A Timeline Metaphor for Analyzing the Relationships between Musical Instruments and Musical Pieces

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Abstract: Digitization projects make cultural heritage data sustainably available. However, while digital libraries may capture various aspects, relations across different sources often remain unobserved. In our project, musicologists aimed to relate musical instruments with historical performances of musical pieces, both contained in different sources. We defined a similarity measure taking instrumentation, temporal as well as geospatial metadata into account, with which we were able to hypothesize potential relations. We propose a novel timeline design that offers a specific semantic zoom metaphor enabling the collaborating musicologists to observe and evaluate the results of our similarity analysis. The value of our system for research in musicology is documented in three case studies.

1 INTRODUCTION

In musical instrument museums, we encounter historical musical instruments or musical instruments from around the world (Dawe, 2012). Instruments are typically arranged in glass showcases or separate subdivisions, only a few instruments can be played in sound laboratories or heard during performances. In rather modern, global collections, as offered by the Musical Instrument Museum (MIM)[1] in Phoenix, Arizona (United States), the exhibition is further enriched with video and sound material from performances conveying sound and functionality of instruments. However, in historical collections, such enrichments can hardly be offered. This is caused by most instruments not having recording data and the instruments not being in a playable condition without risking to damage or destroy the rare or unique items. Further, even musicologists sometimes wonder in which particular composition's performances a historical music instrument was used. The musicological term *auralization* describes this research interest of framing an instrument with related compositions in order to picture its career and to facilitate forming "a mental impression of a sound not yet heard" (Summers, 2008).

Past digitization endeavors provide exhaustive digital collections of musical instruments and performances alike. On the one hand, the "Musical Instruments Museum Online" (MIMO)[2] provides structured information about around 65,000 music instruments, while, on the other hand, the "Répertoire International des Sources Musicales" (RISM)[3] holds a database with information about more than 1,100,000 musical pieces. By matching instrument types, taking geospatial as well as temporal constraints into account, we combined both data sources that prepared the ground to support generating hypotheses for the auralization of music instruments by quantitative, computational means. This paper outlines our interdisciplinary collaboration involving both visualization scholars and musicologists for the development of an interactive visual timeline environment supporting the musicologists' auralization task. In summary, our contributions to the visualization community are:

- **Assigning compositions to instruments**: For various geospatial, temporal and descriptive attributes of instruments and performances, we designed similarity measures that reflect the likeliness of a composition being played with an instrument in accordance to musicological conceptions.

[1]https://mim.org

[2]https://www.mimo-international.com/MIMO/
[3]https://opac.rism.info/

- **Auralization system**: We designed a visual analytics system that is used by musicologists to interactively evaluate hypothesized matchings of compositions and instruments, supporting to gradually form the *aura* of a particular instrument or instrument types.
- **A novel timeline metaphor**: We propose a timeline metaphor for the explorative analysis of instrument/performance matches that are exposed in a historical frame. Additional views can be consulted to foster or refute automatized matching suggestions.
- **Visual encoding for uncertainty**: Within the timeline view, we reflect temporal uncertainties for instrument datings as well as the likeliness of a detected match visually, preventing the user from drawing false conclusions.
- **Semantic zoom**: We propose a customized semantic zoom approach that satisfies quantitative (distant reading) and qualitative (close reading) research interests alike.

We emphasize the utility of our visual matching system for musicologists by providing various usage scenarios. In a storytelling style, each scenario exemplifies how our system can be used for generating hypotheses on the auralization of an instrument or instrument type. Additionally, we report experiences gained during our project, which includes the iterative evaluation of our auralization system with musicologists, limitations due to the nature of humanities data and future prospects.

2 RELATED WORK

Schlegel and Lüdtke (Schlegel et al., 2011) arrange instruments — Lutes and lute-like instruments — on a timeline to convey developments in instrument making. Annotated with descriptive metadata and related compositions for those instruments, the development of this instrument type can be explored visually. In opposite to the printed form, interactive timeline visualizations have been proven valuable for related research inquiries in digital humanities applications, typically directed towards person groups (André et al., 2007; Daniels, 2014; Khulusi et al., 2019; Khulusi et al., 2020a; Miller et al., 2012; Zhao et al., 2012). Similar to time periods influencing a person's life, the development of instrument types is likely influenced. Much research has been done concerning time-oriented data visualization. Examples are given by Aigner et al. (Aigner et al., 2011) and Brehmer et al. (Brehmer et al., 2016). Both include different timeline visualizations, and the latter one proposes a taxonomy for timeline visualization in particular. These works highlight different visualization strategies for temporal data, like parallel lines or theme rivers (Bunout, 2016; Havre et al., 2002) and their ability to help in analyzing trends.

