.

Users can click on the "i" information button to view the tooltip for syntax help and examples (Figure 7).

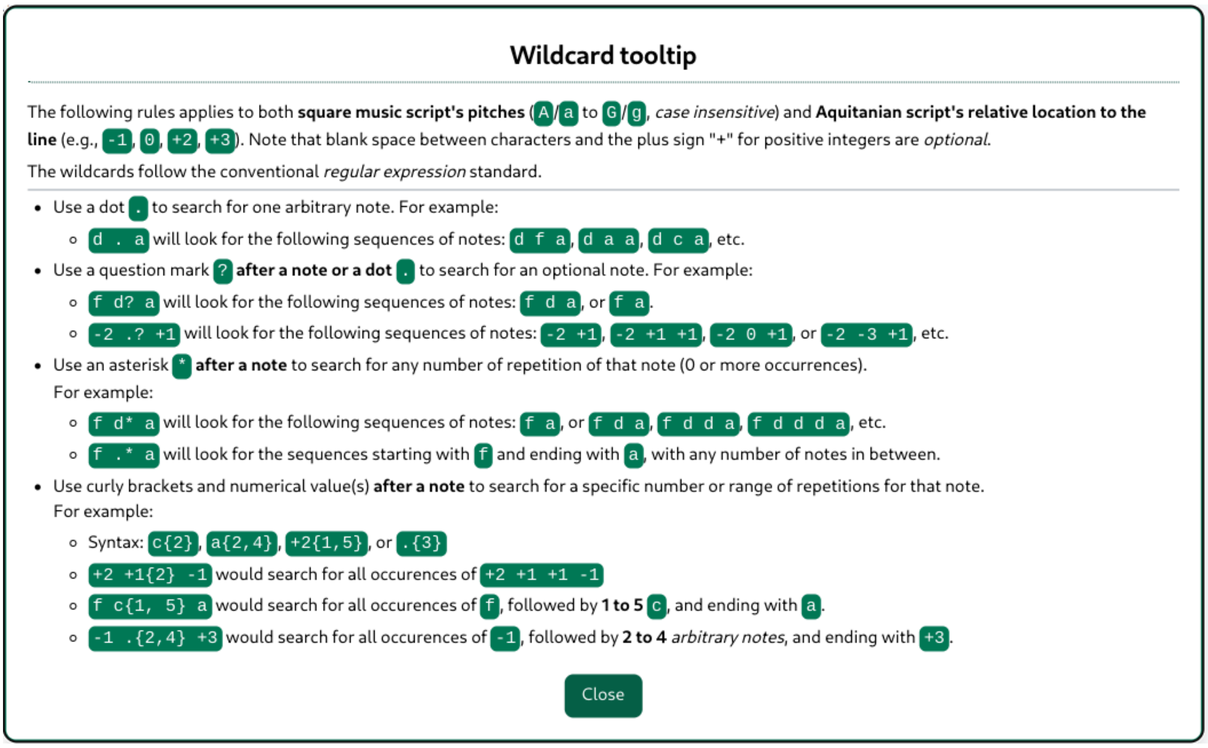


**Figure 7:** Tooltip for the wildcard search feature.

### 1.2.2 Contour search

The contour search, or search by melodic intervals, retrieves chants that share the same up/down/unison movements. This method accounts for transposition, a phenomenon that otherwise the only pitch search could not detect. Users can perform a contour search in two ways:

- By entering a **sequence of integer values** (e.g., +1 -2 0 to search for a melody that moves up one step, then down two steps, and then stays the same).

[8] A quick guide to Regular Expression can be found here: https://www.rexegg.com/regex-quickstart.php.

- Using a **sequence of letters**, with “u” representing “up”, “d” for “down”, and “s” for “same”.

### *1.3 Filter by chant features*

Users can filter chants by their music script or by the presence of ornamental figures, such as liquescence, quilisma, and oriscus (Figure 8). Although the exact musical meaning of these shapes remains uncertain, they are important for understanding vocal performance and scribal practices. Syllables containing ornamental neumes are highlighted on the “Text” column of the search result table as follows (Figure 9):

- **Liquescent**: solid blue underline.
- **Quilisma**: wavy orange underline.
- **Oriscus:** dashed violet underline.

The use of different colours and underlines styles is intended to improve accessibility, particularly for users with colour vision deficiency.[9]

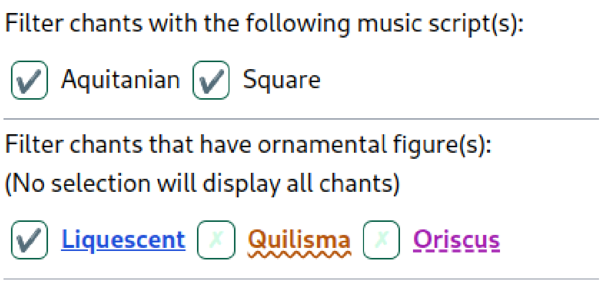


**Figure 8:** Music script and ornamental figures filters.

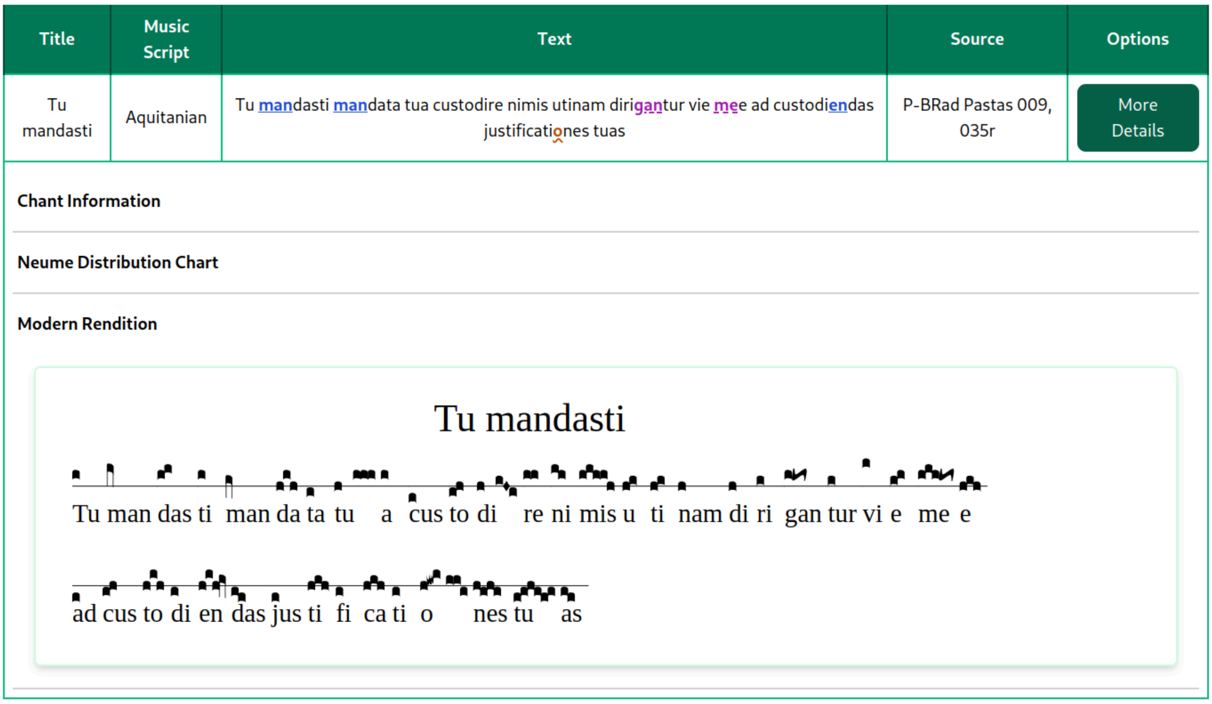


**Figure 9:** Example of a chant containing all types of ornamental figures.

[9] Recommended terminology by the *National Center on Disability and Journalism* https://ncdj.org/style-guide/.

### *1.4 Melisma highlighting*

Users can search for melismatic syllables by setting the minimum number of notes a syllable must have (Figures 10, 11).

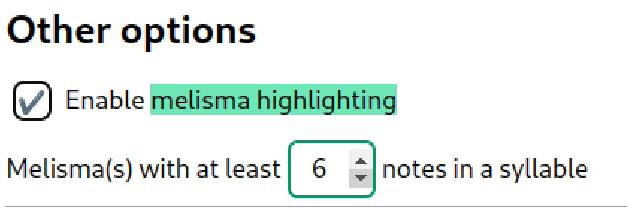


**Figure 10:** Melisma highlighting option.

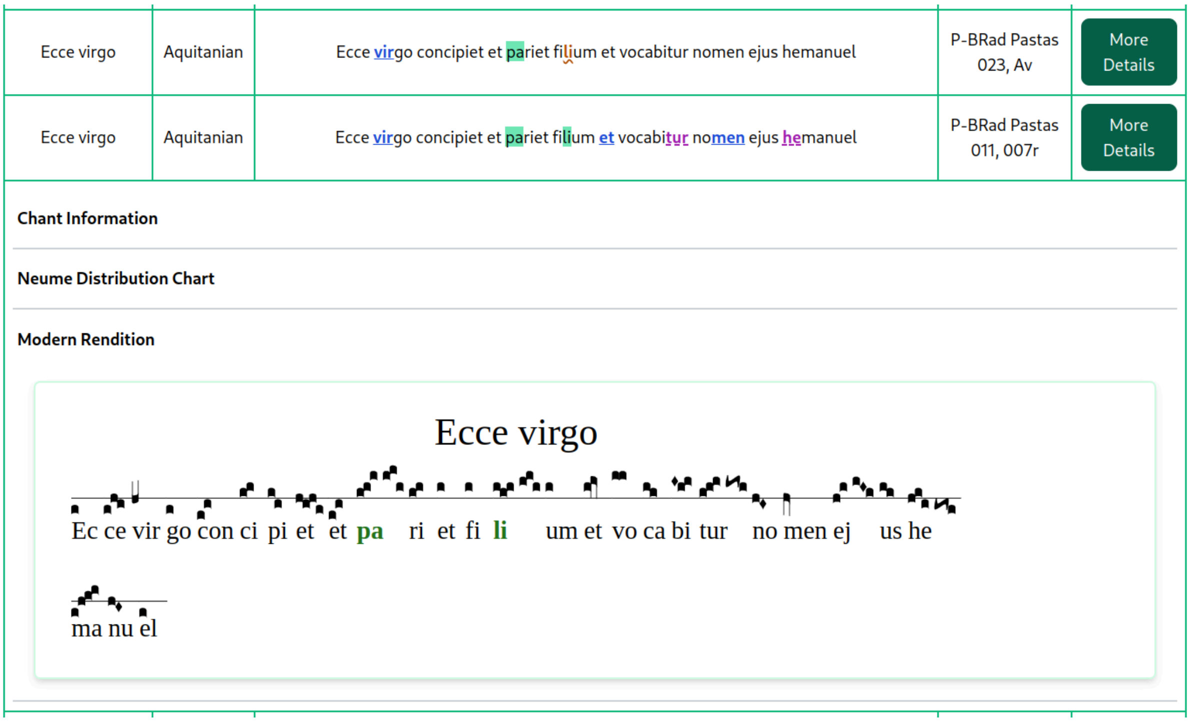


**Figure 11:** Melisma highlighting in green of syllables with at least 6 notes.

## 2 Analysis toolset

The analysis toolset offers detailed information about the chant, supported by a bar graph to assist in mode identification (Figures 12 and 13). It presents note frequency (pitches in square notation or relative locations in Aquitanian notation), ambitus (melodic range), and finalis (final note). For Aquitanian chants, it also indicates the presence of rhombus-shaped neumes, which may signal a semitone and aid mode analysis.


**Figure 12:** Analytical information of the chant “Benedicite omnes”.

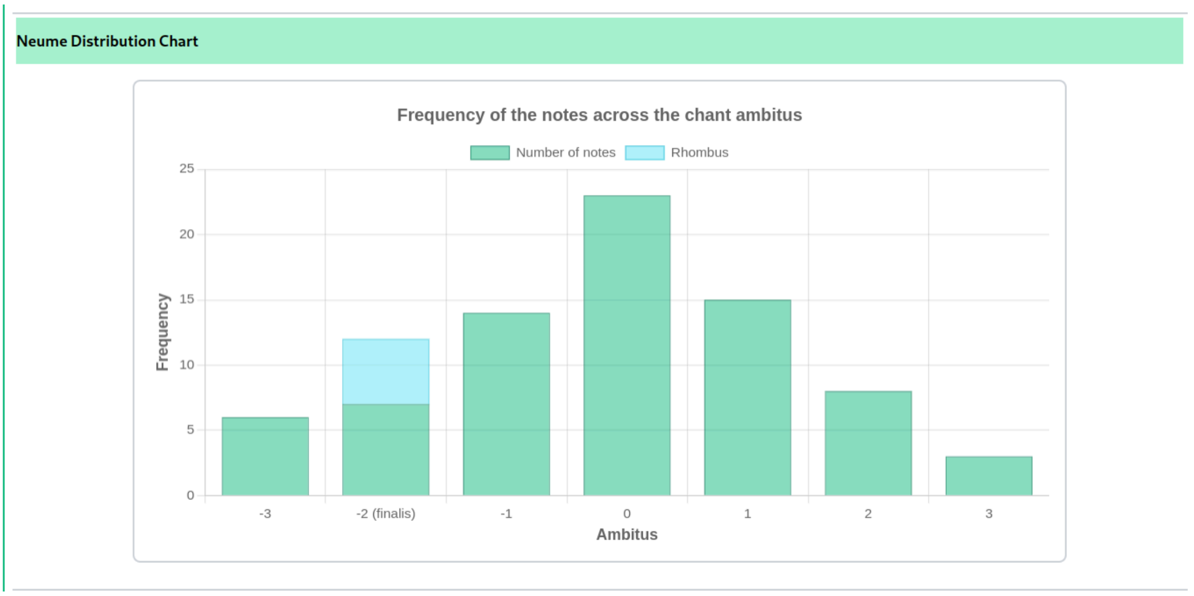


**Figure 13:** Neume Distribution Chart of the chant “Benedicite omnes” as found in the fragment P-BRam, Nº 003 Códices, written in Aquitanian neumes.

# 3 In-text melody and chant visualisation

## *3.1 Pitch/Location with each syllable*

PAM allows users to view the notes’ pitch or location along with the syllables (Figures 14, 15). Moreover, for chants in Aquitanian neumes with detectable mode, users can select to see the pitch values instead of Aquitanian locations (Figure 16).

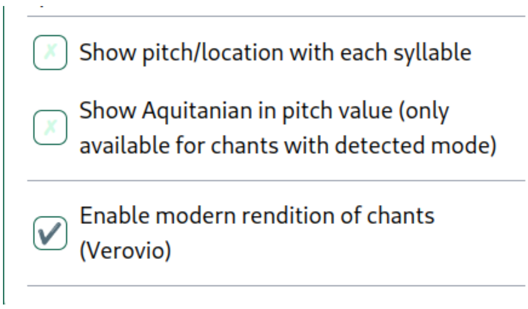


**Figure 14:** Options to enable pitch/location with each syllable, Aquitanian location in pitch value, and modern rendition of chants.

| | | |
|---|---|---|
| Martinus Abrahe | Aquitanian | Martinus Abrahe sinu letus excipitur martinus hic pauper et modicus coelum dives ingreditur hymnis coelestibus honoratur<br>Mar(-2)ti(-21-1-1-2)nus(-2) A(-210)bra(12)he(2) si(23)nu(2) le(23)tus(2) ex(20)ci(12)pi(32)tur(2) mar(3244)ti(5)nus(32) hic(2) pau(323)per(1) et(1) mo(0-111)di(-2-1-2)cus(-2) coe(-2)lum(-10) di(0-10)ves(-1-2) in(-1)gre(12)di(1332201)tur(10) hym(2)nis(324) coe(2)le(212)sti(1-1)bus(-1-2) ho(-3)no(-110121-121-121-1101-11-2)ra(-2-1-2)tur(-2) |
| Martinus Abrahe | Square | Martinus Abrahe sinu letus excipitur Martinus hic pauper et modicus caelum dives ingreditur hymnis coelestibus honoratur<br>Mar(g)ti(gcaag)nus(g) A(gcb)bra(cd)he(d) si(de)nu(d) le(de)tus(d) ex(db)ci(cd)pi(e)tur(d) Mar(d)ti(edefg)nus(e) hic(d) pau(ede)per(c) et(aa) mo(cb)di(ag)cus(g) cae(g)lum(ab) di(bab)ves(ag) in(a)gre(cd)di(ceddbc)tur(cb) hym(d)nis(edefg) coe(e)le(ede)sti(dc)bus(cb) ho(ac)no(cdcadcacbcacg)ra(gag)tur(g) |

**Figure 15:** Pitches and locations shown with each syllable.

| | | |
|---|---|---|
| De fructu operum | Aquitanian | De fructu operum tuorum Domine satiabitur terra ut educas panem de terra et vinum laetificet cor hominis ut exhilaret faciem in oleo et panis cor hominis confirmet<br>De(f) fru(ga)ctu(a) o(a)pe(a)rum(a) tu(g)o(a)rum(g) Do(g)mi(f)ne(fe) sa(f)ti(ag)a(a)bi(g)tur(f) ter(fgag)ra(gf) ut(f) e(f)du(ga)cas(f) pa(g)nem(f) de(e) ter(fg)ra(f) et(f) vi(fgab)num(a) lae(a)ti(caaga)fi(g)cet(efg) cor(fe) ho(d)mi(def)nis(ed) ut(fga) e(a)xhi(cab)la(fgf)ret(ggf) fa(fg)ci(f)em(f) in(fd) o(ef)le(dedcd)o(dc) et(f) pa(efg)nis(agabg) cor(fe) ho(f)mi(ba)nis(gafe) con(f)fir(e)met(f) |
| De fructu operum | Square | De fructu operum tuorum domine faciabitur terra ut educat panem de terra et vinum laetificet cor hominis ut exhilaret faciem in oleo et panis cor hominis confirmet<br>De(f) fru(ga)ctu(a) o(a)pe(a)rum(a) tu(g)o(a)rum(g) do(g)mi(f)ne(fe) fa(f)ci(ag)a(a)bi(g)tur(f) ter(fgaga)ra(gf) ut(f) e(f)du(ga)cat(f) pa(g)nem(f) de(e) ter(ff)ra(f) et(f) vi(fgbab)num(a) lae(a)ti(caaga)fi(f)cet(egga) cor(fe) ho(d)mi(defede)nis(ed) ut(fga) ex(a)hi(caa)la(gagfg)ret(gf) fa(fg)ci(f)em(f) in(fd) o(ef)le(dedcd)o(dc) et(f) pa(efg)nis(agaba) cor(fe) ho(f)mi(ga)nis(abgf) con(e)fir(ee)met(f) |

**Figure 16:** Aquitanian location in pitch value, in comparison with the square notation version of the same chant.

The result of the melodic and contour search—whose corresponding syllables are marked in the chant's text with triangular symbols (as described in Section 1.2)—can also be highlighted in purple by selecting the "Show pitch/location with each syllable" checkbox (Figure 17).

| | | |
|---|---|---|
| Ecce virgo | Square | Ecce Virgo concipiet et pariet Filium et vocabitur nomen ejus hemanuel<br>Ec(d)ce(cfe) Vir(fg)go(d) con(de)ci(ga)pi(ge)et(fefd) et(de) pa(gaccda)ri(ga)et(a) Fi(a)li(abca)um(a) et(a) vo(cc)ca(ag)bi(bab)tur(gaba) no(fe)men(f) e(gaba)jus(ag) he(fgeed)ma(dfga)nu(fed)el(d) |
| Manducaverunt | Square | Manducaverunt et saturati sunt nimis et desiderium eorum attulit eis dominus non sunt fraudati a desiderio suo<br>Man(de)du(c)ca(d)ve(fg)runt(afgaag) et(ga) sa(g)tu(fe)ra(fa)ti(g) sunt(f) ni(g)mis(d) et(d) de(fe)si(f)de(ga)ri(g)um(g) e(g)o(fef)rum(dec) at(fg)tu(f)lit(f) e(f)is(fgabgabag) do(f)mi(fgagfg)nus(gf) non(a) sunt(g) frau(f)da(gg)ti(d) a(deffed) de(c)si(d)de(fg)ri(g)o(gafgfe) su(defef)o(ed) |
| Mercennarius | Square | Mercennarius est cujus non sunt oves propriae videt lupum venientem et dimittit oves et fugit et lupus rapit et dispergit oves alleluia<br>Mer(g)cen(g)na(c)ri(a)us(gaba) est(bcb) cu(b)jus(c) non(d) sunt(e) o(d)ves(c) pro(b)pri(cd)ae(d) vi(b)det(d) lu(c)pum(b) ve(a)ni(b)en(ga)tem(g) et(g) di(a)mit(c)tit(b) o(gabg)ves(a) et(g) fu(efg)git(g) et(ga) lu(c)pus(b) ra(gabg)pit(ag) et(f) di(g)sper(a)git(b) o(g)ves(f) al(g)le(gf)lu(e)ia(e) |

**Figure 17**: Highlighted notes from melodic pattern search with its corresponding syllables.

### *3.2 Modern visualisation*

A modern rendition of the chants is available through the Verovio engraver library (Pugin et al., 2014), as shown in Figures 18 and 19 for chants in Aquitanian and square notation, respectively. It can also highlight the melodic pattern search results, displaying the matching notes in purple and melismatic syllables in green text (Figure 20).

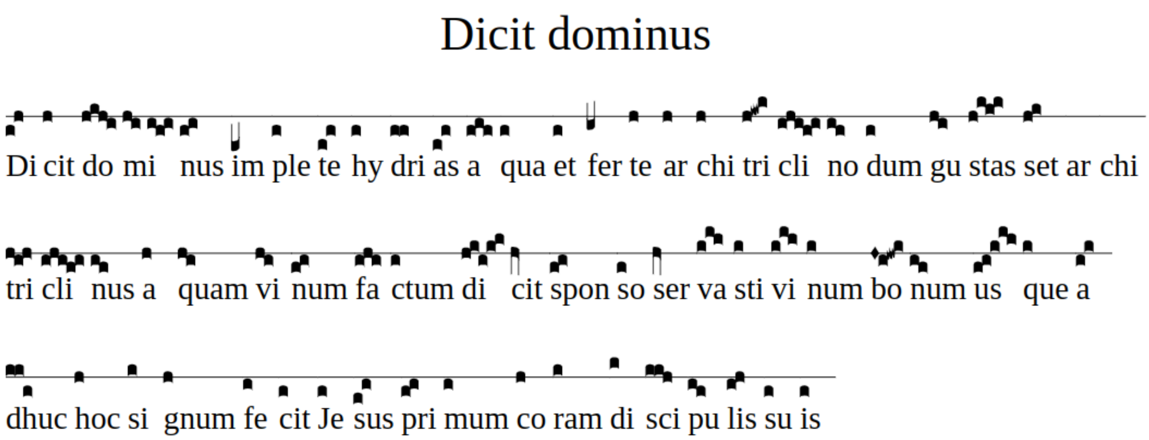


**Figure 18:** Modern rendition of the chant “Dicit dominus” in Aquitanian neumes.

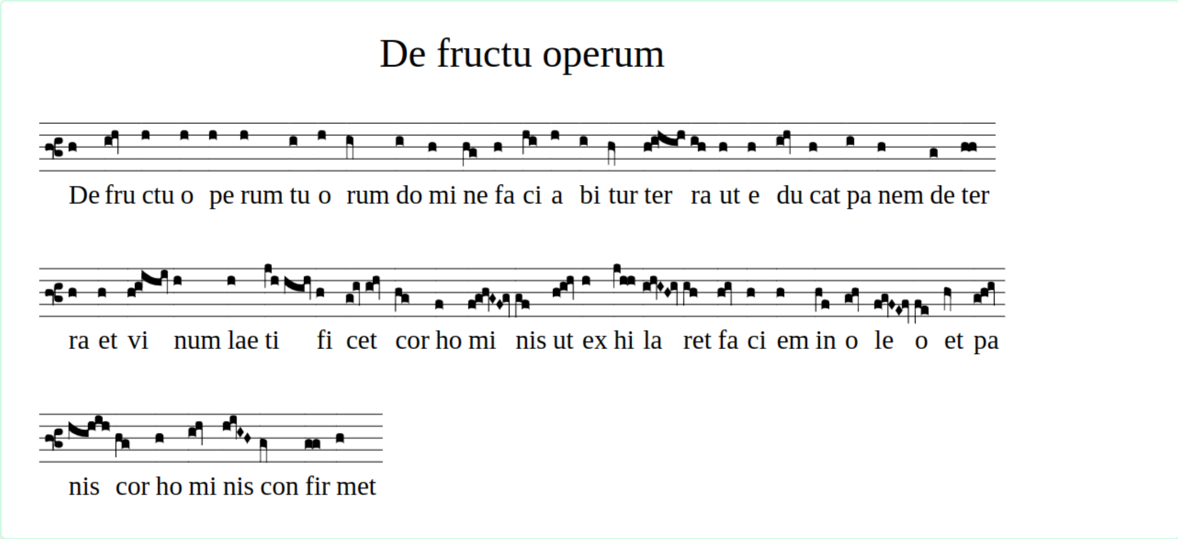


**Figure 19:** Modern rendition of the chant “De fructu operum” in square notation.

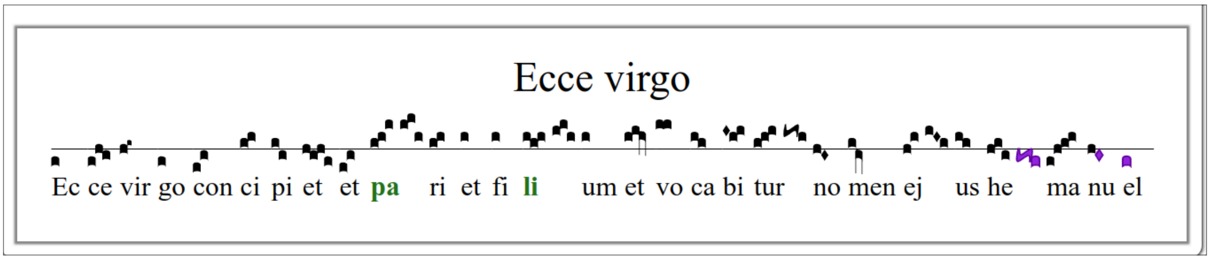


**Figure 20:** Melisma text and notes highlighting. In **green**: Syllables that bear a melisma of 6 notes or more. In **purple**: melodic pattern “-1 -2”.

# Conclusion

PAM offers a range of search and analysis options for exploring features and melodic patterns across a large corpus of chants in Aquitanian and square notations. This innovative and forward-looking tool assists musicologists to conduct sophisticated analysis and comparisons, supporting a more detailed and nuanced understanding of plainchant transmission over the centuries.

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# Let's do the ScoreWarp again! Shifting notes to performance timelines

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## Introduction

As per Hargreaves et al (2005), music is a fundamental channel of communication in which expressive intentions and meanings flow from a composer's intention to a performer's intention, usually using the score as a medium, and from there via the performer's interpretive actions to a listener's perception. The existence of critical score editions implies a secondary target audience for music notation: not only performers, but also music scholars, scientists, and others interested in a critical analytical understanding of the music.

Music is typeset accordingly to cater to these two use-cases: performance scores are designed with the musician in mind, with care taken in adjusting the placement of system- and page-breaks, the density of notation on page, and numerous other layout-specific factors to optimise performance comfort. Meanwhile, critical score editions are designed to best convey music-semantic factors of interest, varying significantly based not only on the material conveyed but on the specific target focus – with genetic edition, e.g., primarily concerned with the process of composition, even more than with the musical content itself. For these reasons, critical editions are often unsuitable, if not entirely incompatible, with music performance.

A third use-case of music notation involves the injection of music semantics into extra-musical information contexts. This applies particularly where the phenomenon of primary interest unfolds over a (physical) timeline, but reflects or is influenced by a musical structure. Examples abound in performance science, music psychology, and other empirical research on performing arts that capture human behavioural or physiological parameters over time in the presence of a performed musical score.

# 1 Visualising timed information in alignment with scores

Prior research has investigated the alignment of music scores and performance timelines from different perspectives: alignment algorithms have become a core topic of research in music informatics (Dixon & Widmer, 2005; Nakamura et al, 2017; Müller et al, 2021); whereas the modelling of such aligned timelines presents an interesting problem for digital musicology (Fields et al, 2011; Nurmikko-Fuller et al, 2015). The issue of how to visualise such alignments has received less formal attention, though approaches may be roughly categorised according to the presence and use of a (physical- or score-) time axis, as follows:

**No time axis.** In this approach often taken when visualising performance characteristics or listener behaviours (e.g., Langner & Goebl, 2003), no time axis is visualised; instead, observations are plotted against axes representing the dependent variables of interest, with time represented through animation and/or through the use of colouring to indicate temporal currency (e.g., by gradually fading out older observations as they are replaced by new ones). Alternatively, data may be plotted against an abstracted structural representation of the score, preserving ordering but otherwise omitting temporal information (e.g., mean valence/arousal responses to specified music segments as in Yang et al, 2021).

**Temporal information displayed against a score-time axis.** Here, measurements taken in physical time are displayed in positional alignment with a musical score, such that observations are plotted in alignment with the score positions they coincide with – either through a visually displayed score, or simply against an axis running proportionally in score-time from the beginning to the end of the piece or excerpt of interest. This visually warps the physically measured timeline to coincide with a depicted score time. Examples include tempo or inter-onset interval curves such as in Gabrielsson (1983) or Repp (1998).

**Physical-time axis with visual score-time alignment indicators.** Typically this is achieved by using angled lines to connect time instants of interest from one or several visualisations of physically-timed information to corresponding elements in a displayed score (Flossmann et al, 2010; Goebl & Palmer, 2013). Alternatively, score fragments may simply be visually juxtaposed in approximate alignment with the physical time, either as an additional horizontal layer (e.g., Goebl, Flossmann, & Widmer, 2010) or as small fragments associated with highlighted time intervals (e.g., Egermann et al, 2013).

**Implicit physical timeline through playback ("*score following*").** Alternatively, an implicit physical timeline may unfold alongside a depicted score, through the playback of a corresponding MIDI rendition or performance audio recording, with the alignment typically visualised using automated paging or scrolling of the score, via an animated cursor, and/or through visual highlighting of score elements, such as in Freischütz digital

(Röwenstrunk et al, 2015) or the playback functionality of the MEI Viewer[1], mei-friend[2] (Goebl & Weigl, 2024), or the Verovio Humdrum Viewer[3].

**Combined approaches.** Different aspects of the above strategies may be combined in order to provide synoptic views connecting physical- or score-timelines with score depictions, typically including score following. For example, the TuttiTempi performance comparison tool (Viro, 2021) warps timed information to fit a score-time axis in juxtaposition with an automatically scrolling and highlighting score. In the performance comparison tool “Listen Here!” (Weigl et al, 2023), multiple physical performance timelines are aligned through the placement of markers or a playback cursor (akin to ‘score following’, but in absence of a visible score); additionally, score annotations may be imported into the application, and are projected into physical time through highlighting of the corresponding intervals on each performance timeline.

# 2 Warping the score

Here, we propose a new approach, thus far largely neglected, we suspect, due to the previously-high level of technical difficulty in its implementation: to display timed information on a physical time axis, but to depict this using a warped version of the music score, in which elements are physically shifted so that their location linearly coincides with the physical time of their sounding.

When performing such a warping operation globally over all elements within a score system, ordering along the horizontal axis is retained. The warped score thus remains a reliable source of music semantics, but conveys accurate temporal information in physical time. It is of course no longer optimised for performance, nor necessarily for music-critical scholarship; instead, it becomes available as a music-semantic visual index into timed data.

Such an approach has been previously approximated by juxtaposing piano-roll-like notations with score fragments (Nettheim, 2001). The proposed warping process obviates the need for the additional piano-roll element and thus simplifies the cognitive task of understanding the position of performed notes in physical time. We have implemented this approach on MEI-encoded scores rendered using Verovio (Pugin et al, 2014), with the toolkit’s semantically structured SVG output greatly simplifying the task of performing this operation.

Our ScoreWarp library takes two files as input: a single-system score SVG object rendered from an MEI file with the help of the Verovio engraving library, and a MAPS alignment file (Weigl, 2020). The latter contains the results of a matching process with an entry for each note element in the score pointing to the corresponding performance timestamp. Multiple notes with an identical timestamp are represented by the same entry. For our demo, the alignment is achieved using the MIDI-to-MIDI matching algorithm by Nakamura et al (2017) with post-processing to match score-time points to MEI note identifiers. Figure 1a shows a score excerpt with lines connecting the note positions with the performance timeline.

ScoreWarp takes the horizontal coordinates of the first and the last note in the SVG score graphic and uses these to scale the first and last performance timestamp within the MAPS

[1] https://editor.verovio.org/ (accessed 22 April 2025)
[2] https://mei-friend.mdw.ac.at/ (accessed 22 April 2025)
[3] https://verovio.humdrum.org/ (accessed 22 April 2025)

alignment data. It creates a mathematical function to linearly interpolate the intermittent timestamps in the MAPS file in order to proportionally shift elements that do not strictly coincide temporally with a timestamp, such as barlines, hairpins, directives, etc. Having executed the `warp()` function (see [Figure 1b](#)), it proceeds through a list of SVG elements, horizontally shifting (and where required, scaling) each element according to the mathematical function, by adding a SVG `@transform` attribute. The first note inside a chord is used to shift the entire chord element. Spanning elements such as slurs or beams are shifted and scaled relative to the corresponding notehead coordinates. The ledger lines are shifted, making use of the `@data-related` attribute through the `svgHtml5` option of the Verovio toolkit to associate them with their corresponding noteheads.

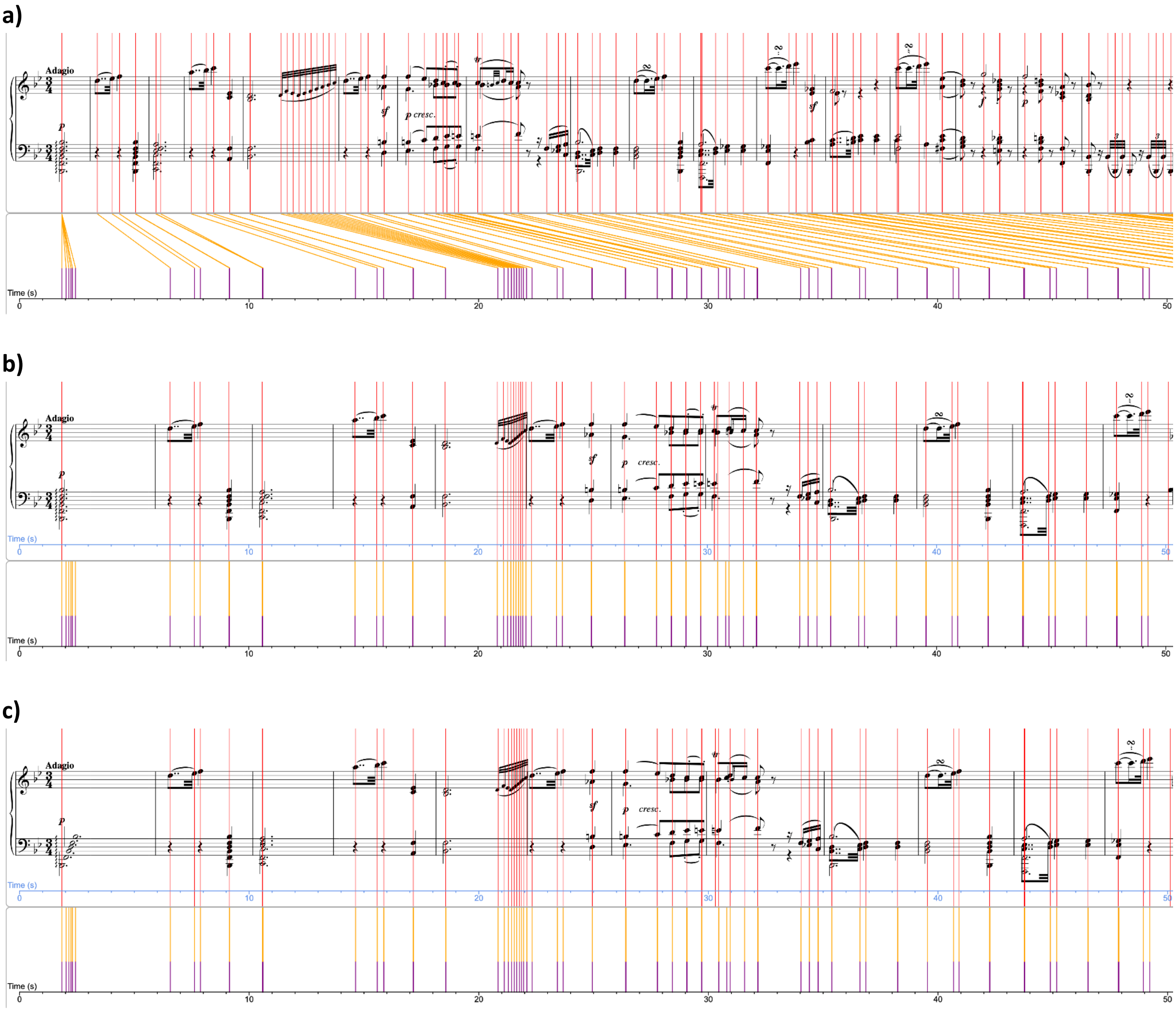


**Figure 1**: Screenshots of the beginning of the second movement of Beethoven's Sonata Op. 31 No. 2 showing a score timeline (marked by red vertical lines) and performance timeline (purple lines) connected by orange lines. **a)** Unaltered score with orange lines connecting score timeline elements with corresponding performance timeline instants. **b)** Warped score matching the performance timeline; chords are shifted to match the instant of their first sounded note. **c)** Score warped on an individual note level, visually reflecting arpeggios or other performed asynchronies. Please note here the spread of the score notes in the initial arpeggiated chord in the second staff.

While the `warp()` function shifts all notes of a chord to a single timestamp, performance data available from recordings on MIDI-enabled instruments (e.g., Yamaha Disklavier, Bösendorfer CEUS) contain fine-grained performance timing data for each note. To make full use of this additional detail, the `warpIndividualNotes()` function adjusts the position of each note to the corresponding timestamp, visualising performance effects like arpeggios or the melody lead phenomenon (Repp, 1996, see Figure 1c). ScoreWarp finally adds a physical-time axis to the warped SVG graphic as a separate group element (`<g>`), providing a readily-available alignment target for time-series data which may be included in post-processing.

ScoreWarp is available on a demonstration page at https://iwk-digital.github.io/scorewarp/ featuring several example pieces and performances. The demo page exposes the functions of ScoreWarp to the user and provides download access to the warped SVG file for inclusion in other applications. It also allows users to upload their own files, consisting of one MEI file and one or multiple MAPS files, each corresponding to a performance. These are then warped in batch, with the resulting SVGs provided for download as a zip file. The codebase is available under the GNU AGPL v3.0 license at https://github.com/iwk-digital/scorewarp.

# 3 Conclusion and future work

We have proposed a novel approach to solving the problem of visualizing information captured according to physical- and score-time modalities. Rather than relying on visual or auditory-visual juxtaposition, or warping physical-timeline information to suit a particular score layout, we instead warp the positioning of notation elements within a score to fall onto coinciding physical-temporal positions. We have presented a feasibility evaluation of the proposed approach in the open-source ScoreWarp prototype, which should allow relatively simple reuse of the idea within external applications. We plan to extend the set of compatible alignment input formats beyond MAPS. As a next step, we are ourselves planning to implement ScoreWarp-panels within the performance analysis tool “Listen Here!” in order to make temporal differences between performance renditions (tempo, rubato, …) assessed by the tool’s users more immediately apparent.

We expect that visualizing timed information using a warped score in the way proposed here will provide for a more intuitive understanding of empirical data measured in the contexts of music listening and/or performance (including extra-musical observations, e.g., physiological measurements such as heart rate, respiratory behaviour, and galvanic skin response) relative to the prior approaches described in Section 2. However, this intuition should be tested thoroughly, both in terms of the specific use-case and of the type and complexity of music employed.

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# Building an Interpretations-Edition

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## Introduction

Presently, many MEI editions leverage the affordances of digital spaces to make critical apparati more apparent than has previously been possible in printed editions. In doing so, MEI has mirrored musical philology in pursuit of assembling 'the' definitive version of a work via notation alone. Even for musical traditions where performance is conceptually equal or even greater than notation, both analog and digital editions prioritize the notion of fixity. Music, of course, is a sounded, temporal entity predicated on the acceptance, if not expectation of variance in performance, even if in small degree. What results, then, are representations of temporal or dynamic processes through atemporal or static objects. Further complicating issues are logocentric tendencies in musicological discourse that continue to prioritize scores as musical works, thus inherently de-prioritising creative labor of performers. Doing so has resulted in a largely digital imprint of the analogue biases of musical philology–a musical history of music composers rather than makers presented as a conceptually historical singularity, despite philosophical and practical evidence to the contrary.

## 1 Musical Work of Interpretation

Rather than abandoning one methodology for another, a blended approach accounting for the creative labor of both composer and performer(s) is a meaningful step forward. Leveraging MEI's assertion that it works toward defining best practices for a broad range of musical documents, this paper describes the process of constructing a descriptive interpretations-edition for use in the Fritz Thyssen Stiftung funded project *Creating Schubert's „Die Winterreise" in Performance with Dietrich Fischer-Dieskau* (Neumann, 2024), which focuses on performance in relationship to notational variation rather than score genesis or veracity. In doing so, it raises important questions about the breadth of and actual kinds of musical documents encodable within MEI. Moreover, it acknowledges a need to reconsider the exclusive centrality of the score in musical life and (digital) scholarship, as practical, conceptual, and ethical impetus if the goal is an accurate artistic history.

