Detmold musical Instrument Timbre Explorer (DmITE): Interactive visualization of musical instruments radiation pattern using IEEE 1599

Davide Andrea Mauro
davide.mauro@uni-paderborn.de
Paderborn University
Paderborn, Germany

Luca Andrea Ludovico
luca.ludovico@unimi.it
University of Milan
Milan, Italy

Hamit Batuhan Aydin
hamit.aydin@stud.hfm-detmold.de
Hochschule für Musik Detmold
Detmold, Germany

Axel Berndt
axel.berndt@uni-paderborn.de
Paderborn University
Paderborn, Germany

Timo Grothe
timo.grothe@hfm-detmold.de
Hochschule für Musik Detmold
Detmold, Germany

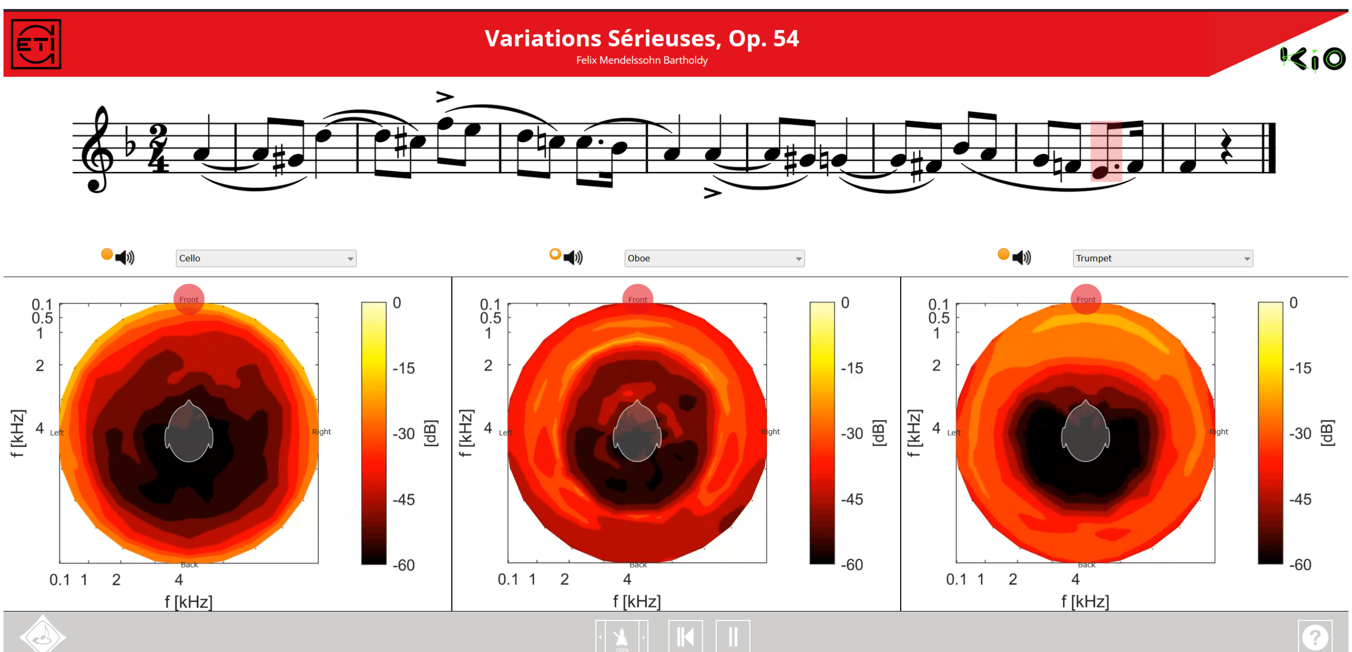

Figure 1: Interface of the application.