The time-dependent inspection of the instrument's careers visualization is as of now under-represented in literature. Typically, visualizations of instruments focus on structural aspects of instruments, often obtained through X-ray or computed-tomography (Borman and Stoel, 2009; Hopfner, 2018; Kirsch, 2019). Further, functional analysis of how an instrument generates sound is visualized (Berthaut et al., 2013; Bouënard et al., 2008).

The static visualization by Schlegel et al. (Schlegel et al., 2011) is our motivation, but we propose an interactive visualization, making use of the timeline metaphor and digital interaction methods to help musicologists getting insight into the careers of instruments. A similar system is Continuum (André et al., 2007) that utilizes a semantic zoom functionality for a timeline but does not consider human career information. Another comparable approach is MusikerProfiling, which performs a similarity analysis for musicians based on their biographical data (Jänicke et al., 2016). This work also addresses the visualization of uncertain temporal data, which has also been discussed in other works (Khulusi et al., 2020b; Mchedlidze, 2019). Communicating such uncertainties is also subject to our work to prevent misinterpretations.

3 DESIGN

In close collaboration with musicologists, we designed the system in an iterative and user-centered process to maximize the usability of our approach. Two musicologists specialized in organology and restoration were mainly involved in the development. This section reports on the project following the nested model by Munzner (Munzner, 2009).

3.1 Domain Situation

Musicologists focusing on organology know much about the history and properties of inspected instruments. When instruments seemed outdated, they were restored, repaired or modified to get them ready for next performances. As it is mostly not easy to state which musical pieces were performed on a historical instrument, this work is motivated by musicologists who strive to picture an instrument's career with possible musical works (or genres) performed with it, creating an instrument's "aura". With traditional, analog means this task is near to impossible to be done. Due to various branches of musicology like composition analysis and organology, different methods and conventions of musical terminology exist. This makes it difficult to find exact matches among repositories listing musical instruments and compositions. We support generating hypotheses for the task of matching the instrument to musical pieces by digital means and a tailored matching algorithm considering instrumentation, time and location, to create hypothetically matches for further investigations. The two digital repositories on which our analysis is based on are explained in the next subsection. We further propose an interactive timeline visualization that helps to analyze the hypothesized matching pairs. All in all, we propose a system that supports musicologists investigating the research question *Which musical pieces have been performed on a particular instrument?* with an interactive tool outlined below.

3.2 Data & Task Abstraction

The data was harvested from different online sources and then transformed and cleaned to make them compatible with each other. Information on instruments are extracted from MIMO, a project for the standardized description and archiving of digital and multimedia information about around 65,000 music instruments in a database. The records include keywords and classifications, for the type of the instrument, as well as images and detailed events with different types. An instrument is defined with properties as described below:

$$I_i = \begin{cases} I_i^{titles}, \text{ set of instrument titles} \\ E(I_i), \text{ set of instrument events of } I_i \end{cases} \tag{1}$$

Where an event is described by its type, date and location (place name and coordinates).

Information on musical works are listed in RISM, an international online documentation of more than 1,100,000 musical sources. Information like title and scoring were harvested for each source. Many musical works are annotated with related performance events, for which provided location and date are used for the matching task. Musical sources are described as:

$$P_j = \begin{cases} P_j^{title}, \text{ title of musical source} \\ E(P_j), \text{ set of performances of } P_j \end{cases} \tag{2}$$

After extracting and cleaning the data sets for the further processing, the resulting numbers were:

- 6,670 musical instruments $I_1, \ldots, I_n$ – with 6,826 events $E(I)$ and
- 24,760 musical pieces $P_1, \ldots, P_m$ – with 29,192 performance events $E(P)$.

Due to the geocoding during the cleaning process some place names could not be resolved and got lost and so some extracted events were discarded. Thus, the amount of completely described instruments and sources was minorly decreased.

3.2.1 Similarity between Instruments and Sources

The matching between instruments and sources is determined on the basis of locations, dates, and instrument type of the corresponding events. Only events with all those information were taken into account. For musical sources, the instrumentation is given, and an instrument is labeled with terms for its type. For a matching task, one musical instrument or a group of musical instruments can be selected and matching scores for all possible pairs of instruments and musical pieces are determined dependent on three similarity scores. The similarity $S\big(e(I_i), e(P_j)\big)$ between an instrument event $e(I_i) \in E(I_i)$ and a musical performance event $e(P_j) \in E(P_j)$ is determined as

$$\begin{aligned} S\big(e(I_i), e(P_j)\big) = w_{inst} \cdot S_{inst}\big(e(I_i), e(P_j)\big) \\ + w_{time} \cdot S_{time}\big(e(I_i), e(P_j)\big) \\ + w_{geo} \cdot S_{geo}\big(e(I_i), e(P_j)\big) \end{aligned} \tag{3}$$

where w_k is the weight of the corresponding similarity measure S_k. The weights can be adjusted by the users during the matching process to modify search results. The combined similarity score is used to generate a result set of pairings. A limited number of t best matches for each instrument is taken into account for processing the visual output. Each similarity measure is described in the following.