Beginning with a review of two open-source basis-score possibilities, the need for maintaining notational philology is immediately obvious. One of these sources, the *Schubert Winterreise Dataset* (SWD), is based on the Max Friedlaender's 1890 edition and encodes the voice part's g-clef with a lower octave displacement indicating a male singer (Weiß, et al., 2021). Other changes in this encoding center on facilitating easier machine readability regarding repeat signs surrounding specific sections of music by 'spelling out' the musical content therein (Weiß, et al., 2024). The second source, the *OpenScore Lieder* project (OSL), relied upon citizen science and scholarly review to produce its *Die Winterreise* corpus (Musescore), using the Breitkopf & Härtel 1895 version as basis text. Additional scores that either definitively were (Schubert, 18XX and the versions used to generate SWD and OSL digital copies), or possibly were available to Dietrich Fischer-Dieskau at some point in his career (Schubert, 1979), along with his own edition collaboratively edited with Elmar Budde (Schubert, 1985), and the autograph (Schubert, 1828) comprise the manifestation list. As a primary focus is the preserved audio contents of each of twenty-four recordings, a single MEI file for each recording of each Lied emerges as the primary MEI output. In this perspective, then, each recording is the final manifestation (Figure 1).

```xml
<manifestationList>
   <manifestation xml:id="dwdfd0e63fb41-f2fa-46a2-b161-e3e8cf6ec03a" label="OpenLieder" n="1" type="basis">↔</manifestation>
   <manifestation xml:id="dwdfd93012b6f-2724-4fb5-95f4-82bf3c316a30" label="Fischer-Dieskau/Budde Edition" n="2" type="Fischer-Dieskau">↔</manifestation>
   <manifestation xml:id="dwdfd9eb224fd-7aed-4c53-b944-a6cf2d44ee8d" label="Schubert Winterreise Dataset" n="3" type="Winterreise_Dataset">↔</manifestation>
   <manifestation xml:id="dwdfddfdf8401-7618-45b6-90d4-c471946e6e19" label="Neue Ausgabe sämtlicher Werke" n="4" type="Neueausgabe">↔</manifestation>
   <manifestation xml:id="dwdfd93072fd5-23ea-4775-9c62-947e4c93d7b9" label="Morgan Library Autograph" n="5" type="Autograph">↔</manifestation>
   <manifestation xml:id="dwdfdc9075d0e-7aaa-4a82-bfa0-06eb81584587" label="Fischer-Dieskau's copy with annotations" n="6" type="Fischer-Dieskau">↔</manifes
   <manifestation xml:id="dwdfdfc36bb84-7597-4e8c-b32b-6c12e00a1046" label="1948_Billing" n="7" type="audio_recording">↔</manifestation>
</manifestationList>
```

**Figure 1**: Manifestation list providing overview of notational and recording sources. Encoding made using mei-friend (Goebl and Weigl, 2024).

## 2 Coding Idiosyncrasies

Given the systemic coding differences in the SWD and how it affects the musical content as it appears for the purposes of linking with audio data, the OSL version is used as basis-text. From this open-source basis, comparison with other editions commenced and expressive markings were integrated. Editions of primary interest here are: Dietrich Fischer-Dieskau's own critical edition and autographs held at the Morgan Library and the Wienbibliothek im Rathaus, respectively. A primary additional source of notationally-based information is the Fischer-Dieskau estate papers held at the Staatsbibliothek zu Berlin. What results, then, from this process is the inclusion of as many expressive indications as Fischer-Dieskau likely would, or could, have known in preparing *Die Winterreise* for performance.

Situating a score as a guide and reference text rather than a purely legalistic dictum more readily enables research on the *how* of performance. Perhaps expectedly, this conceptual shift also requires a technical shift in tracking available editions and the notational content unique to each. MEI's flexibility in relation to metadata proves particularly useful. Here, score-based instructions appearing in editions other than the basis edition are enclosed with supplied elements (<supplied>), and their relevant sources demarcated with source attributes. Because @source can contain multiple references to manifestations, clearly structuring the manifestation list is imperative. Markings that appear in the basis edition but not in others are enclosed with deletion elements (<del>) and sources tagged accordingly.

For cases where notation and/or textual variation occur between editions, the same approach was employed. Fischer-Dieskau's own annotations (<manifestation n="6"...> in Figure 1) are treated as additions (<add>). Both tagging manifestation origins (via @source) and adjusting the Verovio renderings to color code these markings illuminates the wide array of possibilities (Figure 2).

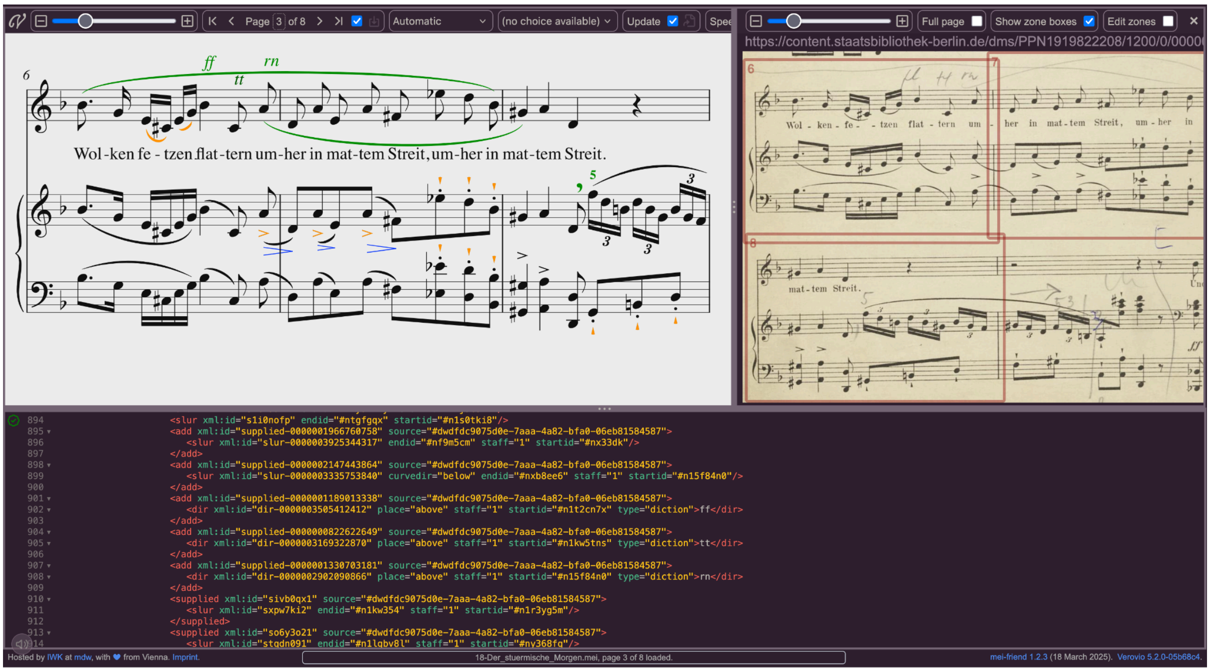


**Figure 2**: Measures 6-6 from #18, "Der sturmische Morgen," showing color-coded Verovio rendering of annotations (orange=<supplied>, blue=<del>, green=<add>), facsimile of Fischer-Dieskau's own copy (Schubert, 18XX), and underlying coding. Encoding made using mei-friend (Goebl and Weigl, 2024).

The approach of <supplied>, <del>, or <add> with source tagging is not designed to present an edition for dissemination, but rather one to use as the basis for linking with audio data extracted from each of Fischer-Dieskau's twenty-four recordings. This usage makes further conceptual sense as there is no (genetic) lemma (<lem>) from which to derive subsequent printed editions, only a variety of information that may or may not be present in a given performance, whether occurring onstage for an audience or in a studio. Each realization—what a performer actually does in performance—is then a single iteration of the cycle, and the variations apparent in notation cannot therefore constitute apparatus (<app>) status.

# Conclusion

In addition to this decidedly more process-than-object approach to the use of MEI, further consideration of recordings as FRBR manifestations with metadata that is both unique to their aural nature and common with visual/notational documents becomes necessary. Conceptually, the relationship between recordings and performances is identical to that of manifestations and expressions. Within MEI, however, recordings can only be a child element of performance, which is only a child element of music, meaning that a recording within MEI cannot currently be cataloged according to the conceptual (i.e. - FRBR) realities appropriate for it (Neumann and Richts-Matthaei, 2024). The questions arising herefrom highlight the reality that encoding music digitally affords democratization of research credit and research subjects, but only if intentional efforts are made to do so (Neumann et al., 2024). The absence of such deliberateness–encoding according to a business-as-usual approach–only enhances the risk of encoding, preserving, and ossifying preferential biases and socio-economic prejudices of score and (some) composer idolization (Kijas, 2024). As MEI usage continues to expand beyond the conventional canon of European art music, interpretations editions can, in tandem, become a vehicle for enhancing the ethics of musical edition making as historiographical praxis that accounts for a truly broad range of musical documents.

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# Switching Between Standard and Original Score Order: Encoding, Transforming and Rendering Alternative Score Definitions in Digital Music Editions

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# Introduction

Since their inception, printed music editions have been faced with a critical dilemma regarding the determination of the score order at the beginning of the editorial process. On the one hand, the standardized score order that emerged in the 19th century and became firmly established in the 20th century offers several practical advantages: it allows for a more compact score by grouping separate parts played by the same type of instrument on a single staff, and it provides a convention that is universally accepted and used for editions of works from all historical periods. This layout is also taught in conducting curricula and corresponds to standard orchestral seating arrangements on the concert stage. On the other hand, the standard score order often differs significantly from the original parts arrangement chosen by the composer. As a result, it may overlook important aspects of the compositional process and the composer's intention in structuring the score in a particular way. Furthermore, the standard score order may no longer reflect the historical ensemble configuration originally intended by the composer, which could affect the performance interpretation of the composition. Presenting the score in a layout that differs from the composer's original may also influence the critical apparatus of the edition and affect the musical analysis of the work.

For these reasons, some printed music editions – such as those of the complete works of Jean-Baptiste Lully, Georg Philipp Telemann, and Carl Maria von Weber – have restored the original order of the scores. However, by adhering to a historically accurate disposition of parts, these editions run the risk of not being affirmed in performance practice and being replaced by less philologically rigorous editions based on the standard score order. This may explain why the majority of printed editions, despite being aware of the philological issues involved, continue to maintain the standard score order.

The *Neue Mozart-Ausgabe* (NMA) is a paradigmatic example of this editorial dilemma, not only because Mozart's oeuvre dates from the 18th century – long before the standard score order had been established – but also because Mozart frequently chose different score orders for his compositions in order to adapt the disposition of instruments and voices to meet the specific requirements of each work and its performance circumstances. In other words, not only is Mozart's scoring practice distant from the modern score order, but it is also impossible to define a single, general "Mozartian" scoring system. Therefore, the adoption of a standard score order seemed the only viable solution to unify the vast and varied body of Mozart's work under a common denominator, ensuring its transmission to the public and inclusion in performance practices. At the same time, recent critical voices (Aringer, 2011; Schmid, 2019) have convincingly argued that the specific score order chosen by Mozart for each composition is musically and musicologically significant and should therefore be taken into account in the edition.

Using Mozart's *Exsultate, jubilate* KV 165 as a case study, the paper proposes a solution to this editorial dilemma in a digital edition by offering the choice between different score orders.

# 1 Encoding

Unlike printed scores, where only a single stave order can be defined at the beginning of the piece, the MEI framework is capable of alternative score definitions (MEI, 2023: 11.1.3 Variants in Score Definitions). However, the MEI guidelines do not take into account the more complex case of split or merged staves in alternative scores. In fact, standard score orders do not only change the original position of the staves, but often also merge onto a single staff parts that are notated on different staves in the original score order. For example, in the first movement of Mozart's *Exsultate, jubilate* KV 165, the two oboes are not only positioned differently in the autograph compared to the NMA score, but are also split into two staves (Figure 1, red arrows).

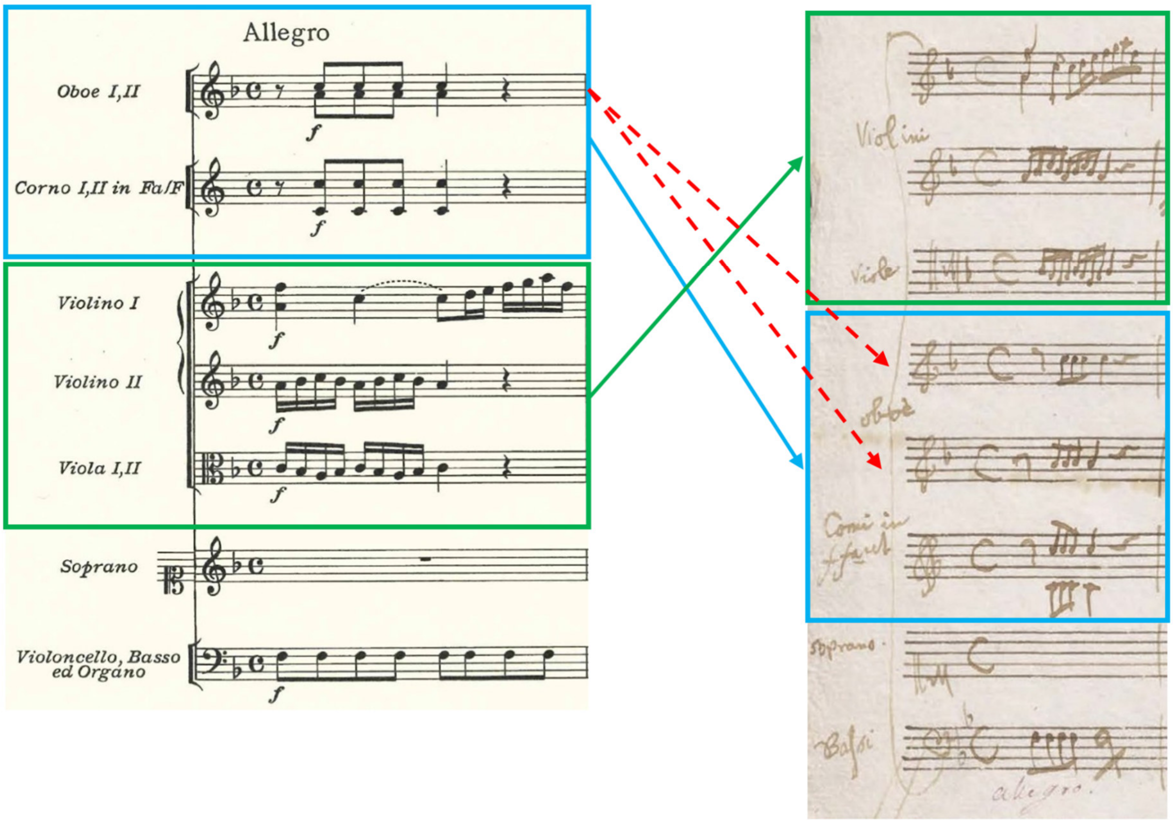


**Figure 1**: Wolfgang Amadé Mozart, *Exsultate, jubilate* KV 165/1, Standard Score Order (NMA) vs. Original Score Order (Autograph): **blue** and **green** = position change, **red** = splitting.

After briefly exploring various methods of encoding multiple score orders in an MEI file, the paper will focus on the advantages in terms of efficiency and precision that result from encoding each part of the score as a semantically independent layer, regardless of whether it has its own staff or shares its staff with other parts. The proposed encoding practice aims to make each part potentially independent of the score order in which it may occur, thus allowing the same musical content in an MEI file to be transformed from one score order to another. In this way, the MEI file can ultimately be displayed by a music notation rendering tool in any score order.

# 2 Transforming

Based on the proposed encoding practice, the paper will present a new transformation tool that allows switching between alternative score orders, focusing on a particularly challenging issue: the splitting of parts notated on a single staff into separate staves. To this end, the presentation will specifically examine the case of transforming from a standard score order, in which parts played by instruments of the same type are notated on a single staff (e.g., Oboe I, II), to an original score order in which these parts are separated into independent staves (e.g., Oboe I and Oboe II). Using Mozart's *Exsultate, jubilate* KV 165 as an example, the two steps required for the transformation will be illustrated in detail:

1. Reordering staves: Changing the positioning of the staves;
2. Splitting staves: Separating the layers of the two oboe parts into different staves.

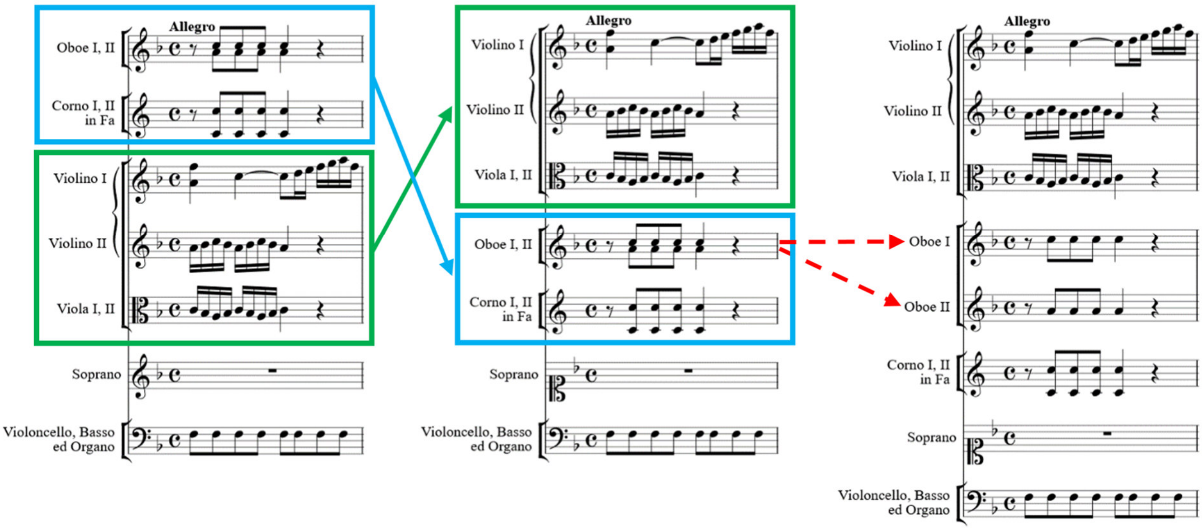


**Figure 2**: Wolfgang Amadé Mozart, *Exsultate, jubilate* KV 165/1: Transformation steps of the score order from standard to original.

In the first step, a new <scoreDef> element is injected and the staves are reordered. Although MEI states that it is sufficient to change the order of the <staffDef> elements and it is possible to preserve the order of the <staff> elements (MEI, 2023: 11.1.3 Variants in Score Definitions), it is more convenient to work with a file in which the order of the staves corresponds to the actual rendering. Therefore, all <staff> elements are reordered, including updating the @staff attribute of the corresponding ControlEvents. This transformation step is performed by the Reorder Staves tool. It expects an alternative <scoreDef> placed inside a //choice[@type="scoring"] element in the MEI file and a mapping of a new staff orders defined in a JSON file or passed as a parameter.

The second step, the splitting of the oboe parts, involves more sophisticated transformations. For this purpose, the recently developed *Extract Parts* tool presented at the TEIMEC23 (Sapov-Erlinger, 2023) has been re-engineered and extended with a "split staves" feature. The tool is also capable of transforming complex, nested encodings such as editorial markups and multiple choice variants (e.g., <choice> and <app>). This allows editorial interventions in a diplomatic transcription of the original score or notation variants to be visualized in both the standard and original score order, making the display of these complex features independent of the chosen score order. However, the handling of variants is a challenging area of development and the current version of the tool (5.1.1) only partially supports variants. *Extract Parts* expects an encoding structure of the MEI file that conforms to the specific encoding guidelines mentioned previously. The parts to extract can be selected using an XML configuration file.

The transformation pipeline is released by the *Digital Mozart Edition* (DME) on GitHub under the Educational Community License, version 2.0: https://github.com/ism-dme/

Original-Score-Order. The repository contains detailed information on installation, usage and limitations.

As a future development, the transformation pipeline could be extended to include the ability of merging separate staves into a single stave.

# 3 Rendering

The transformation results in an MEI file that can be loaded into Verovio Viewer, mei-friend or other rendering tools. In addition, the paper presents a web application that utilizes the described transformation pipeline and provides the ability to switch between the standard score order of the NMA and the original score order of the autograph. Setup and performance considerations of this application will be briefly discussed.

# Conclusion

The definition of the score order is a fundamental structural aspect of music editions. The unresolved dilemma in printed editions of deciding between the standard and the original score order presents a concrete scenario for the need to handle multiple score configurations. The paper proposes a solution to this issue for digital music editions. By encoding each part in MEI as a semantically independent layer, each part can be relocated into alternative score configurations using a dedicated transformation tool. As a result, the MEI file, originally encoded in one score order, can potentially be displayed in any other score order. This finally enables switching between the standard and the original score order in a web application.

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# Let's get visual. Dealing with layout information in MEI.

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## Introduction

Since there are no audio recordings from anything earlier than the late 19th century, most of the music from past centuries is transmitted to us in written form only. In order to explore such music in its original form, one has to deal with music notation. Consequently, in the first paragraph of its Guidelines (version 5), MEI considers itself a "framework for describing music notation documents". However, there are multiple perspectives on music, typically referred to as musical domains. Chapter 1.3.1 of the MEI Guidelines explains their use in the MEI framework (guidelines, section 1.3.1). Here, it is stated that "very often, MEI prioritizes the visual domain over the gestural [sounding] domain by (partly) conflating the logical and the visual domains". While the handling of different domains is mostly well-balanced, the conflation of visual and logical perspectives as currently implemented in MEI sometimes doesn't seem to be the ideal solution yet. In this paper, we seek to evaluate an alternative approach to encode visual information in MEI for different use cases.

When it comes to overall structure, current MEI prioritizes logical over visual encoding. The first-class hierarchies in an MEI file are <mdiv>, <section>, and <measure> elements (in case of the CMN repertoire) – all of which capturing "logical" units, whereas the "visual" units page and system can only be reconstructed by retrieving the content between any two adjacent <pb> (page begin) or <sb> (system begin) elements. These elements are so-called milestones, indicating positions instead of grouping content. Retrieving the content of a page or system is perfectly possible, but definitely more complex than retrieving the content of a measure because, for a measure, one simply needs to retrieve its descendants in the

XML hierarchy. This unequal treatment of logical vs. visual units is a direct consequence of the structures imposed by the implementation of MEI in XML. However, as this only prioritizes one perspective on music, but does not make other perspectives impossible, this seems to be an almost arbitrary design choice, and certainly a focus on visual units would have led to similar results.

At the same time, there are use cases for MEI where the focus is primarily on layout information rather than logical structure. We can mention, for example, the Liber Usualis project at McGill University, or some encoding stages in *Beethovens Werkstatt* in Bonn and Paderborn. In this paper, we discuss an encoding approach addressing such needs in the light of different use cases, and the requirements for conversion to and from “regular” MEI. Eventually, this is not a proposal for an alternative structure of MEI, but we hope to explore if there is sufficient community interest to propose an additional customization, which goes along with existing structures in clearly defined and documented relationships. Ideally, this paper will help to achieve an improved shared understanding of the relationship of logical and visual information in MEI.

# 1 Facsimile in MEI

The <facsimile> encoding structure in MEI is very similar to the one in TEI. It is encoded using a dedicated subtree that acts as a linking layer between the textual data (semantically structured) and one (or several) corresponding image(s). This layer is pretty much domain-agnostic and is represented with a subtree of <surface> and <zone> elements representing areas on the image. Everything is brought together with references to the elements in the facsimile subtree using xml:ids. The model we’re proposing is based on the idea to provide a <zone> for each music component, like <note>, <staff>, or <accid>. This setup is already built into MEI. It has been widely used in digital music editions for interlinking the musical text with images and for facilitating navigation in interactive music editions, and has already proven to be quite powerful. Accordingly, our proposal is about establishing best practices for using these methods for different use cases.

# 2 Diplomatic Transcriptions

[Feder 1987, p.138] describes two types of diplomatic editions, one labelled as “facsimile-like”, which he describes as reproducing the visual appearance of a manuscript very closely, and the other as using “regular typography”, which, according to Feder, is not even required to follow the original page and system layout, but concentrates on preserving accidentals, clefs, score order and other visual aspects. Whereas the latter poses very little challenges for an encoding with MEI, the first requires to faithfully reproduce the placement of individual notes and their alignment with other staves and notational features. This is not currently well-explored and documented with MEI. While there are several attributes that support precise alignment, we do not know that these attributes have ever been brought to use. In fact, a strong diplomatic encoding – one that Feder would have called “facsimile-like” is not necessarily trying to capture a meaningful musical text, as the material to be encoded may not even have such meaning. In this case, it seems more appropriate to fully disentangle visual from logical domain, and provide a double encoding, where both aspects are captured independently, and then linked selectively. That way, the interpretations necessary for transcribing are given more room, and can be evaluated more easily – the encoding becomes more verifiable and transparent. The suggested facsimile-based profile of MEI supports this use case, making it a valid model to encode diplomatic transcriptions for philological / editorial purposes. While it is still challenging to convert such an encoding to regular MEI, these challenges really originate in philological issues of uncertain reading / meaning of the music to be encoded, but not in the markup structures required by MEI. By capturing the content in two parallel, interlinked encodings, this can be stated more explicitly, ultimately leading to both more adequate and more clear digital diplomatic transcriptions.

# 3 Optical Music Recognition

Optical Music Recognition (OMR) is by nature a process where graphical signs on an image are linked with encoded music notation. More precisely, it is about the process of building these links, going from graphic primitives to fully reconstructed and identified music symbols. While there are a number of recent approaches that do not identify graphic primitives in user-accessible ways, this is a complicated process that typically requires multiple steps. In practice, therefore, OMR applications often need to store data at various stages of the process, either internally but also potentially externally for sharing data for training or evaluation purposes. While MEI is now widely recognized as a natural choice as a final target format for OMR tools, there is an important potential to be leveraged in using MEI at various steps of OMR processes. To what extent OMR research and applications can benefit from the outcome of the work presented in this paper remains to be determined. However, the needs are clearly very similar to the ones of diplomatic transcriptions, and similar (if not identical) solutions can probably be applied.

# 4 Facsimile rendering with Verovio

One of the distinct features of Verovio is that its implementation is based on an internal structure instantiating the MEI tree directly. That is, without converting MEI back and forth when loading an MEI file. In practice, however, Verovio is strongly affected by the aforementioned focus on logical structures, since its purpose is to render a visual representation of these logical structures. This means that Verovio is currently not able to render situations with “conflicts” between these structures without resolving these conflicts, for instance by splitting a measure with a contained page break into two separate measures. However, using a facsimile-based approach as mentioned above, it is possible to bypass Verovio’s normal rendering algorithm, and lay out the music using the positioning information given by facsimile zones.

While this can be fairly straight-forward for some elements, there are some open questions that still need more consideration. This includes cases where one logical element is represented by multiple visual elements, like slurs spanning across page breaks or clefs repeated at every system begin.

## Conclusion

Where more complex approaches for separating presentation from content have been explored in the past (see Pugin 2012), the model proposed here convinces through its proximity to regular MEI, and its apparent applicability for different layout-centric use cases for music encoding. There are some important challenges left, which seem to require a broader discussion than typically encountered during the technical implementation of such changes to MEI. Our paper seeks to initiate such a discussion in the wider music encoding community by introducing typical use cases and highlighting the remaining challenges of dealing with layout information in MEI. As a first step, the focus will be on *Common Western Music Notation* (CMWN), but other notation types will be considered in the future.

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# Automated MEI Transcription of a Dataset of Electronic Drum Kit Recordings

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## Introduction: Drum Notation

Drummers have long played without scores. When the first drum kits appeared, at the beginning of the 20th century, they were instead expected to improvise rhythmic accompaniment while following the scores of their fellow co-players. Drum notation was introduced later for the purpose of education, of transmission of different styles to the apprentice or professional drummer, and of preservation of remarkable performances for future reference.

The main drum notation systems currently in use are based on Common Western Music Notation (CWMN), following its hierarchical symbolic representation of durations, and using note pitches to distinguish between the different elements of a drum kit. Figure 1 illustrates the representation of the elements of a typical drum kit (see Figure 2) on a CWMN five lines staff, according to two notation standards: the one of the Agostini Drum School (Agostini, 1977), used in Europe, and another, called universal, used in the US. Roughly, in

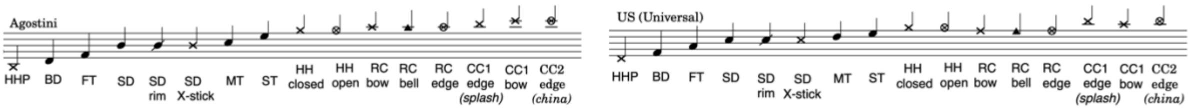


**Figure 1.** Pitches and note heads denoting the drum kit elements and play modes.

both cases, the notes below the second bottom line of the staff shall be played with the feet, using pedals activating the *bass drum* or the *hi-hat* (a pair of cymbals that can be joined (*closed*, HHC) or disjoined (*open*, HHO)); the notes above the top line of the staff are played (with sticks) on the different kinds of *cymbals*, including the hi-hat - others are *ride* or *crash cymbals* (RC, CC); and the notes in-between are played on the *snare drum* (SD) or the *toms* (FT, MT, ST). The note heads represent the playing modes. That includes which part of the instrument shall be hit, e.g. the *bow*, the *edge* or the *bell* of a cymbal, or the *head* (i.e. the skin, the most common case) or the metallic *rim* of the snare drum or a tom. Moreover, note heads may denote some particular techniques, such as *cross-stick* or *rim-shot*, where both the head and the rim of the snare drum are hit. Some ornamentation is also possible, like the *flam* which is the combination of a grace-note and a main note, both played on the head of the snare drum or a tom.

A crucial issue in drum notation is its readability, with several percussive instruments gathered in a single staff, and simultaneous rhythmic patterns, sometimes complex. In order to clarify the notation, the score content can be organized into two or more *voices*, with stems pointing up and down. For instance, each voice may group together a subset of elements of the drum kit represented by close pitches, such as the pedals, or the cymbals.

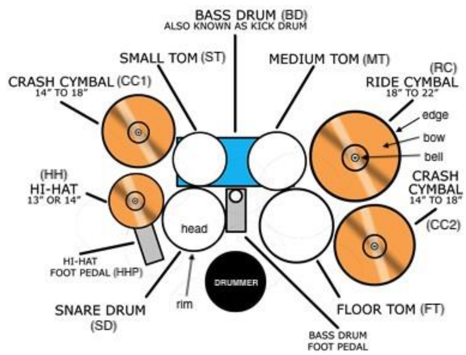


**Figure 2.** The elements of a typical drum kit. © John Blinco

Moreover, voices may highlight several lines, e.g. a pattern repeated on the ride cymbal or hi-hat, together with more sporadic patterns on the snare drum. In general, a voicing schema is fixed through a score, each instrument of the kit being assigned a unique voice.

All the above required features are supported by MEI. Therefore, there is no reason for not using MEI for drum scoring. However, we are not aware of the existence of MEI datasets of drum scores.

We present in this abstract the main lines of an approach for the automatic transcription into MEI scores of electronic drum kit recordings, in the form of MIDI files, and its application to an existing large dataset. Our approach is based on a general framework for MIDI-to-score (M2S) transcription, that proceeds in two main steps described in the next sections 1 and 2.

# 1 Parsing Drum MIDI Sequences

Most of the work on automated drum transcription (ADT) actually focuses on the conversion of audio recordings into performance MIDI files (Wu et al., 2018). Our purpose is therefore complementary in an end-to-end ADT perspective. Traditional M2S transcription methods perform quantization of timing values by alignment of the MIDI events to a set of evenly spaced time points called a *grid*. A difficulty is then to find an appropriate grid step: choosing a larger step will produce a simple notation too different from the input, and a smaller step will usually result in an overly complicated score. Some other M2ST methods use statistical models like HMM (Shibata et al., 2021) or Transformers (Beyer and Dai, 2024) for sequence-to-sequence processing. We proceed differently.

Our approach indeed aims at extracting a hierarchical structure from the sequential MIDI input (akin to a parse-tree in Language Processing) that shall be the backbone of the output score. For this purpose, we consider some operators for splitting time intervals: bar splits one interval into one measure and the rest, and div$_k$ divides into $k$ sub intervals of equal duration. A nested application of the above operators defines some (uneven) time points

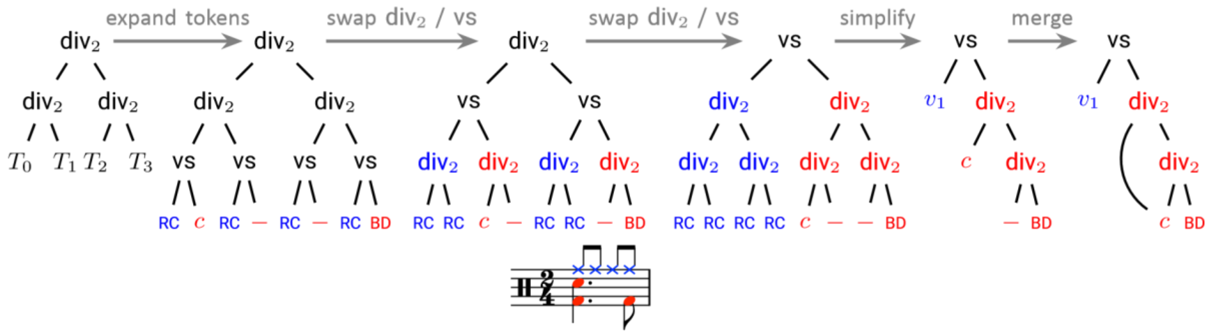


**Figure 3.** The tokens are $T_0 =$ {RC, SB, BD}, $T_1 = T_2 =$ {RC}, $T_3 =$ {RC,BD}, $c$ is the subtree ch(SD, BD) and $v_1$ is the left child of the 4th tree.

for the alignement of MIDI events. We consider a prior formal language, defined by a Weighted Tree Grammar (Comon et al., 2007), associating a *cost of readability* to every parse tree labeled with the two above operators (it roughly corresponds to the complexity of operator nesting). A *token* is defined as a group of input MIDI events aligned to the same time point, which therefore represents simultaneous elements in a score (i.e. occuring at the same theoretical date), like a chord or a flam. For every token $T$, we compute the *cost for aligning* the events in $T$ to the associated time point. A token $T$ containing too many events in order to be played by a drummer with two hands and two feet is discarded by giving it an alignment cost of $+\infty$.

Using a $n$-best parsing algorithm (Huang and Chiang, 2005), based on Dynamic Programming and tabulation techniques, we estimate, for a given MIDI input sequence, a parse-tree with a minimal combination of the readability and alignment costs. The output of this parsing procedure is a tree $t$ whose inner nodes are labeled with div$_k$ or bar, and leaf nodes are labeled with tokens.

# 2 Intermediate Representation and MEI Score Generation

Starting from a parse tree as above, we expand the tokens in leaf nodes into sub-trees labeled with symbols providing more details about a score representation. There is one note symbol for each instrument of the kit, one rest symbol denoted −, symbols flam and ch to build flams and chords containing notes. Moreover, we consider a voice splitting operator vs. Based on a prior partition of the elements of the drum kit into voices, we dispatch the events in a token into the arguments of vs, each argument representing the content of one voice. This operation is illustrated in the two leftmost trees in Figure 3.

The labeled tree obtained is then post-processed in order to move up the vs symbols. It is done by repeated application of a rewriting rule swapping div and vs, as follows (see Figure 3 for an illustration of applications of this rule):

$$\text{div}_2(\text{vs}(x_1,\ y_1), \text{vs}(x_2,\ y_2)) \rightarrow \text{vs}(\text{div}_2\ (x_1,\ x_2), \text{div}_2(y_1,\ y_2)).$$

The above rewriting steps, as well as the prior parsing, may introduce unnecessary rests. Some other rewrite rules are then applied to remove them, simplifying the notation, like the following one, applied in Figure 3.

$$\mathrm{div}_2(x,-) \to x \qquad \text{where } x \text{ is a note or a rest or a chord or an ornament.}$$

For transient instruments like drums, a rest is indeed often considered as a continuation of the previous note.

Moreover, other rewrite rules will merge tree nodes when they can be represented by a single note figure in the score, following the restrictions in use in CWMN (Gould, 2016). For instance, in the last rewrite step of Figure 3, a chord node is merged with a following rest node with half its duration, resulting in a dotted chord. We also extract dynamic information from the velocity values of MIDI events, to detect accents and so called ghost notes.

The result is an abstract representation of a drum score, in the form of a labeled directed acyclic graph (dag). This abstract structure is finally exported into an XML/MEI document, using the C++ library libMEI (Hankinson et al., 2011).

# 3 Transcription of the Corpus GMD into MEI

The above stepwise process for converting MIDI recordings of electronic drum kits into MEI scores relies on a general framework for M2S transcription, made of two separate modules implemented in C++[1], corresponding, respectively, to the parsing of Section 1 and the score model construction, transformation and export to MEI of Section 2. Some functions specific to the processing of drums notation have been written in C++, in particular for the tokenization and rewrite rules for rest simplification. Additionally, a Python binding to these functionalities has been written to help with experiments.

The Groove MIDI Dataset (Gillick et al., 2019) (GMD) contains 13.6 hours of human performances in MIDI format, captured by professional or semi-professional drummers, performing with a metronome, on an electronic drum kit ROLAND T-11. The performances are either short rhythmic fills (one to four measures), or full-length rhythm sequences (beats) of 4 to 260 bars. We have processed successfully, without pre-training or manual adjustments, 333 of the 442 beat files of the GMD, with various genres (funk, rock, jazz...) and time signatures (4/4, 3/4, 6/8). The tempo, the style, and the time signature of each file are given in the file names of the GMD, and used for parsing. The MEI files were moreover rendered in PDF using Verovio (Ver, 2021)[2].

By lack of existing reference scores for the GMD, we could not evaluate systematically the accuracy of our transcription procedure on this dataset. Some quantitative evaluation could be possible by counting transcription failure and probable errors, like e.g. triplets spanning over a whole 4/4 bars. Some other errors are more subtle to detect, in particular the ones resulting from captation flaws in the MIDI files. However, this case study shows that automated M2S transcription of drum performances into MEI is possible. This is already an interesting result, considering the time that manual transcription can take for this instrument.

[1] https://gitlab.inria.fr/qparse/qparselib branch beta

[2] The MEI score files, PDFs as well as the grammar files describing the prior languages (one for each time signature) can be found at https://github.com/florento/MEI-GMD/

The next step will be to improve the transcription results, and to manually curate the MEI files obtained with the help of experts, in order to provide an MEI companion of the GMD, usable as a base for the evaluation of tools for end-to-end drum transcription or OMR, as well as for studies involving computational analysis for this specific kind of MEI content.

# Acknowledgements

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# ‘Mein vleis und mue’: MEI Support for Lute Tablatures

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## Introduction

Tablatures differ from other music notation types in that they do not describe abstract music semantics directly, but rather prescribe actions for the musician(s) performing the music. Though tablature notations exist for many instruments (e.g. keyboards and accordions), it has central importance for plucked-string instruments such as the lute (from the late 15th to the 18th century) and guitar (particularly in popular music of the 20th century).

We are pleased to announce the inclusion of plucked string tablatures into MEI 5.1, with a particular focus on historical notation for the lute and related instruments. In our paper, we describe the community process that has given rise to this, the changes to the schema and guidelines, and the tooling that supports working with tablature in MEI.

## 1 Plucked string tablatures

Tablatures for lute, guitar, and related instruments generally indicate the combination of course[1] and fret to play, along with amount of metrical time between successive actions. Until the rise of modern guitar tabs, a single duration sign applied to all notes in a chord, with no direct polyphonic rhythms possible.

[1] Course is a term referring to a co-notated string grouping of one or more physical strings (so, for example, a six-string and a 12-string guitar both have six courses, tuned to E-A-D-G-B-E.

Several notation types are identified based on the way in which the course/fret combination is indicated: French lute tablature (FLT) has courses represented as 6 staff lines, with the bass courses at the bottom of the staff, and letters indicating frets; Italian tablature (ILT) is vertically inverted and uses numbers to indicate frets; spanish and modern guitar tabs both use numbers, but have bass strings at the bottom; and German tablature (GLT) has no staff lines, relying instead on a larger set of symbols to code both fret and course.

# 2 Community process

Although the MEI schema has always had minimal tablature support, a proposal for a substantial model for lute tablature was first proposed in 2015 (Lewis, Lewis & Crawford, 2015). A community began to be gathered around the task, supported by a developer meeting in Oxford in 2018, culminating in the formation of the MEI Interest Group on tablature in 2020 to further develop the model. The model initially focussed on FLT and ILT and, to a lesser extent, modern guitar tabs. A proposed model for encoding GLT in MEI was first presented at the Joint Text Encoding Initiative and Music Encoding Conference in 2023 (de Valk et al, 2023). The model proposal was further refined in a dedicated day-long session of the MEI Development Workshop in January 2024, with valuable input provided by the E-LAUTE project (Schöning et al, 2025), the Tablature Interest Group, and members of the wider MEI community; and implemented in regular meetings involving project and Interest Group representatives.

The implemented extensions were validated from two perspectives: by members of the MEI technical team who reviewed the corresponding Pull Requests as part of the regular MEI contribution process; and by a team of GLT experts (lutenists and music scholars) at the annual E-LAUTE whole-project meeting in September 2024, which resulted in further additions to the model.

The revised module for string tablatures, including GLT support, was formally accepted into the development version of the MEI schema in October 2024, and released as part of MEI v5.1 (January 2025). Tablature-related adaptations of the Verovio codebase, led by Paul Overell, have adapted the tool to support the new module, with rendering of GLT encodings possible as of Verovio release v4.5 (December 2024).

# 3 The string tablature module

The string tablature module introduces new elements and attributes to the MEI schema to handle a variety of tablature-specific concerns, including:

**Tuning.** Because string tablatures specify which frets and strings to play on the instrument, rather than abstract pitches, it is necessary to know the tuning and setup of the instrument in order to map these instructions to sounded notes. The `<tuning>` element allows for the definition of a numbered collection of `<course>` child elements, the tuning of each being captured by the `@pname` and `@oct` attributes, alongside an optional `@accid` to encode chromatic alteration. As most tablature sources employ one of a small number of standard tunings, these can be specified using a closed vocabulary of values on the

`@tuning.standard` attribute of `<tuning>` in order to obviate the need for individual `<course>` elements in most cases.

**Notes.** Individual tablature notes, corresponding to finger-placement instructions on the fretboard, are encoded using the `<note>` element. `@tab.fret` and `@tab.course` are used to encode the prescribed finger position horizontally across the frets and vertically across courses, respectively. Sets of vertically-aligned tablature notes, corresponding to chords whose notes are played at the same time, are grouped within `<tabGrp>` elements. The duration of such a group may be indicated visually with a rhythm flag symbol, encoded using `<tabDurSym>`. Consecutive rhythm flags may be joined together using a `<beam>` parent element. Rarely occurring special rest symbols below the rhythm sign may be encoded by adding a `<rest>` to the `<tabGrp>`.

**Notation type.** The tablature string module is conceived to prioritize the encoding of tablature semantics, rather than visual aspects of tablatures. Thus, it is very straightforward to switch between the different types of string tablatures supported by the module by simply modifying the `@notationtype` attribute of the `<staffDef>` element. Values include: `"tab.guitar"`, `"tab.lute.italian"`, `"tab.lute.french"`, and `"tab.lute.german"`.

**GLT vertical organization.** Although tablature semantics are prioritized, visual aspects of GLT sources pertaining to the vertical organisation of notes requires special attention. As each tablature note in GLT conveys both course and fret information simultaneously, vertical positioning of notes may instead reflect aesthetic or layout conventions, or, in certain cases, be used to indicate voice leading. The string tablature module provides `@lines`, `@tab.align`, and `@tab.anchorline` on `<staffDef>` to encode the alignment rules followed by a particular source, as well as `@tab.line` on `<note>` where placement deviates from such predictable positioning.