Abstract

In this contribution, we present Detmold musical Instrument Timbre Explorer (DmITE), a web application that allows for advanced interaction with multimedia materials. For the ACTOR (Analyses, Creation, and Teaching of ORchestration) project, a database capturing the same melody played by different instruments at various angles around the instrument has been collected. For each instrument, a visual representation of timbre is provided by a polar spectrogram. This work connects the development of the ACTOR Project with the IEEE 1599 standard, an XML-based format aimed at representing music in its multiple aspects. Structured as a multi-layer document, an IEEE 1599 file supports multiple and synchronized instances of scores and audio renderings. The integration of the heterogeneous materials collected for the ACTOR Project within a dedicated web platform based on the IEEE 1599 standard allows for advanced features, such as side-by-side graphical visualizations and fast audio track switching. This application offers user-focused learning experiences, making it valuable for educational purposes in sound engineering, orchestration, composition, musical acoustics, and timbre research.

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CCS Concepts

• **Applied computing** → **Sound and music computing**; *Education*; • **Information systems** → *Multimedia streaming*; Extensible Markup Language (XML).

Keywords

IEEE 1599, ACTOR, Web Application, Technology-Enhanced Education, Visualization, Radiation Pattern

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1 Introduction

Musical instruments project sound in various directions. The quality or timbre of the sound varies depending on the direction, a factor that plays a key role in their recording.

Musical instrument radiation has been well-documented in acoustics literature beginning with Juergen Meyer's classic book from the 1970s [17]. These topics have received a significantly increased interest in the past 15 years, with the emergence of applications in virtual acoustics, immersive audio and auralization [20].

Publicly available directivity databases offer detailed parametric source descriptions using spherical harmonics expansions [1, 9, 11]. The high spatial resolution of these radiation data sets have been proven useful for generic instrument classifications by directivity [18] or radiation pattern similarity [13]. For auralization purposes, this increased degree of detail in directivity poses challenges in finding proper source descriptions. These potentially need to encompass pitch-dependent directivity [15, 21], shadowing effects of musicians, and their movements on stage [2] to achieve naturalness.

On the other hand, more traditional timbre representations focussing on spectral characteristics of mono recordings [14, 19] may be biased by directivity and/or by room conditions.

Both types of scientific studies hardly allow to *experience* aspects of directional tone color [21]. Recording engineers who wish to capture instrument specific timbre by one or few spot microphones often rely on rules of thumb (e.g. [3]) followed by position finetuning on site.

In addition to these resources, we propose a systematic, perceptual approach to musical instrument timbre with an emphasis on self-guided learning. Key features are the animated spectral representation of a microphone array measurement, the option to switch the playback quickly and seamlessly between the arrays channels, and the synchronized playback of tracks from different instruments playing the same piece of music in the same room conditions.

The information is encoded using the IEEE 1599 standard. As better explained in the following, such an XML-based format allows for multi-layer description and advanced interaction with the materials, also providing accurate synchronization between the different audio sources. Through a dedicated web application, it is possible to support seamless transitions between the different angles while playing, thus allowing for analytical listening.

This application goes in the direction of technology-enhanced open education, allowing access regardless of users' physical/geographic location and supporting asynchronous forms of communication.

The remainder of this contribution is structured as follows: Section 2 provides an overview of the IEEE 1599 format; Section 3 discusses the database collected in the context of the ACTOR Project; Sections 4 and 5 respectively present and discuss the web application; finally, Section 6 draws the conclusion.

2 The IEEE 1599 Standard

IEEE 1599 is an international standard designed to encode music-related information. While an in-depth description is outside the scope of this contribution, some general concepts behind the format, and how they are implemented, can clarify our approach.

IEEE 1599 is an XML-based format designed to offer a comprehensive and multi-layered representation of music and music-related materials. It focuses on providing multiple representations of the same piece within a unique XML document.

IEEE 1599 can link multiple and heterogeneous representations of the same music piece through a structured approach that organizes information into six interconnected layers. The General layer contains metadata about the piece, including title, composer, and other catalog-related information. The Logic layer aims to describe the symbolic content of the score, focusing on score symbols (chords, rests, etc.); forms of notation other than Common Western Notation are also supported. The Structural layer describes the hierarchical organization of the piece, thanks to the identification of music objects and their relationships (e.g., sections, tonal areas, music themes, etc.). The Notational layer provides one or more graphical representations of the score. The Performance layer stores performance-related data, including MIDI sequences or other computer-driven representations. Finally, the Audio layer contains digital recordings of the piece. Moreover, layers can host multiple instances, e.g., many audio tracks or score versions for the same piece.