3.2.2 Instrumentation Similarity S_{inst}

Matching instrument and the musical piece is only possible if the instrument type is part of the composition. Therefore, we check if the labels of an instrument appear in the list of considered instruments for the musical piece. As the terminologies used in both repositories are not coherent, they needed to be mapped to each other. Each instrument is tagged with a set of titles, to describe what type of instrument it is. These could be special types of instruments, classes, and families of them. On the other side, the musical sources are equipped with information for what instrumentation the work is intended. The instrumental scoring of a RISM source is given by a list of abbreviations for each instrument playing parts of the musical piece, e.g. "vl, t-fag". "vl" corresponds to "violin" and "t-fag" to "tenor bassoon". Both title sets are available in different languages (e.g., English, German, French, Italian), which further complicated the matching task. An instrument is a possible candidate according to the titles, if one of its terms, or its translation, is included in the instrumentation of the source. S_{inst} is ranging from 0.0 to 1.0 depending on if it is an exact match, a substring match or none within the extended title set out of translations and overlying classes:

$$S_{inst} = \begin{cases} 1.0, \text{ exact match}, \\ 0.5, \text{ substring match}, \\ 0.0, \text{ no match} \end{cases} \tag{4}$$

While an instrument with the title "violin" matches with score 1 due to the exact match, the instrument "bassoon" results in a score of 0.5 because of a substring match with the full RISM name "tenor bassoon". This rather simple approach is used as the underlying repositories do not use uniform terminology. Instrumentation of a musical source from RISM is only given as a list of abbreviations. On the other hand, the available amount of information about the MIMO instruments ranges from names for the instrument, instrument families and partially concepts out of the Hornbostel Sachs classification (Von Hornbostel and Sachs, 1961), but these classification is missing in RISM. The collaborating musicologists pointed out that terms for historic instruments are inherently ambiguous and that there is not a comprehensive classification for instruments, especially not for such between different groups. Thus, a string matching based approach was best suited to determine instrumentation similarity.

3.2.3 Temporal Similarity S_{time}

The temporal similarity score S_{time} between two events depends on the difference between the corresponding dates Δ_y in years and the maximally allowed temporal distance y_{max} and is defined as:

$$S_{time} = 1 - \frac{\Delta_y}{y_{max}} \tag{5}$$

This maximally allowed temporal distance with a default value of 25 years is user-configurable. By adjusting this value, the user is enabled to customize the matching process, depending on the research question at hand.

Due to the textual tradition of information, the granularity of temporal data ranges from exact dates to periods like years or centuries. Both sources comprise such temporal uncertainties. Annotations like "first half of 18th century" were translated into timestamps for the earliest and latest possible dates. In the case of a period for a given event, it is mapped to a single day (the mean day between the upper and lower border of the period) to be used for comparison. Furthermore, the temporal similarity is decreased by subtracting the period length in years $\Delta_{y_{span}}$ proportionally to the maximum temporal distance y_{max}. This is caused by the uncertainty of the exact event dating within the given period. So, the result strongly depends on the maximum temporal distance chosen by the user in combination with temporal uncertainties. In the case of temporal distances and in consideration of the mean day the maximum distance could be the worst case of $0.5 \cdot \Delta_{y_{span}}$.

$$S_{time} = 1 - \frac{\Delta_y}{y_{max}} - 0.5 \cdot \frac{\Delta_{y_{span}}}{y_{max}} \tag{6}$$

So, a given event in 1805 matches an event annotated with 1807 with a similarity around 0.866, with a maximal possible time difference of 15 years. Whereas an event in the period of 1800-1810 would match to 1807 with a value of around 0.533, even if the difference in years to the mean day is the same, due to its uncertainty. The temporal similarity is also defined between 0.0 and 1.0, so in cases of $S_{time}(e(I_i), e(P_j)) < 0$ we set $S_{time}(e(I_i), e(P_j)) = 0.0$.

3.2.4 Geographical Similarity S_{geo}

The score for geographical similarity S_{geo} refers to the actual geographical distance between two places $p_1(x_1, y_1)$ and $p_2(x_2, y_2)$ that is computed with the great circle formula delivering the distance in kilometers (Head, 2003):

$$\begin{aligned} G = 6378 \cdot arccos\big(sin(y_1) \cdot sin(y_2) + \dots \\ + cos(y_1) \cdot cos(y_2) \cdot cos(x_1 - x_2)\big) \end{aligned} \tag{7}$$

With the user-configurable maximum permitted distance between the places of two events G_{max} (default value is 50 kilometers), S_{geo} is then defined as

$$S_{geo} = 1 - \frac{G}{G_{max}} \tag{8}$$

3.3 Task Abstraction

The outcomes of our algorithm are hypothetical matches between an instrument and a performance event. But the numerical results are hard to evaluate by the musicologists, they require interactive visual access in order to be able to regard a result in the musicological context to assess its reliability. To describe user requirements of the system, we utilized the task taxonomy by Munzner (Munzner, 2014):