The new elements and attributes introduced in this section are described in further detail within new documentation integrated within Section 7 of the MEI Guidelines.

# 4 Encoding environment and tooling innovations

Verovio now supports these new developments in MEI (Figure 1), meaning that lute music is correctly displayed and may be edited using mei-friend (Goebl & Weigl, 2024). Nonetheless, coding tablatures from scratch in MEI is a laborious process; providing a workflow arriving at MEI encodings by conversion from the output of a notation editor is clearly desirable, and makes the encoding process more widely accessible. However, editing lute tablatures is most often done in specialised applications, such as Fronimo[2] and

[2] Available at https://sites.google.com/view/fronimo/home

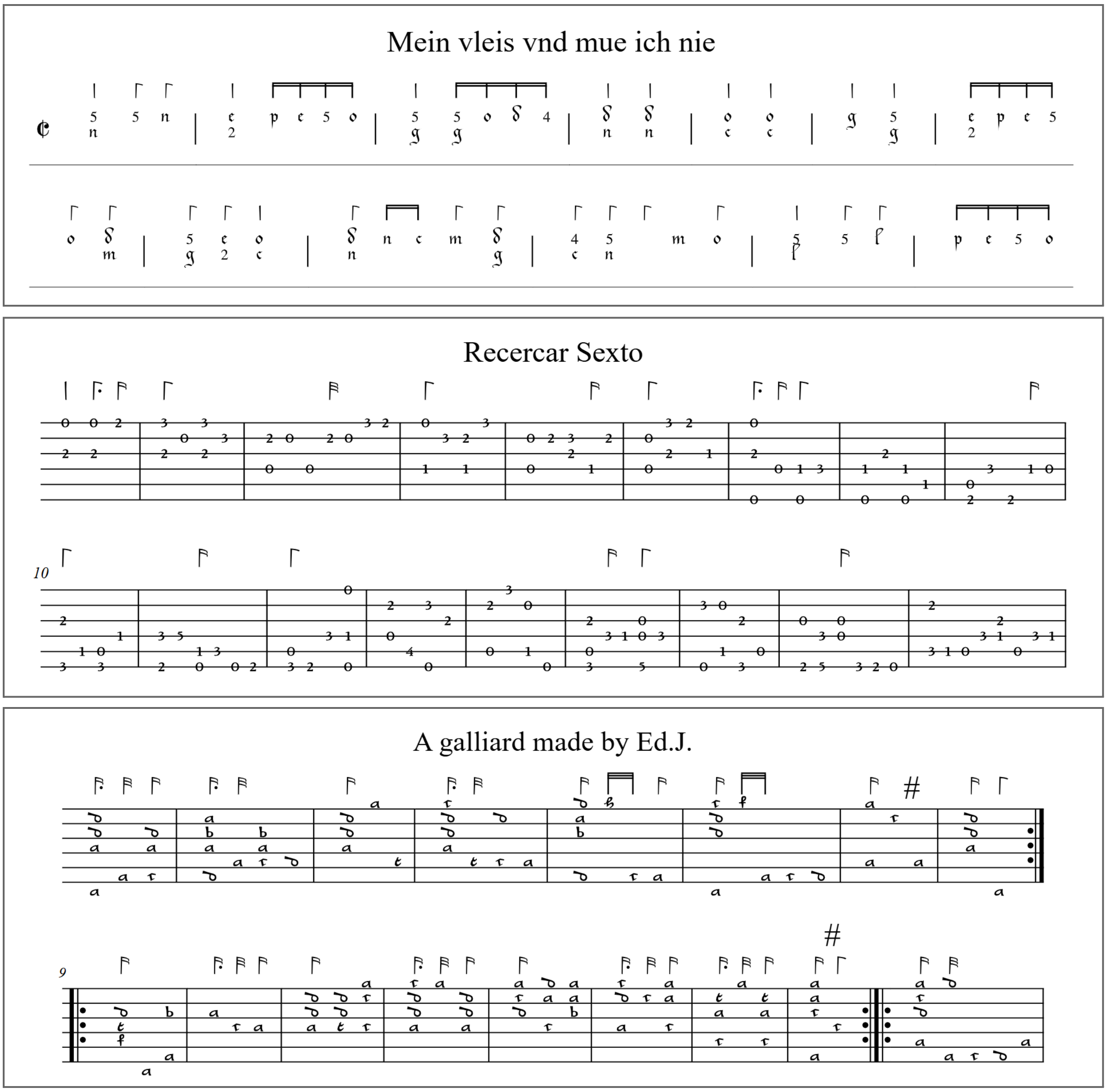


**Figure 1**: Verovio renderings of three lute tablature document fragments. **Top:** D-Mbs Mus.ms. 1512 'Mein vleis vnd mue ich nie', 1530-1550, f 3r (German lute tablature notation); **Middle:** Giovanni Maria da Crema, 'Ricercar', Intabolatura de lauto, Venice, 1546 f 5v-6r (Italian lute tablature notation) **Bottom:** Edward Johnson, 'Galliard', in William Barley, A new book of tablature for the orpharion, London, 1596 (French lute tablature notation).

Fandango[3], which support more aspects of the notation (and are unusual in supporting GLT at all). Thus, although Verovio has supported conversion to MEI from ILT, FLT, and guitar tablatures encoded in MusicXML (generated, e.g., by the MuseScore graphical editor) since 2021, this misses most users, and excludes GLT entirely.

These editors produce outputs in proprietary formats. The problem of converting from these
to MEI has been addressed by Paul Overell's luteconv[4], a command-line (CLI) tool capable of

[3] Available at https://fandango.musickshandmade.com/
[4] Available at https://bitbucket.org/bayleaf/luteconv/

converting between a host of standard and proprietary formats and lute notation types. However, work with a CLI-tool is not necessarily familiar to all music encoders, who arrive in this activity from an interdisciplinary variety of backgrounds and may not necessarily have vast prior technical experience. Manual conversion, storage, and file organisation is a particular challenge when collaboratively establishing large collections of encodings, as is the case in the E-LAUTE project. To address this, we have developed a Web-based environment aiming to simplify the flow of activity from specialist lute notation editors to collaboratively edited MEI encodings as much as possible. We have implemented a Web-wrapper[5] around the luteconv utility, exposing all of the CLI-tool's functionalities through a simple Web interface. Further, we have implemented a REST API around this interface in order to open luteconv's functionalities to external programmes. Finally, we integrated this API within the open-source mei-friend editor, allowing Fronimo files to simply be opened within mei-friend without any further thought to the conversion process. We have also extended mei-friend's GitHub integration to support the parameterization and triggering of GitHub Actions from within the editor, allowing the automation of routine post-conversion clean-up tasks, further simplifying the editing process.

## Conclusion and future work

Official support for tablatures within the MEI schema has been a long time coming, and it is very gratifying to have achieved the inclusion of GLT alongside the more prominent tablature notation types, both within the schema and being rendered by Verovio. However, several open challenges remain, both in terms of the immediate priorities of the E-LAUTE project and of the long-term ambitions of the Tablature Interest Group.

A number of code points are absent from the specification of the standard music font layout (SMuFL) that are important for rendering lute tablature, with especially many symbols absent from the core set needed for GLT. E-LAUTE representatives have already gathered and documented the missing glyphs for GLT, and the issue of their absence has been logged in the SMuFL issue tracker, with their inclusion targeted for the next major SMuFL release (v1.5).

Although MEI does now have core support for guitar tabs, there are many aspects of the notation that are not well covered, and other major notations – such as the various keyboard tablatures and non-Western forms – are currently absent. These will be important areas for future development by the Interest Group, and we welcome contributions from the community to help realise this.

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[5] Available at https://luteconv.mdw.ac.at

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# *Exalting Natural Genius*: Francesco Geminiani's Pedagogy of Harmonic Creativity

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## Introduction

In the preface to his *Guida Armonica* of 1752, Francesco Geminiani condemns the dominant pedagogy of music composition of his time, saying:

> The Rules for Modulation, which have been received by many within these Forty Years, are extremely short and defective; […] there are but few modern Composers, […] who can truly be said to have produced anything new with respect to Melody, Harmony, and Modulation. What can this be owing to, but imperfect and defective Rules? Which instead of guiding the Students of Harmony, mislead them; instead of assisting, improving, and exalting natural Genius, confine and depress it.

With the *Guida Armonica,* Geminiani offers an utterly idiosyncratic solution. This presentation discusses the historical context of Geminiani's critique, presents a digital implementation of the *Guida*, and demonstrates its use as a practical aid to composition and as an interface to the harmonic sensibilities of a well-regarded 18th-century composer and pedagogue.

## 1 Geminiani's intervention

### *1.1 The Critique: Contemporary Compositional Pedagogies*

Geminiani's standing to comment on the quality of musical composition in his time was well-earned. In the decades after his death, Charles Burney credited him with contributing "a great deal of the art and contrivance" in music and John Hawkins lauded his "original and multifarious modulations" (as reproduced in Careri, 1991, p. 42; Careri, 1993, p. 53). The objective truth behind Geminiani's criticism of mid-18th compositional variety is also recognized today: as Robert Gjerdingen and others have described, the stock harmonic progressions of around a dozen identified Galant schemata can be found throughout the

18th-century repertoire and numerous pieces can be analyzed as pastiches of these stereotyped building blocks (Gjerdingen, 2007; Sanguinetti, 2012). The dominant 18th-century pedagogical practice of partimento realization relied on the use of these stock harmonic progressions and their coordinating melodic conventions to inculcate composition students with the reflexive and improvisatory vocabulary that pervades the Galant repertoire.

### *1.2 The Solution: Guida Armonica*

The *Guida Armonica* offers the composition student 2236 fragments of figured bass in D minor, each beginning and ending with one of 21 common chords (Figure 1). The student is instructed to begin with one of the root position D minor chords, choose a fragment to continue the passage, then follow the indicated page number to find more fragments that could extend the first chosen fragment. This process would be repeated until the student reached a cadence and was satisfied with the musical result.

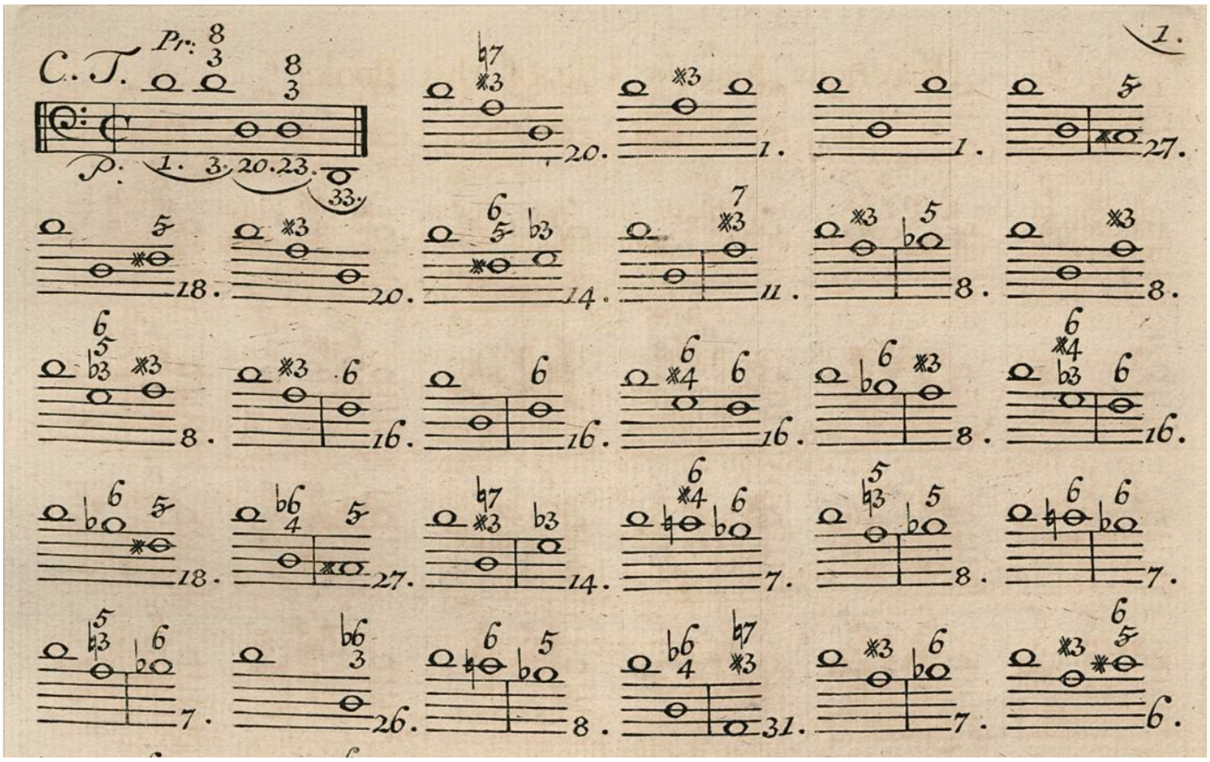

**Figure 1**: Excerpt from page 1 of Francesco Geminiani's *Guida Armonica* (1752).

Reactions before and after its publication were skeptical at best, and few seem to have meaningfully engaged with the process that Geminiani lays out. The most thorough review was penned by Jean-Adam Serre, an amateur music theorist who, in 1763, published a series of essays on his own theory of harmony and extensive commentaries on the theoretical works of Rameau, d'Alembert, Tartini, and others (Pau, 2018). Serre accepted the mechanistic premise of Geminiani's system but argued that the dictionary structure would benefit from a more logical ordering and the ability to index the fragments in both the forward and reverse directions.

# 2 Digital Implementation

## *2.1 Data encoding*

The page, row, column, next page number, editorial notes, and musical content (including all pitches, rhythms, ties, barlines, and bass figures) of each fragment in the *Guida Armonica* was manually transcribed into a Google Sheet using LilyPond syntax. A Django API to a Postgres database parsed the transcribed data, converted fragments to Humdrum syntax, and further processed the fragment data. Ongoing corrections to the transcription are automatically propagated to the database.

A React website accesses the *Guida* fragment data and presents users with two interfaces for interacting with the *Guida*: **Compose** and **Search**. The implementation website, **Guida Armonica Interactive*,*** is publically available at [https://guida.jkg.app](https://guida.jkg.app).

## *2.2 Guida Armonica Interactive:* ***Compose***

The **Compose** interface enables users to navigate the *Guida* and compose figured bass passages according to the procedure described by Geminiani, with the aid of computational conveniences (Figure 2). When users choose a fragment to include in their composition, the possible next fragments are displayed. In the forward direction, i.e. building a passage by adding fragments to the end, the process and experience of composing from the Guida is essentially identical to that of an 18th-century user — the only difference is the use of digital music notation, and thus the ability to quickly undo and redo. Users can also have the passage extended at random, allowing for the rapid generation of random walks through the harmonic network.

The **Compose** interface also allows users to select a fragment to end the passage and work in reverse, as suggested by Jean-Adam Serre. By combining both the forward and reverse processes, users can explore paths from both sides until they find a satisfactory solution that connects in the middle.

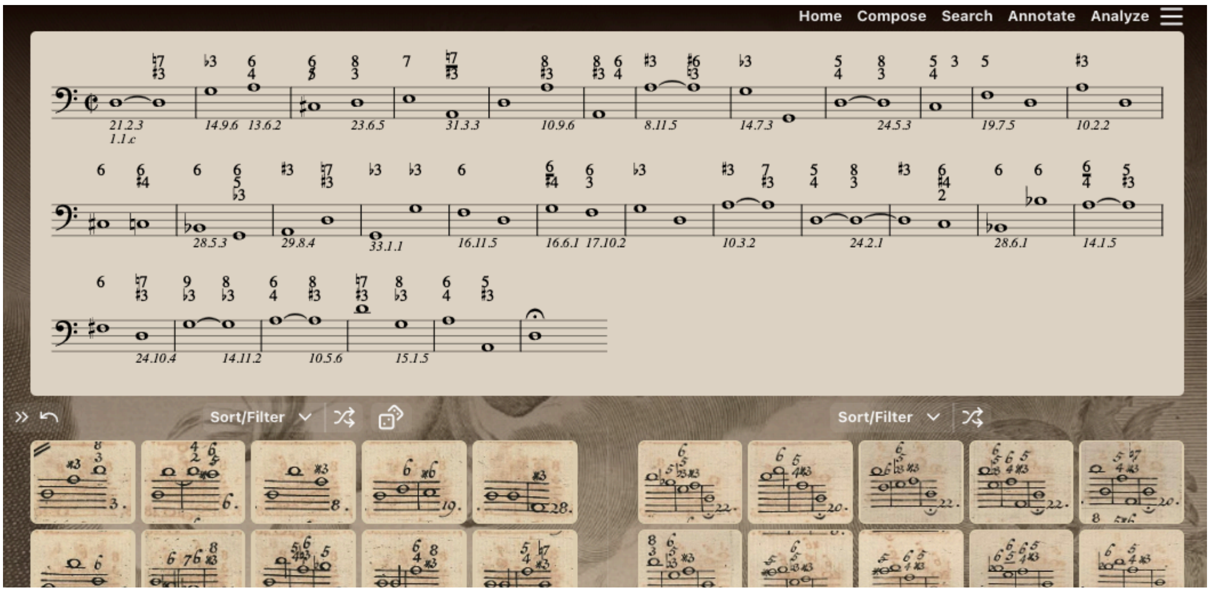


**Figure 2**: Composition view of Implementation Website. Each chosen fragment in the score is annotated with the page, row, and column where it can be found in the *Guida.* This passage was generated by randomly selecting each successive fragment (the dice icon).

Simple fragment filtering and sorting options are also provided to users, including sorting by ascending and descending pitch in both the forward and reverse directions and filtering for the presence of barlines, ties, cadences, half notes, rests, and specific chords. While these digital functions go beyond the imagination of Geminiani and his contemporaries, they allow modern users to quickly navigate the musical content of the *Guida* without having to assimilate the harmonic vocabulary through a lengthy process of exploration and use.

When users are satisfied with the figured bass passage that they have created, the rendered notation can be exported in PDF or SVG formats and the encoding can be exported in Humdrum or MEI formats, or opened directly in Humdrum Verovio Viewer (see Figure 4 for example result). MIDI playback of the passage pitches (without harmonization) is also enabled.

## 2.3 Guida Armonica Interactive: **Search**

The **Search** interface goes beyond the compositional process as envisioned by Geminiani to provide access to the complex network of chord progressions generated by the 2236 fragments of the *Guida*. When users input a pitch sequence, all possible passages using the *Guida* fragments that contain that sequence are presented. Because this can generate many highly redundant passages, the chord progressions of the passages are summarized in a network diagram as shown in Figure 3.

The network of chord progressions is annotated to indicate which chords appear in sequence in the search results. Edges are rendered as solid lines if a majority of the passages include a barline between the two chords and dotted otherwise. The chord nodes can be selected by the user to filter for passages that include that chord at that position and the edges can be selected to require or prohibit barlines at each position.

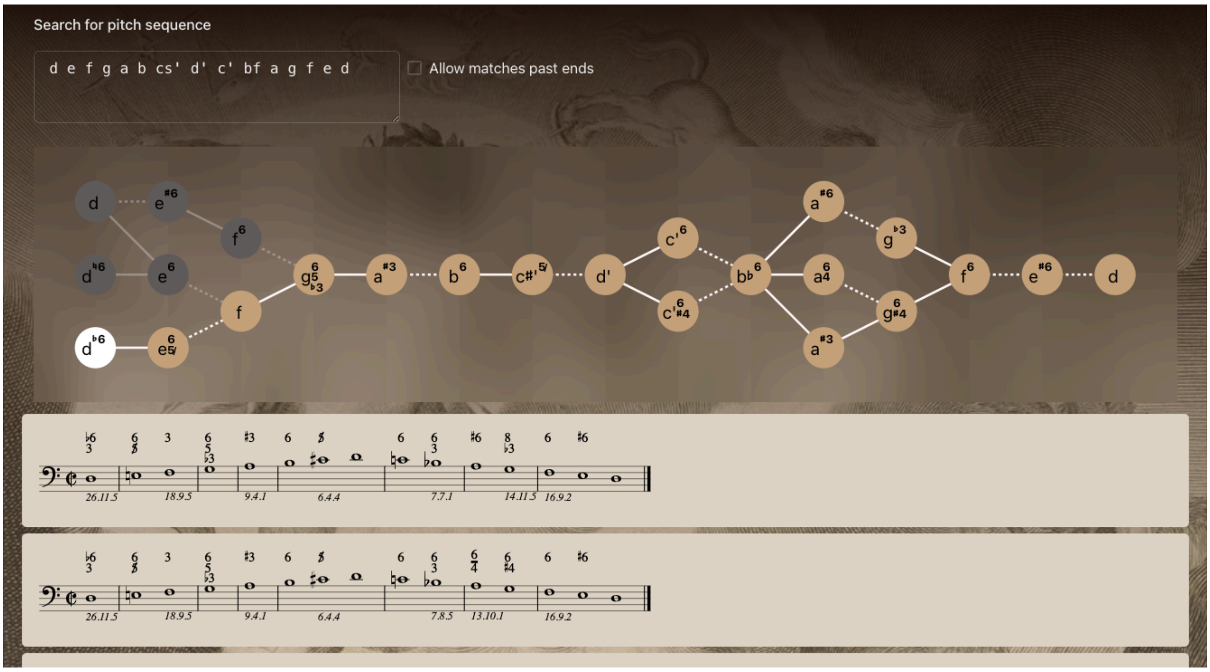


**Figure 3**: Search view of implementation Website. When a user inputs a sequence of bass pitches, a network of possible harmonizations using the fragments of the *Guida* is generated.

When users find a passage of interest in the search results, they can open the passage in the **Compose** interface to modify or extend it. Thus, the **Search** interface enhances the composition process for users with a particular bass pitch sequence in mind while also offering access to the *Guida* as an analytical tool for the music of Geminiani and his contemporaries. Expansion of the **Search** functionality for music analysis is an ongoing effort.

# 3 Demonstration

As an initial demonstration of composition using the Guida, an entirely random passage was generated until reaching a full cadence (Figure 2). A realization of this random passage as a trio sonata movement was created (Figure 4). This composition required substantial creative thinking—distinctive melodic gestures in the bass and implied by the figures were exploited to incorporate repeated motives and thus a coherence as a complete movement. The Guida did not write a piece of music without intelligent intervention, but it did produce a complete unit of creative material - everything necessary from the domain of, in 18th century terms, modulation.

# Conclusion

Despite the algorithmic nature of the *Guida Armonica*, Geminiani's goal for the work was not to automate music composition. Instead, he intends the *Guida* to "be of the greatest use to the students of Harmony, by enlarging their Ideas and giving them just and complete notions of Harmony and Modulation" (Geminiani, 1752, Preface). Unlike aleatoric composition games of the late 18th century (Klotz, 2014; Moseley, 2016, pp. 121-177), the *Guida* does not generate plausible music without creative intervention — rather, it offers the user's creativity an abundance of musically grammatical possibilities.

The creation of a digital interface to the musical possibilities contained in the *Guida Armonica* realizes Geminiani's vision of a creatively liberating tool for aspiring composers in the 18th-century style. The next steps in this project are first to explore other ways of using the *Guida* to guide composition. For example, the way that motives are able to appear in all the voices of the realized random example suggests that, instead of the first-movement Adagio style of the example, this harmonic material might be well-suited to deploy as a fugue. Partimento training included writing fugues based on similar prompts, so the methods that apply there might be transferred to Geminiani's harmonic vocabulary.

Current work-in-progress on the digital implementation includes the expansion of the **Search** function from its current capacity to work with continuous sequences of bass notes to annotation of whole movements of repertoire. Major challenges in this work include fuzzy search to allow for bass ornamentation and non-chord tones; modulation into secondary key areas; and dynamically controlling annotation density for effective rendering and access to metadata.


**Figure 4**: A piece realized from a randomly generated passage from the Guida, in which opportunities for motivic coherence have been exploited. The realization was added manually in Verovio Humdrum Viewer, to which the Implementation Website connects directly. [Link to this example in VHV]


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# The Computational Study of Musical Form: Challenges for Encoding and Analysis

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## 1 Introduction: Goals and Challenges

Form can be viewed as a high-level structural domain of music, which is informed by and interacts with other domains, such as tonality, meter, repetition, as well as texture and orchestration (Webster, 2009, p. 128; Yust, 2018). On a general level, analyses of musical form identify and illuminate temporal relations within, across, or integrating all of these domains. The ways in which the musical parameters influence formal analysis and warrant the use of certain analytical terms are, however, rarely made explicit. In this contribution, we assess what is needed to encode analyses of musical form in a way that explicitly models the multi-dimensional interplay between structural domains and emergent formal functions. We argue that an ontology-backed encoding will be an important step towards a unifying computational model of musical form, including applications such as music generation and automated analysis.

The computational study of musical form is hampered by a host of challenges: First and foremost, a generalized model of how musical elements and features integrate into formal designs does not exist to date. The main challenge for computational musicology is to come up with a unified model capable of faithfully representing different musical features and their annotations. A prerequisite for encoding formal analyses therefore concerns the robust and multi-layered encoding of temporal dimensions in absolute time for recordings or in musical time for music scores—or both. 'Robust', here, means that timespan indications correctly resolve to concrete positions in the original representation. This is particularly relevant when we want to flexibly integrate competing or mutually informative layers of analysis. It could include form annotations stemming from different readings or analytical traditions, hence benefitting the music-theoretic field of Formenlehre, which is dispersed into a diverse range of theories, approaches and terminologies — both historical and modern (Caplin et al., 2009; Schmalzriedt, 1985; von Appen & Frei-Hauenschild, 2015, p. 6). Also, representations of different domains interfacing with form can be integrated (say, an automated timbral analysis based on a recording with a thematic-motivic analysis based on a score). By creating such rich analytical encodings of music for diverse corpora of music, the field could move towards a theory of musical form that is explicit and empirically grounded, while also being more flexible in terms of its application to a wide range of music.

In our contribution, we discuss the needs that this research endeavour poses in terms of encoding annotations, and discuss the extent to which these are covered by existing tools. Then, we present an example of integrating the strengths of different tools using stand-off annotations (Pierazzo, 2015).

# 2 Specific Needs and Survey of Existing Tools

From the challenges outlined in the introduction, we have compiled a list of features that an (ideal) annotation app should have. In summary, these include support for symbolic as well as audio representations, annotation of timespans as well as events on the note or stave levels, and the ability to bring together different types of analyses, ideally in a user-friendly GUI. We consider five current annotation tools regarding their ability to satisfy these criteria:

- *MuseScore*: a music-notation software, which can be used to create chord- or text-labels. These can be parsed into tabular data for further processing (Gotham & Ireland, 2019; Hentschel & Rohrmeier, 2023).
- *Dezrann*: a web platform for creating and sharing analyses, primarily of notated music (Giraud et al., 2018).
- *MuseReduce*: a web app developed for reductive analysis of MEI files (Ericson et al., 2023; Ericson & Rohrmeier, 2020).
- *mei-friend*: a web-based editor for digital music encodings (Goebl & Weigl, 2024).
- *TimeLineAnnotator (TiLiA)*: an annotation tool designed for complex annotations on video and audio files (Martins & Gotham, 2023).

| | Annotation Needs | | | | | | | | | | | | | | | Usability | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Real time reference | Musical time reference | Score annotation | Audio/Video annotation | Generic timespans | Stave timespans | Note-level annotation | Hierarchical segmentation | Overlapping Timespans | Alternate analyses | Graph structure | Tailored to form | Tailored to harmony | Distinct annotation domains | Time markers | Git integration | Collaborative/Reviewing | Toggle layers | Webapp | Annotation GUI |
| MuseScore | | ✓ | ✓ | | (✓) | ✓ | (✓) | | | (✓) | | | ✓ | (✓) | (✓) | | | | | |
| Dezrann | (✓) | ✓ | ✓ | ✓ | ✓ | ✓ | | (✓) | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| MuseReduce | | (✓) | ✓ | | | | ✓ | | | | ✓ | | (✓) | | | | | ✓ | ✓ | ✓ |
| mei-friend | | (✓) | ✓ | | (✓) | (✓) | ✓ | | | | | | | | (✓) | ✓ | ✓ | ✓ | ✓ | |
| TiLiA | ✓ | (✓) | (✓) | ✓ | ✓ | | | ✓ | (✓) | ✓ | | ✓ | ✓ | ✓ | ✓ | | | ✓ | (✓) | ✓ |

**Table 1**: Comparative synopsis of selected features for five different music annotation apps. ✔ = feature is supported; (✔) = feature is planned or indirectly supported.

Unsurprisingly, no single annotation tool currently satisfies all features relevant for the described research endeavour. *MuseScore*, *MuseReduce* and *mei-friend* exclusively support symbolic data. *Dezrann* has been expanded to support cross-modal annotations (Garczynski et al., 2023). *TiLiA* is focussed on audio data, but support for symbolic scores and musical time is currently under active development.

The apps in question currently support either time-span or note-level annotations, but not both: The two MEI-based tools are able to reference concrete elements on the note level, but cannot directly represent time segments (the *<section>* element is not yet made readily available for complex analytical annotation). Conversely, *Dezrann* and *TiLiA* are designed for time-span annotation, but lack access to the note level. In terms of timespans, only *TiLiA* represents hierarchical relationships explicitly, while timespans in *Dezrann* are more flexible in how they can overlap and be applied to individual staves.

Several of the tools support the combination of analyses concerning different musical domains. While some tools (such as *Dezrann* and *TiLiA*) are generic annotation tools allowing for the application of custom text labels, other tools are more domain-specific: *MuseReduce*, for instance, is specifically designed for hierarchical note-level annotations, such as motivic or voice-leading analysis, which are particularly relevant for formal analysis. Beyond its generic functionality, *TiLiA* specifically offers formal annotations differentiating between "types" and "functions" (Caplin, 1998; 2013, p. 73). *MuseScore* is particularly effective for creating harmonic annotations for symbolic music. Adding several other analytical layers is possible but quickly leads to clutter, as there is no way of easily turning them on or off. Nor can labels in *MuseScore* address timespans directly, they can only mark changes at given points. *mei-friend* offers distinct advantages such as git integration and the inclusion of solid technology (Sambra et al., 2016), but its support for music analytical annotation is as of yet rudimentary.

In conclusion, annotation tools tend to be limited either by a certain media type, annotation level, or by practical concerns. On the positive side, the survey shows that all of the articulated needs, ambitious as they may be, are addressed by at least one of the tools. From here, there are in principle two ways of proceeding. The first would be to select a single tool which covers the most important aspects, and to accept compromises or workarounds. The other way, which will be explored here, is to try and use different annotation tools to their individual strengths, while coordinating the resulting data using stand-off annotations (Pierazzo, 2015). As a side effect, this will facilitate the re-use and enrichment of existing analyses from different sources.

## 3 Integration of analytical layers from diverse sources

An initial step towards our approach is illustrated in Fig. 1, using the first movement of W. A. Mozart's Piano Sonata No. 5, K. 283 as an example. The table demonstrates a technical means for navigating analytical annotations of distinct musical domains, independently created by different researchers with various tools, while flexibly correlating them to multiple music representations. The left-hand columns represent the analytical layers shown in Fig. 1a) and result from combining two datasets within the *Dezrann* app. The analysis of key, harmony, cadence, and phrase beneath the score has originally been created in *MuseScore 3*, and converted to *Dezrann*'s file format for integration with the underlying MEI representation. The high-level sonata-form labels and measure-wise texture labels above the score have been created directly in *Dezrann*. All analytical labels are enhanced by *Dezrann*'s alignment of the score with a recording by Klára Würtz. The right-hand columns of the table result from integrating in *TiLiA* a set of harmony labels created and provided as a text file in RomanText format (Tymoczko et al., 2019) with form-analytical labels generated using a spreadsheet. As shown in Fig. 1b), this integration is based not on a score, but on an audio recording (by Paavali Jumppanen) with an aligned measure-beat grid. The highlighted columns in the table center represent the backbone of the suggested integration procedure, which uses a MeasureMap (Gotham, Hentschel, et al., 2023) for aligning all analyses. As a result, analyses originating from different tools can be flexibly cross-evaluated, and, despite their symbolic origins, correlated with two different recordings.

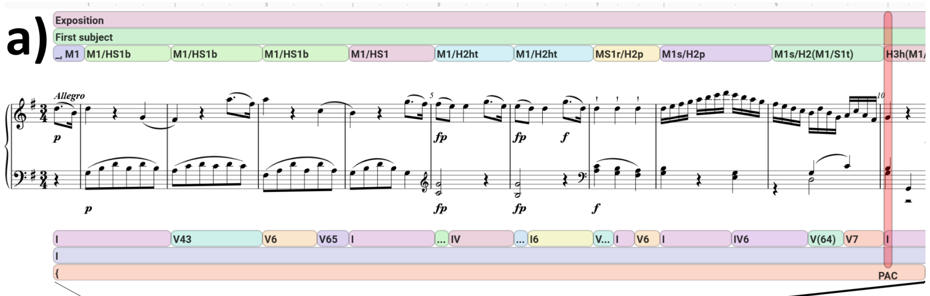
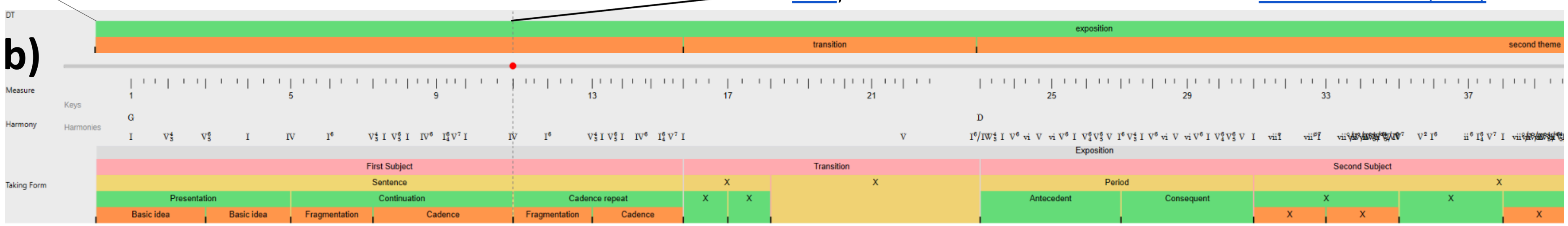



**Figure 1**: Integration of multiple analyses of W.A. Mozart's *Piano Sonata No. 5 in G major*, K. 283, I. Allegro into a single tabular representation, aligned with two recordings. The table shows for mm. 1-10 the alignment of all analytical labels with two renditions and the score. **a)** A screenshot from Dezrann showing mm. 1-10 of the texture analysis from Couturier et al. (2022) (above) and of the harmony and phrase annotations from Hentschel et al. (2021) (below). **b)** A screenshot from TiLiA showing mm. 1-39 of Dmitri Tymosczko's harmonic analysis (Gotham, Micchi, et al., 2023) and of the hierarchical form annotation from Gotham & Ireland (2019).




| Compiled analyses in the Dezrann app & recording by Klára Würtz | | | | | | | | MeasureMap | | D. Tymoczko's analysis; recording by P. Jumppanen | | | | | Analysis from Gotham & Ireland (2019) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Structure** | **Structure** | **Phrase** | **Local Key** | **Harmony** | **Texture** | **start (s)** | **start (♩)** | **ID** | **number** | **start_beat** | **start (s)** | **DT_1** | **Key** | **Harmony** | **TF_1** | **TF_2** | **TF_3** | **TF_4** | **TF_5** |
| Exposition | First subject | { | I | I | _, M1 | **0** | 0 | 1 | 0 | 3 | 1.1 | exposition | G | I | Exposition | First Subject | Sentence | Presentation | Basic idea |
| | | | | | M1/HS1b | 0.50 | 1 | 2 | 1 | 1 | | | | | | | | | |
| | | | | V43 | M1/HS1b | 1.99 | 4 | 3 | 2 | 1 | 3.58 | | | V4/3 | | | | | |
| | | | | V6 | M1/HS1b | 3.48 | 7 | 4 | 3 | 1 | 4.88 | | | V6/5 | | | | | Basic idea |
| | | | | V65 | | 4.47 | 9 | 4 | 3 | 3 | | | | | | | | | |
| | | | | I | M1/HS1 | 4.97 | 10 | 5 | 4 | 1 | 6.35 | | | I | | | | | |
| | | | | IV(4) | M1/H2ht | 6.46 | 13 | 6 | 5 | 1 | 7.84 | | | IV | | | | Continuation | Fragmentation |
| | | | | IV | | 6.71 | 13.5 | 6 | 5 | 1.5 | | | | | | | | | |
| | | | | I6(6) | M1/H2ht | 7.95 | 16 | 7 | 6 | 1 | 9.2 | | | I6 | | | | | |
| | | | | I6 | | 8.20 | 16.5 | 7 | 6 | 1.5 | | | | | | | | | |
| | | | | V43 | MS1r/H2p | 9.44 | 19 | 8 | 7 | 1 | 10.68 | | | V4/3 | | | | | Cadence |
| | | | | I | | 9.94 | 20 | 8 | 7 | 2 | 11.08 | | | I | | | | | |
| | | | | V6 | | 10.43 | 21 | 8 | 7 | 3 | 11.48 | | | V6/5 | | | | | |
| | | | | I | M1s/H2p | 10.93 | 22 | 9 | 8 | 1 | 11.89 | | | I | | | | | |
| | | | | IV6 | | 11.92 | 24 | 9 | 8 | 3 | 12.54 | | | IV6 | | | | | |
| | | | | V(64) | M1s/H2(M1/S1t) | 12.42 | 25 | 10 | 9 | 1 | 13.21 | | | I6/4 | | | | | |
| | | | | V7 | | 13.41 | 27 | 10 | 9 | 3 | 13.55 | | | V7 | | | | | |
| | | PAC | | I | H3h(M1/HS2), M1 | **13.91** | 28 | 11 | 10 | 1 | 13.9 | | | I | | | | | |

# 4 Discussion

The use case posed by the computational analysis of musical form greatly highlights the importance of interoperable data formats and representations. To ensure robust temporal references, representations such as MeasureMaps (Gotham, Hentschel, et al., 2023) can be used for different annotation tools to create interoperable encodings of different structural aspects of music. This approach is in some ways complementary to that of the Music Annotation Ontology (MAO), which is based on identifying musical content independent of temporal location (Lewis et al., 2022).

Another key question concerns the analytical vocabulary and its underlying ontological basis. Modern annotation tools such as the ones showcased here tend to accommodate any custom labels, which leaves validation to the users and potentially makes them incomparable. In the future, it might be useful to define the vocabularies used by different analytical frameworks, for example by means of one or several formal ontologies. For instance, a parent layer defined as a “period” in a Caplinian analysis would automatically generate two timespans labeled “antecedent” and “consequent” on the lower level, as these terms are connected by definition (Caplin, 2013, p. 73ff.). Even more ambitiously, such an ontology could determine relationships across terminological divides, pointing to synonymous or functionally analogous terms in a different framework.

The proposed solution, consisting in combining different annotation apps via the consistent intermediary representation of time, and using a rich uniform ontology, enables the unification of diverse datasets and hence facilitates the study of musical form on a large scale.

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# SHORT PAPER

# Using MEI to Create Accessible Music Scores: Findings from a Pilot Study

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## Introduction

Archives typically make music scores available online as PDF or JPEG files, and most newly created music scores are PDFs; if they are archived, it is usually as a PDF or PDF/A (Akau, McKinney, & McNellis, 2023). Unfortunately, PDFs are frequently inaccessible to Disabled users. musicXML and MEI files can be converted to accessible file types, but archives do not use them as frequently as PDFs or JPEGs (Pineo, 2025c). As a result, most archives' digital music scores are inaccessible to many Disabled users. Encoding scores using MEI makes them compatible with MuseScore, which can be used to create more accessible scores, including Braille music notation (BRF), modified stave notation (MSN) (see: UK Association for Accessible Formats, 2019), and audio files (WAV or WAVE). Therefore, this paper will present the findings of an exploratory study that examines the feasibility of a workflow used to create these file types for use and dissemination in an online archive setting.

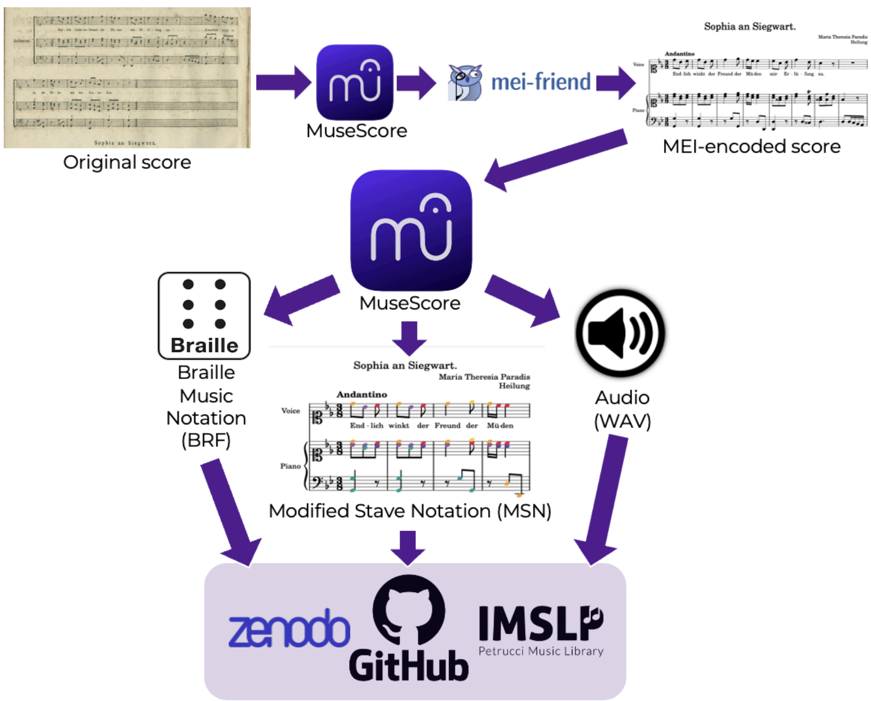
## 1 Literature

Previous work has explored the efficacy of talking music scores (Schuiling, 2023) and haptic feedback for graphical scores (Karpodini & Michailidis, 2022), though not in an archival context. In education, Challis (2009) provides an overview of accessibility in music technology and finds that music technologies have not, historically, been designed with disability in mind. Presently, most score accessibility initiatives are based on the highly interoperable musicXML format (ChoirCommunity, n.d.; Higman, 2024; OpenScore, n.d.; Talking Scores, n.d.; The DAISY Consortium, 2024a). In addition to MEI files, the workflow explored here also creates musicXML files, which makes it compatible with such initiatives, though its focus remains on MEI due to its preservation benefits (discussed below). Taking advantage of existing infrastructure of the growing MEI community will likely be imperative to the long-term success and adoption of this workflow.