A key feature of IEEE 1599 is its synchronization mechanism, which allows different representations (such as an audio recording, a score, and a MIDI file) to be linked to the same logical structure. Thanks to the adoption of a data structure called the *spine*, heterogeneous information is not only available and organized within a unique XML document but also interconnected. Synchronization among different materials uses time-based references (e.g., for audio and video) or location-based references (e.g., for graphical content). This makes it possible to switch seamlessly between different formats or modalities and navigate interactively within a musical piece.

IEEE 1599 allows the design and implementation of advanced browsing tools, capable of presenting and synchronizing heterogeneous information. The format's versatility makes it particularly suitable for applications in music analysis [8], education [6], and interactive performance [5]. Score-to-audio alignment is one of the most typical functions implemented by an IEEE 1599-based tool; other common scenarios include the interactive experience of music content and on-the-fly comparison of different sources. Both these functionalities are present in DmITE.

Please refer to [16] for an in-depth discussion of the IEEE 1599 format and its possible application fields.

3 The ACTOR Project

3.1 Mission of the Project

The name of the project, ACTOR, is an acronym standing for Analysis, Creation, and Teaching of ORchestration. The ACTOR Project is a 7-year-long, large-scale project involving multiple research centres from Canada, Europe, and the US. The project is articulated into 15 workgroups covering areas from music acoustic research, to timbre semantics and orchestration pedagogy.

The ACTOR partnership seeks to elevate the role of timbre and orchestration in music by integrating them more prominently into scholarship, artistic practice, and public engagement. Collaborating with leading artists, scholars, and scientists, the initiative connects orchestration traditions from North America and Europe while fostering the development of innovative digital tools that support learning, creativity, and analysis across concert, club, film, and video-game music. Additionally, ACTOR aims to inspire young audiences by deepening their appreciation for the richness and complexity of high-quality music.

By applying advanced analytical tools, ACTOR seeks to uncover previously unexplored aspects of over four centuries of music. It also pioneers sound-based music analysis methods that enable the study of un-notated music and recordings of notated works. This approach will significantly impact research in fields such as musicology, music theory, music psychology, popular music studies, and ethnomusicology, where the role of timbre has often been overlooked or insufficiently explored.

The initiative enhances the education of composers, arrangers, and orchestrators by developing technological tools that bridge symbolic notation with sonic outcomes. Furthermore, ACTOR creates innovative computer-aided orchestration environments that harness advanced signal processing and machine-learning techniques, expanding creative possibilities across diverse musical genres. To accomplish these goals, ACTOR's research is organized into three main areas: analysis, technological tool development, and the creation of innovative outputs across multiple domains.

With DmITE we contribute specifically to two of these areas, as DmITE is a technological tool for analysis of instrumental radiation and respective variances in timbre.

3.2 The ACTOR Database

In the framework of DmITE, a key role is played by an ad-hoc database of recordings. The underlying idea is to obtain the timbre fingerprint of a musical instrument by revealing the spatial timbre variations in sound radiated from the instrument itself. To this end, we recorded the same melody, namely a short excerpt from *Variations Sérieuses* Op. 54 by Felix Mendelssohn Bartholdy, in the respective middle register. The theme was chosen as it is a nearly full chromatic scale spanning an octave. Recordings took place in an anechoic chamber, under the same room conditions, with a surrounding microphone array to sample 24 angles, thus with a resolution of 15°, in the horizontal plane.

The sound recordings with this array provide radiation information that characterizes musical instruments' timbre. We use a so-called polar spectrogram, a visualization similar to an isobaric chart for loudspeakers. In such 2D contour plots, frequency is on the horizontal axis, angle typically ranges from -180 to 180 degrees on the vertical axis, and color indicates level.