- **Analyze:** At the beginning of our project, the musicologists outlined their needs and wishes for the system in their application field. Most of all they wanted to see and *discover* interesting new patterns or anomalies in the combination of the two data sets to generate and verify hypotheses for possible new research questions. In comparison to the numerical, algorithmic results, visualizations make it much easier to detect such groupings and patterns. Also, the communication of uncertainties benefits from visual encoding. With further qualitative investigation, they are able to *derive* new knowledge about the correlations of musical instruments and musical pieces. New and already known relationships have to be *present*able for the discussion between musicologists as well. Also, an *enjoy*able use of the visualization is focused, e.g. with a poster depicting all the modification states of a special musical instrument, enhanced through appropriate music, besides its presentation in a museum for visitors.
- **Search:** To interact with the underlying repositories, the users require to *search* the data sets in manifold ways. The musicologists need to *lookup* already known correlations for hypothesis verification. The search interface enables them to *locate* object identifiers and special instrument titles of interest. The visualizations and even the search interface encourages to *browse* and *explore* through the results and data sets by filtering for areas in temporal or geographical space.
- **Query:** Further tasks supported by the system are *query*, *identify*, *compare* and *summarize*.

4 VISUAL ENCODING & INTERACTION IDIOM

The presented visualization aim to display the results by focusing on temporal and geographical similarity and show them in separate, but linked views. To enable the user to inspect the results in an interactive way and to create hypotheses for further investigations, we created a comprehensive metaphor and visual encoding. To do so, we utilized a consistent color coding for the two entity classes, which are symbolized with two color schemes inspired by ColorBrewer (Harrower and Brewer, 2003). Instrument events are colored in different discrete colors with a high red component, depending on the type of the event. Whereas musical piece performances are colored in green with different saturation from a continuous color scale, to visually encode the similarity score of the matching between the two entity classes. The overall legend can be seen in Figure 1. Also visible there is the choice of different shapes to symbolize instrument events as ellipses and matching piece performances as rectangles.

Figure 1: Overall color coding, with two color schemes for the different entity classes. The color scale over the saturation of green encodes similarity of one piece performance to a instrument event.

4.1 Timeline

We use a timeline to visualize the resulting matches in dependence of the temporal dimension (S_{time}). To minimize the visual clutter, we group the result set entries by single instruments. So every matched instrument $I_i \in I_1 \dots I_n$ is symbolized by one row on the y-axis, started by an eventual image of the instrument to offer the first view of it. If no image could be found for the instrument, the place at the beginning of the row stays blank. The x-axis represents the time, so the temporal located instrument's career events $e_1 \dots e_o \in E(I_i)$ are placed along with the row's horizontal extension. These events are enhanced by the matched musical pieces $P(e)$ with $e \in E(I_i)$ to show their relation.

4.1.1 Uncertainties

In the case of uncertainty, the inaccuracy is communicated by an out fading border and width of the event's glyph, as visible in Figure 2. The height of each row (I_i) is given by the maximum amount of matches from $P(E(I_i))$ in it.

One upcoming challenge was the fact, that large objects draw more attention than smaller ones. Due