# 2 Methods & Workflow

To test the workflow (Figure 1), I used a set of scores written by Maria Theresia von Paradis (1759–1854), herself a Blind composer. I began by downloading the original scores from the International Music Score Library Project/Petrucci Music Library (IMSLP). Then, I entered them manually into MuseScore. From there, I exported the scores to musicXML and used mei-friend to clean up the resulting MEI files and add metadata to them. After exporting them from mei-friend, I had a full MEI version of the scores, which I brought back into MuseScore. From there, I exported the scores to BRF and WAV files and created two types of MSN scores, one with black noteheads and one with colored noteheads. After creating all of the scores, I uploaded the completed files to GitHub (ElizabethPineo, 2025) and IMSLP (IMSLP, n.d.); I will also upload them to Zenodo. Overall, I found that the workflow is feasible. The primary challenge with the workflow arose from a need either to manually input each score note by note or to check and correct the results of optical music recognition (OMR) programs' output. For guidance on implementing the workflow, see: Pineo (2025a) and Pineo (2025b).

**Figure 1**
*Step-by-step illustration of the workflow*




After creating the accessible music scores, I conducted usability tests with four users to determine if they were more useful and usable than currently available scores. After analyzing the results, I found that the scores were indeed beneficial. While they were imperfect, all four participants indicated that the scores were helpful and an improvement over the PDF scores that are usually available in an archival context. Long-term, my goal is to replicate this process in a real-world archival context, where I can monitor how users interact with the scores and conduct further usability testing with users.

## 3 Preservation Benefits

If archivists increase their creation of MEI-encoded scores for accessibility purposes, production of MEI-encoded scores would likewise increase. The Library of Congress' recommended formats for music scores are, in order: musicXML, MEI, and any of the portable document formats (PDFU/A, PDF/A, PDF/X, and PDF) (Library of Congress, 2024). MEI files hold not just music notation information, but also information about the music notation (Music Encoding Initiative, n.d.). MEI also supports mensural and neume notation and "can record the relationships between notational features and digital page images and audio recordings" (Music Encoding Initiative, n.d.). MEI files also do not degrade the way that PDF files eventually do (Lee, 2000; Wilson, 2020). Each of these features is beneficial to archivists' preservation goals. As a result, implementing this workflow in archival settings will benefit both accessibility and preservation initiatives.

## Conclusion

Archivists must center accessibility in all that they do, for accessibility touches all aspects of archival work. This is particularly true in music archives, where accessibility initiatives have yet to turn their attention to music scores, which comprise much of the material found in music archives. Not only is the workflow tested here highly beneficial to long-term preservation efforts, but it is also an imperative step toward building more accessible music archives. Based on my experiences interacting with other archivists about accessibility in archives, archivists are eager to learn how to make their collections as accessible as possible to their users. By implementing this workflow, not only will archivists be able to build more accessible music archives, but they will also be able to provide true access to historically inaccessible collections. Thus, this workflow can help archivists begin that complex, crucially important journey.

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# A Minimal Publishing Model for Text and Music Notation

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## Introduction

Methods for the digital edition of text or music notation typically rely on established encoding standards like TEI or MEI. However, digital editions that alternate between different modalities such as text and music notation—e.g., in the context of music theory treatises, textbooks, music journals, composers' correspondence, and editions of sheet music with accompanying peritexts—face significant challenges, as combining these technologies is far from trivial.

This paper builds on a bachelor's thesis dealing with source materials from the project *Digitizing the Dualism Debate* (cf. Moss/Bavaud et al. 2021; Moss/Köster et al. 2021; Moss/Nápoles López et al. 2022). It also connects to the recently reactivated TEI Music SIG, which aims to harmonize and integrate music encoding with the practices of the Text Encoding Initiative (TEI), focusing particularly on the transitional areas between the two technological stacks. The overarching goal is to offer one or more accessible and sustainable technological solutions for publishing digital editions that include music notation. This approach is intended to support projects without institutional infrastructure for digital editions.

The integration of text and music notation initially appears to be a topographical issue of text presentation. From a text encoding perspective, the problem can be addressed by integrating graphical representations of music notation as digital images. However, from a music encoding perspective, this approach is insufficient, as it prevents the formulation of relationships between text and music notation within the data (cf. Roeder/Moss/Köster 2023). Therefore, the objective is to model and encode both text and music with comparable structural and semantic depth, and to host it within a long-term sustainable environment. While the presentation could integrate scanned or vectorized music notation graphics alongside embedded MEI data, the preferred approach is to generate the presentation directly from the data without intermediate formats (while providing a fallback solution with embedded graphics if necessary).

To illustrate this approach, we propose using two tools closely associated with TEI and MEI: Verovio for rendering music notation and CETEIcean, a lightweight tool for TEI processing. Both operate on JavaScript and require only a standard web server, as TEI and MEI are both processed client-wise.

## 1. Representation: Organizing and Modeling the Data

Due to the different encoding standards, it is necessary to decide how to organize text and music notation data at the file level. To avoid potential namespace conflicts between frameworks, separating them into distinct files has proven effective. This does not necessarily mean generating one TEI file and numerous MEI files; MEI data could also be consolidated into a single file and referenced section by section using IDs.

For example, a treatise with alternating text and musical examples could use a primary TEI file for the text and a single MEI file containing all musical excerpts, each tagged with unique IDs for cross-referencing. This approach reduces complexity while maintaining semantic depth.

## 2. Presentation: Rendering the Data

Depending on the chosen data organization, the rendering process must be arranged for the browser. With the selected combination of CETEIcean and Verovio, HTML and SVG code are generated live using JavaScript. This requires precise timing: a music notation section can only be rendered by Verovio once the corresponding HTML element has been generated by CETEIcean.

To achieve this synchronization, the frameworks are orchestrated via monitoring. When CETEIcean processes an XML element referencing a musical excerpt, it temporarily hands over control to Verovio to render the notation dynamically. This interplay ensures a seamless user experience without relying on pre-generated images or static files.

## 3. Stabilization: Hosting Environment and Citable Archiving

Dynamic site digital editions are often precarious resources, as they often depend on complex server environments. Even standard solutions (e.g. with TEI Publisher) require regular maintenance, which projects and their institutions are not able to guarantee in long terms. For rendering components such as CETEIcean and Verovio, however, simple hosting solutions for static sites like GitHub Pages or any another web server are sufficient (cf. Cayless/Viglianti 2018). GitHub offers advantages such as temporal organization of data and code into release sequences. Additionally, GitHub can be linked to Zenodo, enabling the repository and its individual releases to obtain DOIs and ensuring that each release is archived independently of GitHub on Zenodo.

This combination allows projects to achieve both low-cost deployment and academic curation. For instance, an edition hosted on GitHub Pages could be continuously updated, while its key versions remain permanently accessible via Zenodo.

## Outlook

The Würzburg project *DigiMusTh: Aufbau einer offenen digitalen Sammlung historischer musiktheoretischer Texte aus dem deutschsprachigen Raum anhand von Beispielen aus dem 19. Jahrhundert* (“Development of an open digital collection of historical music theory texts from the German-speaking world based on examples from the 19th century”) will adopt this new presentation model in 2025 using the described approach. Simultaneously, this approach will serve as an example for the TEI Music SIG, showcasing its potential for other interdisciplinary projects. The next step involves modeling the dense relationships between text and music notation and integrating these into the presentation. This will provide a richer and more interactive experience for researchers, educators, and enthusiasts alike.

By exploring how closely related encoding practices can coexist and complement each other, this project aims to establish a flexible and sustainable foundation for future digital editions of hybrid materials.

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# An Annotation Interface for Protovoice Analysis

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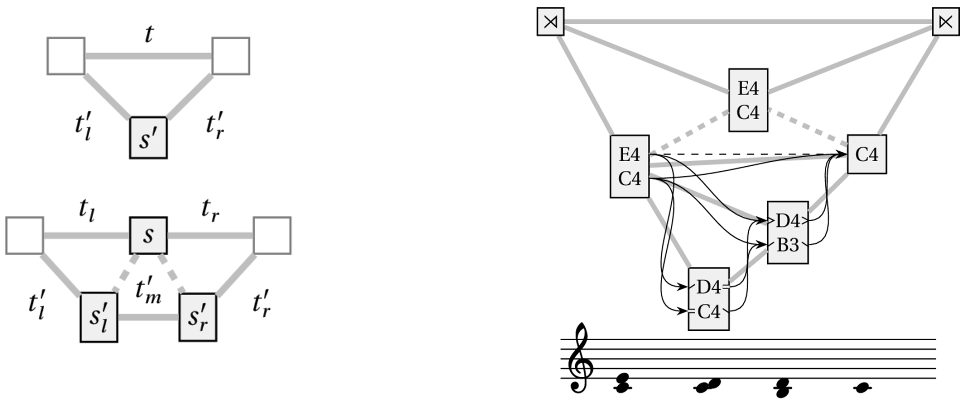
## Introduction

Corpus and machine-learning research on music relies on high-quality datasets that often involve annotations and analysis by experts. In creating these annotations, it is important to ensure formal consistency and machine readability, but also a high musical expressivity. Annotation workflows can either rely on general music notation tools such as the Verovio Humdrum Viewer (Ricciardi, 2020; Rodin & Sapp, 2010) or MuseScore (Hentschel et al., 2021), or work with dedicated tools for creating specific types of annotations (Ericson et al., 2023; Giraud et al., 2018; Tomašević et al., 2021).

This paper presents a set of tools for working with protovoice analyses, a formalism introduced by Finkensiep & Rohrmeier (2021). In the protovoice model, the structure of a piece is described as a derivation, the execution trace of a generative process that produces the piece from a small set of operations. During this process, two types of generic relations are tracked: horizontal connections between notes that belong to the same "protovoice", and the vertical organisation of notes into "slices". At every point in the generation process, the current state of the piece is represented as a sequence of slices and transitions, where the slices contain notes and the transitions contain edges connecting these notes.




**(a)** Split and spread operations.

**(b)** An example derivation.

**Figure 1**: Basic operations in the protovoice model (a) and an example of a derivation (b).

A step in the derivation process has two phases: First, the temporal structure is expanded by either splitting a transition, creating a new slice between two existing slices, or spreading a slice into two slices. Figure 1a shows both operations in a planar graph notation similar to Yust (2006): The top row of slices and transitions shows the original state of a piece (or segment of a piece), while the elaboration produced by splitting or spreading is shown below it. The split operation introduces new notes that serve as ornaments to the existing notes (repetitions, neighbor notes, or passing notes), while the spread operation distributes the notes of a slice (arpeggiation). At the end of a derivation, every note of the piece's score has been generated (Figure 1b). For a more detailed description of the protovoice model, refer to Finkensiep & Rohrmeier (2021).

The tool presented in this paper consists of three components:

- an annotation interface for creating analyses of a given piece,
- a viewer for embedding visualizations of analyses in webpages,
- a shared library for representing, manipulating, and encoding derivations.

# The Annotation Interface

The annotation component is a web-based tool[1] that facilitates the annotation process by guaranteeing a correct formal structure of the analysis and highlighting annotation inconsistencies (Figure 2). The tool is implemented in Purescript[2] using the Halogen framework[3] and the VexFlow library[4]. It works entirely on the client side without requiring any server-side backend structure.

[1] https://dcmlab.github.io/protovoice-annotation-tool/.
The source code is provided at https://github.com/DCMLab/protovoice-annotation-tool.
[2] https://www.purescript.org/
[3] https://github.com/purescript-halogen/purescript-halogen
[4] https://vexflow.com/

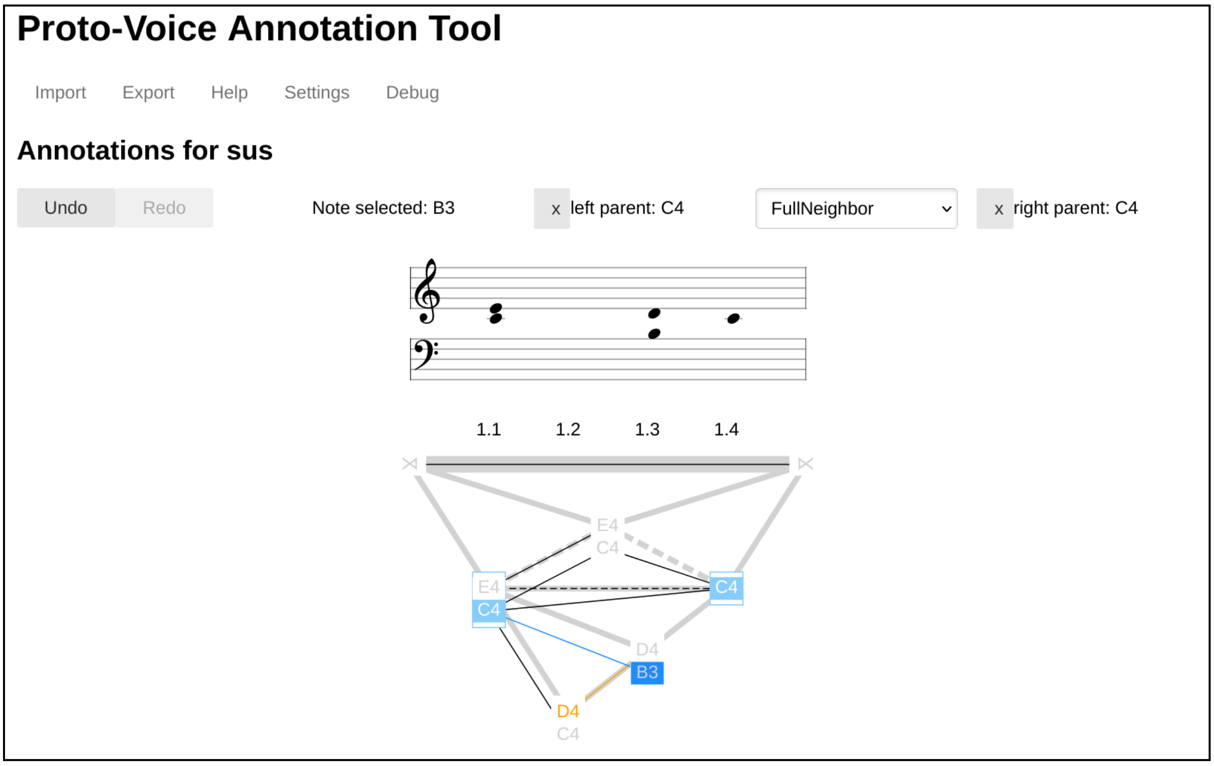



**Figure 2**: Overview of the annotation interface.

The annotation workflow inverts the generative process described above. A user loads a piece they wish to analyse either in a special JSON-based notelist format (described below) or directly from MusicXML. The notelist format can be created manually using a separate conversion tool.[5] The annotator reduces the piece step by step until each note in the piece is explained. The resulting analysis can be exported to another JSON-based format,[6] which can be loaded again later to edit the analysis. In addition, the tool can export TikZ code for creating visualizations in LaTeX documents. Other visual representations can be generated by the viewer component. Unique IDs are used to link notes between score and analysis files.

[5] https://github.com/DCMLab/musicxml-to-pvpiece

[6] To make it easier to distinguish pieces and analyses, the file extensions `.piece.json` and `.analysis.json` are used, respectively.

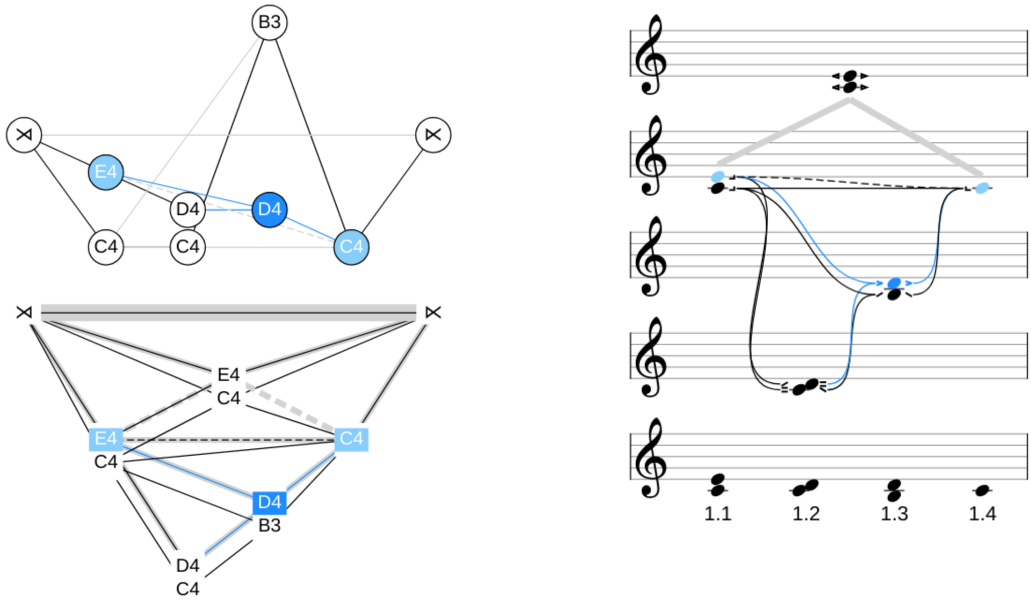



**Figure 3**: The viewer widget can create different interactive visualizations of a derivation.

# The Viewer Widget

The viewer component provides an interactive frontend for displaying and exploring analysis. It is provided as a standalone JavaScript module that can be easily included into a webpage.[7] The module has a single entry-point that creates a widget and binds it to an HTML element on the current page. The shown analysis is provided in the analysis JSON format at creation time. In addition, certain settings such as the zoom level or the shown derivation step can be pre-configured.

The widget shows the analysis in an interface that resembles the annotation tool, or in a staff-based notation (Figure 3). In addition, a graph of the internal connections between the notes at the current step can be shown. The user can step through the derivation in leftmost-derivation order and select notes to see their functional role and related notes.

# The Internal Library

The common functionality of the annotation interface and the viewer widget is collected in a separate PureScript library. This ensures the compatibility of the two components and permits reuse of the functionality in third-party tools. The library covers three aspects of functionality: A set of types for representing (partial) analyses in a type-safe way, high-level editing operations on these data structures, and conversion functions from and to JSON. Since PureScript compiles to JavaScript in a transparent and straightforward way, the library can be used from both PureScript and JavaScript.

# Data Formats

The tools described in the previous section use two JSON-based formats to encode input pieces and analyses. The input piece is encoded as an array of slices, each of which contains

[7] An example page can be found at https://dcmlab.github.io/protovoice-annotations/.

a timestamp string of the form `measure.beat.subbeat` as well as an array of notes. Notes have a pitch (a string like `"Ab4"`), an ID (optional), and a flag that indicates whether the note is continued in the next slice.

The encoding of an analysis consists of two parts: The top of the derivation is a list of alternating slices and transitions that provide the starting point of the derivation. The derivation itself is encoded as an array of steps, where each step encodes the details of a split or spread operation.

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# The Encoding of Insular Polyphony in English Mensural and Pre-mensural Notations

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## Introduction

The Music Encoding Initiative currently has two fairly robust modules for the encoding of vocal repertoire notated in important medieval notation systems, namely the MEI Neumes module (for plainchant) and the MEI Mensural Notation module (for polyphony). Franco's systematic rule-based system for mensural notation made a significant intervention in the history of music when he asserted that the notational symbol (the 'figure') ought to represent a fixed duration. Franco famously wrote that 'since sounds are the cause and principle of the modes, and notes are the signs of sounds, it is obvious that we ought to explain about notes, or about figures, which are the same…A figure is a representation of a sound arranged in one of the modes. From this it follows that the **figures ought to indicate the modes and not, as some have maintained, the contrary**'. Franconian notation is in some ways context-based—meaning that the ultimate rhythmic duration of longs, breves, and semibreves are determined by their position relative to each—but his system outlines a small number of rules that a computer can process relatively easily (for this, see Thomae 2017).

A significant portion of the western European polyphonic repertoire is notated in notations that preceded Franco's rule-based system that associated fixed durations to specific symbols, including, for example, the Aquitanian and Parisian polyphonic repertoires. BROKENSONG, a five-year project funded by an ERC Consolidator Grant, examines polyphonic singing and written culture in late medieval Britain and Ireland, from c. 1150-c. 1350. As part of the project, the entire extant repertoire is being encoded (approximately 600 compositions, many of them fragmentary, notated in approximately 120 fragmentary manuscript sources). While many compositions are notated in Franconian and extended Franconian notations, a large portion of the repertoire is notated in notations that can be broadly categorized as either modal, modal with Insular characteristics, and pre-mensural or mensural with Insular characteristics (Bent, Wibberley, Lefferts, Losseff). These notations are more flexible than standard Franconian notation and frequently informed by local practice. The interpretation may be dependent on notational dialects used in a particular geographic location, or by a particular scribe, or indeed the interpretation may be unclear. In this paper, I introduce two case studies from the BROKENSONG repertoire copied in Insular notation and present some of the most significant issues related to their encoding.

# 1 Case studies

## *1.1 Miro genere* in London, Lambeth Palace, MS 457

The notation of this two-voice conductus has been discussed and edited in several studies (including Sanders, Losseff, Deeming). The scribe uses two different notational forms for single notes - a virga and a rhomb - but whether these are intended to signify differences in rhythmic duration is a matter of debate. For the notation in the original manuscript, see **Figures 1**. Losseff maintains that this piece defies any attempt to interpret the rhombs as breves (ibid., p. 114) and Deeming edits *Miro genere* using stemless unmeasured noteheads aligned in score; Sanders offers a more definitive rhythmic interpretation. Pieces like *Miro genere* have aspects that potentially could be accommodated by the syllable-based focus of the MEI neumes module, where the encoding of polyphonic voices could be aligned according to the syllables of the underlaid text, without necessarily having to force a modern rhythmic interpretation upon it. As the MEI Guidelines for the element <syllable> state: ‘Neume notation can be thought of as “neumed text”. Therefore, the syllable element provides high-level organization in this repertoire’. The text has a similar high-level organizational function in pre-mensural notation of music that early theorists designated as ‘cum littera’ (‘with words’), as in this conductus example.

## *1.2 Ave tuos benedic* and *Ave Maria salus hominem* in Oxford, Worcester College, MS 213*

On the other hand, the compositions in Oxford, Worcester College, MS 213* are in a transitional notation that approaches a common notation type in Insular sources, where the virga and rhomb definitively indicate long and short rhythmic durations respectively (see Figure 2). Modern scholarship has termed this type of notation ‘English Mensural Notation’ (EMN) since it, like Franco’s system, associates fixed durations with specific notational symbols. Again, however, like Franco’s system, elements of a context-based system are found in EMN. In this case study, I outline the rules base for EMN, and discuss how a @notationsubtype (=’EMN’) of the Mensural Notation module’s @notationtype could potentially accommodate this particular ‘flavour’ of mensural notation.

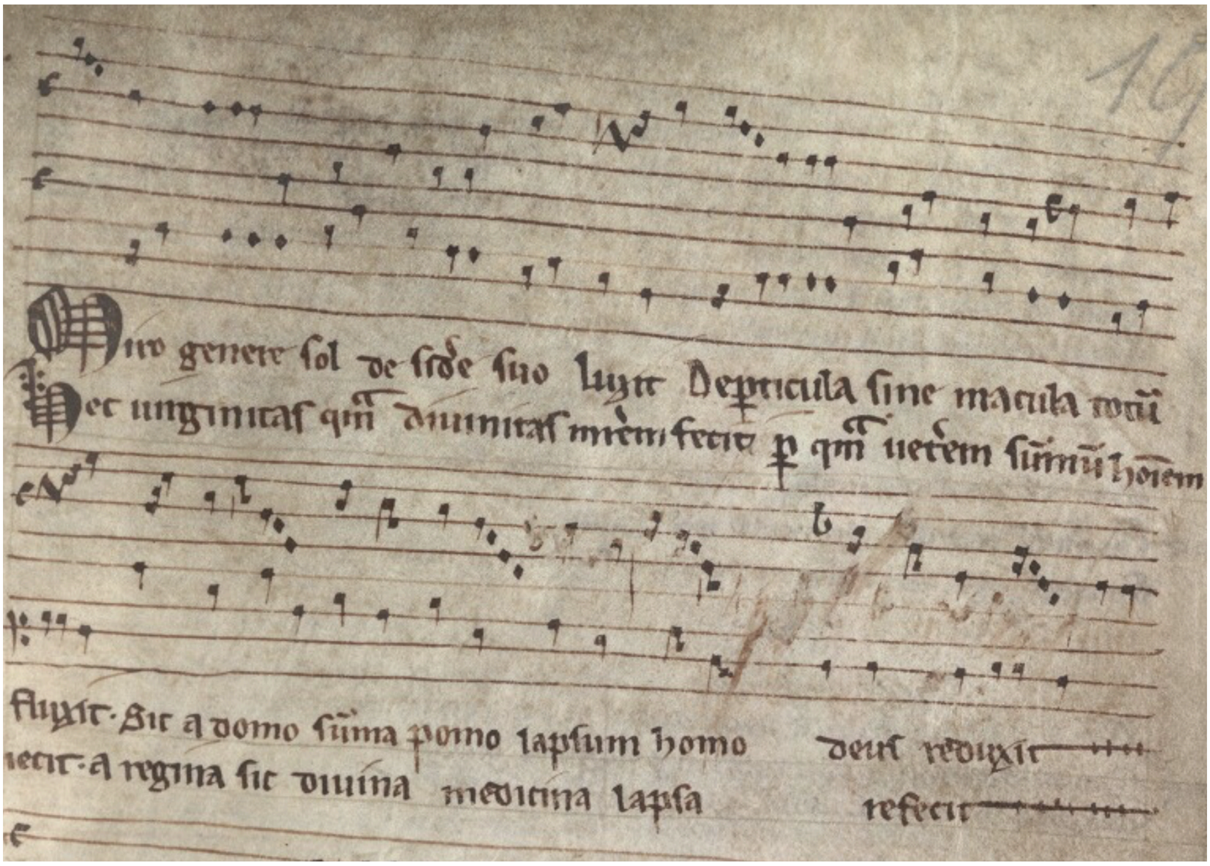

**Figure 1**: The beginning of *Miro genere*, in two-part score. London, Lambeth Palace, MS 457, fol. 192r (detail).

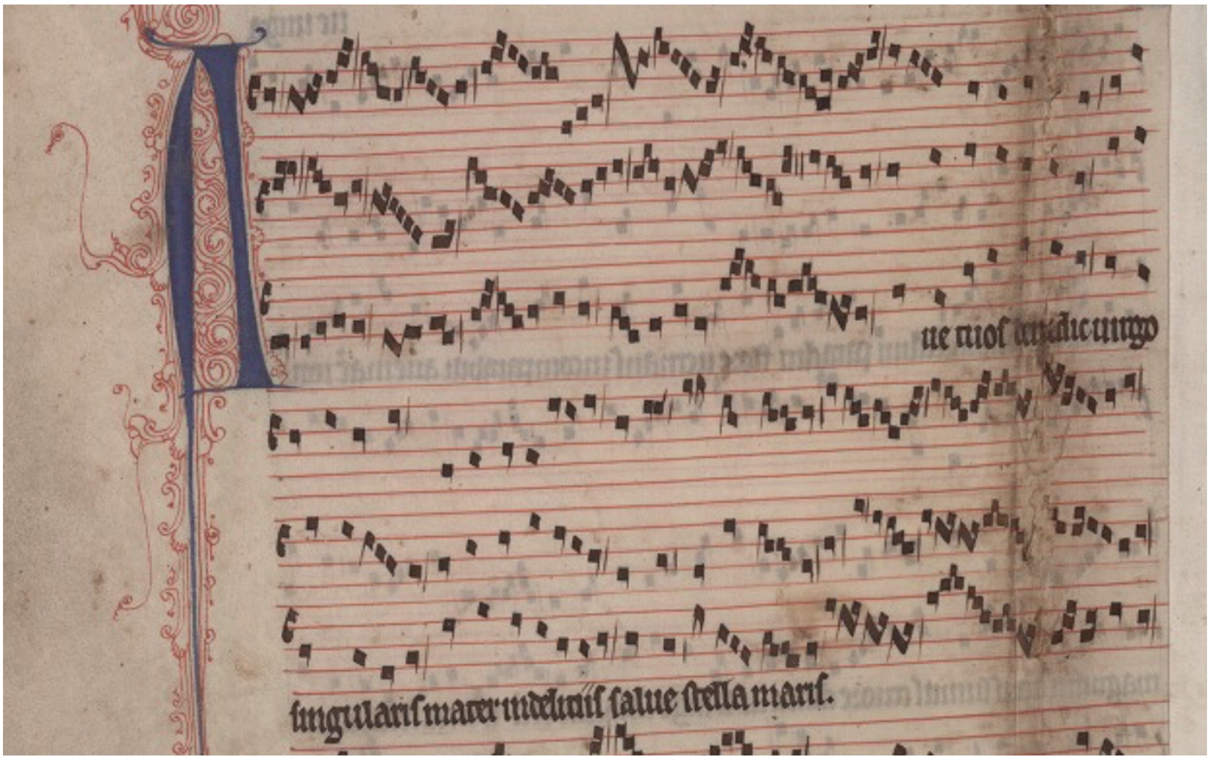

**Figure 2**. *Ave tuos benedic*, Oxford, Worcester College, MS 213*, fol. 1v (detail)

# Conclusion

A key activity of the BROKENSONG project is to work with the MEI Community to develop encoding standards for these Insular notations that are flexible enough to capture the basic meaning of the signs (especially so that polyphonic voice parts can be aligned correctly), but also specific enough to capture nuances of scribal habit or notational dialects.

# Acknowledgements

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# Challenges of Modelling Metadata for Film Music in MEI

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Erich Wolfgang Korngold (1897–1957) exemplifies the multifaceted and dynamic trajectory of musical modernism, characterised by creative diversity and historical upheaval. His oeuvre spans all major genres, including chamber music, opera, theatre music, concertos, and symphony. Between 1934 and 1946, Korngold also worked as a film composer in Hollywood. Max Reinhardt invited him to arrange Mendelssohn's *A Midsummer Night's Dream* (1934/35, Warner Bros.) for his film adaptation of the same name. This collaboration marked the beginning of Korngold's regular engagement as a composer for Warner Bros. Studios in Los Angeles, where he played a key role in shaping what is now recognised as the "Hollywood sound". Following Austria's annexation in 1938, Korngold emigrated to the United States, where he dedicated the following eight years to film composition. Over this period, he produced 19 film scores and won two Academy Awards for *Anthony Adverse* (1936, Warner Bros.) and *The Adventures of Robin Hood* (1939, Warner Bros.).

In addition to his vocal, stage, and instrumental works, the Erich Wolfgang Korngold Edition Project will also include his film music, introducing unique challenges in the development of hybrid editions. Alongside traditional written sources—such as sketches, short scores, full scores, and instrumental parts—film-specific materials including scripts, cue sheets, and audiovisual sources must be integrated as well. Notably, these audiovisual elements necessitate the use of multimedia formats to incorporate them effectively into a digital scholarly edition.

While written sources can be fully modelled using MEI, the close relationship between music and film—as well as the independent status of the film as a work—presents a distinct challenge. Although the integration of music that is both performed and recorded into digital editions is not new, film music occupies a unique position: it is not only experienced through the film but also composed specifically for it. When necessary, Korngold was present on set, actively intervening to synchronise scenes, dialogue, and music according to his artistic vision. This exceptionally close bond between music and film makes modelling their interrelationship particularly complex. Within the FRBR framework, the film and its music can be understood as two distinct yet interconnected works. This intricate relationship may be represented with all its variations, adaptations, and corresponding digital manifestations, as well as the links between the two.

However, in translating the abstract FRBR model into concrete metadata structures, a musicological edition project focused on the “music” in “film music” encounters resource-related limitations, even in light of the close ties between the media. Just as the corpus of source materials must be confined to a manageable subset of the often vast number of film cuts, language versions, and other variants, so too must the metadata selection be curated. Do we, as a music edition, truly require detailed records for every camera operator involved in a production? What core film metadata is essential to adequately reflect the intricate interplay of film and music? Ultimately, our editorial objectives determine which metadata standards are most appropriate for modelling the selected data.

This paper reflects on the challenges and potential solutions associated with modelling metadata for (a) the film, (b) the film music, and (c) the various relationships between them. Using *The Adventures of Robin Hood* as a case study, we aim to model all relevant metadata and their interconnections in MEI, highlighting the issues encountered throughout the process. To what extent can film metadata be effectively represented in MEI? At what point are its limitations reached? Is MEI the appropriate tool, or is it being stretched beyond its intended scope? What alternative metadata standards exist for film modelling, and how might they be meaningfully integrated with MEI? The aim of this paper is not to prescribe definitive best practices, but rather to present the approaches currently being explored within our project, and to invite further discussion on the topic.

# Encoding Interactive, Immersive, and Generative Electroacoustic Music

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## Introduction

This short paper is presented as an invitation to explore the challenges of encoding music for instruments and interactive electronics including immersive 3-D sound and generative computer improvisation. The topic of encoding electronic music has been addressed in the context of fixed media (Zwißler et al., 2021) but works with interactive electronics present further issues, such as scores that vary from performance to performance due to human and computer improvisation. Further, the notation of the electronic part may follow different strategies from that of the acoustic instruments, relying upon digital representations of timbral and spatial information based on audio descriptors and higher-order Ambisonics (HOA). A work for solo percussion and interactive 3-D electronics is presented as a case study to highlight these challenges.

## 1 Case Study: *Prestidigitation*

*Prestidigitation* for solo percussion and 3-D interactive electronics is scored for a custom-built percussion setup and specialized 3-D microphone and loudspeaker, all of which are intimately integrated in the conception of the work. It integrates a critical approach to machine learning embedded within a technical assemblage encompassing performer, instruments, microphone, computer, loudspeaker, and audience (Gioti et al., 2022). The creative process balances the "material engagement" of composer and performer with computer improvisation and embodied spatial sound synthesis in a "dance of agency" between human and non-human actors. The results offer a unique juxtaposition of a fully composed score with passages of spatially situated improvisation made possible through creative engagement with artificial intelligence (AI).

### *1.1 Notation of human and computer improvisation*

The score of *Prestidigitation* features passages of guided live improvisation in which the outcome is shaped by setting the timbral color of the instruments used in each section (Figure 1). This permits the human performer to respond dynamically to computer improvisation, while giving sufficient control of timbre and timing to blend smoothly with fully notated sections. This approach questions the separation of "compositions for improvisers" from work that "'incorporates' improvisation" (Lewis, 1999), leading to a unique juxtaposition of these approaches that would not have occurred without ML.

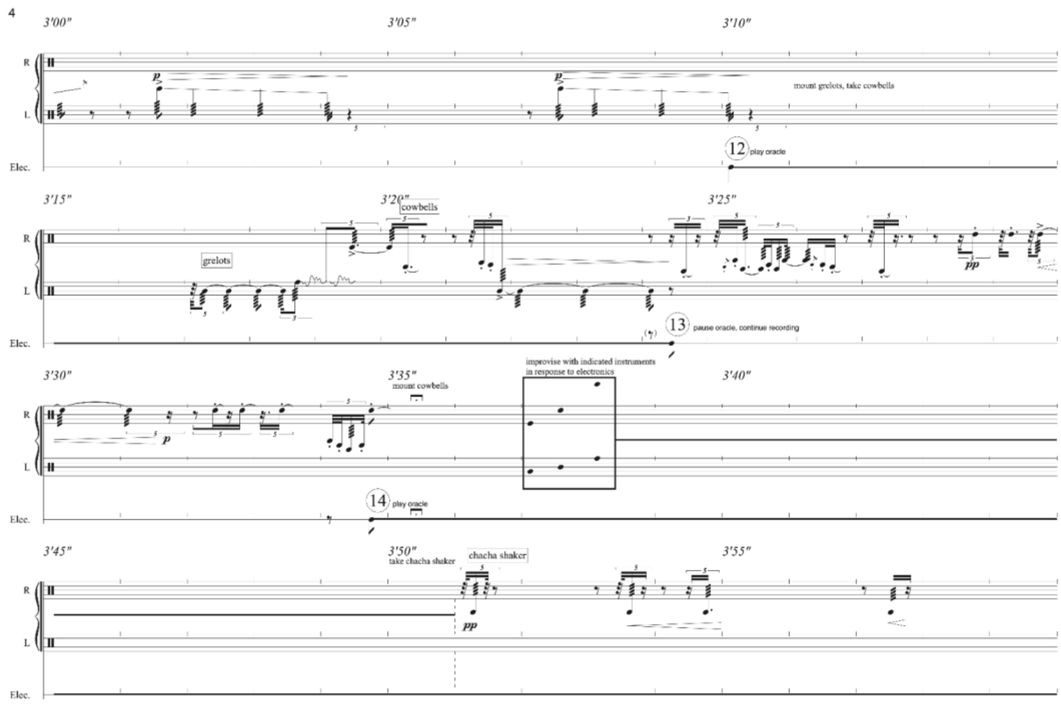


**Figure 1**: Score excerpt of *Prestidigitation* showing an audio mosaic of a recorded percussion improvisation (systems 2-3), used to train computer improvisation, and followed by live human improvisation (systems 3-4). Reproduced with kind permission of Edition Gravis Verlag.

While the computer improvisation is not notated in detail in the printed score, the live electronic patch written in computer program Max does encode these data in a compressed form, referred to as an audio oracle (AO) (Surges and Dubnov, 2013), that can be visualized symbolically or graphically (Figure 2). This could be viewed as a "score" for computer improvisation, containing the necessary information for the ML agent to recreate the generative electronics with each new performance.

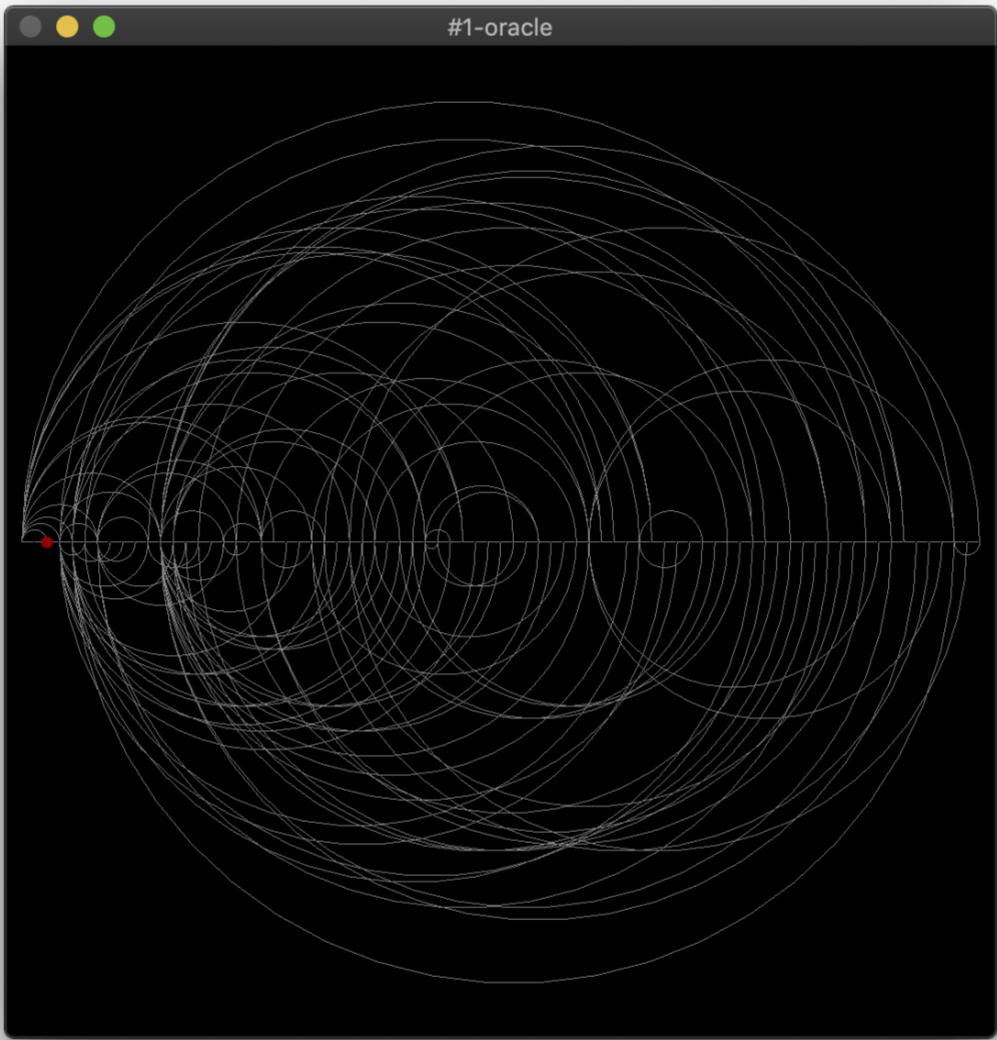


**Figure 2**: Visualization of the AO model for computer improvisation.

### *1.2 Machine learning and interaction*

The interactive electronics of the work rely upon three interacting machine learning (ML) tasks: first, based on an audio descriptor analysis of the live performer, a k-nearest neighbor (k-NN) algorithm is used to select short samples from a prerecorded corpus of percussion. This process represents a live music information retrieval (MIR) task and the result may be referred to as an audio mosaic (Schwarz, 2007). Again, the computer relies upon the conceptual encoding of audio descriptor data as an internal "score" that it interprets to produce the live interactive electronics (Figure 3).