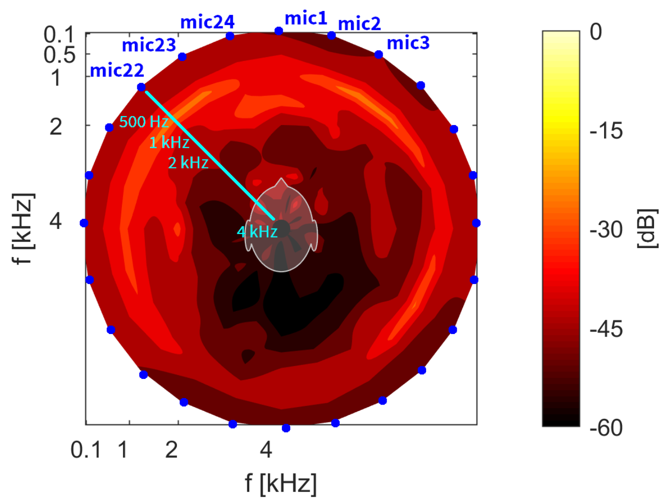

Figure 2: An example of polar spectrogram.

Pitched instruments often have a sparse frequency spectrum that makes traditional isobaric charts uninformative. However, the spectral envelope, with its local maxima known as formants, holds significant timbre information. The polar spectrogram displays LPC spectra in a circular isobaric chart, where the radial dimension represents frequency and the angular dimension indicates the recording angle with color coding for level.

Formants are most relevant at low to mid frequencies, so we show the radial scale ranging from 100 Hz to 4 kHz inversely. This circular mapping shows a top view of the musician (oriented toward 12 o'clock), allowing for intuitive visual assessment of spectral envelope changes and identification of the main directions of dominant formant regions (see Fig. 2).

Signal processing was performed in MATLAB using an open-source acoustics toolbox[1] from RWTH Aachen [10]. Spectral envelopes of the signals from 24 calibrated microphones were calculated using autocorrelation LPC [2] [12] of order 36, with 33 ms windows overlapping by 66%.

In total, 43 sessions have been recorded, thus generating 1008 tracks. In Table 1 a list of the instruments available at the current stage is presented.

4 The Web Application

The goal of the web application developed for the ACTOR Project is to let users interact with the collected database, to give the possibility to explore instrument sound radiation by comparative listening, and to stimulate discussions on meaningful visualizations of "timbre". To this end, the materials have been encoded into IEEE 1599, thus allowing the already-mentioned advanced forms of interaction

[1]https://www.ita-toolbox.org, last access: May 2025.
[2]`autolpc.m`

Sustained Tone						Transient Tone	
Strings	**Woodwinds**	**Brasses**	**Flutes**	**Free Reeds**	**Voices**	**Strings**	**Bars**
Violin 1	Clarinet	Trumpet 1	Flute	Accordion	Male Voice 1	Guitar	Marimba
Violin 2	Saxophone	Trumpet 2	Piccolo		Male Voice 2	Steel String	Marimba (Low register)
Viola	Oboe	Trumpet Muted	Sopranino Recorder		Female Voice	Double Bass Pizzicato	Marimba (High register)
Cello 1	Bassoon 1	Trombone	Soprano Recorder			Double Bass Pizzicato (High register)	Marimba (Highest register)
Cello 2	Bassoon 2	Horn	Alto Recorder				
Double bass	Bassoon 3	Cornet	Tenor Recorder				
Double Bass (High register)	Oboe d'amore	Flugelhorn	Bass Recorder				
	English Horn		Bass Recorder (without Cap)				
			Grand Bass Recorder				

Table 1: Instruments currently available in the database.

supported by the standard. A web platform was preferred as it does not require installation, it can be experienced from a variety of devices, and it is easy to update and enrich with new content.