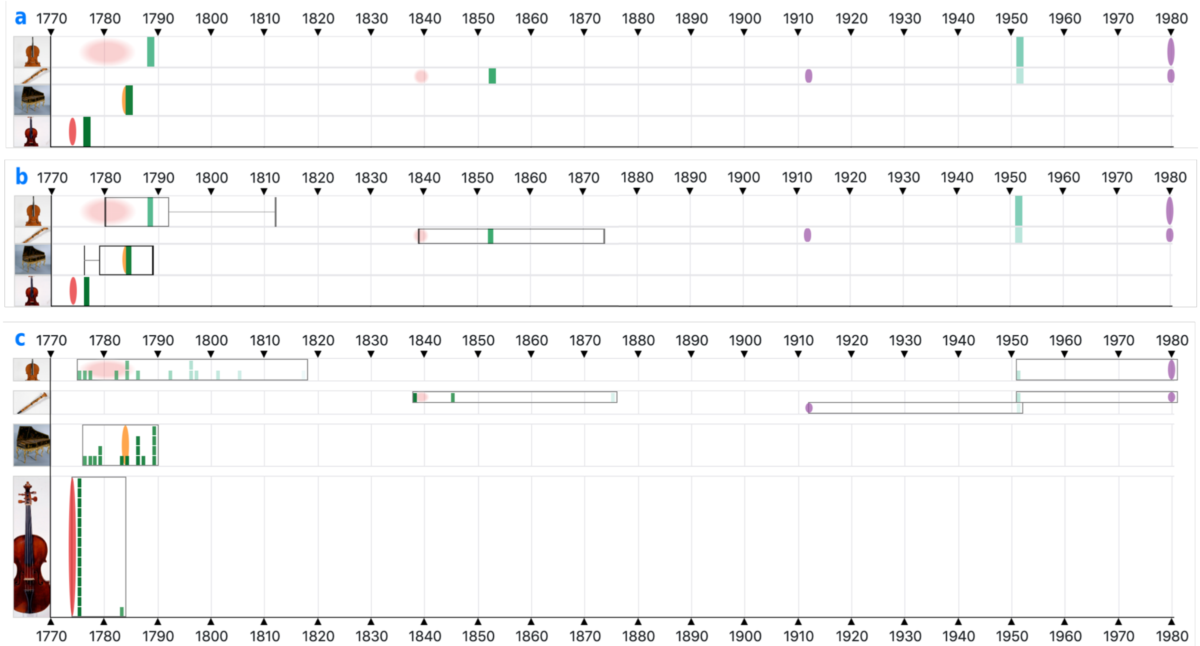

Figure 2: The different semantic zoom levels enable distant reading of distributions of matched results (**a,b**), as well as the close reading of all results in detail. In the highest zoom level (**c**) the musical piece performances are stacked on each other, creating a bar chart and encode the quantities and qualities for each instrument event.

to the uncertainties and the focused similarity measures, lower (more unlikely) matches are getting more screen space on a timeline or map than exact matches in temporal and geographical consideration, because of their higher distances. Equally in calculating and visualizing the result sets, closeness is the significant property to describe likeness. To encounter that, we implemented the continuous color scale and with it, in combination with transparency, the lower matches are fading out towards the borders of the maximally allowed distances.

4.1.2 Semantic Zoom

Following the Visual Information-Seeking Mantra from Shneiderman (Shneiderman, 1996), the user can browse through different semantic zoom levels.

The first zoom level of the timeline shows a first overview of the matched instruments and their events. All possible similar pieces $P(e)$ of each instrument event $e_1 \dots e_o \in E(I_i)$ are summarized in one glyph at this level. This glyph is a rectangle with a width of one year on the timeline, positioned on the average year of all summarized performance events. The color is given by the sum of scores for the temporal similarity of all binned matches. With this view, it is possible to get a first overview of the temporal distribution of the matched events in a distant reading manner. Like on a classical heatmap, whole areas of interest or special outliers could be derived and picked for further investigation. The overview of some matched instruments is visible in Figure 2**a**.

The second zoom level extends the rectangle glyphs to box plots, to uncover the distribution of the matched performances. The previously drawn rectangles remain as medians and get surrounded by their quartiles. Additionally, whiskers indicate the minimum and maximum extension of the quartiles over time, but outliers were ignored. An example of box plots could be seen in Figure 2**b**.

On the last zoom level, the box plots become bar charts to reveal all underlying performance matches. Each matched musical piece is symbolized by its small rectangle at the year of its performance. We stack multiple performances in the same year on top of each other so that they are creating a bar chart like glyph for the distribution of all matches for one instrument event $e \in E(I_i)$. To clarify the connections of the bars, all matched $P(e)$ are framed by a thin border from earliest to latest performance. This time frame could be expanded via one checkbox to show the minimum and maximum possible year (y_{max}), to show if there would be more room for further sources. Periods around the instrument's events are stacked on top of each other too and margins between the rows are growing, to maintain the separation of the instrument rows as visible in Figure 2**c**.

4.1.3 Shape of Similarity

Although the shapes of piece performances are changing over zoom levels, an overall shape of all matches to an instrument is recognizable. Width, height, and saturation are indicating inaccuracy, destination, amount and quality of the underlying matches. A thin, high and saturated shape of e.g. a bar chart shows much more certainty and quantity than a broad and flat shaped frame around the bars. These are patterns to search for during the analysis, as well as the visual encoding for uncertainty.

4.1.4 Interactions

To explore the result set of matches a variety of interactions were applied to the visual elements. First of all the interactive search form with its text fields, buttons and easy to use filter bar “VisualSearch”[4] enables visual analytics and is visible in Figure 4. Additionally to the dynamic adaption to different research questions and changing search results via search form, the user could change the sorting algorithm of the instrument rows in the timeline. The default is the chronological sorting, where the instruments are sorted by the dates of their matches. Other sorting methods are the average or the sum of all matches of one instrument, to get a ranking by quality and quantity of resulting instrument/piece pairs. With them, it is possible to encounter the demands of different research questions, like the penalty of the set of matches through low similarity scores via the average.