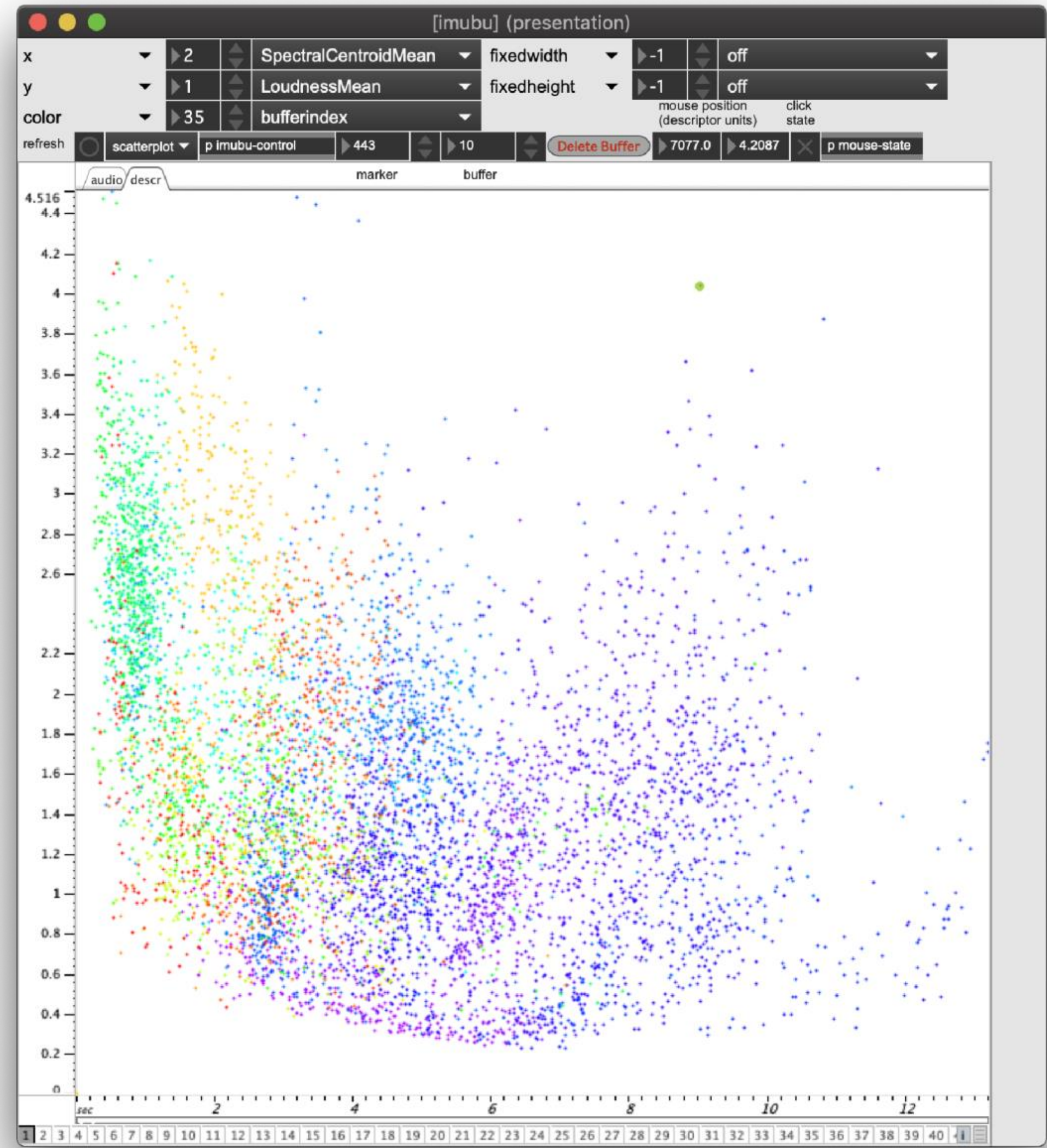


**Figure 3**: Two-dimensional representation of a prerecorded sample corpus plotted by audio descriptor axes of spectral centroid and loudness, with color representing different percussion instrument sample recordings.

Second, a Gaussian mixture model (GMM) associates each of these short samples with a database of 3-D radiation patterns derived from acoustic instruments that are then used to diffuse the samples spatially. These radiation patterns were measured and made publicly available by Technisches Universität Berlin (Weinzierl et al., 2017). The radiation pattern for each sample is encoded by 25 spherical harmonic coefficients corresponding to 4th-order HOA, as can be visualised in Figure 4. This database is stored internally in the patch and the computer refers to this spatial "score" for each sound before it is diffused electronically in 3D.

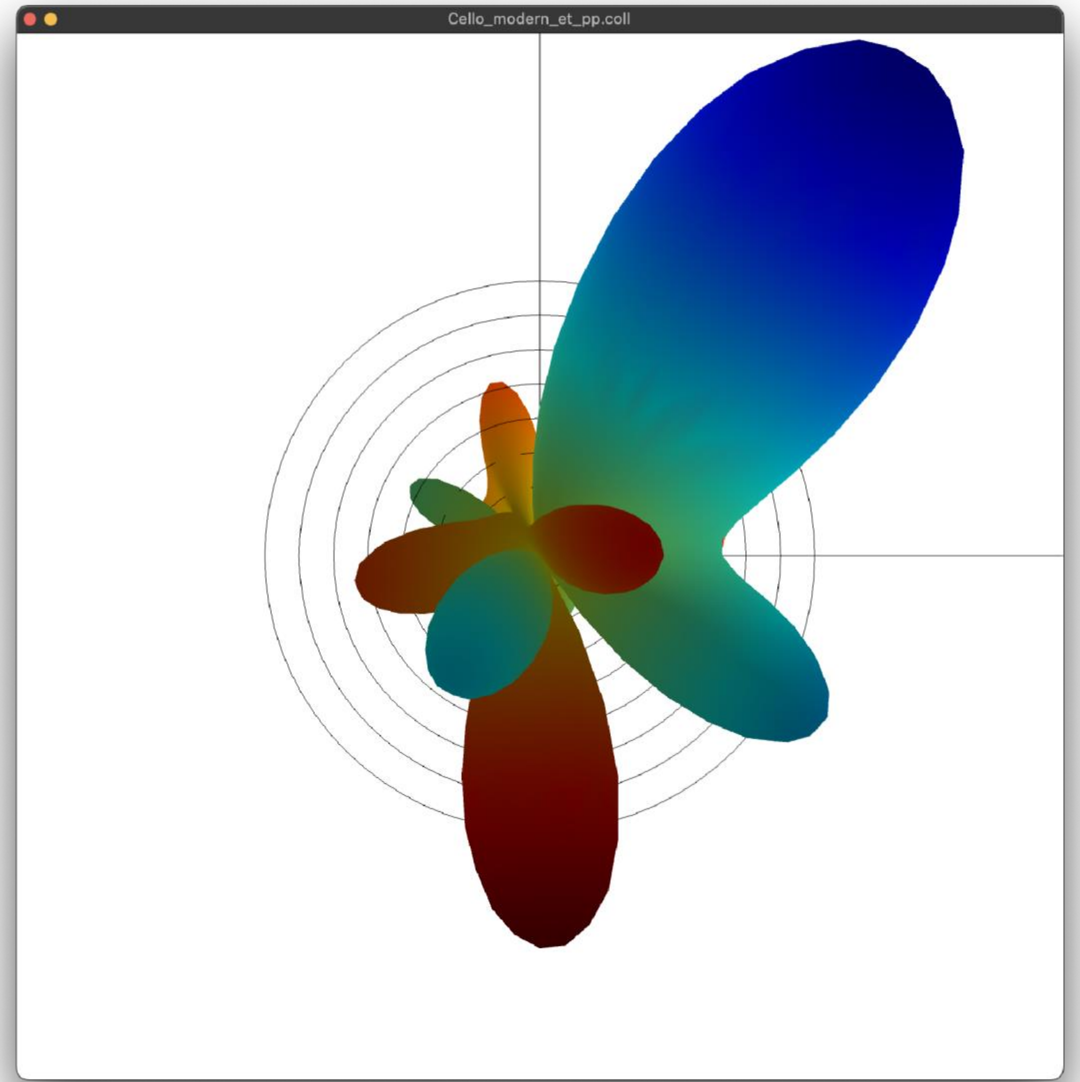


**Figure 4**: Visualization of a 3-D radiation pattern based on its 4th-order HOA representation.

Third and last, the audio oracle (AO) models the sequence of these samples in time. This serves as training data for computer improvisation by connecting samples based both on timbral and contextual similarity. A visualisation of the AO was shown in Figure 2.

# Conclusion

*Prestidigitation* exemplifies some of the unique features and challenges for music encoding offered by a work for live instrument and interactive electronics. Beyond the notation of the acoustic instrumental performance, human improvisation, and interactive electronics in the score, the work's Max patch conceptually encodes data for audio mosaicking, 3-D sound spatialisation, and computer improvisation, that each enable the computer to produce the live generative performance.

## Acknowledgements

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# POSTER

# Enhancing the Experience of Contemporary Classical Music through Dynamic, Interactive Visualisation

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## Introduction

We address the topic of music visualisation – specifically, exploring the possibilities and challenges associated with dynamic and interactive representations of musical content, displayed on a screen or projected on a surface while a piece is being performed live or played back on a device. We address this topic in the context of our aim to develop more effective, engaging, and appealing ways to communicate contemporary classical music (CCM) to a modern audience, whose exposure to this repertoire is often limited to media such as film, videos and games, rather than in traditional concert settings.

## 1 Motivation

Art Music Denmark highlighted in a newsletter that classical and contemporary music often receive only minimal media attention and lack prominent dissemination in mainstream culture (Petersen, 2023). This observation aligns with Emerson's (2020) large-scale study (N = 1428) involving twelve CCM concerts across ten different European countries, which emphasized the importance of innovative approaches to engaging audiences. From her analysis, Emerson concluded that significant extra-musical features could enhance and intensify the audience experience. One of her four key recommendations to institutions organising CCM concerts was to “take risks with format” (Emerson, 2020, p. 256) and involve audiovisual pieces, installations and participatory formats to attract newcomers to CCM. Such results and considerations provide motivation for developing improved methods for conveying the aesthetic potential of CCM through immersive and interactive experiences, thus serving to sustain and promote art music culture.

We explore the potential and the challenges of providing dynamic, interactive visualisations, designed to engage audiences during music-listening experiences. Two core principles guide our discussion: (1) the visualisations should ideally be self-explanatory, allowing intuitive understanding; and (2) they must captivate the audience’s interest, while also enhancing the *listening* experience. We propose that these two goals can be achieved by drawing on empirical and theoretical research in information and data visualisation aesthetics, principles of design aesthetics, and formal models of creativity and aesthetic value.

# 2 Background

Insights from the fields of information aesthetics and data visualisation offer valuable principles for designing effective music visualisations, emphasizing the balance between visual appeal and functional clarity. Foundational concepts from the emerging field of informational aesthetics, as noted by Pawłowski (1976), highlight key principles such as *Auffälligkeit* (salience) and *Gestalthöhe* (structural complexity), underscoring the need for visualisations to capture attention while maintaining a coherent and meaningful organization of complex content.

Contemporary approaches expand on these early ideas. Manovich (2008) and Sack (2011) emphasize that effective visualisations must simplify complexity without diminishing informational depth, thereby fostering intuitive understanding. The principle of achieving maximum effect for minimal means, as articulated by Hekkert and Leder (2008), highlights the value of elegance and efficiency in design. Lau and Vande Moere (2007) further assert that information aesthetic visualisation techniques should enable both intrinsic insight – such as pattern recognition – and extrinsic understanding, revealing deeper contextual meaning. Additionally, interactivity is increasingly recognised as a core component of modern visualisation design, allowing users to explore and interpret data on their own terms (Stoll et al., 2024).

These evolving perspectives resonate strongly with the challenges of music visualisation, where dynamic, interactive representations must balance clarity, engagement, and opportunities for user-driven exploration. At the heart of the problem is the question of what types of visualisation most enhance the experience of a listener – and, in particular, a listener who may be unfamiliar with the music. This presents different challenges from those addressed by, for example, Isaacson (2023), who focuses on the problem of effectively visualising musical structure for analytical purposes. Moreover, in the listening setting, animated (and even interactive) three-dimensional effects may be employed to represent more aspects of the music, whereas in the analytical setting, visualisations are typically static and focus on representing relationships between different structural constituents in the music. A set of different challenges and affordances emerge, therefore, when one attempts to design dynamic, interactive visualisations that enhance the experience of audiences who may be new to contemporary classical music (or even new to classical music in general).

Lima et al. (2021) carried out an extensive survey of the literature on the use of music visualization techniques in the field of Music Information Research (MIR) in which they reviewed 122 publications. They observed that the majority of previous methods in this field had focused on visualizing pitch-related information (e.g., harmonic, tonal, melodic structure) and that many used score notation as the basis of the visualization, though some more recent methods involving virtual reality tended to use geometrical shapes to represent sound features. They also provide a useful taxonomy of different types of interaction that have been employed in visualizations (e.g., select, explore, etc.). However, their survey targeted various types of music professional rather than the general listener, so it is unclear how far their conclusions transfer to the problem that we focus on here.

# 3 The space of challenges

One significant challenge lies in balancing audience attention between the music and the visualisation itself. How can supportive visual elements enhance the musical experience without drawing attention away from the music? On one hand, the visualisation should deepen the audience's engagement and understanding; on the other, if it attracts too much attention, it risks detracting from the music itself. This necessitates a delicate balance to ensure that visualisations genuinely support and enrich the listener's immersion in the musical experience.

A second challenge to be overcome is that of guiding listeners through what they might perceive to be "difficult" music, whilst simultaneously setting as few constraints as possible on how they actively and creatively construct their own interpretations of what they are hearing. The visualisation should ideally encourage listeners to take ownership of the music by developing their own interpretations rather than constrain them into understanding the music in particular ways. Listeners should feel that they maintain control over how they experience the music.

In the playback setting (as opposed to the live performance setting), one way to activate users might be to provide a visualisation along with controls that support non-linear listening – e.g., selecting particular passages or parts to listen to, changing the playback tempo, or changing the relative loudness of different parts or patterns. The user may also be provided with the means to customise the visualisation itself, controlling, for example, which aspects of the music are represented (pitch, timbre, time, instrumentation) and how these aspects are mapped onto graphical elements. The visualisation then becomes more like a user-interface of an application. However, this gives rise to a third challenge, since providing such extra affordances for control and interaction may come at the price of making the visualisation more complex and difficult to use – recall that the first of our "core principles" was that the visualisation should be self-explanatory, so that a listener does not need to spend a significant amount of time learning how to control the visualisation system before starting to listen to the music. This is particularly important in the live performance setting, where such a learning phase would need to be an integral part of the whole participatory experience. Moreover, if the listener is required or encouraged to make choices about how and what to represent in the visualisation, this could take cognitive resources away from experiencing and interpreting the music itself. While such interactive features can enhance engagement and allow for a more personalised experience, they therefore also present a dilemma: the choice-making involved in interactivity may reduce immersion in the music itself and thus reduce the effectiveness with which the aesthetic and semantic aspects of the music are communicated.

A fourth challenge in the design of a music visualisation is that of providing some idea of where one is located, globally, within a piece of music, whilst not giving away too much about what is to come later on in the piece. Music is inherently temporal, unfolding in time with a sense of linear progression and development. Informing users of where they are in a full and detailed “road map” of a piece therefore risks disclosing the music’s development prematurely, potentially undermining one of the most vital aesthetic qualities of music – the “sweet anticipation” (Huron, 2006) that arises from the tension between what the listener expects and what actually occurs. On the other hand, the end result of having listened to a piece of music should typically be a coherent, unitary conception of the piece as a whole. Also, having some idea of where one is within a piece (e.g., whether one is close to the end, in an exposition or development section) allows a listener to interpret what they are hearing within a broader context, which can enrich the listener’s experience.

## Summary and directions for the future work

In this paper, we consider the problem of designing dynamic, possibly interactive, visualisations, to be presented synchronously with performances of pieces of contemporary classical music. The goal of such visualisations is to enrich listeners’ experiences of the music, so as to support them in achieving more rewarding and deeper interpretations. Drawing insights from previous work on aesthetics, creativity and information theory, we identify the following four particular challenges or dilemmas that emerge when attempting to design such visualisations:

1. A visualisation should enhance the experience of the music without distracting listeners from what they hear.
2. A visualisation should guide listeners through the music whilst also encouraging them to construct *their own* interpretations of the music.
3. Providing listeners with the means to interact with the music and customize their experience can enhance engagement. However, this must be done without making the visualisation/interface too complex – the visualisation should, ideally, be self-explanatory. Also, the interface should not distract attention away from the music itself.
4. Providing listeners with a means to locate themselves within the music can enrich their experience by providing context. However, this must be done without disclosing the music’s development prematurely.

We have stated these four challenges in the form of claims that we plan to test empirically through appropriately designed experiments. Such experiments will involve participants listening to music under various conditions (e.g., with and without visualizations, with various different types of interaction) and will include both online experiments where listeners hear recorded music and investigations carried out on audiences at live concerts.

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# A Step Forward in Lute Tablature Studies with *MEI.Tablature*

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## Introduction

The *Ricercar Lab* of the *Centre d'Études Supérieures de la Renaissance* in Tours (France), in collaboration with the Ente Olivieri in Pesaro (Italy) has initiated a scientific partnership to promote a remarkable collection of lute tablatures from the Albani archives, rediscovered in 2018. These archives, housed in the Villa Imperiale of Pesaro, comprise 38 musical manuscripts containing 2,700 images, including 26 volumes dedicated to lute music from the late Renaissance and early Baroque periods.

The project, *Tablatures from the Albani Collection*, aims to comprehensively index the manuscripts, enrich them with detailed musicological metadata, and integrate them into the Ricercar database—a resource that has been systematically developed over the past three decades. The enriched dataset, together with the corresponding images, will be openly accessible via a Mirador IIIF viewer. Additionally, the project's image repository will be integrated into the Biblissima+ portal, accessible through an API (Application Programming Interface). This initiative advances the open digital publication of Renaissance musical heritage and fosters innovative methodologies in digital musicology.

## 1 Methodology and Challenges

As part of creating musicological datasets, the project will provide an incipit for each individual piece in the manuscripts, allowing users to visualize or download the incipit while viewing the corresponding source image. The incipits are encoded in the MEI format, which enables viewing via the integrated Verovio viewer and facilitates detailed research. This approach not only supports the study of relationships and historical context within the Albani manuscripts but also enables broader comparisons with other musical sources encoded in MEI and published by parallel projects. This choice aligns with the growing trend of adoption of MEI among scholars to facilitate research. Additionally, MEI files allow for the visualization and comparison of music across different notational formats, such as French and Italian lute tablature, and support integration with a wide range of tools.

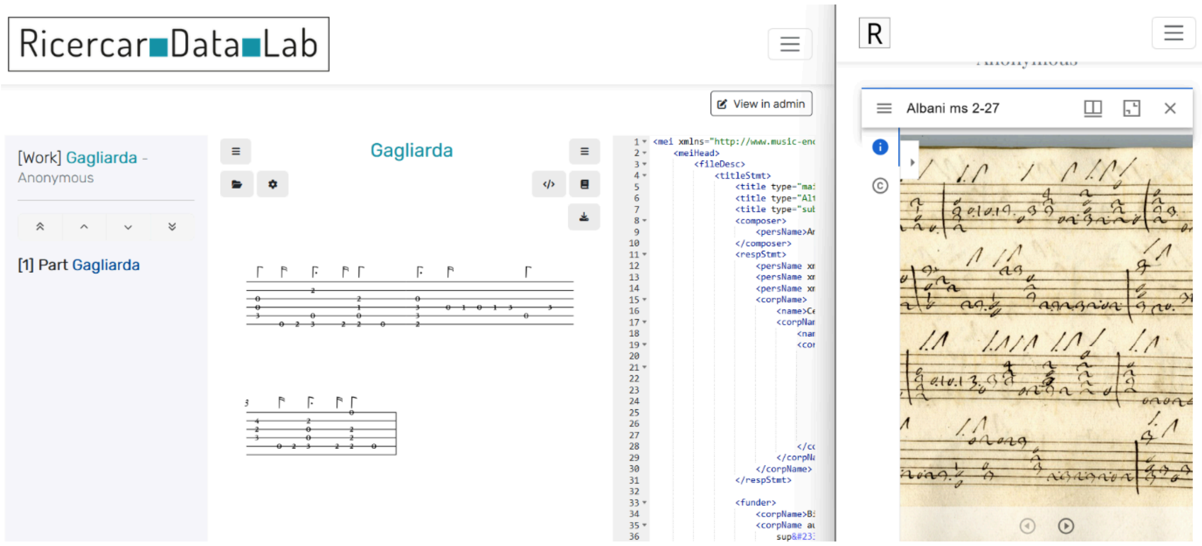


**Figure 1**: Interface of the *RicercarLab* database displaying the Albani project, featuring manuscript images, metadata, incipit, and the MEI-encoded file.

Given that the MEI.tablature module, primarily designed for plucked-string instruments such as the lute, is relatively recent and still under development, the project faced certain challenges. Some required features are either absent or problematic in the current MEI.tablature implementation. Notably some issues include features essential for the general use of the tablature module for early music instruments. This presentation highlights some of these challenges and proposes areas for development, which could serve as a basis for further discussion within the MEI community. For example, certain elements that have been borrowed from the CMN module may convey wrong concepts given the shared conceptual framework between lute tablature of the era and mensural notation.

Other issues are associated with the tools for visualizing and editing MEI files, particularly Verovio and Mei.friend. The extensive application of MEI in this project has yielded valuable insights, which we aim to share with the community to contribute to tool enhancement.

Other challenges relate to scorewriter applications, which are indispensable for producing MEI files. As the study of Klaus Rettinghaus in the 2023 MEI conference on comparing MusicXML export capabilities showed, “The best solutions at present are Sibelius with the Dolet plugin and MuseScore, the latter being a hair's breadth ahead.” While MuseScore offers a plugin for direct MEI file export, it does not yet support tablature notation. A workaround has been to export MusicXML files and convert them to MEI using Luteconv, a command-line utility developed by Paul Overell. However, Luteconv currently has limitations, particularly in its Windows version, where certain features, such as rhythm scheme adjustments, are unavailable.

To create MEI files for the Albani project incipits, our workflow involves writing the tablature in MuseScore, exporting it as an uncompressed MusicXML file, converting this file to MEI via Luteconv, and then manually editing the output to align with the project's requirements. This workflow, while functional, is time-consuming, introduces opportunities for human error, and is constrained by the limitations of MuseScore and Luteconv. For example, MuseScore does not support certain features required for this project, such as writing notes without duration (the dur element in MEI). Additionally, the MEI files generated by Luteconv present additional challenges; in the Verovio editor, the visualized tablature is not synchronized with the corresponding lines of code, complicating subsequent edits.

## 2 *ReTab*: Customizing Lute Tablature Encoding

To overcome these challenges, the project has developed a web application, *RéTab*, specifically designed to meet the needs of lute tablature encoding. This tool aims to streamline the workflow and reduce dependence on external applications like MuseScore and Luteconv. Implemented as a Vue.js web application with an Express.js server-side component, *RéTab* provides a minimalist user interface for rapid and accurate lute tablature entry, free from the metric constraints imposed by conventional score-writers, accommodating historical practices. The server-side application generates MEI files, with musical concepts (e.g., notes, measures, staffs) instantiated as classes that render the MEI hierarchy. Importantly, *RéTab* resolves the synchronization issues between visualized tablatures and MEI code lines in editors by generating XML IDs for each element within the encoded file.

To ensure accurate and simple MEI headers, *RéTab* includes a dynamic search feature that allows users to fetch metadata directly from a linked database. This feature increases efficiency and reduces the likelihood of errors during data entry. The use of JavaScript (TypeScript) facilitates integration with frameworks such as Electron.js, enabling future deployment on desktop platforms (Windows, macOS, Linux). At present, *RéTab* supports Italian and French lute tablatures, with plans to extend functionality to German tablature. Future development goals include multi-platform deployment using Electron.js, the creation of standalone client-side web application to meet different needs of future projects. One objective of this presentation is to engage with the community and gather feedback to inform further development of RéTab, ensuring its utility for similar projects in the future.

## Conclusion

In conclusion, the Albani project represents a significant advancement in digital musicology, particularly through its adoption of the MEI.tablature module. As a concrete, ongoing initiative, the project offers valuable insights and proposals for the development of the

MEI.tablature module, fostering broader adoption and expanding the encoded corpus of lute tablature. Finally, the open-access *RéTab* application accelerates and simplifies tablature encoding, providing a customizable tool for similar projects in the future.

## Statement on the use of generative AI

We acknowledge the use of generative AI tools (ChatGPT, OpenAI) for textual editing and refinement of this paper. All scholarly content, arguments, and research findings remain the original work of the authors.

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# Beyond Bars: Distribution of Differences in Music Prints

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## Introduction

For several centuries people have been thinking of music as being divided into bars. In terms of music in its written form, this is not surprising. Bars help organise several voices in time and simplify reading music notation. However, for some perspectives on music and its notation, this idea can be a hindrance. Since digital and statistical methods have become more important due to an increasing interest in large-scale corpus analysis, it can be desirable to not only look at scores or bars but at distributions of musical elements. One of those perspectives is the one on the distribution of differences in several musical scores. In our research we investigate this distribution to find where differences are likely to occur in comparisons of different prints of Beethoven's Piano Sonatas.

## 1 Starting point

In our research we investigate the transmission of Beethoven's Piano Sonatas in as many prints as possible published in 19th-century German-speaking countries. To do so, we compare these prints to each other and find differences between the sources and, in a first step, count them. Differences concern all the graphical elements used in a print to represent music. The main aim of the investigation is to find out what relationships exist between the prints. It also examines the hypothesis whether a development took place in the 19th century that led to a consolidation of the text of the work, so that the various prints gradually converged in their textual form (inspired by Goehr, 1994). The number of prints that can be part of the investigation is huge. On average, there are more than 50 prints per sonata to be compared. As it is impossible for us to fully encode all of them, only samples from the prints will be encoded and compared.

# 2 Procedure

The main challenge is to use samples that best represent the prints. The first step must therefore be to evaluate different methods to draw samples and analyze the results. We present a pre-study in which we tested three different algorithms to sample bars from a score. We used a test corpus, namely Beethoven's *Bagatellen* Op. 33 and compared six different prints. We then used the algorithms to draw random samples of bars. With these samples, new files were created and compared to each other. With the result of the comparison of the whole pieces and the result of the comparison of the sample-pieces, we were able to find the best algorithm to draw representative samples. From this we can draw conclusions about the distribution of differences in the editions.

The first of the algorithms draws a random sample out of all the bars without any further knowledge about the notes and other signs inside the bar. The second algorithm also takes into account the number of relevant elements in a bar. The third algorithm draws bars based only on the number of elements.

Using algorithms one and two we drew samples containing about 10% of all bars in the piece. The third algorithm drew an arbitrary number of bars which together should contain 10% of all the elements in the piece. For each algorithm we drew 10,000 samples. We then compared the sample-pieces and counted the differences in each comparison.

With six editions under investigation 15 comparisons per sample are performed which results in a total of about 3.2 million comparisons. We count the number of differences for each sample and create visualisations of the results for each pair of prints in all 10,000 samples. To visualize the results, they are being plotted as can be seen in figure 1.

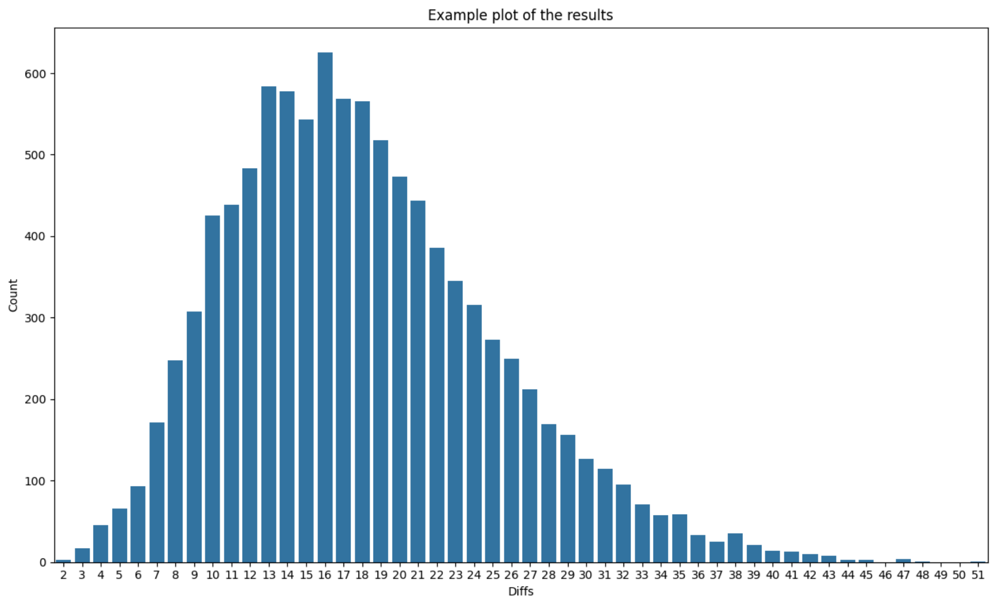


**Figure 1:** Example plot of the results for one pair of editions.

## 3 Results and interpretation

As a result we obtain distributions for each of the three algorithms but with differing mean and scale parameters for each algorithm. We interpret this finding to demonstrate that thinking of music in terms of bars is not sufficient for finding a sample that represents the basic population. Instead, it is necessary to take into account the density of the musical events in the scores.

## Conclusion

This research addresses issues for the computational analysis of music, where the data is too large to be encoded completely. It addresses the question whether one needs a fully encoded corpus to do corpus studies. It contributes to research of the transmission history of musical works and the history of music publishing.

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# Wanted! Approaches for Search in Polyphonic Lute Music

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## Introduction

Search is one of the key issues in music information retrieval. For monophonic melodies, this task is relatively straightforward. However, for symbolically encoded, unvoiced polyphonic music—such as music notated in various types of lute tablatures—the challenges are significantly greater. This poster aims to present the requirements of searching within lute tablatures, present examples of existing methods and approaches, and ask for feedback and further ideas. This research is part of my bachelor thesis in Computer Science at TU Wien.

## 1 Corpus: Pieces notated in German Lute Tablature

Although many of the questions and challenges apply to any type of polyphonic music, the corpus I am working with consists of pieces in German lute tablature, encoded in MEI (TabMEI and CMN). The transcriptions are provided as a result of the E-LAUTE[1] research project. Some pieces in the corpus are lute interpretations, known as intabulations, of pre-existing vocal music. These vocal pieces, encoded digitally, are referred to as "vocal models." One search task involves retrieving different intabulations of a given vocal model. Another task focuses on identifying pieces that contain a specific melody or chord progression (eg. from a vocal model), either at the beginning (*incipit search*) or elsewhere in the piece. Understanding the nature of search approaches for polyphonic lute music is also crucial for developing tools for automatic music analysis and comparison.

A distinctive feature of lute tablature is that voicing is not explicitly notated. Lute tablature intentionally omits this information, making it challenging to see polyphonic structures in the music (see Figures 1 and 2). Some pieces are more homophonic and chord-based, while

[1] https://e-laute.info/

others are more polyphonic. These differences in the texture of the music should probably impact the design of search methods.
Additionally, historical instructions for creating lute tablatures from existing vocal music could be taken into account during preprocessing steps. Another characteristic of lute music is the inclusion of notated ornamentation and musica ficta (notated accidentals).

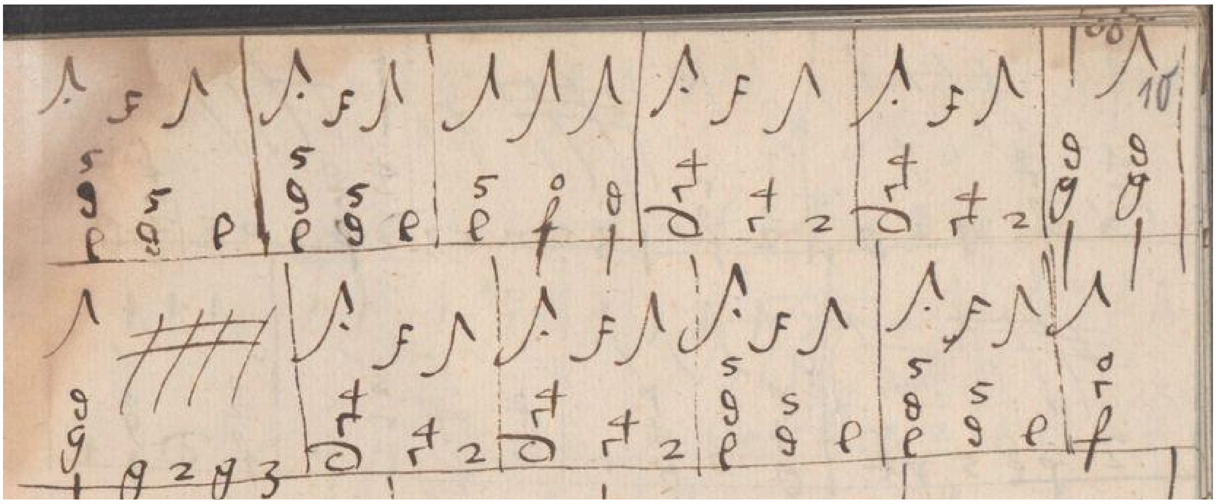

**Figure 1**: The beginning of *Calata alla spagnola* in German lute tablature taken from the *Lautentabulatur des Stephan Craus (A-Wn Mus.Hs. 18688*), fol. 10r.[2]


**Figure 2**: The same beginning of *Calata alla spagnola* from the *Lautentabulatur des Stephan Craus (A-Wn Mus.Hs. 18688*), fol. 10r., transcribed into tablature-MEI (line 2), transformed into a notehead notation via abTab[3] (line 1) and rendered in Verovio[4] via mei-friend[5].

[2] The source *A-Wn Mus.Hs. 18688* in the catalogue of the Austrian national library: https://search.onb.ac.at/permalink/f/sb7jht/ONB_alma21308235690003338, view the whole page of the source here: https://digital.onb.ac.at/RepViewer/viewer.faces?doc=DTL_4439424&order=24.
[3] https://github.com/reinierdevalk/abtab
[4] https://www.verovio.org/index.xhtml
[5] https://mei-friend.mdw.ac.at/

These features make a degree of "fuzziness" in search methods necessary, as the same base melody might appear in different versions. A robust search should identify similar melodies, not just exact matches. Transposition adds another layer of complexity, as does the notated length of notes, especially in CMN transcriptions, as the tablature does not always explicitly indicate the length of a note.

## 2 Existing approaches

Various approaches to polyphonic music search can be found in the literature. These include pattern matching using geometric algorithms (Meredith, 2024), regular expression-style searching (Dovey, 2001), dynamic programming-based algorithms (Laitinen & Lemström, 2011), combining segmentation with transportation distances (Typke, Wiering & Veltkamp, 2004), and n-grams (Doraisamy & Rüger, 2003). Machine learning-based approaches are less common, perhaps due to the fact that much of this research predates the widespread adoption of deep learning in the 2010s, and maybe also because of the lack of training data. However, there is one approach that uses deep learning to estimate voice entries to separate voices (de Valk & Weyde, 2018). This approach could serve as a preprocessing step for a voice-based search. A less recent but concise overview of polyphonic search methods is provided in Lemström & Pienimäki, 2006, while a more general and recent review of music similarity measures in music information retrieval is found in Gurjar & Moon, 2018.

## Conclusion

Existing approaches often stem from a rather technical perspective, but the search in lute music is also a musicological task. The concept of musical similarity is not purely a mathematical concept—it also depends on the context and musical meaning of a piece. How this can be accomplished—specifically also for lute music—needs to be discussed as much in the technical community as in the musicological. In summary, the challenges of searching within lute music are diverse and may require a combination of approaches. A review of existing methods is also essential to identify the most suitable search strategies for the corpus of historic German lute music.

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# Visualising Gregorian Traditions: ChantMapper

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## Introduction

The systematic search for traditions in Gregorian chant is ongoing, both in terms of repertoire (Hesbert, 1963-79; Hiley, 1981; Ottosen, 2008), and melody (Hornby & Maloy, 2016; Karp, 1998). Recently, computational research (Eipert & Moss, 2023; Hajič jr. et al., 2023) has been enabled by standardised digital encoding of chant sources, especially by the Cantus Index network of databases[1] (Lacoste, 2022).

For analysing traditions, Cantus Index itself provides the Cantus Analysis Tool (CAT),[2] which can construct synoptic tables of repertoire (as shown by Alstatt (2014)). CAT treats any difference in repertoire between sources as a split between traditions, which, while useful for manual analysis, may obscure broader trends. Methods that reveal such trends would thus be a useful complement. Furthermore, any research of chant traditions would benefit from a map interface for visualisation. Since chant transmission required material processes, physical proximity is inherently relevant, and it is within the context of geography that transmission networks which are less constrained by proximity, such as those of monastic orders, stand out.

We present ChantMapper,[3] an online open-source tool for computing and visualising chant repertoire traditions on a map. We treat traditions as “soft” entities, allowing inexact matching. A default office dataset from Cantus network databases is available, but users can upload their own data. An example of the ChantMapper interface is shown in Figure 1.

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[1] https://cantusindex.org/

[2] https://cantusindex.org/analyse

[3] The tool can be found on https://chantmapper.owx.cz/map_repertoire/, source code is available on https://github.com/DvorakovaA/ChantMapper.

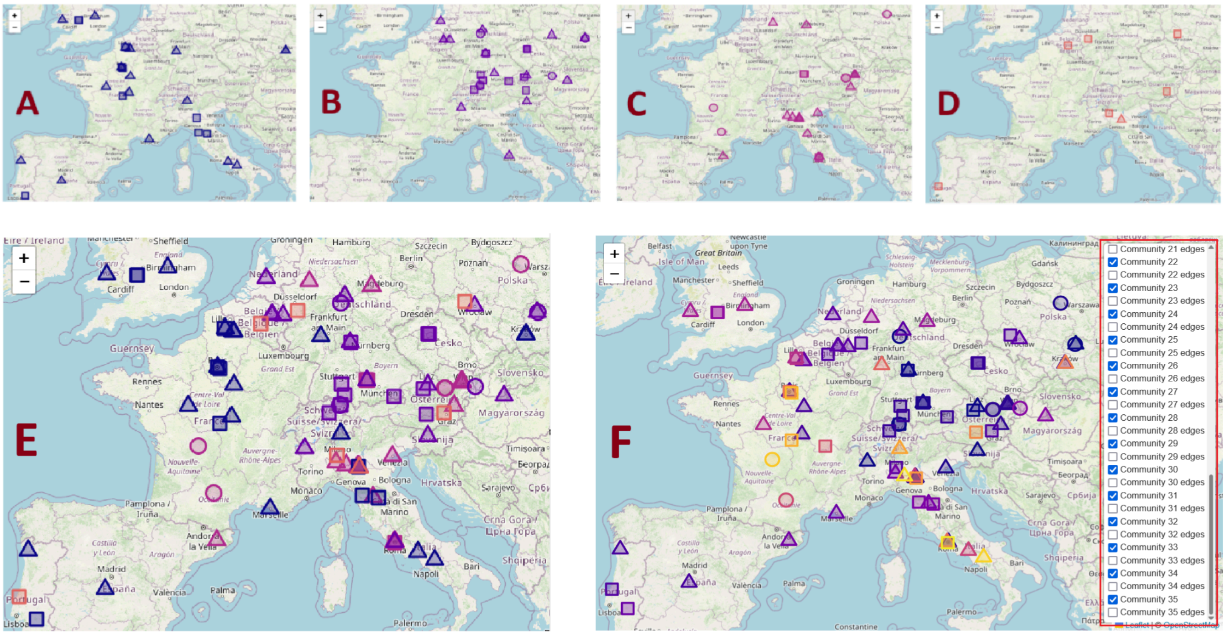


**Figure 1**: Mapping the Lauds from *Purificatio Mariae*. Maps *A-D* show individual traditions computed via Louvain community detection, *E* shows them all. Map *F* shows results constructed at the granularity of CAT, which results in 35 small communities, obscuring rather than exposing broader trends.

## Built-in dataset

In order to be immediately usable, ChantMapper has a built-in dataset. Together with previous research (Hesbert, 1963-79; Ottosen, 2008, Hajič jr. et al., 2023) and the CAT (Lacoste, 2022, Alstatt, 2014), we focus on office repertoire. We restrict ourselves to antiphons and responsories, which comprise the majority of office repertoire and therefore are most robust for computational processing, and populate ChantMapper with the largest readily available dataset: chants aggregated by Cantus Index.

The data represents a subset of the Cantus Index network as of February 2024[4]. Chant data was obtained from Cantus Index via its JSON endpoint. Table 1 summarises the dataset. Source metadata was scraped from databases from which it was technically possible: Cantus Database (Cantus), Portuguese Early Music Database (PEM), Medieval Music Manuscripts Online (MMMO), Cantus Planus in Polonia (Polish), Fontes Cantus Bohemiae (FCB), Slovak Early Music Database (Slovak), MusicaHispanica (Hispanica), and Austriamanus (Austria). We retain only sources containing 100+ chants to avoid possibly misleading fragments. We emphasise this is merely an initial dataset – most research using ChantMapper will likely involve custom data.

[4] The state of Cantus Index and its databases changes every day, not only thanks to all researchers indexing new sources but also due to ongoing migrations to a different software solution. Our plan is to update this ChantMapper default dataset approximately once a year (while making sure older versions remain available to maintain replicability).

| Database | Cantus | MMMO | Hispanica | FCB | PEM | Slovak | Austria | Polish | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Antiphons | 180 317 | 8 075 | 21 056 | 12 039 | 8 070 | 5 432 | 79 | 7 018 | 242 086 |
| Responsories | 90 702 | 3 239 | 10 325 | 5 717 | 4 096 | 2 743 | 25 | 3 699 | 120 546 |
| Sources | 170 | 206 | 46 | 26 | 39 | 201 | 38 | 21 | 747 |
| Sources with 100+ chants | 153 | 22 | 29 | 17 | 12 | 7 | 1 | 9 | 250 |

**Table 1:** Size and composition of the built-in dataset.

We follow CantusCorpus[5] (Cornelissen et al., 2020) when naming data fields, which in turn retains most Cantus Index JSON names. We keep only the fields relevant for ChantMapper (Figure 2).

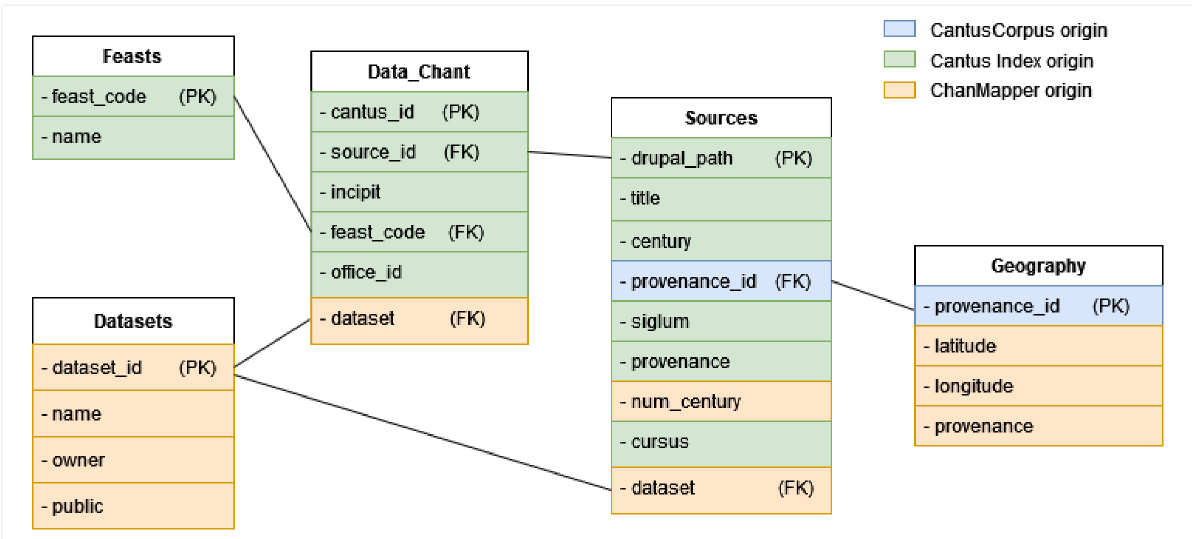


**Figure 2**: The schema of the ChantMapper database.

To allow mapping, we added latitude and longitude for source provenances. During this geocoding process, a lack of standardisation in provenance naming became apparent. We followed Cornelissen et al. (2020) in CantusCorpus dataset by adding a *provenance_id* to each place. Figure 2 represents schema of ChantMapper database fields. Note that the value of *provenance* in the Geography table may differ from *provenance* in the Source table. This is because a single location may have different names in different source records, but in the Geography table, it is desirable to have a consistent name for each location for display, as indicated by Figure 3. This is an issue for future standardisation across the Cantus network of databases.