4.1 Graphical User Interface and Functionalities

The graphical user interface of the application is shown in Figure 1. The upper area displays the score excerpt. Below, three instrument sections are presented. At the center of each section, the corresponding video is displayed. Overlayed on each video is a control that allows the user to select the angle. For each of the three sections, a drop-down menu button above each video allows the user to select the instrument. While all videos play at the same time, the currently active audio is selected through a radio button. Playback controls are placed in the page footer.

At the core of the web application sits a JavaScript library that loads an IEEE 1599 document and the related materials. In this case, there is a single score and multiple audio/video files.

The library was originally developed in 2011 and is constantly updated. One of the most recent publicly-available examples is the "Music Archive" section of the IEEE 1599 portal.[3] See [7] for a more in-depth discussion. The problem of managing multimedia streams, as required by the use of IEEE 1599 over the web, was originally discussed in [4].

The original library implemented the following advanced functionalities:

- **Synchronization:** All time-based media (i.e., audio tracks and video contents) are mutually synchronized and the user can switch between them in real-time, even while music is playing. This also includes different performances of the same music for which different time positions are aligned with each other.
- **Score following:** In addition to the synchronization of purely time-based media, graphical music representations are aligned with audio and video contents as well, i.e., audio-to-score alignment. When the user clicks the Play button, music starts, and cursors run over the graphical representation of the score so as to highlight the music events currently playing.
- **Interaction with music content:** The IEEE 1599 library provides multiple ways to interact with music content. In addition to usual media controls, such as Play/Pause buttons and progress bars, and thanks to the previously described score following mechanism, the score is also interactive in that clicking at a certain score position will trigger the playback to jump to or start at the corresponding position in the audio and video. This allows the user to easily jump to a specific music event and compare its multiple descriptions.

Previous versions of the library supported multiple graphic scores and audio/video tracks. Moreover, the goal of concurrent tracks usually was to encode different performances of the same music piece (e.g., different sopranos singing the same aria), each one with its own timing, rather than providing a multi-angle view of the same performance. The goals of DmITE required a rethinking of some of the features of the IEEE 1599 standard and the functions of the original library. In particular, we have a single score excerpt to show, but we need to extend the audio/video capabilities of the platform allowing a huge number of concurrent media streams and the simultaneous presentation of up to three videos.

The set of functionalities explicitly developed for this project includes:

- **Tempo change/time stretching:** Thanks to the metronome buttons, it is possible to alter the original tempo lowering it by up to 50%. This operation is performed using the `HTMLMediaElement` playbackRate property which offers very good performances, including pitch correction, with negligible performance impact.
- **One-Note mode:** When the user interacts with the score by clicking on a note, the tempo is slowed down to 15%, the playback lasts only for that single note, and the videos, after the end of the note, resynchronize to the middle point of the note. The idea is to allow the user to focus on the sustained part of the note, and to provide a representative still image when playback has stopped. This enables side-by-side comparisons of the same note played by different instruments.

[3] https://ieee1599.lim.di.unimi.it, last access: May 2025.

Multiple instrument visualizations: At any given time, 3 instruments are active and their videos are played simultaneously. In this way, despite asynchronous recording, the radiation pattern shown during playback are synchronized to the score, which facilitates the comparison between instruments in terms of time variance of the radiation pattern. Users can select current instruments through a drop-down menu.

Fast audio switching: While multiple videos are active at the same time, only one audio is played back. The knob control drawn on top of the individual videos allows the selection of one of the angles sampled in the database. For the active instrument, switching between angles is gap-less and rendered by 100 milliseconds cross-fade. This allows to aurally and visually experience phenomena related to *directional tone color* [21].

The music excerpt has been encoded with MuseScore[4] and exported to IEEE 1599 using a dedicated plugin.[5] The plugin also exports the graphic mappings of the score for the MuseScore-generated rendering. Concerning the audio mappings, we benefited from the metadata collected in the database, which includes onset times for each individual note of each instrument.

4.2 Multiple Media Stream Management

For the task of synchronizing multiple media playing concurrently, and ensuring gap-less transitions between audio, the original IEEE 1599 player underwent modifications and extensions.