For a closer look at one single instrument and its matches, it is possible to click on the instrument images or their event glyphs, to filter the whole result set. There, due the small number of elements, the elements are able to become larger. Some information about the matched events are accessible via mouse hover over their drawn glyphs, like seen in Figure 3. Both, timeline and map, are connected through the hover effects, to bring geographical and temporal dimension into context.

[4] https://documentcloud.github.io/visualsearch/

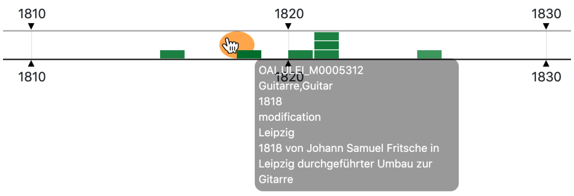

Figure 3: The tooltip uncovers, that this lute was converted into a guitar by Johann Samuel Fritsche in 1818 in Leipzig, Germany.

4.1.5 Map

Analogous to the timeline, the map is focusing on the geographical similarity of the different events. Also the most visual metaphors are the same. Shape, size, and color are indicating entity class, amount of summarized entries and type, respectively the geographical similarity score. Because of the different dimensions, and thus overlapping of events, it is not possible to group the result set after instruments in the same way as at the timeline, but overlapping data points get clustered. The clusters are divided into separate glyphs for summarized instruments and piece performance events in that cluster, as seen in Figure 6. If multiple types of instrument events are clustered together, they are symbolized by a pie chart in the mentioned color map. When zooming into the map, clusters of less than eight items of one entity class are split into single features, placed around the first feature in the center on a circular path. It is possible to show a circle around the single instrument events to display the maximum allowed distance between the matched items, analogous to the time frames around the timeline’s bar charts. To highlight the connections between the entities, lines could be drawn, which connect instrument events with their matched piece performance events, as visible in Figure 5. We waive to draw the detailed connections between split single elements, because of the visual cluttering.

5 USE CASES

In discussion with four musicologists, we observed multiple use cases during their use of the system, which underline the work with the visualizations and the system and point out possible improvements as well.

5.1 The Protestant Trombone

The first is the case that an object is exhibited in a display case e.g. in a museum. With the knowledge about all of its conversions and stations, its life could be enriched by possible musical piece performances. For a trombone of the Music Instrument Museum of Leipzig University (Germany)[5], they chose to set $G_{max} = 200\ km$ and $y_{max} = 50\ years$. Inspecting the timeline from Figure 4**a**, the musicologists saw two distinct red production events of it, in each case with a given period of 10 years, indicated by the stretched and out fading ellipses. When hovering

[5] https://mfm.uni-leipzig.de

Figure 4: The timeline of a trombone from the Music Instrument Museum of Leipzig University in its different zoom level states.

over the events, they noticed that the production of the whole instrument is divided into the manufacturing of the lower part around 1740 and the upper part around 1785. When zooming in (**b** of Figure 4), the glyphs get enhanced by the box plots around them, uncovering the distribution of matched performances. A first glance shows, that the left box plot has a longer range of whiskers than the other one. On the next zoom level (**c** of Figure 4) the single matched performances become visible. To assess the quality of the recommendations the musicologists wanted to get insights into the first matched performances for each instrument event. Without question, the first half of the trombone is not playable without its other half. Nevertheless, a closer inspection of the first musical pieces by hovering revealed, that some of them are different parts of an opera. Also striking is, that many of the matched musical pieces are sacred songs. That leads the users to the geographical similarity of the result set. Both parts of the trombone were manufactured in Nuremberg (Germany) and the musical pieces were performed in cities around that place in the radius of G_{max}, as displayed in Figure 5. With the additional knowledge of the musicologists, it turns out, that all cities have been Protestant, except for Munich, which was Catholic. So considering the high amount of Protestant pieces, from Protestant composers, in the result set, e.g. Frankfurt am Main is culturally closer to the instrument from Nuremberg, than Munich, although Munich is geographically nearer. Despite everything, for users it is at least possible to get an insight into the music e.g. operatic arias composed for trombones in Southern Germany around the late 18th century.

5.2 The Playlist for a Violin

Another possible use case is the generation of a "playlist" around a special instrument or a group of it. For example an imagined chamber orchestra with multiple concertmasters, who play Italian violins. With the system now it is possible to easily generate a playlist of matching musical pieces for a themed concert or the production of recordings around ancient violins. The musicologists started with the first look on all of the available violins in the data set and their best matches. Selected settings here were $y_{max} = 25\ years$ and $G_{max} = 50\ km$. Noticeable at first glance was the clear gap between matches around 1850 and 1870. Looking at the map showed, that most of the instruments were located in Germany and just circa 10 percent of them in Italy. Focusing on the