Outside of geocoding data, we rely on the source databases for data accuracy.

[5] https://github.com/bacor/cantuscorpus

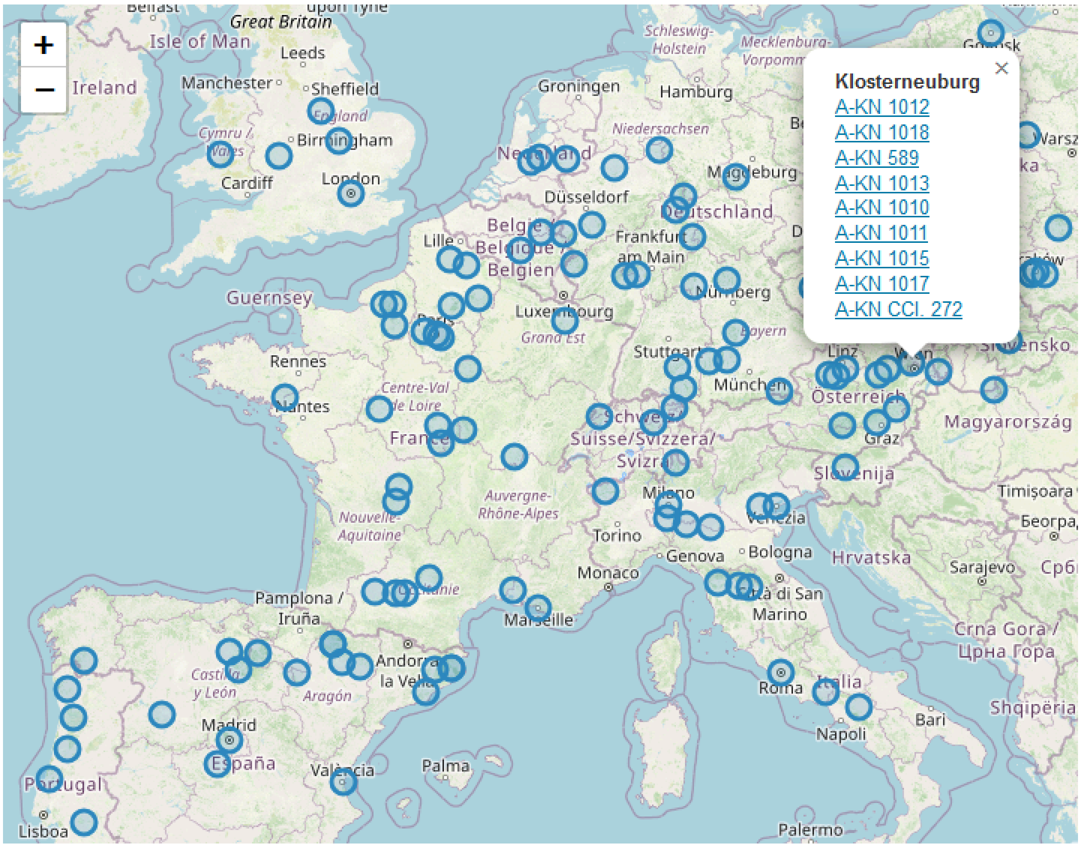


**Figure 3:** Overview of all available provenances. Sources for a provenance are shown upon clicking the node.

# Methods for building “soft” traditions

There are many methods for automatically grouping sources into traditions based on the similarity of their repertoire. ChantMapper starts with three, each serving a different purpose. The Louvain community detection algorithm (Blondel et al., 2008) is a known method that has previously been applied to chant repertoire (Eipert & Moss, 2023). Latent Dirichlet Allocation (LDA; Blei et al., 2008; Hoffman et al., 2010) is a possible alternative that has not yet been applied to chant, and ChantMapper can be used to examine whether it is applicable. Finally, to provide a familiar baseline, ChantMapper can emulate the Cantus Analysis Tool (CAT, see Introduction) by building synoptic tables with no tolerance for differences.

The Louvain algorithm detects communities in networks by maximising modularity (the ratio between within-community edge weights compared to links between different communities). It iterates community assignment and merging steps (as indicated in Fig. 4). Importantly, it does not require setting a target number of communities in advance. In ChantMapper, each source is a vertex, each pair of sources is connected by an edge, and edge weights are computed simply by the Jaccard index (intersection over union, Figure 4) between the sets of Cantus IDs (CID) present in the two sources after filter application (e.g. feast selection). We use Louvain implementation from the networx[6] library (Hagberg et al., 2008). The resolution parameter was set to 1.0, which we found to be most robust to the randomness inherent in the Louvain algorithm.[7]

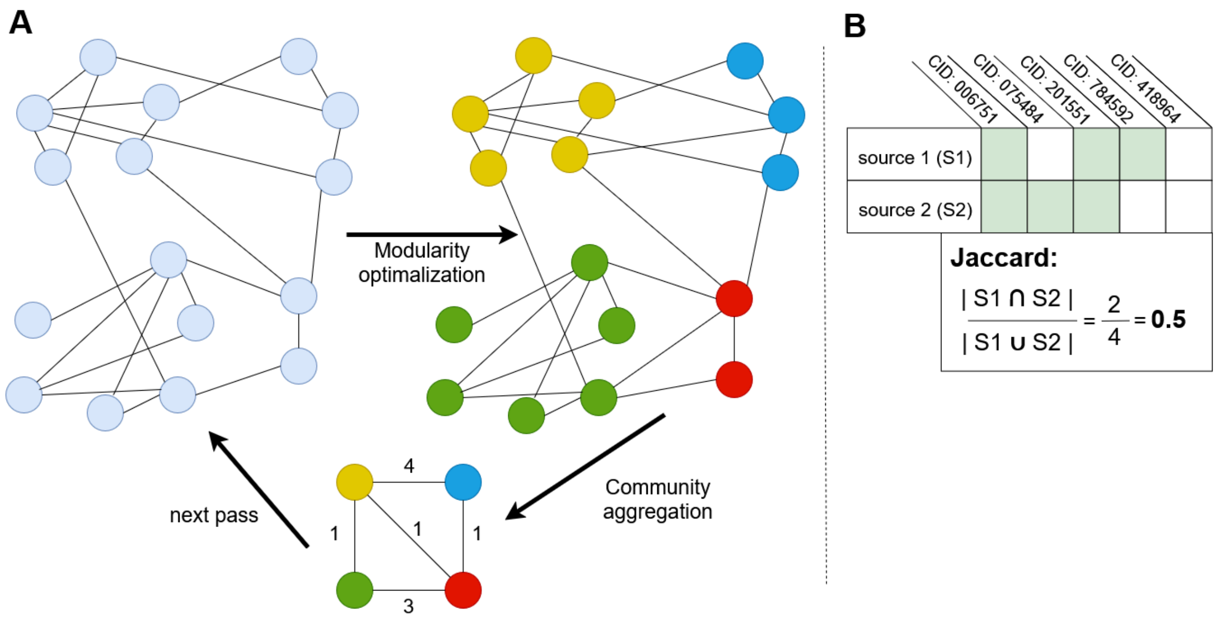


**Figure 4**: *A* is a schema of the Louvain algorithm. Note that in our case, the graph is complete, but the edges have different weights; the diagram illustrates a situation with binary edge weights (1/0), zero edges not being displayed. *B* shows computation of the Jaccard Index (our edge weight) on sets of chant records.

In the absence of "ground truth" traditions against which to evaluate methods for inferring traditions automatically, ChantMapper can serve as an interface for expert assessment of these methods' results. As an example, we precomputed a topic model, specifically Latent Dirichlet Allocation, over the built-in dataset. Topic models relax the condition that every source belongs to a single tradition – instead, they model sources as coming from a mixture of *latent* traditions. These may perhaps apply to only subsets of feasts, such as the influence of Cistercians on Marian feasts. We use the LDA implementation from scikit-learn[8] (Pedregosa et al., 2011). While the model seems attractive on the dataset available in ChantMapper too, no useful insides were revealed so far but we intend to analyse it in future work.

[6] https://networkx.org/documentation/stable/index.html
[7] ChantMapper runs the Louvain algorithm 10 times for each request and also reports stability (the average proportion of vertex pairs assigned to the same final community) over the runs.
[8] https://scikit-learn.org/stable/index.html

# Using ChantMapper

ChantMapper's primary input is the Request form (Fig. 6A, accessible via the "Start analysing" button). Its output are the map visualisations of computed communities (Fig. 1 and Fig. 5) and their tabular form (Fig. 5). In the Request form, users select which feasts they are interested in, the offices for which data should be included, the method for inferring communities, and the datasets to be used (Fig. 6A). The results for user requests are provided in three forms: table, the main map focused on communities, and a map focused on centuries of origin (Figure 5).

These filtering options are limited, but flexibility in defining material is provided in a more systematic way: the ability to upload user datasets (interface in Fig. 6C; details in the Help of ChantMapper).[9] When uploading sources with provenances not seen so far among the uploaded datasets, a form is available to match provenances to existing places or to add coordinates for new places (Fig. 6B).

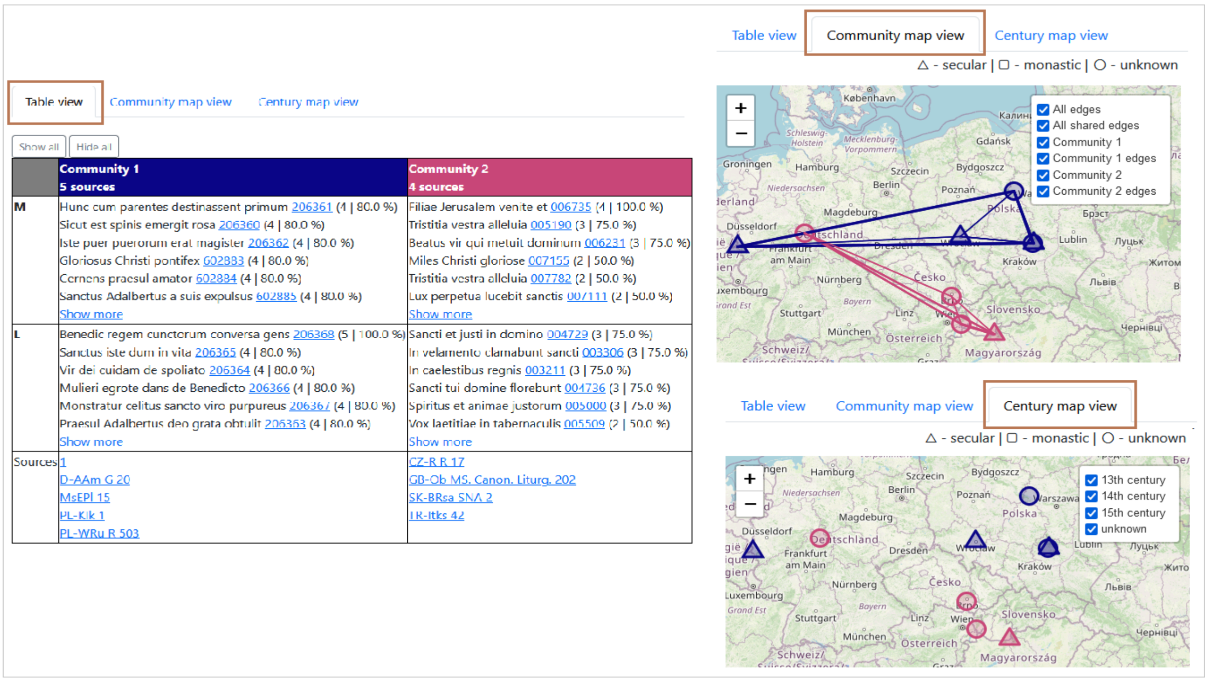


**Figure 5**: Three views of results, here for the feast of *Adalberti*: table, community map, and century map. Node shape reflects cursus: triangular for secular, square for monastic, circular for undefined.

[9] Because experiments with LDA haven't yet led to a useful parametrisation providing stable results, LDA-based traditions are not yet available for user-uploaded datasets.

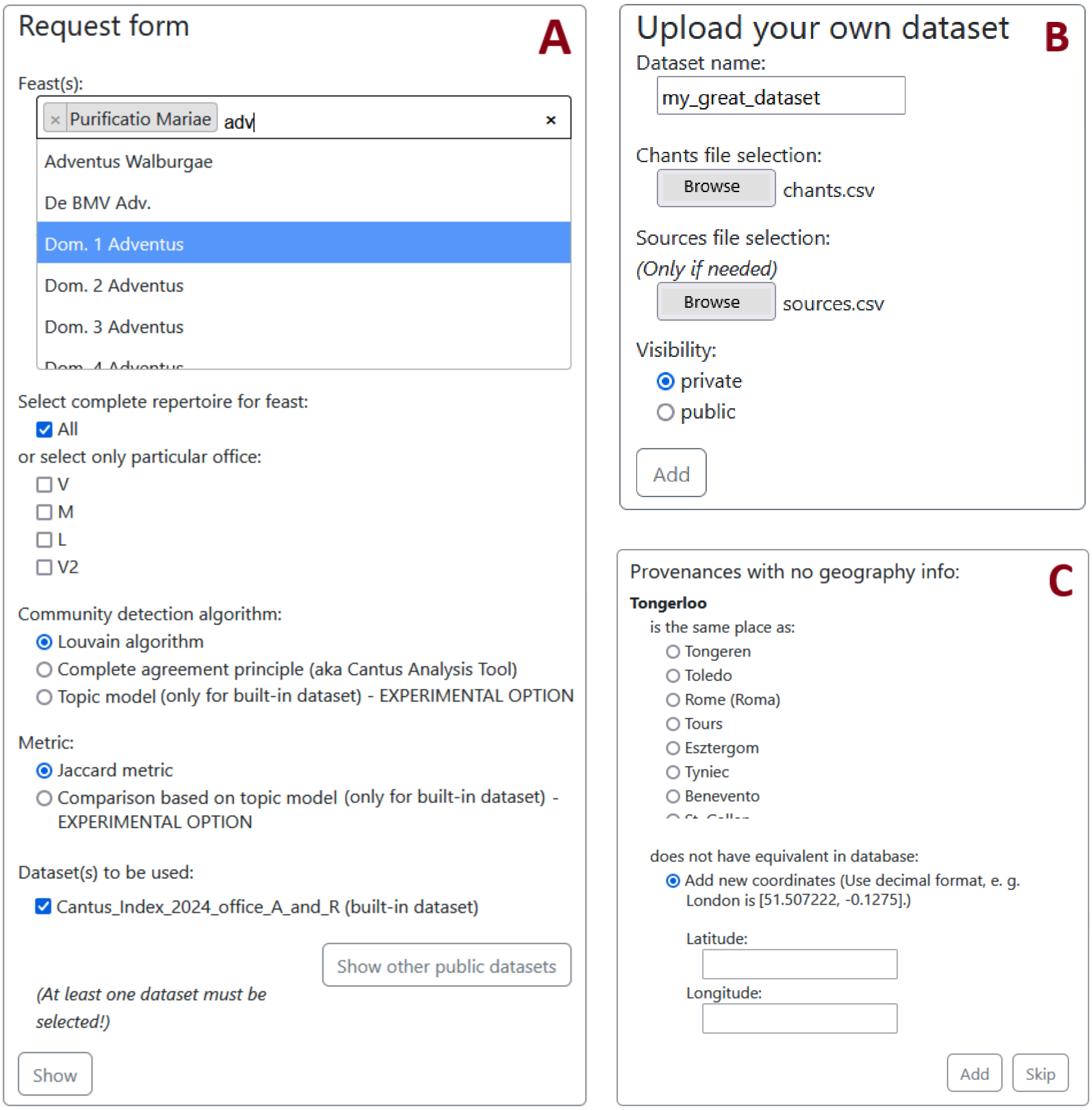


**Figure 6:** Input forms. *A* is the main tool form that allows users to construct community detection requests. *B* shows custom dataset upload. *C* is the interface for adding missing geographic information to provenances.

# Conclusions

ChantMapper visualises the geography of chant repertoire, with computational methods for exploring “soft” traditions. A dataset of 250 office sources from Cantus Index is provided, but ChantMapper readily accepts custom datasets. Improvements should follow: more filtering options, adding a visualisation-only mode to the tool, enabling externally provided similarities or community detection results, and options for quality control of source metadata (esp. cursus). We plan to add further computational methods, such as hierarchical clustering. In any case, we look forward to seeing how ChantMapper will be used, whether in research or perhaps in teaching.

## Acknowledgements

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# Encoding the New Frontier: Adapting MEI and Verovio for Post-Tonal and Spectral Notations

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## 1. Introduction: Verovio in Computational Musicology

In recent years, Verovio (Pugin et al., 2014) has emerged as a significant tool for rendering musical scores in web-based environments. Its Python package is steadily gaining recognition within research settings, evidenced by considerable adoption (e.g., approximately 6,000-7,000 weekly downloads on PyPI[1]), despite being less prominent than its web counterpart. Verovio represents an important and growing resource for computational musicology, providing an efficient alternative to the widely utilized Music21 (Cuthbert & Ariza, 2010). Unlike Music21, which depends on external rendering software like MuseScore or LilyPond—often complicating setups, particularly on server environments used for Jupyter notebooks (Pfleiderer et al., 2024)—Verovio's streamlined integration supports direct handling of kern, MusicXML, and MEI files. This capability greatly enhances accessibility for scholars and researchers dealing with diverse music-related data, especially within preconfigured environments such as Google Colab[2] or Jupyter4NFDI[3], enabling interaction without requiring dedicated Python environment setup. As Python and Jupyter increasingly become standard platforms for computational musicological research, novel applications utilizing Verovio-based rendering continue to emerge.

[1] https://pypistats.org/packages/verovio (accessed 29.4.2025)
[2] https://colab.research.google.com/ (accessed 29.4.2025)
[3] https://base4nfdi.de/projects/jupyter4nfdi (accessed 29.4.2025)

# 2. The AudioSpylt Toolkit: Extending MEI/Verovio for Spectral and Post-Tonal Data

This poster investigates the integration of Verovio within AudioSpylt[4], a Python-based toolkit primarily designed for audio analysis and resynthesis, currently under active development. AudioSpylt aims to replicate and extend analytical and artistic interactions associated with legacy IRCAM software like Audiosculpt (Bogaards et al., 2004; Bogaards, 2005) and OpenMusic (Bresson et al., 2011), incorporating concepts from OpenMusic libraries (e.g., OMChroma[5], OMPrisma[6]) and FFT/DFT-based analyses within a Python/Jupyter environment. The toolkit introduces methods for visualizing pitch structures derived from audio spectra through schematic and symbolic representations. While established symbolic formats (kern, MusicXML, MEI) offer limited support for microtonal, graphical, and advanced contemporary notation, AudioSpylt explores unconventional approaches to accurately encode microtonal pitch data (up to MIDI-cent resolution, e.g., from DFT frames, Figure 1) and temporal parameters (e.g., representations akin to graphic notation for time structures, Figure 2) for representing audio spectrum information symbolically. By leveraging MEI and Verovio, AudioSpylt adapts existing elements for these non-standard notational requirements, effectively extending Verovio's rendering capabilities for microtonal and graphic-like notations while striving to maintain compatibility with default MEI editors.

# 3. Expanding MEI: Broader Needs for Modern Repertoire and Analysis

The implementations developed for AudioSpylt highlight a general need for enhanced encoding solutions. The increasing availability of microtonal compositions entering the public domain—such as Charles Ives's Three Quarter-Tone Pieces (1925) and works by Russian avant-garde composers like Arthur Lourié and Arseniy Avraamov (Ader, 2015)—alongside contemporary composers releasing scores under open licenses (e.g., Johannes Schöllhorn[7], Eduardo Mogiliansky[8]), underscores the growing necessity for robust encoding of complex and unconventional notation. Furthermore, in analytical musicology, models stemming from GTTM (Lerdahl & Jackendoff, 1983), which combine symbolic representations with graph and nested structures (e.g., Marsden, 2001; Yust, 2006; Finkensiep & Rohrmeier, 2021), would benefit from the introduction of new graphic elements within MEI to expand analytical possibilities, particularly within Jupyter/Python environments where integrating new graphic elements currently requires SVG overlays, a method often incompatible with default MEI editors.

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[4] https://github.com/egorpol/audiospylt (accessed 29.4.2025)
[5] https://github.com/openmusic-project/OMChroma (accessed 29.4.2025)
[6] https://www.idmil.org/project/omprisma-spatial-sound-synthesis-in-open-music (accessed 29.4.2025)
[7] https://johannes-schoellhorn.de/tigre_de_lamour_partitur.pdf (accessed 29.4.2025)
[8] https://moguillansky.wordpress.com/wp-content/uploads/2008/11/bauauf3-score.pdf (accessed 29.4.2025)

| | Frequency (Hz) | MIDI Value | Cent Deviation | Pitch Name | MEI Step | MEI Octave | MEI Alter |
|---|---|---|---|---|---|---|---|
| 0 | 31.25 | 23 | +21 | B0 | B | 0 | n |
| 1 | 75.00 | 38 | +37 | D2 | D | 2 | n |
| 2 | 127.50 | 48 | -44 | C3 | C | 3 | n |
| 3 | 238.75 | 58 | +42 | A#3 | A | 3 | s |
| 4 | 321.25 | 64 | -45 | E4 | E | 4 | n |
| 5 | 393.75 | 67 | +8 | G4 | G | 4 | n |
| 6 | 398.75 | 67 | +30 | G4 | G | 4 | n |
| 7 | 518.75 | 72 | -15 | C5 | C | 5 | n |
| 8 | 546.25 | 73 | -26 | C#5 | C | 5 | s |
| 9 | 600.00 | 74 | +37 | D5 | D | 5 | n |

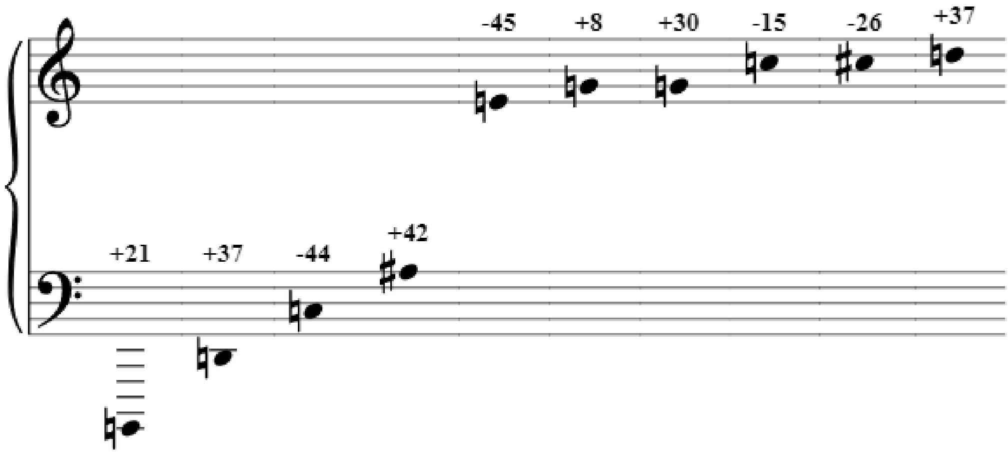


**Figure 1**: Example of a symbolic representation rendered within Jupyter using Verovio, utilizing MEI-based elements (specifically the 'fing' element) to annotate deviations from standard pitch in MIDI cents, representing frequency values extracted from a single DFT frame. The visual style is inspired by the OM-Chord object, and the frequency/pitch data is structured using a Pandas DataFrame.

| | Group (Measure) | Time Start | Time Stop | Num Notes | MIDI Values |
|---|---|---|---|---|---|
| 0 | 1 | 0.03 | 0.10 | 18 | [48, 51, 67, 72, 77, 82, 85, 85, 86, 87, 91, 9... |
| 1 | 2 | 0.10 | 0.20 | 13 | [23, 39, 47, 51, 59, 61, 69, 72, 73, 80, 81, 8... |
| 2 | 3 | 0.20 | 0.40 | 9 | [23, 38, 59, 61, 63, 67, 72, 73, 74] |
| 3 | 4 | 0.40 | 0.75 | 1 | [59] |

**Figure 2**: Example of a symbolic representation of temporal structures rendered in Jupyter using Verovio, depicting frequency values extracted from several successive DFT frames. The spacing between chords encodes temporal duration in milliseconds. The time resolution of the symbolic representation can be adjusted via dedicated parameters.

# 4. Conclusion and Future Directions

This contribution, by presenting innovative strategies developed within AudioSpylt and discussing the limitations of current standards, aims to inspire future initiatives toward creating a more robust, adaptable, and inclusive encoding environment, particularly concerning microtonal and graphic notations.

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# Making computational study of Gregorian melody accessible with ChantLab

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## Introduction

Among the goals of the DACT project[1] is to narrow the gap between musicologists and computer scientists, to better apply computational methods in Gregorian chant scholarship. We report progress towards this goal with **ChantLab**, a web application for studying Gregorian melody, its dialects, and its development using methods from bioinformatics. While these methods have shown potential in studying Gregorian melody (Section 1), applying them to new data usually requires programming, which is unfortunately prohibitive for many musicologists. ChantLab makes it possible to apply the selected computational methods and visualising results via an interactive user interface (Figure 1). Specifically, the main features offered by ChantLab are:

[1] https://dact-chant.ca/

- Aligning arbitrary amounts of melodies using Multiple Sequence Alignment (MSA).
- Interactive visualisation of aligned melodies, incl. conservation profiles.
- Similarity visualisation through distance matrices and dendrograms.
- Pilot phylogenetic tree inference integration.
- Exporting results in standard formats for bioinformatics: FASTA, Newick, or Nexus.
- Pre-populated with CantusCorpus v0.2 (Cornelissen et al., 2020a).
- Uploading custom datasets.

ChantLab is available at https://quest.ms.mff.cuni.cz/chantlab.

# 1 Computational Research of Chant Melody

Computational methods are increasingly applied to the study of Gregorian melody, thanks to large databases – primarily the Cantus Index ecosystem (Lacoste, 2022), or GregoBase (Berten et al., 2013–2024) – that, aside from large amounts of chant texts and metadata, also provide melodies encoded in Volpiano or GABC formats.

There are opportunities for computational research in the study of melodic families (Gevaert, 1895; Frere, 1901-1924) and dialects (Molitor, 1904; Wagner, 1925), where patterns of melodic similarity by time and place suggest an evolutionary perspective may be useful. Evolutionary perspectives on music have been applied across various traditions and genres (Warrell et al., 2024; Savage et al., 2022; Youngblood et al., 2021; Savage, 2019;

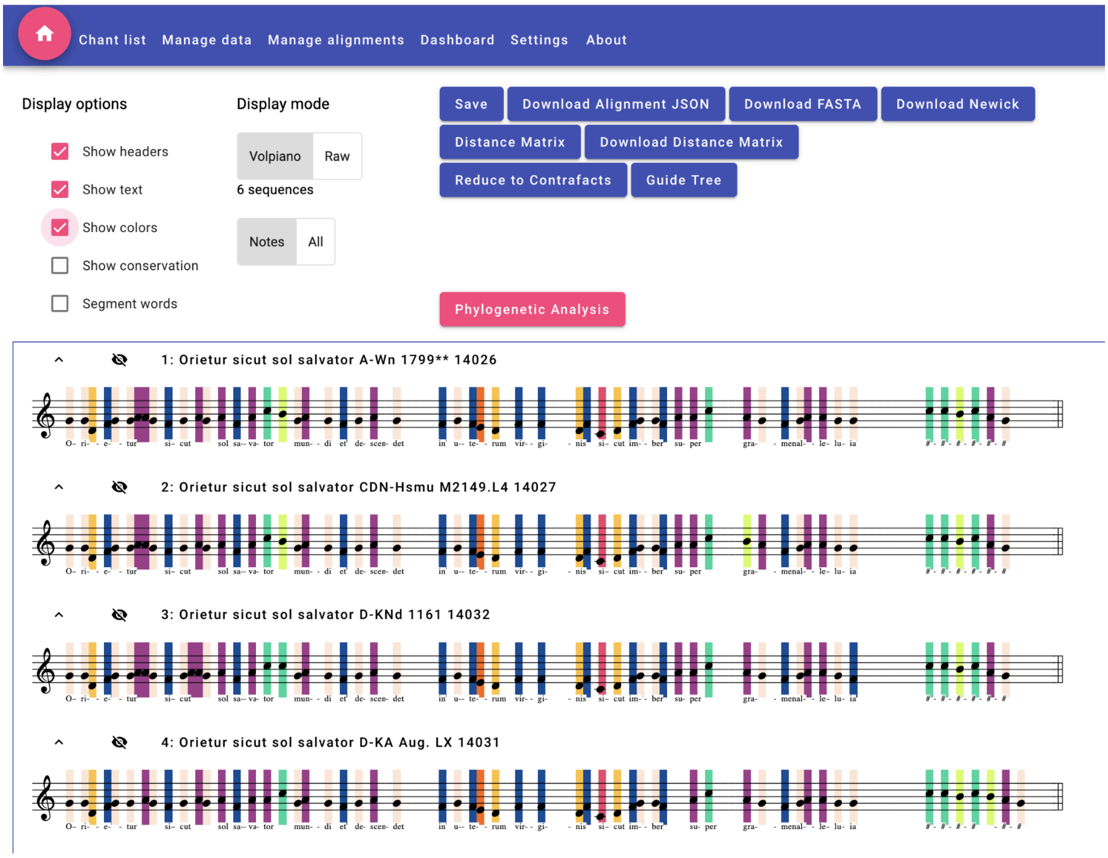


**Figure 1**: Aligned versions of the "*Orietur sicut sol*" antiphon from different sources. Besides color-coding pitches as usual in MSA software (e.g. AliView), positions can also be highlighted by level of conservation.

Le Bomin et al., 2016). In the context of Gregorian chant, Hajič jr. et al. (2023) employed tools such as MAFFT (Katoh & Standley, 2013) for melody alignment and MrBayes (Ronquist & Huelsenbeck, 2003) for phylogenetic tree reconstruction to compare melodies from different sources of Christmas Eve Vespers, leading to meaningful music-historical interpretations (Ballen et al., 2024); MSA for chant is implemented in MonodiKit (Eipert & Moss, 2023) as well. Additionally, Hajič et al. (2023) introduced the *mrbayes_volpiano* tool, which allows applying Bayesian phylogenetic analysis using the Volpiano encoding.

Despite efforts to identify melodic features through computational segmentation (Helsen et al., 2021; Cornelissen et al., 2020a; Cornelissen et al., 2020b, Lanz & Hajič jr., 2023; Lanz, 2023), an alternative to studying melodies in their entirety has yet to emerge.

# 2 ChantLab Functionality

ChantLab provides three main functionalities: aligning melodies, visualizing similarity among aligned melodies, and inferring phylogenetic trees from the alignments.

## *2.1 Melody Alignment*

The core feature of ChantLab is automatically building interactive synoptic tables of melodies with MSA. We use MAFFT (Katoh & Standley, 2013), which supports aligning strings from non-biological alphabets. Users can filter chants by genre, office, and source, select melodies, and align them. The alignment result interface is shown in Figure 1.

ChantLab provides three alignment methods:

1. **Pitch-based**. This method uses MAFFT, a widely used multiple sequence alignment tool, to align melodies by pitches according to a guide tree of pairwise similarities. The cost of aligning non-identical pitches in the same position scales linearly with diatonic steps (a 2nd has a cost of 1, a third costs 2, etc.), and due to uncertainties about implied flats, treats B and Bb as the same tone (Hajič jr. et al., 2023).

2. **Interval-based**. Aligns sequences of intervals instead of pitches. It is thus invariant to transposition, but on the other hand, might introduce spurious similarities. It uses a substitution model similar to pitch-based alignment, where the cost scales linearly with diatonic steps. An encoding is used where the *n*-th letter of the English alphabet represents an interval of *n* half-tones, with lowercase for ascending and uppercase for descending intervals.

3. **Word-based.** A simple alignment using textual boundaries only. Besides serving as a baseline, it is motivated also by recent computational research on the relationship between text and melody (Cornelissen et al., 2020; Lanz and Hajič jr., 2023)

Additionally, ChantLab supports comparing sources, by concatenating melodies of selected chants from each. This is especially relevant for constructing phylogenetic trees, for which comparing versions of a single melody is insufficient (Hajič jr. et al., 2023).

ChantLab's Alignment page allows downloads of aligned sequences in Alpiano (a variant of Volpiano with '-' as a gap used for aligning tones instead of encoding lyric boundaries) as FASTA files, suitable for further bioinformatics tools. Users can also download the MAFFT-generated guide tree in Newick format for external visualisation or further analysis.

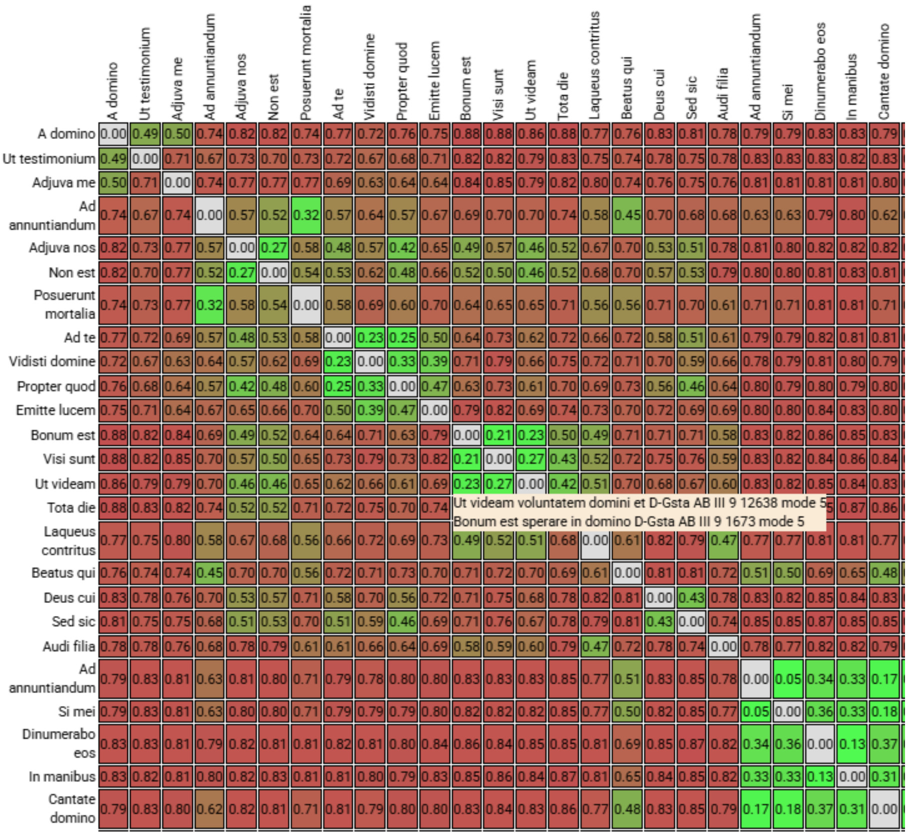


**Figure 2**: Part of the distance matrix for aligned melodies of all graduale verses from source D-Gsta AB III 9.

## *2.2 Visualising similarity*

While detailed manual inspection is irreplaceable, ChantLab complements it with two methods of visualising broader patterns of similarity. The first is a distance matrix (Figure 2) that highlights similarities between melody pairs, suggesting candidates for closer examination. Distances are simply the count of differences between aligned melodies normalized by their lengths.

Second, the guide tree generated during alignments can be shown as a dendrogram (Figure 3). Both visualization examples are based on pitch-based melody alignment.

## *2.3 Pilot Integration: Phylogenetic Tree Analysis*

ChantLab includes preliminary support for Bayesian phylogenetic tree inference, to explore possible evolutionary relationships between given melodies or sources beyond the pairwise hierarchical clustering computed by the guide tree. The method is particularly relevant for diastematic sources, where melodic structures can be compared more systematically. While the method shows potential (Ballen et al., 2024; Hajič jr. et al., 2023), it is not yet fully adapted for intuitive and practical use.

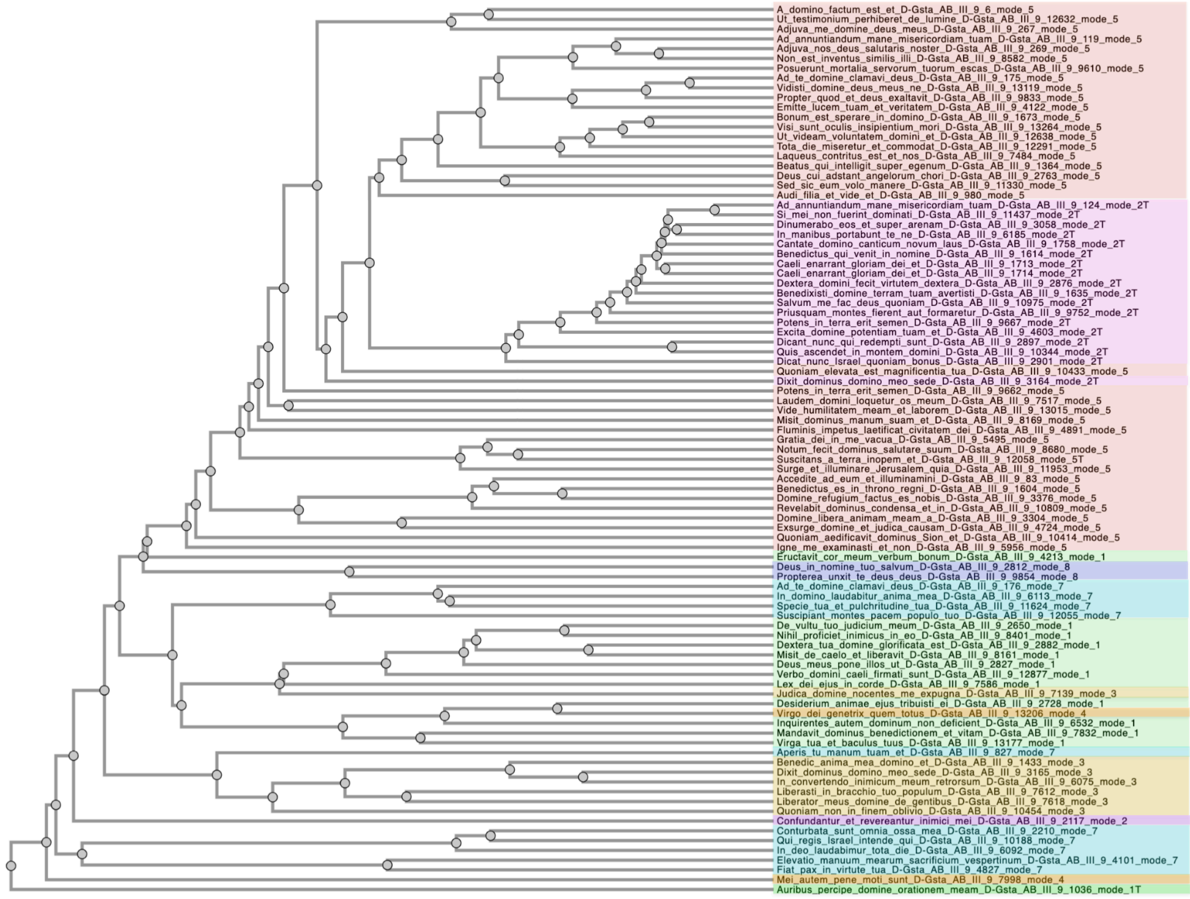


**Figure 3**: Dendrogram visualisation of the MAFFT guide tree for all *graduale* verses (GrV) in D-Gsta AB III 9. Colors indicate mode in the figure.[2] Perhaps most interestingly, mode 7 verse melodies (light blue) form two distinct melodic clusters, with the first group closer to mode 1 and 3 melodies than to the other mode 7 group.

Besides the scientific uncertainty connected to the applicability of phylogenetic models to chant, phylogeny inference is a computationally much more demanding step than MSA. Significant technical work will therefore be needed: refactoring the back-end for a job queue, integrating user accounts, and connecting ChantLab to more scalable computational infrastructure.

# Conclusion

ChantLab offers an interactive interface for analysing Gregorian melodies with computational methods (MSA and phylogenetic tree inference), visualising the results, and exporting them in standard formats for further processing. While there is work remaining (especially support for user-defined substitution models, custom melody encodings (e.g., neumes), user accounts, and a REST API), we believe ChantLab enriches the selection of methods for studying chant melody available with minimal technical barriers, and presents a significant step forward for the DACT project.

[2] They are not yet implemented in the application, but we add them to illustrate the value such visualisation can bring for chant melody research.

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# Towards new representations and methodologies for detecting concordances in symbolic music corpora pre-1600

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The “common practice” period (17–19th centuries) placed particular emphasis on compositional originality, with works during this time increasingly viewed as ‘complete and discrete, original and fixed, personally owned units’ (Goehr, 1992, p. 206). Pre-1600 music, by contrast, has consistently resisted reduction to such fixed forms, as practices of reworking, parodying, quoting, and oral transmission common in the Medieval and Renaissance periods resulted in multiple and divergent versions of ostensibly the same music (Owens, 1997, pp. 64–73; Treitler, 2003). This fluidity naturally gives rise to extensive intertextual relationships that connect works through shared motifs, melodic patterns, and structural similarities. Identifying and cataloguing these smaller-scale concordances is therefore a key task for understanding early music repertories. While significant progress has been made through the creation of *catalogues raisonnés* in the 19th and 20th centuries, the continuing discovery of new relationships (e.g. Steiner, 2024; Cuthbert, 2024a) demonstrates that this remains an ongoing and incomplete endeavour.

In a recent presentation, Michael S. A. Cuthbert, amid presenting a remarkable number of interrelationships within medieval music that he had found using his own digital concordance system, expressed the somewhat pessimistic view that ‘post-2020’ AI showed little promise for the identification of further concordances in early music as ‘our data are too small’ to train these data-hungry systems (Cuthbert, 2024a). This poster aims, in part, to respond to Cuthbert’s claims in a more optimistic light, arguing that there is in fact a lot of data available in early music notation but that current approaches lack the feature extraction and embedding representation methodologies capable of harnessing this data in its entirety.