For these new functionalities, we need to have 1 audio stream and 3 video streams playing concurrently. To ensure gap-less transitions between the audio we have two possibilities: the first is to have only one audio stream running at a time (or two during cross-fade), and when the user selects a different stream the new stream is first loaded, the playback synchronized, and then a cross-fade with the previous stream is performed. One problem with this solution is that the change is not performed instantaneously (depending on the time taken for loading the new media), thus not providing a way for fast switching that allows for comparisons between audio tracks. The solution that we currently adopt relies on loading all the audio tracks for the instrument currently selected. They are all muted, except for the angle currently selected. At this point, whenever a new angle is selected, the cross-fade can immediately be applied.

When a new instrument is selected, or set as playing, the old audio tracks are unloaded, all the new ones are loaded, and then the playback is resumed.

In the original library concurrent playback of media is not implemented, due to a the depreciation of the `HTMLMediaElement:mediaGroup` property. This was a feature originally intended for the purpose of grouping together multiple media elements, such as `audio` and `video`, and controlling them with a single controller. This would have automatically ensured synchronization of the media playback. Unfortunately this feature was deprecated in 2016.[6] As a result, a number of changes needed to be introduced: Timer-based callbacks are already used in the library (for example, to update on the score the note currently played in the audio), and so the idea to include them to regulate the multiple streams has been adopted. However performance is not always satisfactory. As stated in the HTML specifications,[7] this API does not guarantee that timers will run exactly on schedule.

5 Discussion

At the current stage a number of challenges remain present. In terms of technical challenges when a user wants to compare different instruments, unlike when changing angles, the switching process is not instantaneous and gap-less. Solving this problem will require finding better solutions to handle an increasing number of media streams playing concurrently.

We are continuing our work to improve the reliability of the synchronization mechanism when playing multiple media streams concurrently. One of the main challenges is that while the Web Audio API provides sample-level accuracy for audio, it does not support videos.

One of the most notable limitations of the DmITE application is that it examines only one instrument at a time. We know that in real scenarios the situation becomes increasingly more complex as more instruments are introduced. Having the possibility of combining multiple instruments, each one with its own miking, could be a very valuable tool, however posing new challenges with regards to clean intonation. These could either be solved with very careful recordings, note-by-note manual post-processing, or by use of real-time pitch correction.

The GUI for the application, specifically the instrument section, remains quite "abstract". If the database in the future will include the vertical axis, presenting information on a 2D can pose challenges. We envision the possibility of having a 3D representation where the user can navigate the space. In this direction it would be interesting to see if VR applications, nowadays available on the web and with an increasing availability of devices, can be of help, in particular if the idea of a "virtual tour" and virtual mixing is implemented for this application.

We have not yet performed a formal evaluation of the proposed tool for educational purpose but we remain confident that it can be a useful addition to what is already available for students.

6 Conclusions and Future Works

In this contribution we presented an interactive web application that can be used by students and practitioners to experience first hand differences of the directivity of musical instruments. We plan to continue the dissemination of this tool inside and outside of the ACTOR community. The website is available at https://dmite.lim.di.unimi.it/.

Regarding future development, we are considering improving the current media player with libraries such as Tone.js,[8] which will allow us advanced functionalities without the need to reimplement them at a lower level, for example with the Web Audio API. This

[4]https://musescore.org, last access: May 2025.
[5]https://github.com/LIMUNIMI/musescorePlugins, last access: May 2025.
[6]As stated at https://developer.mozilla.org/en-US/docs/Web/API/HTMLMediaElement/mediaGroup, last access: May 2025.
[7]https://html.spec.whatwg.org/multipage/timers-and-user-prompts.html, last access: May 2025.
[8]https://tonejs.github.io/, last access: May 2025.

can take care, for example, of problems with playing and synchronizing multiple media streams (i.e. the 24 audio streams for each instrument).

The database could be further expanded to include new instruments, and at the same time the possibility of using different microphones can be explored.

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