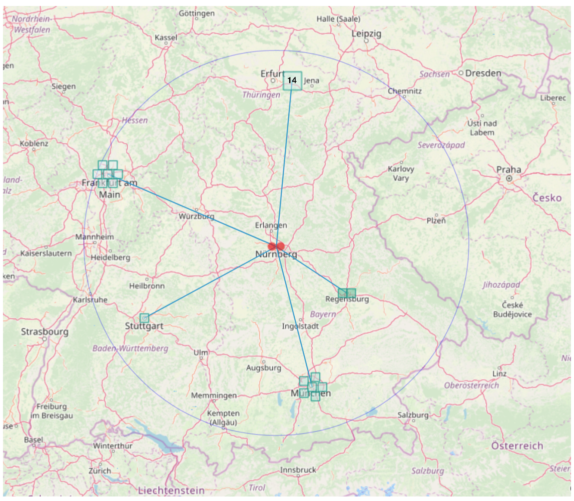

Figure 5: The map for a trombone from the Music Instrument Museum of Leipzig University, produced in Nuremberg (Germany), surrounded by its matched piece performances.

Figure 6: All Italian violins with their piece performance matches within a distance of 30 years and 75 kilometers.

seven violins from Italy with matches within a distance of 30 years and 75 kilometers, the timeline is changing to Figure 6. With such a condensed set of instruments and nevertheless a manifold variation of possible musical pieces, the musicologists suggested “A foray through the Italian baroque for the violin” as one name for the playlist, where stations could be Rome around 1710, Cremona around 1750 and Parma around 1810. Matching pieces are from composers like Antonio Vivaldi or Andrea Bernasconi and primary operatic arias. Interesting to see is the already mentioned gap after 1820 in Italy and the raising violins and performances on the north side of the Alps. Also noticeable by further investigations, is that Italian music was not just played in Italy. For example the source “Didone abbandonata”[6] made its way from Milan (1738) over Venice (1741) to Munich (1756).

5.3 The Conversion of Lutes

The lute instruments are an ancient plucked string instrument family. Due to their high value the lutes, some particular instruments experienced multiple developments and changes over the time from classical lutes over mandolins and theorbos to guitars, picturing the passed trends. The search for such instrument families in the presented system creates the timeline and map view from Figure 7.

Apparently, the timeline is divided into three different characteristic epochs. The first episode is for the renaissance and baroque european lutes like the one in the row **d** in Figure 7. Unfortunately, musical pieces for lutes from RISM are very rare (a search on RISM for lute as instrumentation gives 38 results). After that period, the music culture was changing and with it, performance practices. The lute was displaced from the established ensembles because it had no place in the rising orchestras.

The many exact datings of instrument productions in the second epoch (1770 - 1860) may come from the high amount of good logged contract manufacturing for the courtly culture, the analyzing musicologists assumed. Most of the instruments in that period are mandolins and first guitars. The data of the lute-guitar in row **c** of Figure 7 is manually enhanced and corrected by a musicologist specialized on lutes. In MIMO the instrument is tagged as lute-guitar with two production events. The information, that the instrument was manufactured as a classical lute (first half of the 17th century) is only available in the textual metadata of the events. As well as the conversion of the instrument into a lute-guitar in 1818 is written down, but not easily automatically processible, as seen in Figure 3. Such example shows the real value of the system to visualize and auralize a particular instrument career, cause of the musical changes of matched piece performances to its station.

The last episode is dominated by uncertain production dates of guitars. Due to that the amount and quality of matches are decreased. The musicologists working with the system assumed the more industrial production of instruments. These instruments were produced on stock and not for a specific customer who made an order. This might be the reason for the uncertain manufacturing records. Besides, the lutes experienced a revival through the conversion to lute-guitars or bass lutes, like the one in row **b** of Figure 7, which were used in operas e.g. the hypothetically matched “Meistersinger von Nürnberg” [7] by Richard Wagner.

5.4 The Historical Performance Practice

Even the other way, finding matches to one selected musical piece, is conceivable. Imagined a given music manuscript, with its past performance dates and maybe additional knowledge about the work e.g. the composition event. With such information, feasible historic instruments come into consideration by the use of the system, to perform the musical piece in a way of historically informed performance practices, with appropriate instruments.