Existing feature extraction methodologies such as those present in *jSymbolic* (McKay, 2023) and *EMMSAP* (Cuthbert, 2024b) typically formalise music-theoretical rules into computer code so as to process symbolic notation into features. These rules pertain both to basic features of Western music – such as chromatic interval distance and rhythms – as well as more complex analyses generated through the application of a number of curated heuristics, such as chord analysis and cadence types (Cumming et al., 2018). One of the strengths of these rules-based approaches is that they encode pre-existing musicological knowledge about what features are viewed as important in music. Nonetheless, this reliance on hand-crafted features limits the capability of feature extraction to quantifiable aspects of music at a note-to-note level. Concordances between pre-1600 musical notations are not note-to-note copies however, but include more nuanced formulaic constructions where the answers to musicological questions surrounding concordances cannot be answered categorically, and there are no definitive rules for what constitutes a concordance.

The runaway successes that 'post-2020' AI has seen, particularly in the field of natural language processing (NLP), are not the result of hand-crafted feature extraction and rules-based processes, but representation learning using neural networks ingesting learned features from data (Jurafsky & Martin, 2023, pp. 103–133). However, whereas language can quite simply be modelled as a linear sequence of tokens, anything other than the simplest monophonic musical notation contains complex simultaneous and hierarchical relationships, particularly in polyphony (Stutter, 2024). Feature extraction, a vital initial stage to convert symbolic musical notation into a representative vector space and therefore enable further analysis by machine learning models, is still an area that requires improvement.

This poster evaluates three different methodologies for feature extraction, using the CANDR dataset of 13th-century polyphony (Stutter, 2025): 1) hand-crafted melodic feature extraction using *jSymbolic* and *music21* (Cuthbert & Ariza, 2010); 2) modelling notation as text using the common NLP word embedding methodology *Word2Vec* (Mikolov et al., 2013); and 3) modelling notation as a directed graph using a relational graph convolutional network (R-GCN) embedding, after Karystinaios & Widmer (2024). Each resulting vector space is then evaluated by a combination of metrics: silhouette score, Calinski–Harabasz index (Caliński & Harabasz, 1974), and the performance of a simple logistic regression classifier on the data.

The analysis demonstrates that, while no methodology provides a definitive solution as each technique has a different standard of what an embedding provides, the 'post-2020' R-GCN methodology is capable of extracting as many data points as there are notational elements, providing evidence contrary to Cuthbert's claims of data paucity, and with the possibility for more data generated by data augmentation strategies. The R-GCN methodology performs far better in every evaluation metric selected here than the hand-crafted extraction, and this is likely due to the fact that this methodology extracts not just the melodic and monophonic features possible from this early notation dataset, but also a sense of where elements sit within a wider polyphonic notational context, thereby performing much better by creating a more representational clustering of similar elements, and leading towards new methodologies for concordance detection and measurement.

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# Community-Driven Open Source Development of Edirom-Online 1.0 and Beyond

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Edirom-Online is a scholarly editing software that enables users of historical-critical music editions to access digital facsimiles, place them side by side for comparison, display concordant measures in parallel, and engage with critical annotations that highlight differences between sources. Thanks to its data-driven approach, Edirom generates these forms of presentation on the basis of MEI and TEI encodings. Over many years – going back to its origin of the research project *Entwicklung von Werkzeugen für digitale Formen wissenschaftlich-kritischer Musikeditionen* in 2006 – Edirom has been used in several long-term edition projects like the *Max Reger-Werkausgabe* and *OPERA – Spektrum des europäischen Musiktheaters*. The *Weber-Gesamtausgabe* for instance is also using Edirom as a collation tool in its daily work in preparing the printed volumes. Moreover, recent endeavors, like the *Bernd Alois Zimmermann-Gesamtausgabe* and the *Erich Wolfgang Korngold Werkausgabe,* and smaller research projects, such as *Sarti-Edition*, *Henze Digital*, *Baumann Digital* and *Tanz/Musik digital*, are using Edirom, and it is additionally used for private research purposes. Recently, the increasing demands of projects using the Edirom has led to growing community involvement in its development.

Community involvement has been integral to Edirom's growth and longevity as an open source project. Regular community meetings, hackathons, and workshops ensure an open dialogue between developers, researchers, and users. These interactions help identify user needs, coordinate feature development, and promote skill-building among participants. The establishment of a collaborative GitHub repository[1] and adherence to open-source and sustainable software development principles (Chue Hong et al. 2022; Barker et al. 2022) ensures transparency and fosters a participatory environment.

Despite its success, Edirom's reliance on aging technologies has necessitated significant redevelopment to meet the evolving demands of modern scholarship. The "Edirom-Online Reloaded"[2] project, in conjunction with Edirom's community of open source developers and users, seeks to address these challenges by modernizing the software, enhancing its usability, and fostering community engagement. The community recently finalized the official release of the 1.0 version of the software – its first major release since 2021. More than 12 contributors have spent additional time outside of their official project work to engage in unpaid open source development, fixing countless bugs and making the Edirom platform more stable. This poster aims to celebrate the release of the first stable version of Edirom and as a demonstration of successful collaboration in open source research software development.

[1] Edirom-Online GitHub Repository: https://github.com/Edirom/Edirom-Online
[2] Edirom-Online Reloaded project: https://www.uni-paderborn.de/projekt/1332

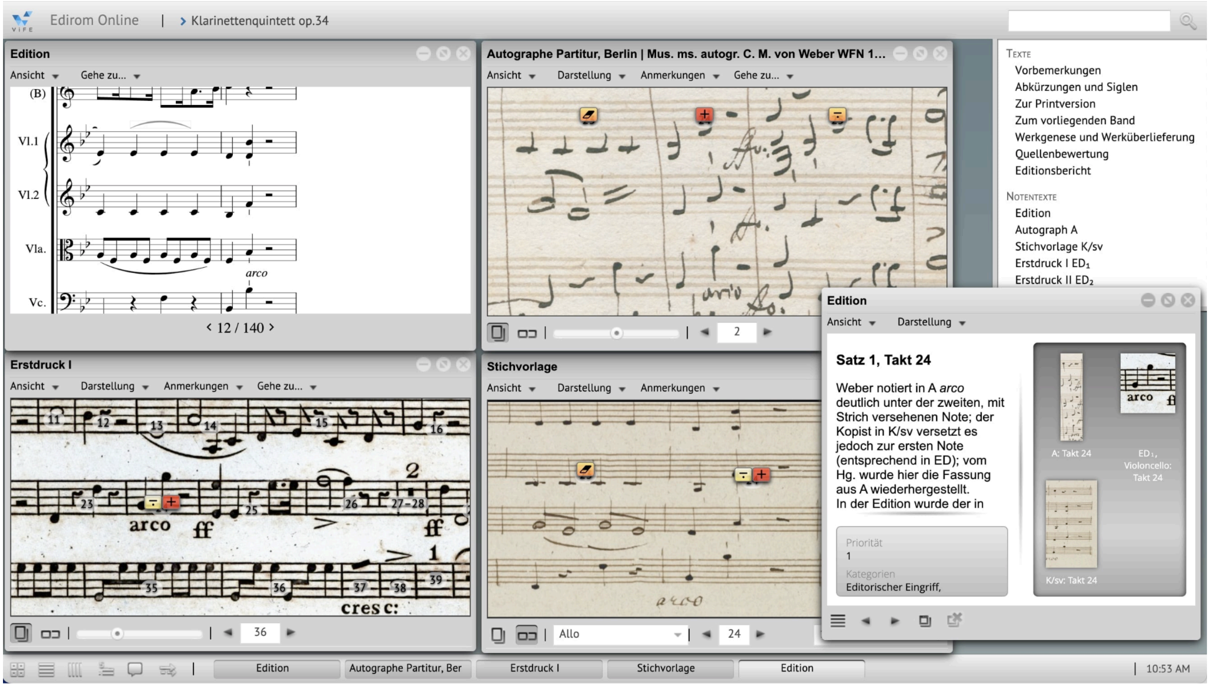


**Figure 1**: Carl Maria von Weber, Clarinet quintet, digital edition presented with Edirom-Online. The image shows understanding an editorial intervention using the associated sources mentioned in an annotation. The edition is coded in MEI and rendered with Verovio.

Looking ahead, the project envisions a future where Edirom thrives as a community-driven and self-sustaining development. The *Zentrum Musik–Edition–Medien (ZenMEM)* will continue to provide foundational support, ensuring long-term maintenance and alignment with infrastructure initiatives like *NFDI4Culture*. By addressing legacy limitations and adopting modern software practices, Edirom aims to strengthen its role as an important tool for digital music editions. After the release of version 1.0, the community plans not to rest but instead to build on the momentum and start work on future versions[3]. Moving to a modular architecture based on the Web Components standard is the vision for a 2.0 release. Another key goal which will be reached soon is the clear separation of the frontend[4] and backend[5] components. The backend, hosted in an eXist-native XML database, will feature a clearly defined REST API that adheres to the OpenAPI standard, allowing seamless interaction with other open source tools and interfaces. Meanwhile, the frontend will gradually be moved away from using proprietary libraries and will function as an independent application with encapsulated web components. This separation enhances maintainability, facilitates independent updates, and enables the integration of specialized features into external projects, thus broadening the usability and adaptability of Edirom.

[3] Edirom-Online GitHub Milestones: https://github.com/Edirom/Edirom-Online/milestones
[4] Edirom-Online Frontend GitHub Repository: https://github.com/Edirom/Edirom-Online-Frontend
[5] Edirom-Online Backend GitHub Repository: https://github.com/Edirom/Edirom-Online-Backend

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# Stravinskys way of sketching - A digital preparation of the sketches for *Le Sacre du Printemps*

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The premiere of *Le Sacre du Printemps* has been the subject of much discussion within the field of musicology, as well as in the broader academic community, due to the perceived scandal surrounding the piece (Stravinsky et al. 1972). Nevertheless, the work is widely considered to be one of the most significant of the 20th century. The genesis of the work in particular poses difficulties for musicologists, and to date there has been no edition of the work, nor have Igor Stravinsky's sketches for *Le Sacre* been edited. But large parts of them have been collected in a sketchbook and were published by his assistant and close friend Robert Craft, replenished by a comment on the sketches (Stravinsky/Craft, 1969). The comment by Robert Craft has proven to be very helpful in the process of assigning the sketches to the correct parts of the final work, and all the Russian comments by Stravinsky have been translated in this comment.

In this initial approach to creating a digital edition, I aimed to design a website that provides information about *Le Sacre du Printemps* and Igor Stravinsky, along with the original sketches, their edited versions and the conclusions that can be drawn from them. Especially the focus on Stravinsky's compositional process provides a significant body of insights. The sketches are encoded according to the Music Encoding Initiative (MEI) standards, ensuring machine-readability and standardisation and are supplemented by a critical report. Verovio was used for the display of the edited sketches, which are available on the website along with an image of each original sketch and descriptions of the sketches. In this description, the sketches have been annotated to both the other sketches and the *Boosey & Hawkes* edition of 1997.

The selection of just the sketches belonging to *Les Augures printaniers* makes the compositional process of this particular section comprehensible, with an emphasis on Stravinsky's compositional methodology: His use of the piano in composition and the resulting 'piano score-like' sketches, along with their vibrant design (Figure 1), are particularly noteworthy. Additionally, the mechanical design of the sketches becomes discernible; Stravinsky creates 'building blocks' that are initially sketched individually and then assembled into increasingly larger sections. The question of which motifs are included in the final score, and which are omitted, is also of great interest.

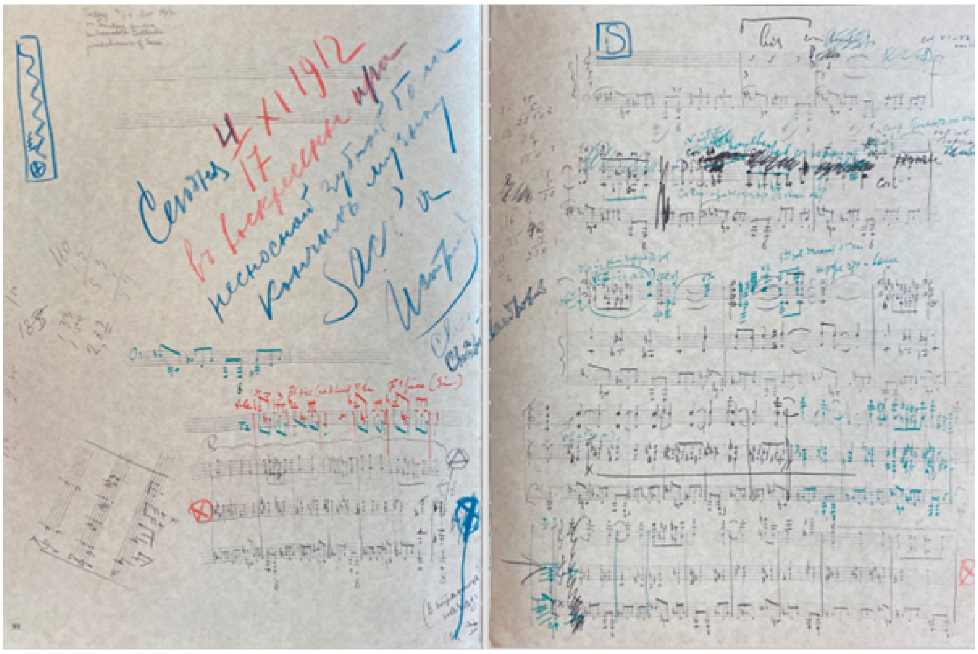

**Figure 1**: Page 96/97 of the Sketchbook, edited by Robert Craft, (F-Pn, MS-20648 ).

The present project explores the digital edition of sketches and offers a proposal for the digital edition of Stravinsky's *Le Sacre du Printemps*. The close analysis of the sketches has proven to be a profitable exercise for the present study, and even a limited selection of sketches provides valuable insights into the composers working process.

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# How to Infer Repeat Structures in MIDI Performances

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## Introduction

MIDI performances are generally expedient in performance research and music information retrieval, and even more so if they can be connected to a score (Cancino-Chacón et al., 2018, Peter et al., 2023). This connection is usually established by means of alignment, linking either notes or time points between the score and the performance. The first obstacle when trying to establish such an alignment is that a performance realizes *one* (out of many) structural versions of the score that can plausibly result from instructions such as repeats, variations, and navigation markers like '*dal segno/da capo al coda*'. A score needs to be *unfolded*, that is, its repeats and navigation markers need to be explicitly written out to create a single timeline without jumps matching the performance, before alignment algorithms can be applied. In the curation of large performance corpora this process is carried out manually, as no tools are available to infer the repeat structure of the performance (Bukey et al., 2024).

To ease this process, we develop a method to automatically infer the repeat structure of a MIDI performance, given a symbolically encoded score including repeat and navigation markers. The intuition guiding our design is: 1) local alignment of every contiguous section of the score with a section of a performance containing the same material should receive high alignment gain, whereas local alignment with any other performance section should accrue a low or zero gain. And 2) stitching local alignments together according to a valid structural version of the score should result in an approximate full alignment and correspondingly high global accumulated gain if the structural version corresponds to the performance, and low gain for all other, ill-fitting structural versions.

In Section 1 we provide a detailed description of our proposed method, and in Section 2, we demonstrate its application on the (n)ASAP dataset (Peter et al., 2023) . The method proves a reliable and useful preprocessing tool for large-scale performance data curation and even uncovered several previously unknown errors in the dataset.

# 1 Method

The proposed method is based on three steps. First, we perform local sequence alignment to identify well-aligned segments in the performance that correspond to segments in the score. Next, we combine these local alignments into a global alignment for all possible structural versions of the score, recording their respective global alignment gain. Finally, we select the structural version that maximizes the global alignment gain.

## *1.1 Local Sequence Alignment*

Local sequence alignment algorithms such as the Smith-Waterman algorithm (Smith and Waterman, 1981) are well-suited for identifying segment-wise correspondences. We adapt an existing symbol-level DTW-type alignment algorithm (Peter, 2023) into a Smith-Waterman-style local alignment algorithm by incorporating match gains, mismatch penalties, and constraining the gain to non-negative values. We use a purely pitch-based symbol-level feature representation paired with a pairwise metric for alignment which is designed to work with arbitrary polyphonic scores and performances. The score is represented as an array where each element is a set of MIDI pitches corresponding to a unique score onset:

Score = $[\{P_1, \dots, P_n\}, \{P_1, \dots, P_m\}, \{P_1, \dots, P_o\}, \dots]$ where $P \in \{0, \dots, 127\}$.

The performance is represented as an array of consecutive MIDI pitches: Per = $[P_1, \dots, P_n]$

The local metric between a score onset pitch set and a performed pitch is then defined as:

m(i,j) = m(Per[i],Score[j]) = m($P_i$, $\{P_1, \dots, P_n\}$) := 1 if $P_i \in \{P_1, \dots, P_n\}$ else -1

Note that the features and the local metric only process pitch information. Uncommon in music alignment, the metric represents a gain and not a cost value, that is, matching pitches result in a higher value. To compute the accumulated gain from this local gain, we use a modified Smith-Waterman dynamic programming algorithm. Figure 1 shows the output of this gain accumulation. Following this visual intuition we assume the performance to be in the vertical direction (each row index corresponds to a performed MIDI pitch) and the score in the horizontal (each column index corresponds to a set of pitches at a unique score onset). The algorithm loops over all performance and score indices and the local accumulated gain is computed from one of two possible previous gains: a diagonal step, i.e., a new score pitch set and a new performance note, or a vertical step, i.e., a new performance note at the same score pitch set, can be added to the gain value. The accumulated gain $ag(i,j)$ is then computed by maximizing across the two possible steps:

$$ag(i,j) = max(ag(i-1,j), ag(i-1, j-1)) + m(i,j)$$

The accumulated gain matrix $ag$ is initialized at zero. To ensure non-negative alignment scores, a Smith-Waterman algorithm contains a reset step: $ac(i,j) = max(0, ac(i,j))$. We modify the accumulation bounds by setting upper and lower limits. The maximal gain is bounded by the gain value 10, with exponentially decreasing gain increments approaching this upper bound asymptotically. The minimum gain is bounded by zero, decreasing linearly

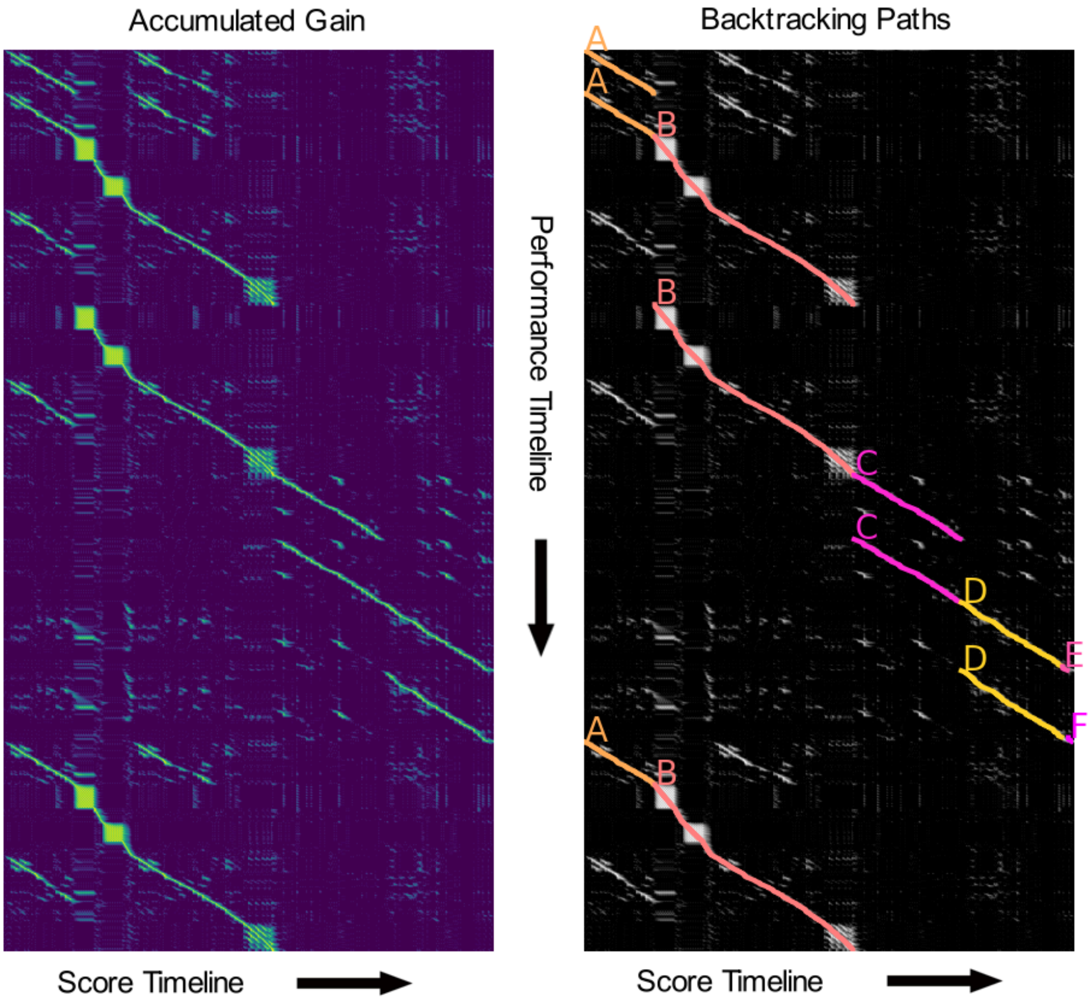


**Figure 1**: An example inference for a performance of Beethoven's Piano Sonata No. 11, Op. 22, third movement. The left image shows the accumulated gain of the local sequence alignment, the performance is in the vertical dimension and starts at the top, the score is in the horizontal dimension. The right image superimposes the backtracked segments. This piece contains four repeated segments (A,B,C, and D), the last one ending in Volta brackets (E and F). After the "Da Capo al Fine" at the end of segment F, the performance plays each segment (A and B) only once.

until reaching a value of 1, after which it asymptotically approaches zero. While the use of bounded gains and only two update directions is a peculiar setup for music alignment, in this case it enables distinct, clearly separated local alignment ridges in the gain accumulation matrix (see Fig. 1) which in turn simplifies the following backtracking step.

### *1.2 Score-informed Backtracking*

Local sequence alignment produces a gain matrix that is used to extract local matching subsequences. However, these local alignments are extracted in an unstructured fashion: backtracking from the highest gain ignores position, does not guarantee full coverage of the performance, and may not preserve sequential constraints in the score. Figure 1 shows the type of path that we would like to backtrack from the accumulated gain matrix (left) in the same matrix with superimposed correct path segments (right). Several candidate alignments are visible which violate musical assumptions, e.g., at the very top (the beginning of the performance) we see two diagonal lines which start in the middle of score segment B. This is not a valid place to begin a performance, yet standard backtracking will produce these local alignments. To address this issue, we use score-informed backtracking. First, we compute all possible, musically valid, structural versions based on repeat, variation and navigation markers (e.g., repeating at most twice, playing the coda once), and label the segments between markers alphabetically.

For each structural version, backtracking starts at the cost matrix position corresponding to the last segment, and continues until it reaches either the start of that segment or a cost of zero, at which point the local alignment is added to the alignment stack of that version. The alignment cost is added to the global alignment cost. The process is then repeated for the next segment, starting from the end of that segment in the score and the performance position where the previous local alignment ended.

This continues until the first segment of the score version is aligned. The global cost is calculated as the sum of the local alignment costs, weighted by a penalty for using more segments. Finally, we select the score version that minimizes this global cost. If the number of possible score versions becomes too large due to combinatorial explosion, this step can be carried out with a smaller subset of commonly performed versions.

## 2 Demonstration

We test our method on all performances of the (n)ASAP dataset and compare against the true repeat structure of the performances. The dataset contains 110 performances with notated repeats or skips (whether actually performed or not), and our method initially returned roughly 85% correct repeat structures for these. Upon closer inspection of the errors, we found that all 17 errors were due to faulty dataset annotations. Among those we found 15 performances where the dataset error is only due to a mismatch in repeats and thus easily fixable. However, there are also two performances which skip musical material outside of marked sections. We did not double-check the correctness of all 93 performances where the predicted structure corresponds to the dataset annotations. As far as these dataset annotations are to be trusted, our method is correct for all performances and uncovered a high number of incorrect annotations.

## Conclusion

In this article, we present a simple, fast, and automatic tool to infer the repeat structure in recorded MIDI performances. Our method builds on previous alignment models and can be used as a pre-processing or checking tool in the curation of large-scale piano performance corpora. It was tested and developed with solo piano performances and works with arbitrary polyphonic music by processing purely pitch-based information.

Our method is available in the python music alignment library *parangonar*:

https://github.com/sildater/parangonar

The (n)ASAP dataset is available on github:

https://github.com/CPJKU/asap-dataset

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# *kernpy*: a Humdrum **Kern Oriented Python Package for Optical Music Recognition Tasks

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## Introduction

Working with symbolic music scores often involves the use of Humdrum **kern (Huron, 1997) and **mens (Rizo et al., 2018), hereinafter referred to as **kern, as used in numerous datasets: *KernScores* (Sapp, 2005), *Polish Digital Scores* (Duguid, 2024), *GrandStaff* (Ríos-Vila et al. 2023), Mozarteum (Rink, 2021), *Capitan* (Calvo-Zaragoza et al., 2019), *PrIMuS* (Calvo-Zaragoza & Rizo, 2018) –rely on this encoding. State-of-the-art Optical Music Recognition (OMR) (Calvo-Zaragoza et al., 2020) models (Ríos-Vila et al., 2024; Steiner et al., 2024) demonstrate the convenience of training models with **kern-encoded datasets.

Manual transcription of **kern scores using tools like Verovio Humdrum Viewer[1] (VHV) (Sapp, 2017) is error-prone, time-intensive, and demands extensive knowledge of **kern notation. Alternatively, score-writing software such as Sibelius[2], MuseScore[3] or Dorico[4] allows faster score creation but lacks native **kern support, requiring MusicXML as an intermediary format. This reliance introduces translation challenges (Nápoles, 2018).

Recent advancements in OMR technology are starting to enable efficient automatic transcription, providing a viable solution for generating large, high-quality datasets from scanned scores. Modern OMR systems handle not only classical notations (e.g., monophonic or piano-form) but also mensural notations, as seen in tools like MuRET (Rizo et al., 2023). Such paired datasets, linking scanned scores with symbolic music representations, expand research opportunities.

Developing advanced OMR models requires substantial datasets, yet high-quality data remains scarce. Constructing datasets from real **kern files –via filtering, normalization, and splitting– is crucial for OMR training workflows. Existing tools like the canonic Humdrum Tools and Extras[5] and HumdrumR (Condit-Schultz & Arthur, 2019), although partially providing this kind of utilities, do not fit seamlessly into deep learning Python based pipelines. Frameworks such music21 (Cuthbert & Ariza, 2010), Partitura (Cancino-Chacón et al. 2022), or musif (Llorens, 2023) offer partial solutions but lack some features like described below.

We present *kernpy*, a Python package that provides comprehensive tools for working with symbolic modern and mensural notations in Humdrum format. It serves as an intermediary tool for data extraction and significantly enhances the performance of Optical Music Recognition Python workflows. *kernpy* addresses the scarcity of symbolic score datasets in **kern/**mens by enabling the creation of large-scale datasets. By integrating formal grammars, *kernpy* offers a unified software for handling Humdrum files within a single, cohesive and user-friendly interface. *kernpy* is a fully open-source project open to contributions available at https://github.com/OMR-PRAIG-UA-ES/kernpy.

# 1 kernpy proposals

*kernpy* provides a suite of tools for generating **kern-based datasets from existing **kern scores, designed to facilitate training deep learning models in Python pipelines. *kernpy* enables the iteration over a score to create smaller **kern fragments or the merging of multiple **kern scores into a single, larger score.

*kernpy* includes many of the functionalities already present in the other Humdrum utilities such as VHV filters and humdrum-tools, such as the ability to select specific spines when

[1] https://verovio.humdrum.org
[2] https://www.avid.com/sibelius
[3] https://musescore.org/
[4] https://www.steinberg.net/dorico/
[5] https://github.com/humdrum-tools/humdrum-tools.git

exporting data, allowing users to isolate particular spine types (e.g. **kern, **mens, **harm, **dyn, **fing or **text) or specific spines of the same type.

A unique feature of *kernpy* is to normalize and process **kern data effectively through an EBNF (Extended Backus-Naur Form) grammar developed using ANTLR4 (ANother Tool for Language Recognition) (Parr, 2013). This approach formalizes the representation of **kern data.

By utilizing ANTLR4, *kernpy* links each token in the **kern file to a corresponding musical category, allowing for precise feature extraction. This capability makes it possible to create new **kern files by selecting specific token categories, simplifying the features an OMR model needs to learn.

Additionally, *kernpy* includes functionalities for generating tokenized datasets (Ríos-Vila et al., 2024), significantly enhancing the performance of training models. The *kernpy* package serves as a robust tool for creating and preprocessing datasets. *kernpy* could be used as it is shown in Figure 1.

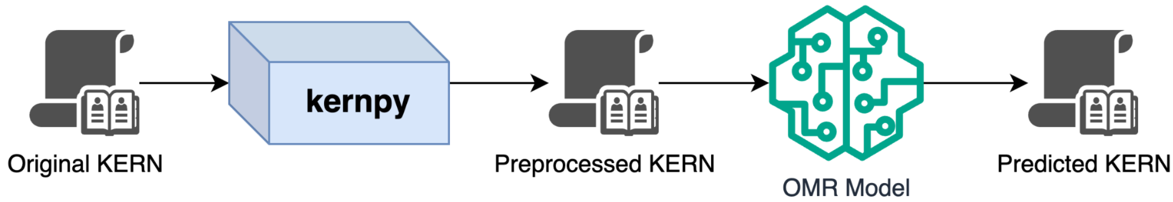


**Figure 1**: A workflow example for using *kernpy*.

## 2 Use cases of *kernpy*

Software capabilities are often described with precision; however, they are rarely fully utilized until their potential is demonstrated in practice. This observation aligns with the principle You Cannot Do What You Cannot See (YCDWYCS). To better understand this package, we will explore several illustrative examples.

### *2.1 Detecting categories: features extraction & filtering data*

Accurate score category detection enables flexible creation of **kern-like files. When a **kern file is loaded, tokens are categorized (e.g., "SIGNATURES", "COMMENTS", "BARLINES", "REST", "PITCH", "DURATION", "DECORATION", "EMPTY"), allowing users to extract specific categories or exclude others. This is particularly valuable for deep learning, as removing non-relevant tokens streamlines datasets for more effective training.

### *2.2 Tokenization and Standardization*

Traditional symbolic music representations in deep learning use compact tokenization, encoding elements like a half B-flat note with a dot and tie as "2.bb-_". While concise, this limits score manipulation flexibility. *kernpy* introduces a flexible tokenization strategy using non-standard delimiters –such as "@" or "·"– to indicate a token's graphic importance. For example, the same element is represented as "2@.@bb@-·_", offering finer control for preprocessing.

*kernpy* provides a deep-learning–oriented standardization of the Humdrum **kern format. Unlike the traditional approach, which allows arbitrary token order and leads to exponential variation, *kernpy* enforces deterministic subcategory-based sorting, ensuring a unique, consistent representation that improves compatibility and usability.

### *2.3 Handling data: creating new files*

Dividing a full-page **kern file into region-level scores is a common task in Optical Music Recognition (OMR). While some systems generate OMR predictions based on regions, very few datasets contain region-level annotations (Duguid, 2024). To address this gap, it is necessary to create synthetic **kern data with appropriate region-level tagging. Refer to the pipeline example illustrated in Figure 2.

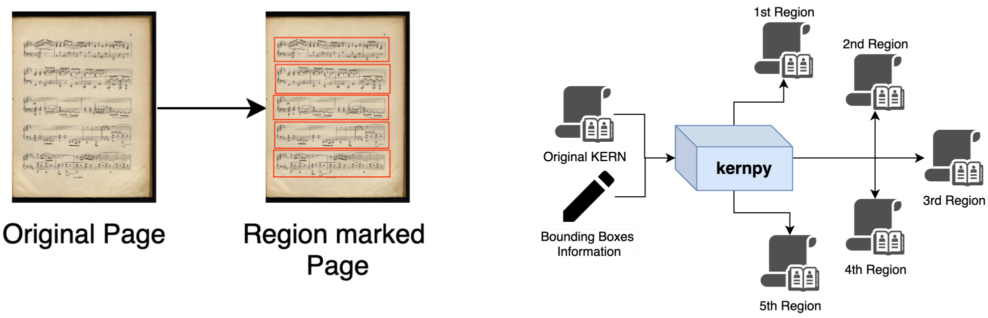


**Figure 2**: Generation of multiple **kern from a full-page score using tagged information and the *kernpy* package .

This functionality is versatile, enabling not only the division of **kern files into region-specific fragments but also for example the conversion of multi-page scores into individual full-page scores, or any **kern division.

*kernpy* also enables the manipulation of **kern files, including merging and splitting. This functionality allows for the creation of multi-voice scores from monophonic sources by merging individual spines. Conversely, it can also be used to decompose multi-voice scores into individual voice scores, such as splitting a sax quartet file into four separate monophonic files.

In addition, *kernpy* provides different strategies for solving existing errors in **kern files.

## Conclusion & Future Work

*kernpy* is a Python package that facilitates the processing of Humdrum **kern files, particularly in deep learning pipelines for OMR. The proven efficacy of **kern encodings in OMR models underscores the need for new robust tools. We are developing methods to evaluate the compatibility of **kern fragments before merging them into cohesive files.

## Acknowledgements

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# Visualizing Wagner: A Combined Annotational Approach to *Siegfried* Act III

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# Introduction

The music of Richard Wagner has always been a challenge. In particular, the question of "form" has been subject to musicological debate (Dahlhaus, 1969; Kleinertz, 2014). Recent approaches try to understand form through the analysis of dynamic musical processes that are closely tied to the progression of the dramatic narrative (Newcomb, 1981; Janz, 2006). A particular challenge is the sheer length and structural complexity of Wagner's works.

This poster addresses questions of form with the help of computer-based analysis. Using the first scene of the third act of *Siegfried* as an example, we try to show how large-format overviews can be helpful in understanding formal progression.

# 1 Methodology

## 1.1 Musicological background

While the initial focus was on so-called leitmotifs, Alfred Lorenz's work on the "secret of form" in Wagner's tetralogy *Der Ring des Nibelungen* (Lorenz, 1924) addressed for the first time questions of large-scale harmonic organisation. He divided every work in successive periods, characterized by one tonal key. Only decades later, his analyses met with fierce criticism, not least because they neglected dramatic development alongside 'architectural' form (Dahlhaus, 1969, 1971; McClatchie, 1998; Thorau, 2003). In contrast, more detailed analyses from the 1960s onwards overlooked the large-scale development (Voss, 2003).

In 1981, Anthony Newcomb published an insightful analysis of several scenes, including the first scene of act III of *Siegfried* (Newcomb, 1981). He emphasizes the role of contrast between stable and unstable tonal passages rather than of specific tonal keys. Moreover, he points to a global view regarding not only tonality, but also other parameters such as tempo or instrumentation. As a result, Newcomb proposes an incomplete ABA form.

## 1.2 Technical requirements and database

For the analysis of harmony and tempo in Wagner's *Ring des Nibelungen*, we use automated methods as well as annotations available in the Wagner Ring Dataset (Weiß et al., 2023). The visualization of harmonic progressions is based on measuring spectral energies from Bernard Haitink's 1990 audio recording (Wagner, 1875/2008).

We transform the spectral information into a chromagram representation by mapping the spectral data onto 12 pitch-class bands, corresponding to the 12 chromatic pitches of the octave. Based on these chroma features, we calculate a probability value for each of the 12 diatonic scales, which is displayed across 12 bands on the vertical axis in the visualization (Figure 1). The "0" band corresponds to the diatonic scales without accidentals, i. e., the pitch content of the C major or the A minor scale (absolute diatonic scale measurement). The remaining bands are arranged with respect to the circle of fifths, e. g. -1 corresponds to F major or D minor, +1 corresponds to G major or E minor etc. (Weiß & Müller, 2021).

We calculate tempo values using measure annotations from 16 recordings of the *Ring* (Weiß et al., 2023). This results in a tempo curve representing the average tempo for each measure, providing sufficient accuracy for depicting tempo across larger sections of the work. To minimize interpretive deviations, we calculate the mean value for each measure across all

16 recordings. Additionally, speaker roles (Weiß et al., 2023) and Lorenz's periods have been annotated and integrated into the visualization of scale probabilities and tempo.

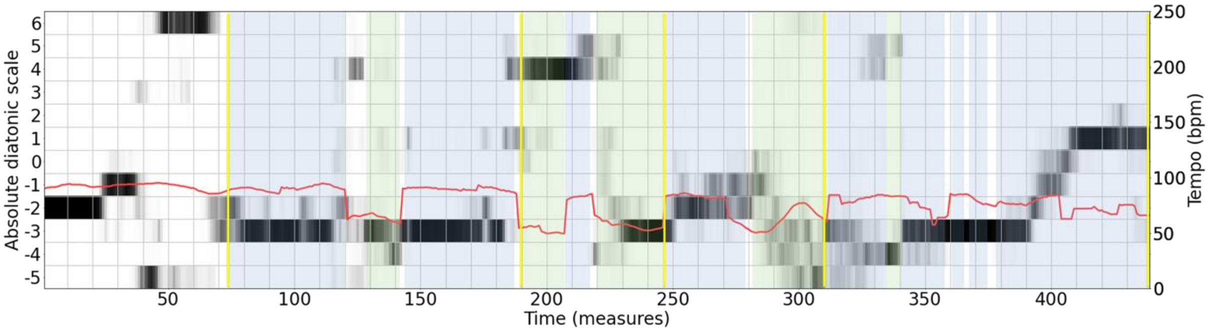


**Figure 1**: Visualization of *Siegfried*, Act 3, Scene 1: The probabilities for diatonic scales are represented in grayscale and overlaid with a red tempo curve (in bpm). Transparent, colored areas indicate the singer activity of the characters Wotan (light blue) and Erda (light green), respectively. The thick yellow lines refer to Lorenz's periods: mm. 1–73, prelude in G minor; mm. 74–190, 1st period in G minor; mm. 191–245, 2nd period in A♭ major; mm. 246–310, 3rd period in E♭ major; 311–439, 4th period in G minor.

# 2 Describing visualization

The instrumental prelude opens the scene with the tonic G minor (-2) to which it returns at Wotan's [Der Wanderer] entrance at m. 74. His wake-up call and speech to Erda moves on tonally quite stable around the -2 and -3 regions, whereas he takes over the prelude tempo at ca. 117 bpm. We observe a clear break at m. 121: The tempo abruptly slows down to about 80 bpm and tonal keys move to distant regions. These two features characterize the awakening Erda. Wotan's response (m. 143) brings back the former tempo and he returns to E♭ major. At this point Lorenz's first period ends. He defines E♭ major as tonal centre for his second period. We observe a clear concentration on the -3 region around m. 230, but this and the following passages are hardly defined tonally. In the ongoing dialogue, Wotan adapts Erda's unstable tonality, maintaining however the faster tempo. Erda instead reaches at some points tonally stable regions (e. g. +4 around m. 200) and abandons her slow tempo firstly after m. 291. Due to Wagner's fermata ("long silence") such interactions come to an abrupt end at m. 351. Then, beginning in E♭ major, Wotan's final speech regains its tonal clarity.

# Conclusion

Despite his preliminary considerations, Newcomb discusses the scene nearly exclusively regarding harmonic progressions and dramatic interactions between the protagonists Erda and Wotan. Neither tempo nor references to Lorenz's periods are taken into account. Our combined visualization of different annotations is meaningful from both points of view: 1. It confirms Newcomb's observation on the importance of stable and unstable tonal passages. Such a contrast characterizes the two speakers as well as the overall form. Newcomb's suggested ABA form (A: mm. 74–189, B: mm. 190–356, A: mm. 357–439) is reflected in the -3 black zones (E♭ major) framing the A parts. 2. The visualization shows that the same is true for the tempo contrast as well between Wotan and Erda as between the sections. A comparison with Lorenz's periods, however, is difficult: Only his first period corresponds to section A, the other periods have no correspondences and are less convincing from the visualization perspective.

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# Evaluating Music Encoding Approaches: An Accuracy Analysis of Tools and Standards.

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## Introduction

Digital encoding of music allows the transformation of both audio and notation scores into digital formats. This process facilitates storage, editing, and distribution, enabling the interactive and accessible creation and encoding of music from analog. It has revolutionized music editions, improving precision, global access, and the preservation of information, integrating technology and art in a digital environment.

For that reason, music encoding is widely used in current musicological projects. Many of them still use manual encoding approaches, either directly inputting music codes (Duguid, T.

2024), or by means of notation applications (Torrente & Llorens, 2021). In some cases, Optical Music Recognition (OMR) (Rebelo, et al., 2012; Calvo-Zaragoza et al., 2021) is used, which facilitates the process by converting digitized images into digital scores (Rizo et al., 2024).

It's not only important to consider the effort to do it either with OMR (Alfaro et al., 2021) and manual entry tools (Sapp, 2017), or through notation programs (Nowakowski, 2023). But also to select the appropriate encoding standard, such as Plaine and Easie Code (PAEC) (Brook, 1965), MusicXML (Good, 2001), MEI (Hankinson, et al., 2011), or **kern (Huron, 1997) among others, and to take into account possible conversion needs due to information loss in the process (Nápoles et al., 2018).

This experiment explores different approaches to encode music to determine from a quantitative and qualitative point of view which method is more efficient and accurate based on different usual tasks of music information retrieval and musicology projects.

# 1 Method

For our purpose, monophonic instrumental pieces written in common Western notation have been selected from "The Dance Music of Ireland" (O'Neill & O'Neill, 1901), with a length of between 17 and 67 measures, that allows for a detailed but accessible analysis of the transcription and encoding. These pieces are chosen to ensure that the transcriptions are not overly complex, allowing for an effective comparison of different encoding formats and tools. Monophonic music ensures that the accuracy of the transcription of a single melodic line can be assessed, without interference from harmonies or counterpoints.

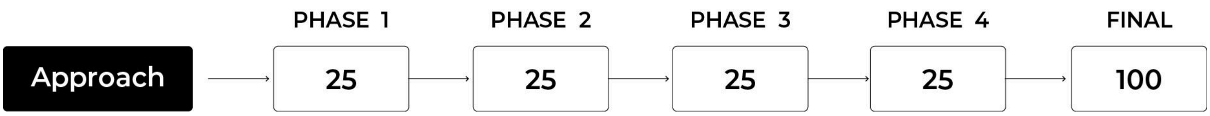
The process that will be carried out in three stages: a) encoding input, b) encoding accuracy evaluation, and c) analysis. Seven different encoding approaches have been evaluated, some use manual direct input of the encoding format: PAEC with an online interactive *ad-hoc* viewer[1] that utilizes Verovio to render the input encoding to facilitate the process, **kern with Verovio Humdrum Viewer[2] (Sapp, 2017), MEI with MEI-friend[3] (Goebl & Weigl, 2024). Two of them manually using notation programs, Musescore[4] using the computer keyboard and mouse, and Sibelius[5] accelerating the process with a MIDI keyboard, and finally two OMR applications, the latest version of Photoscore[6] and its correction with Sibelius, and MuRET (Rizo et al., 2023).

## *1.1 First stage*

The objective pursued in the first phase is to compare the previously introduced encoding approaches, in key aspects such as accuracy, ease of use, flexibility, and efficiency (Nowakowski, 2023). This phase consists of encoding 100 pieces and then transforming

[1] https://grfia.dlsi.ua.es/paec/paec.php
[2] https://verovio.humdrum.org/
[3] https://mei-friend.mdw.ac.at/
[4] https://musescore.org/
[5] https://www.avid.com/sibelius
[6] https://www.avid.com/products/photoscore-and-notateme-ultimate

them into the different format intrinsic to each approach, as shown in Figure 1. For instance, the main exported format used when encoding in MEI-friend is MEI.




Where approach is one of PAEC, Verovio Humdrum Viewer, MEI-Friend, Musescore, Sibelius with MIDI, Photoscore, MuRET

**Figure 1**: Organization of our encoding experiment in phases.

For each approach, the process will be done in 4 phases of different 25 pieces each to identify potential transcription errors (Figure 2). The different partitions are balanced in terms of song length and complexity.

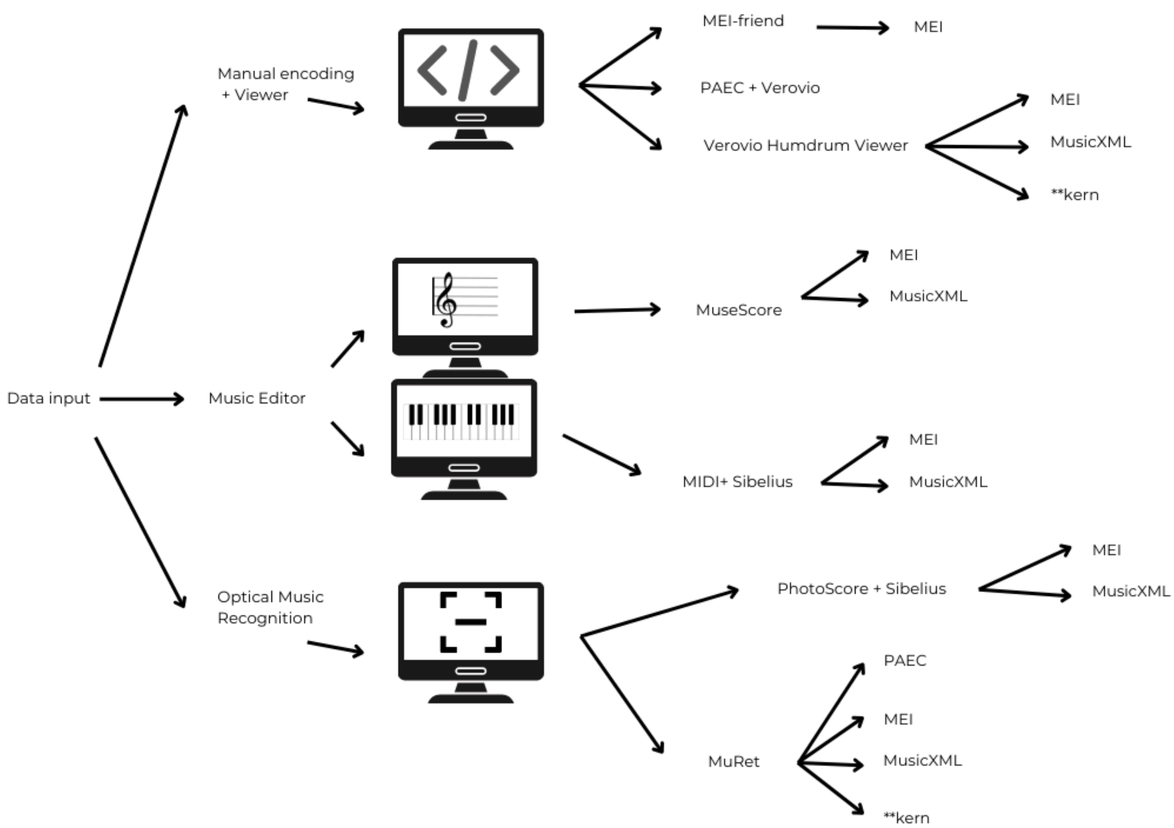



**Figure 2**: A workflow example.

## *1.2 Second stage*

Once the pieces have been transcribed with these tools, the next step will be the evaluation of the encoding accuracy to describe quantitatively and qualitatively the possible problems introduced by each approach, either by the software used or by the coding itself.

For those approaches using a direct format input method (VHV, PAEC, MEI-Friend), both the representation capability of encoding formats with missing or ambiguous features and the engraving using Verovio will be evaluated. In the latter case, the evaluation will be performed by visually comparing the rendered output with the original source.

In the case of music notation programs and OMR tools, in addition to the fidelity of the tool's engraving with respect to the source, the different export formats they support will be evaluated, assessing the accuracy of the encoding obtained with respect to the source (see Figure 3).

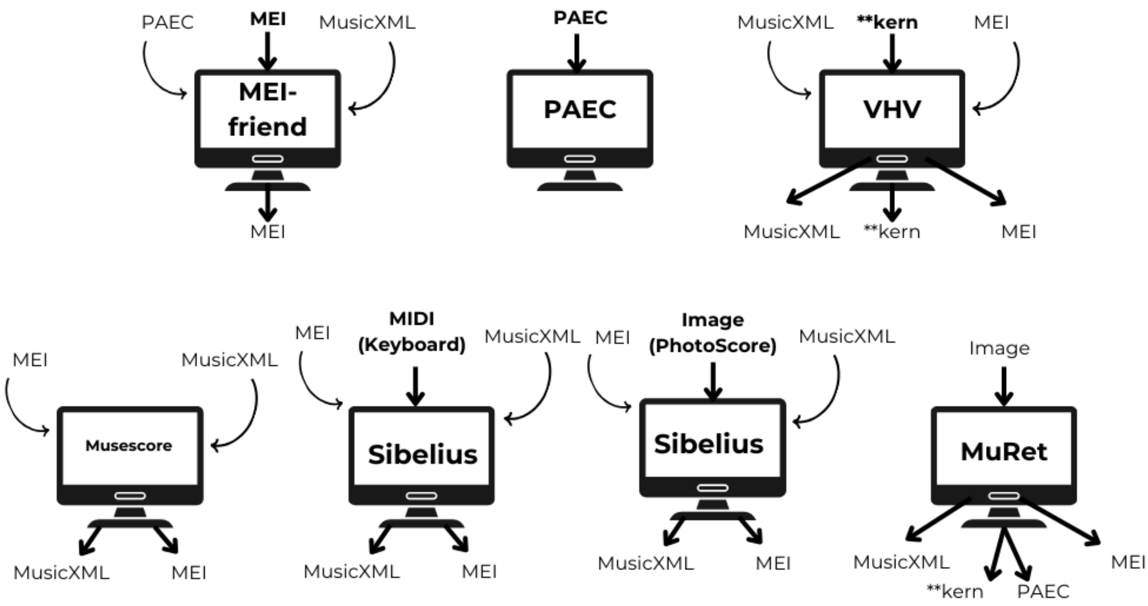



**Figure 3**: Different approach outputs used in the evaluation of the encoding accuracy.

# Conclusion

The proposed experiment allows for evaluating various approaches to music encoding and the tools used to transcribe and transform scores into multiple formats. The results will likely provide a clear insight into the efficiency and accuracy of the formats mentioned. In conclusion, it will help identify the most suitable method based on the specific needs of music projects, such as detailed score representation, ease of use, or transcription process efficiency. Additionally, the impact of conversion between formats and the potential transcription errors that may arise can be assessed. The results will help optimize digital encoding and transcription tools, thereby improving precision and accessibility in music research and practice, facilitating the work of musicologists and musicians.

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# Pushing the standard to its limits: MuseScore as a feature-complete MusicXML editor

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## Introduction

The de facto standard format for the exchange of symbolic music notation today is MusicXML. More than twenty years have passed since the first version was published at the beginning of 2004, and the format has developed considerably since then and the encoding possibilities have been greatly expanded. In the latest version 4.0 in particular, the addition of the “smufl” attribute makes it possible to encode and use the entire range of glyphs defined in the SMuFL standard in many places. However, the degree of implementation varies greatly from application to application, and a visual tool that supports all available options is still missing. Is it even possible to achieve full compliance?

## 1 Prerequisites and fundamentals

In an initial study (Rettinghaus et al., 2023), the export capabilities of MusicXML of various music notation programs were examined and compared. Surprisingly, there were very strong differences between the individual programs. In particular, most programs still lack the corresponding support for the symbols that have been added in MusicXML versions 3.1 and 4.0.

The program with the broadest support in the study at the time was MuseScore (now called MuseScore Studio to differentiate it better from the score-sharing platform MuseScore.com). Although there were also weaknesses here, the examined functionality showed a clear lead over the competition.

This, in turn, prompted an extended exploration of the MusicXML format and its possibilities, which revealed that there is much further potential for supporting this format in MuseScore Studio – both for export and import. Since MuseScore is open source and has made great progress in development since the release of version 4.0 at the most, it was decided to address missing or incorrectly implemented MusicXML support features. This is relatively easy, as the development of MuseScore Studio takes place on GitHub, an online service for software development and version management. The further development of MusicXML itself, its potential successor MNX and other coding standards such as MEI and TEI also takes place on this platform.

# 2 Status Quo

To date, a considerable number of modifications and additions have been made, some of which have already made it into subsequent versions of MuseScore Studio.

For example, it is now possible to import and export the (relative) sizes of the staves, to export scores in concert pitch and accidentals on ornaments like turns and mordents. Also the support for colored elements has been massively expanded. And with the upcoming release it will be finally possible to handle an larger set of metadata.

Although it is desirable that all MusicXML features work for both import and export, this project focusses a little more on export. Nevertheless, some missing functions have been added on the import side to enable round trips, for example working with feathered beams. Ideally it would be possible to import and export a MusicXML file without loss of information. Currently it is even possible to store and retrieve some details of the score in MusicXML, that are not preserved with MuseScore's own standard file format.

# 3 Outlook

Improved support of MusicXML promises the scientific community significant new impulses for the potential of findings in musicological projects. The more musical information can be preserved in these exported files, the more things can be examined in large repertoires. (Nápoles López et al., 2018)

PDMX, the *Public Domain MusicXML Dataset*, (Long et al., 2024) for example, was created by scraping MuseScore.com, the forementioned online forum where members of the community can upload their own music engravings and compositions. It is possible to download the sheet music provided in various formats, including MusicXML. So the ultimate goal would be to have a feature-complete MusicXML editor with MuseScore Studio that is capable to preserve almost all engraving details in the exported MusicXML files

# Conclusion

The poster presented is intended to provide an insight into the additions and further developments to date. A live presentation and hands-on session is also offered for interested parties. However, it also aims to highlight limitations, as MusicXML contains a number of ideas that are unlikely to be covered by any program like MuseScore in the foreseeable future. Feedback from the community on yet missing features and possible prioritizations is hoped for.

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# Is it a work – and if yes, how many? Considerations for the further development of a metadata editor for MEI data

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## Introduction

Work on catalogs of works and sources is currently undergoing major changes. Many such catalogs have emerged as “by-products” of decades-long critical edition projects. They list either a) all sources that are relevant to a composer's oeuvre (source catalogs), and/or b) all information relating to a composer's oeuvre (catalogs of works). The former typically originates from physical evidence in the sources; the latter from intellectual concepts of the “work” supported by source documentation.

In reality, the distinction between these approaches is never clear-cut. Especially in the context of Linked Open Data (LOD), entities are interconnected in complex networks. Every source entry requires at least minimal information about its associated work and authorship. In a data environment that emphasizes granular, interconnected, and independently addressable information units, the autonomy and verifiability of each data point becomes essential. These units must be capable of standing alone while being framed with clear genre-specific contexts and functions.

# MerMEId: to the present

Does this mean that approaches based purely on the musical "work" are still up to date? Is a work-centric approach still the best way to model such catalogs, regardless of the nature of the musical entities they describe? And what about tools that reinforce this approach by exclusively supporting this form of data modeling? Should not tools be free of scientific premises and disciplinary biases that are arbitrarily exclusionary, and should not they rather offer researchers a technical basis that they can use to document their findings using technical instruments?

MerMEId (Metadata Editor and Repository for MEI Data) is a tool that may provide an answer to this question. It is the most widely used editor for producing MEI metadata—data that is required, for instance, in the creation of digital work catalogs and that can be enriched with content from other repositories like RISM. MerMEId pursues a work-centered approach—at least implicitly. Originally developed for 19th-century work catalogs (e.g., Carl Nielsen, Niels W. Gade, Johann Adolph Scheibe), it is now used in international projects across diverse repertories.

In these contexts, MerMEId has proven broadly useful—even if a bit more flexibility would be desirable in some places. However, as the only available editor for MEI metadata, it is often pressed into service for use cases it wasn't designed for. For example, MerMEId's internal data model makes it unsuitable for building a pure source catalog, which doesn't assume a single "work" as the starting point. Such catalogs reflect the diverse, often non- hierarchical realities of musical creation more accurately—especially in repertories where the "work" is a later abstraction.

# MerMEId: The Future

The DFG funded project "MerMEIding to the Future – A Community based approach for high quality metadata in digital Musicology" (*project number 528785591*) is addressing these challenges directly. How can the MerMEId editor be further developed so that it can be used more flexibly in different project contexts and focuses more on the creation of connectable metadata than on hierarchical modeling? Is it still appropriate to create ONE large MEI file that contains all metadata from the work to all versions of a work (including performance material, audio recordings, video recordings, adaptations, etc.), all associated sources and copies (printed and handwritten, from the printed copy to every special copy that is existent, etc.)? Should not such an editor rather create the possibility of mapping the small information units already mentioned above and offer extensive linking options, including to other data formats, so that on the one hand an entry point can be freely selected and on the other hand information can be compiled as required? This is the only way to create a long- term interconnectivity of individual entities, including works and versions, but also musical sources, which point beyond the work of individual composers. Classification in an overarching context is only possible in this way and only if all projects pursue a similar strategy, if data modeling is coordinated, if corresponding ontologies are stored and the concepts are harmonized and coordinated.

This undertaking both implies and requires a great deal of detailed work to fulfill. Considering large contexts is different from discussions project-specific details, and the relationship between narrow and broad scope must also always be considered in addition to these different hierarchical levels. Almost every project has its own special features, but these do not necessarily mean that the big data system cannot be coordinated in larger contexts. It is therefore necessary on the one hand to find a form of coordination for the large entities (versions, sources, etc.) and on the other hand for the finer details, which include classification of the sources and sources containing diverse kinds of musical contexts. Experience has shown that each project has developed its own source classification and used it within the project. But are the concepts really so different? The types and qualities of different versions must also be precisely defined in a data model. If this approach were pursued, it could bring great progress in terms of clarity and transparency while also ensuring research findings are preserved and shared, rather than remaining locked within project contexts.

## Conclusion

All these considerations are currently being discussed at the Center for Digital Music Documentation (CDMD). In addition to further developing MerMEId for usability and sustainability, CDMD is also developing an ontology for digital catalogs of musical works. This work will coordinate with various cataloguing efforts, especially those affiliated with long-term projects under the Mainz Academy of Sciences and Literature. All this is being done in close cooperation with NFDI4Culture, the consortium for research data on material and immaterial cultural assets. The presentation will provide an insight into current developments in the field of digital source and work catalogs and considerations as to how these data sets could be brought into a larger context in the future.

# Towards a Digital Critical Edition of the Operas of Vincenzo Bellini

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## Introduction

Established in 2003, the “Edizione critica delle opere di Vincenzo Bellini” (Milan, Ricordi) plans to publish all of Bellini’s music in a critical edition, serving a dual purpose: philological, to present musical texts that reflect authorial intention; and practical, to provide users and performers with reliable scores that correct errors perpetuated by traditional editions. Each volume also seeks to establish, with the highest possible accuracy, textual data corresponding to different, equally legitimate, versions of individual passages or larger sections, thus addressing the typical textual challenges of this repertory – where performers or the composer himself often modified the text of an opera for specific performances.

There is, however, a disjunction between the fluid ontological nature of nineteenth-century Italian opera and the static format of the series' printed editions, which presents several limitations: a) the print format does not allow simultaneous visualization of alternative materials; b) users lack access to the sources on which the editions are based; c) the text of the main score cannot be modified, preventing the incorporation of alternative materials.

This poster illustrates the research objectives of the VerDigital project, which intends to overcome these limitations by combining the meticulous editorial approach of the series (Della Seta and Ricciardi, 2004) with tools offered by digital musicology. Specifically, VerDigital will employ the latest version of the Edirom digital framework and the Verovio music notation toolkit to develop 1) a model of digital critical edition that preserves scholarly rigor while improving the performability of the main text as well as of alternative materials, 2) a complementary model of digital critical edition of Bellini's preparatory materials.

# 1 Model 1

## 1.1 Adelson e Salvini

The first model is a digital critical edition of Bellini's *Adelson e Salvini* (1825), organized using Edirom and comprising: a) a historical introduction; b) encodings of the principal sources (MEI); c) encoding of the newly edited score, from which to extract digital parts (MEI); d) reproductions of the principal sources; e) a critical edition of the libretto (TEI); f) a digital critical commentary; g) reproductions of secondary documents. All elements are accessible either individually or through cross-links.

Bellini's first opera, *Adelson* represents an ideal case study for the model. Written as his final project at the Conservatorio San Sebastiano (Naples), it was later revised in preparation for a professional performance. The opera is documented through the autograph score, which contains several lacunae, and a set of orchestral parts used for the premiere (Toscani, 2001). These parts feature autograph annotations by Bellini and, in some cases, reflect a more advanced textual stage compared to the score. Consequently, the edited text must be established through a conflation of the sources, which can be regarded as a 'single, multifaceted source' (Della Seta, 2019).

The digital edition will not simply provide encodings of the individual sources (which, while enabling the analysis of internal data, do not allow for the reconstruction of a complete edited text that can be used by performers) but will also present an encoding of the edited text, offering data to retrace the editorial process.

## 1.2 Interactive system of usage

The poster illustrates the strategies adopted to develop an interactive system of usage, allowing performers to choose among alternative readings/versions to customize their score/parts. To maintain editorial integrity, the team will furnish preselected alternative materials that can be used to build an authoritative score. Relying on a tailored combination of XQuery, XSLT, and javascript, VerDigital will propose an extension of the Edirom digital edition tool to render dynamically with Verovio alternative versions of any passage encoded with MEI. The digital score can thus be modified at a granular level so that even small changes are reflected in parts that can be extracted for performance.

# 2 Model 2

The second model focuses on Bellini's 'studi giornalieri' (=daily studies), which attest to the preliminary phases of his creative process, during which he annotated ideas of varying length and nature, only some of which would later be selected for actual use: melodies, accompaniment models, harmonic successions, etc. The result is a group of pages crowded with multiple, distinct annotations that may or may not be reciprocally related (Mantica, 2020). The model includes, in particular, eight pages dating from 1823-1824, some of whose ideas were later used for *Adelson*. These do not contain a single text, but a multitude of texts that coexist in the same *Schreib- und Denkraum* (Oppermann 2003; Beethovens Werkstatt) and thus are still influencing each other. This generates two necessities: to view individual pages as unified creative entities, and to isolate the single annotations, in order to analyze them within their genetic process. The poster shows the project's editorial solution to both necessities, seeking to integrate the 'particular' and the 'contextual' gazes required to grasp the compositional process attested by the manuscripts. From a practical standpoint, VerDigital faces the challenge of producing an encoding that can render both a 'diplomatic-interpretive' visualization, based on the actual spatial organization of these pages, and a 'linearized' transcription, centered on the textual features of each fragment. This encoding will be connected to the reproductions of the source, in order to build a 'manuscript-centered' usage of the model that does not assign to the reproductions merely a 'control function' for the transcription.

# Conclusion

VerDigital has significant technological and methodological implications, presenting the first digital critical edition for a nineteenth-century Italian opera series, which will be aligned with the FAIR principles for data management. Designed with both scholars and performers in mind, the first model aims to improve accessibility to the collected data, fostering its practical use beyond the academic domain. Its interactive system of usage, which supports the integration of alternative materials, seeks to facilitate a more dynamic interpretation of Bellini's opera, consistent with the nature of the repertory. Overall, the project's models hold the potential to establish a new standard for future digital critical editions, not only of Bellini's works but also for other nineteenth-century opera composers.

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# PANELS

# Sketching genetic editions: Challenges and Opportunities.

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# Introduction

The digital humanities have been changing scholarly methodologies in musicology for quite a while now. With this panel we would like to explore the possibilities of musicological genetic editions also in the digital realm. Bringing together four doctoral students with different backgrounds, experts on various 19th century composers, the discussion aims to address critical questions about the nature, scope, and practical implementation of genetic criticism into digital editions. Our focus extends beyond the territory of the well known project *Beethovens Werkstatt*, examining how new approaches can accommodate a wide array of musical repertoires, sources, and creative processes (Beethovens Werkstatt, 2024). Each panelist will pitch their research, highlighting the unique selling points of their projects, the challenges posed by their sources, and the innovative models, tools and concepts used to deal with these challenges.

# 1 Exploring the compositional process

Digital genetic editions represent an attempt to document and analyze the creative process of composition through a dynamic representation of its textual and musical sources. These editions seek to move beyond the final stage of the work by shedding light on the intermediary stages of creation.

*Beethovens Werkstatt* – a joint research project by the Beethoven-Haus Bonn (Germany) and the Department of Musicology Detmold/Paderborn (Germany), funded by the Academy of Sciences and Literature Mainz (Germany) – plays a pioneering role in the field of genetic text criticism in music and digital editions. It is a fundamental research project that, for the first time, presents a series of concepts and models, as well as a glossary, for the investigation of writing and compositional processes in music and their digital representation and communication (Beethovens Werkstatt, 2024).

# 2 Research Pitches

The panel is organized around four case studies: the sketches and autograph manuscript for Ludwig van Beethoven's Bagatelle Op. 126, Franz Liszt's autograph manuscript for the Sonata in B minor, the preparatory materials for Carl Maria von Weber's opera *Die drei Pintos*, and the surviving compositional sketches of Johannes Brahms. Collectively, these studies offer a multifaceted view of how digital genetic editions can address diverse repertoires and reveal the creative dynamics embedded in musical documents.

Each panelist will introduce a case study, illustrating how their project expands the boundaries of genetic editions and illustrates the extent to which the research subject could reuse the concepts and (data) models from *Beethovens Werkstatt* and where there is a need to modify or extend them.

## *2.1 Beethoven's Bagatelle Op. 126/6*

The first case involves all of Beethoven's working manuscripts for the Bagatelle Op. 126 No. 6, that is sketches and two versions of the autograph manuscript. Some pages of the sources A50 and BH112 contain the sketches for the Bagatelle. Originally, both sources were part of the sketchbook Landsberg 8/2, which is kept in the Berlin State Library. After Beethoven's death, the last 16 leaves were separated from Landsberg 8/2, 14 of which are now in the archive of the Gesellschaft der Musikfreunde in Vienna under the signature A50. One bifolium lies in the Beethoven-Haus in Bonn (D-BNba, BH 112). This bifolium was originally the inner folium in the last of four layers of A50. (Beethoven 1984, p. 50)

The autograph Mh23, which is located in Bonn too (D-BNba, Slg. H. C. Bodmer, HCB Mh 23) looks like a fair copy but with a section that has been changed a lot and where the compositional problem Beethoven tries to solve becomes visible. There is a second version of the autograph that seems like a fair copy of the work, Ms 81 (F-Pc, Ms 81), which is only missing the first page. This autograph, which is located in the Bibliothèque Nationale de France in Paris, was originally part of Mh23. However, due to the significant modifications made to the musical text and the fragmentary, sketchy nature of many sections, it has become illegible. Therefore, these pages, except for the first page, were removed and rewritten. (Beethoven 1984, p. 63).

However, the fragmented and visually complex nature of the sources, above all the sketches, poses significant interpretative challenges, making them an ideal testing ground for the models and concepts that have already been developed in *Beethovens Werkstatt* to describe and encode writing chronologies and processes. In addition, the fact that the Bagatelle comprises only 74 measures makes it a perfect case study to analyze it as a complete work with all its sources and to describe the writing processes in the sources internally, but also across documentary boundaries, in order to gain a complete impression of the genesis of the work. To properly encode these findings in a data model, some of the models from *Beethovens Werkstatt* are used, for instance the concepts of genetic markup to encode genetic states and their order that has been integrated in the MEI Guidelines. I will discuss areas for which the models are insufficient and in which adjustments, additions or even a completely new data model are required.

## *2.2 Brahms' sketches*

The second case concerns the surviving composition sketches of Johannes Brahms. It is known that Brahms destroyed most of his manuscripts that he no longer considered 'useful', such as manuscripts of unfinished or unpublished works, among which it is thought there may have been numerous sketches and drafts. It is likely that Brahms, who was a friend of Gustav Nottebohm, saw what was happening to Beethoven's sketchbooks and deliberately wanted to remove all traces of his own creative process. However, for the most casual reasons, some sketches have survived his work of destruction. These are preparatory materials for around 30 operas, compositions of various genres and instrumentation covering the composer's entire creative period. Most of the sketches available today are preserved in the archives of the Gesellschaft der Musikfreunde in Vienna (A-Wgm, A 116-122, 128-130). A few other sketches are found in various archives, digital copies are available (Digitales Archiv – Brahms-Institut an der Musikhochschule Lübeck – US-NYpm, Dep. Sammlung Robert Owen Lehman, B8135).

The challenge in analyzing these materials with a comparative view is to borrow the investigative methodologies for studying the creative process of other composers and to ‘import’ them into Brahmsian studies, which, until now, have focused their efforts on other types of materials, such as autograph manuscripts, and consequently, on other phases of the work's creation process.

Among the surviving sketches, we can observe very heterogeneous material from a textual point of view: some present a clean and linear writing, others are characterized by a higher textual dynamism. It is precisely for the latter that a possible digital redynamization may be an interesting opportunity to take a look for the first time inside this Brahms' compositional workshop, which to this day remains relatively unexplored.

### *2.3 Liszt’s Sonata Manuscript*

The third case focuses on the autograph manuscript of the Sonata in B minor by Franz Liszt. Composed between 1852 and 1853 and recognized as part of the piano repertoire shortly after its publication, this Sonata is universally regarded as an absolute masterpiece of piano literature. The only source that transmits a complete version of the Sonata is the autograph manuscript preserved at the Morgan Library & Museum in New York and part of the Robert Owen Lehman collection (US-NYpm, Mary Flagler Cary Music Coll., L774.S627); it consists of 15 blue sheets in vertical format with a variable number of staves. The manuscript is characterized by bold revisions and idiosyncratic notation that reflect his fluid, improvisatory approach to composition. Unlike Beethoven’s sketches, which convey a more methodical process of refinement, Liszt’s materials require an editorial approach that captures the dynamic interplay between notation and performance. Liszt makes extensive use of patches to replace entire sections: this allows us to discover what Liszt decided to replace, thus reconstructing the genetic process of the Sonata. It is also interesting to observe that the manuscript was also used as study material for the pianist Hans von Bülow, who was the first to perform the Sonata: in fact, we find fingering indications written in pencil and red pen. This case raises critical questions about how genetic editions can accommodate performative elements and the often-elusive boundaries between composition and improvisation in Liszt’s music.

### *2.4 Weber’s “Die drei Pintos” Materials*

The last case examines the preparatory materials for Carl Maria von Weber’s opera fragment *Die drei Pintos*. The composer started to work on this comic opera in 1820, but when he died in 1826 he had written down drafts up to the beginning of the second act. The most extensive source of the *Pintos* is stored in the Berlin State Library (D-B, Mus.ms.autogr. Weber, C. M. v., WFN 3) and contains drafts of different shape, number of voices and extension, which are partly notated as a kind of piano reduction, partly as a – rather rudimentary – orchestral piece or particell. Due to different means of writing media, corrections, additional notes, and other codicological characteristics it can be classified as a working manuscript. This writing manner is not only specific for the compositional process on the *Pintos*, but can also be found in other manuscripts of the composer (Jaehns, 1871, p. 421). Although the example seems to be quite similar to the other cases, there is one major difference: the opera is unfinished. This means that the final product to which the sketches were intended to lead cannot be consulted, especially not for comparisons or classifications in the compositional process. In this sense, the research of the work can be more open, but the lack of a compositional goal can also create unresolvable gaps to other aspects.

*Beethovens Werkstatt* aims to develop methods as well as a terminology that should be transferable not only to other compositions but also other composers (Beethovens Werkstatt, 2024). In this sense this *Pintos*-study uses both the vocabulary of *Beethovens Werkstatt* as well as the strategies of different MEI-based transcriptions to elucidate Weber's compositional process.

## Conclusion

These case studies expand the focus beyond a single composer's workshop, addressing different genres, repertoires and creative contexts. They invite comparisons and contrasts, offering insights into how the concepts and models of Beethovens Werkstatt can be adapted to different challenges, from Liszt's fluid revisions to the openness of the Weber manuscript. The presented sources reveal distinct challenges and possibilities for genetic editions, also in digital form.

By focusing on these themes, the panel aims to inspire a broader conversation about the future of digital genetic editions in musicology. Ultimately, this panel envisions a future where digital genetic editions become a central tool for understanding and engaging with the creative processes of composers.

## Structure of the panel

The session is structured to maximize interaction and critical discourse over 90 minutes. The four panelists will each deliver a focused 10-minute presentation on their case studies, accounting for the first 40 minutes of the session. The 40 minutes of presentations will be followed by an approximately 20 to 25 minute discussion among the panelists, moderated to draw out key connections and contrasting viewpoints. After that the floor will be open to audience participation. This interactive segment is intended to get into a wider discussion about the challenges and opportunities in creating digital genetic editions. Questions from the audience will allow panelists to address specific points of interest, share practical insights, and consider alternative perspectives. A researcher from *Beethovens Werkstatt* will assume the role of moderator. Additionally, that person will oversee the debate and, if required, contribute to the discussion and address any queries. By fostering a collaborative atmosphere, the session aims to build a sense of shared inquiry among scholars, practitioners, and other participants. By addressing theoretical frameworks, practical tools, and collaborative models, this session seeks to contribute to the ongoing evolution of musicology in the digital age.

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D-BNba, BH 112
D-BNba, Slg. H. C. Bodmer, HCB Mh 23
F-Pc, Ms 81

# Pedagogy & Public Musicology Round Table

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## Introduction

Student-centered digital pedagogy and projects enable simultaneous engagement with music history and literature as content while developing expertise in critical digital literacy skills. Through assignments or projects that employ music encoding standards, data curation, or creation of public facing scholarship students develop transferable skills that can be applied beyond the classroom and academy. Their knowledge is made visible through open-access projects that can become a resource for future students or scholars in the form of encoding, mapping, and other novel forms of disseminating information. Furthermore, such publicly available forms of publication aim to be inclusive, projecting knowledge and resources beyond the academy.

In this roundtable, we bring together scholars and practitioners with backgrounds in public musicology, digital humanities, libraries, archives, and music encoding who will share their experiences in leveraging digital humanities methods and tools to engage students in experiential praxis-centered music courses and projects.

Drawing on experiences teaching a seminar on music and public scholarship, Will Robin will address how to teach students the concept of the public. One longstanding problem of the phrase “public musicology” has been the assumption that there is a single, unified “public” waiting for scholars to reach it; in this presentation, Robin will discuss the idea of publics: how to conceive work aimed towards imagined and real non-academic audiences, and how to help students execute projects that draw on existing publics or develop new ones.

As part of the public musicology program at Columbus State University, students take four courses in which they undertake several digital musicology projects including editing and encoding music in manuscript form using MEI, database entry, and use of online digital content management systems for exhibits and archiving. After giving a brief overview of the program, Reba Wissner will discuss how music encoding and digital musicology are fundamental public musicology skills for every music student, and how these skills can be incorporated into almost any music history course.

Working with information students presents a unique approach to digital musicology. With an emphasis on creating space for close reading, for preservation, and for generating material that will be useful to future users and researchers, students in a special topics course on Music Encoding at the University of Maryland School of Information encoded a corpus of works by Carrie Jacobs-Bond, based on archival manuscripts at the Library of Congress. They subsequently collaboratively wrote a best practices paper for others embarking on encoding projects. Jessica Grimmer will discuss how this course equips students with technical and conceptual skills in digital humanities fostering connections between scholarly work and public engagement. She will also highlight strategies for using MEI to create accessible, sustainable, and community-focused digital resources.

# WORKSHOPS

# Navigating and Processing MEI Data with XPath and XSLT

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## Conveners

Martha E. Thomae and Perry Roland

## Requirements

- **Participant-supplied laptops** with **Oxygen XML Editor installed** (a 30-day free trial is available at https://www.oxygenxml.com/xml_editor/register.html)

## 1 Overview and Significance to the Community

This workshop offers an opportunity to explore foundational techniques for working with **MEI** (Music Encoding Initiative) and **XML** markup. Designed for researchers, practitioners, and scholars with prior exposure to MEI, this full-day session focuses on two tools: **XPath**, a query language for navigating XML structures, and **XSLT**, a transformation language for processing XML documents.

As MEI has gained traction in the fields of digital musicology and scholarly editions, understanding how to efficiently extract, analyze, and transform XML data has become increasingly essential. Whether one is working with MEI to study musical scores, encode annotations, or structure metadata, XML-based workflows enable richer analysis and presentation. By combining XPath and XSLT, workshop participants will learn not only to *query* their data but also to *process* and *restructure* it for use in research and visualization platforms.

This workshop is particularly relevant to those working on MEI documents who seek a practical way to interrogate and transform their encodings for further research and sharing. The skills introduced during the session will empower participants to move beyond manual manipulations, adopting reusable, programmatic approaches to analyze their data efficiently.

# 2 Topics to Cover

## *2.1 Introduction to XPath and XML Navigation*

We will begin by providing an overview of **XPath**, explaining its role as a query language for XML. Participants will learn how to locate and extract data within an MEI file, navigating through its hierarchical structure. Key topics include:

- **XPath Syntax**: Nodes, paths, and expressions
- Selecting nodes and attributes within MEI structures (e.g., <note>, <measure>, or <score>)
- Using basic XPath functions for filtering data based on conditions (i.e., predicates), such as specific pitch, duration, or metadata

Participants will practice writing simple XPath queries to target and retrieve information from a sample MEI document.

## *2.2 Introduction to XSLT and XML Transformations*

Next, we will introduce **XSLT** (Extensible Stylesheet Language Transformations), a declarative language used to process and transform XML documents. Building on the XPath skills from earlier, participants will learn how to integrate queries into XSLT templates to reformat MEI data. This will be a more theoretical part and less hands on.

Key concepts covered include:

- Understanding XSLT templates and match patterns
- Applying XPath expressions to select data of interest
- Performing basic transformations to create structured outputs

To demonstrate practical applications, we will work on real examples and produce structured outputs for research and visualization including:

1. Transforming an MEI file into another (reformatted) MEI file
2. Transforming an MEI file into HTML, organizing the encoded MEI data for better visualization and human readability
3. Extracting information from an MEI file (and store it in a text file)
4. Extracting tabulated data (e.g., in TSV format) for input into statistical programs or simple spreadsheet tools

By the end of this section, participants will have experience generating export-ready files that can be used in other tools and platforms for further analysis, presentation, or sharing.

# 3 Documentation and Resources

Participants will have access to all the material presented at this workshop, including the XSLT examples. These templates will include clear explanations and comments, helping attendees understand how the code works and enabling them to revise and adapt it for their projects after the session.

# 4 Participant-Supplied MEI Documents (Optional)

We encourage attendees to share representative examples of their MEI encodings and research questions before the session. This will allow us, provided enough time, to include them as part of the workshop and use them to demonstrate solutions for common challenges when querying or processing MEI data, illustrating the application of XPath and XSLT to specific research questions, and allowing participants to see concrete outcomes directly applicable to their projects.

# Conclusion

The *Navigating and Processing MEI Data with XPath and XSLT* workshop will provide participants with practical and scalable skills to navigate, query, and transform MEI documents. Through guided exercises, real-world examples, and some hands-on practice, attendees will gain confidence in applying XPath and XSLT to meet their specific research needs. We look forward to fostering a collaborative and engaging learning environment that empowers the MEI community to advance their work more efficiently and creatively.

# Biographies of Authors

*Martha Thomae* is a postdoctoral researcher for the ECHOES project at the NOVA University of Lisbon. She has a PhD in Music Technology from McGill University, with a dissertation on the digitization and encoding of Guatemalan polyphonic choirbooks. She serves as an *MEI* board member and co-chair for the *Mensural MEI Interest Group*.

*Perry Roland* is Metadata Operations Librarian at the University of Virginia and the originator of MEI.

*Johannes Kepper* is a musicologist and digital humanist at Paderborn University. He works on digital scholarly editions of music for more than twenty.

# Annotating Music Scores: Representing and interacting with annotations using MEI and Verovio

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# Overview

This half-day workshop will address annotations of musical scores, considering their role and structure, and strategies for representing, encoding and visualising them. The workshop will combine presentations, discussion and hands-on activities with new versions of Verovio and mei-friend.

Annotation is an activity common across many walks of life and, for music, it unites scholars, musicians, teachers and composers. The practice is extremely varied, both in the forms it takes and the purposes it serves, and it is used for both physical and digital material. Digital annotations refer to highlights, circles, references, links or other selections made on digital documents or media. User-generated annotations are increasingly seen as a key mechanism for the use and reuse of digital materials across a wide range of applications, while also enhancing the findability and accessibility of that media through its annotations.

While the importance of annotations in music notation is generally acknowledged, there is less of a consensus on how best to integrate them into interoperable software applications. Annotations for music can encompass the association of textual observations with regions of a work; cross-reference between musical passages or from a musical passage to some other, non-musical, material; or they might include categorical or structured music-analytical annotations, such as metrical or harmonic labels; most commonly, perhaps, they are used by musicians and teachers for sharing or remembering aspects of musical interpretation.

Approaches taken in the digital domain include graphical, drawn overlays on top of an engraved score (which is popular in software for musicians and teachers), the use of URLs to specify score regions to be extracted and drawn by a web service (EMA, used by the CRIM project), Web Annotations (a Linked Data standard used by the MELD framework) and the MEI <annot> element itself. Given this diversity, it is essential to align implementation to specific needs and use cases rather than assuming a universal solution.

This workshop consolidates a review of existing digital score annotation implementations, presenting new recommendations for enhanced annotation practice in MEI, and with hands-on experiments for implementing these recommendations in Verovio and mei-friend.

# Workshop purpose

The workshop seeks to address and explore the current state of digital score annotation — in terms of the software and representations available — and the activities and wishes of those who might use them in MEI.  As a starting point for discussion with the community in this workshop, we will share:

- A report on the annotation of musical scores, circulated amongst the MEI community for comments in autumn 2024, and published ahead of the MEC 2025 conference;
- Recommendations for using annotations within MEI, including some proposals for changes to the guidelines and schema;
- An implementation in Verovio based on these recommendations, supporting import, export and visualisation of annotations; and

- An adaptation of mei-friend's previously-existing support for annotations, extending its functionality based on our proposals.

Over the course of the session, we will describe the current state of the contributions above through discussion and workshopping examples, we will explore what is now possible with the tools and encoding standards available, and where there are gaps or problem cases, finding ways to accommodate them now and in the future.

Participants will be invited to bring an example of an annotation that they are most keen on incorporating in a digital tool, which they will be able to talk about and work on during the workshop: either through implementation via the new versions of Verovio and mei-friend, or as a prompt for discussion of future needs and implementations. We will also provide examples for other parts of the workshop and for those who do not wish to bring material.

## Workshop structure

The workshop will be structured in five parts:

1. Participants introduce themselves, their interest in annotation of musical scores, and the chosen example of annotation they wish the workshop to consider (if they have one).
2. An introduction to the annotation of music notation, including existing strategies for digital representation and for tools. We will introduce and discuss new recommendations for annotating using MEI, and their implementation in Verovio and mei-friend. Participants who have brought examples will be able consider how they fit within this wider picture
3. Demonstration of new functionality in Verovio to support annotations, including demonstrations.
4. Hands on exploration of new functionality in Verovio and mei-friend. Participants who have brought examples compatible with the current tooling implementation will be encouraged to prototype their annotation.
5. Reflection and discussion of practical and theoretical implications arising in the workshop. In particular, we will sketch and develop potential future solutions for participants' example annotations which cannot yet be realised in tooling.

Participants will be invited to join a subsequent meeting of the MEI Linked Data Interest Group during which further planning next-steps will be discussed by the wider community, informed by this workshop.

This workshop forms the third of three consultation stages in the 'Annote: Digital Notation Annotation for RISM' (UK AHRC AH/Z506278/1), having been preceded by a survey of music annotation use, and the circulation of the resulting report described above. The results of this work contribute to the E-LAUTE project (FWF/DFG/SNSF) and Elgar's Themes (Leverhulme).

## Workshop leaders

**Kevin Page** leads the Annote project at the University of Oxford e-Research centre, where he is a Senior Researcher and Associate Faculty. In 2014 Kevin co-founded the international Digital Libraries for Musicology conference, and has led the Digital Musicology course at the Digital Humanities at Oxford Summer School since instigating it in 2015. At Oxford he teaches Digital Musicology and Linked Data courses as part of the Masters programme in Digital Scholarship.

**Laurent Pugin** is co-director of the RISM Digital Centre in Bern. He is also the lead developer and maintainer of Verovio and is a project partner for the Annote project. Laurent is a member of the MEI Board and Technical Team.

**David M. Weigl** leads the ‘Signature Sound Vienna’ project and is a national research partner on the E-LAUTE project at the University of Music and Performing Arts Vienna, Austria. He has been closely involved in the development of mei-friend and the ‘Listen Here!’ audio annotation tool. David is a member of the MEI Board and a co-chair of the MEI Linked Data Interest Group. He is an invited expert on the Annote project.

**David Lewis** is a researcher on the Annote project at the University of Oxford e-Research Centre, and a lecturer at Goldsmiths, University of London. He is co-chair of the MEI Tablature Interest Group. David is also the local organiser of MEC 2025.