[6]https://opac.rism.info/metaopac/search?View=rismid=450014602View=rism

[7]https://opac.rism.info/metaopac/search?View=rismid=270000986View=rism

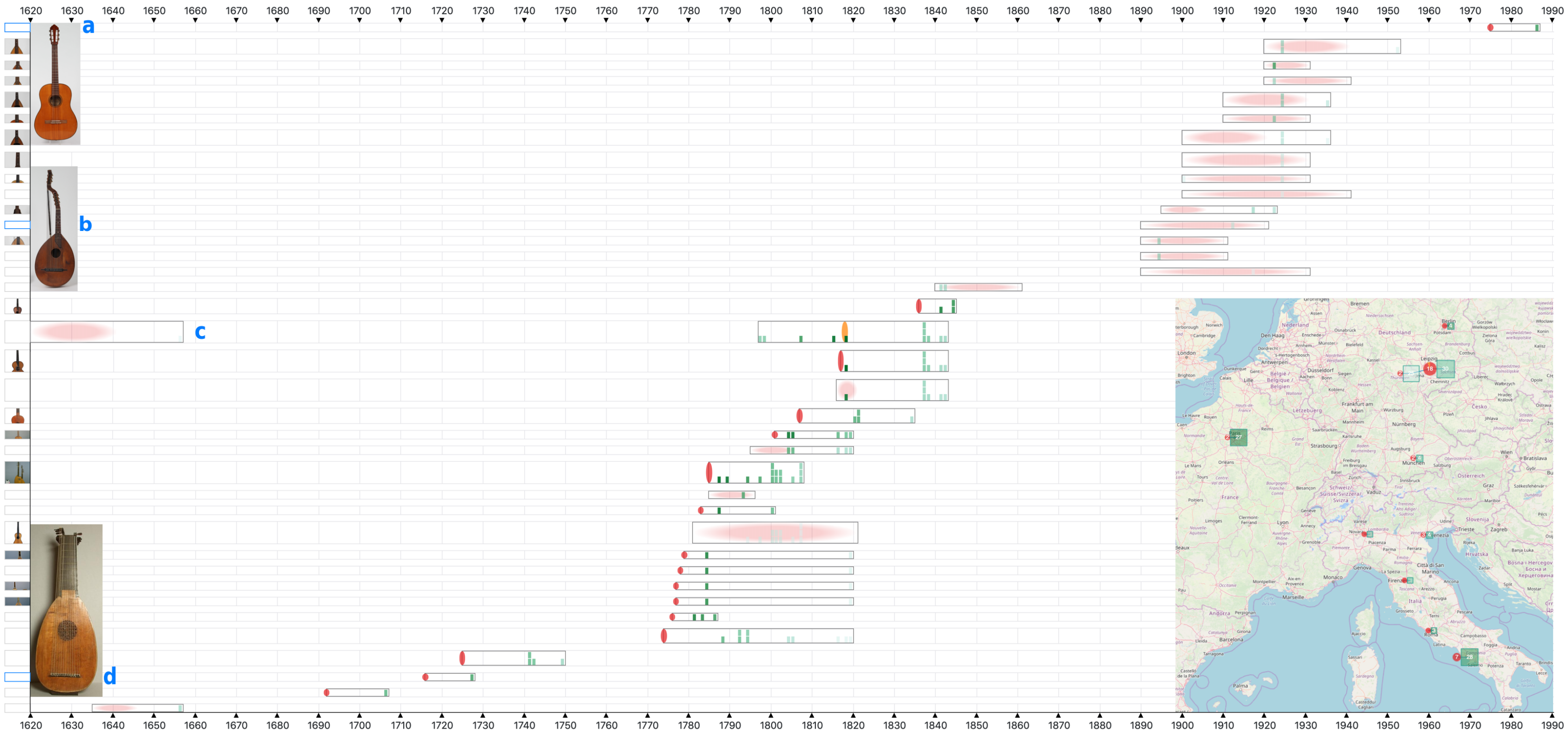

Figure 7: All lutes and its similar instrument families with their piece performance matches within a distance of 50 years and 100 kilometers. Visual striking and interesting are the three distinct episodes and the differences between the certainties inside of them.

6 RESULTS

6.1 Discussion

While evaluating the system through the work with musicologists, we observed the following effects. Different close and distant reading research questions are supported by the system. For resilient results, further close reading is still necessary, but the system is capable of revealing so far unseen correlations, now possible with a digital humanities approach to musicological data. The different levels of the semantic zoom create a smooth transition between temporal granularities. Even if the matching results are not exact matches in the real world, at least we receive indications about how the music was intended to sound at the dedicated lifetime events of one instrument or their instrument family.

One advantage could be the research and education in organology, instrument careers and socio-cultural developments over the centuries of music. Indirectly the system creates a similarity measure for instruments through the analysis of similar events and shared possible performances. The use cases show that available databases and the post-processing of data sets have yet to be improved in order to increase the quality of results of the recommendation system. For example, detailed information about tuning and tones are missing for a better instrumentation similarity analysis. But for now, the system satisfies the intention of creating hypotheses of joint appearance, which can be verified or falsified by further inspections of musicologists.

6.2 Limitations

In general the amount of displayable items is not limited. All instruments in the timeline are stacked atop each other so the scrollable height is growing with each new entry. However, the number of instrument rows and related events is limited by the amount that is humanly processible. We observed a result set with 150 oboes from one museum with the same production event date and location and the same matched musical pieces were stacked on each other, using a lot of screen space. This output requires the screen's height three times (depending on resolution and used minimum of instrument rows height) but is also negligible by the user who is aware of the general quality of the data. Also, the system is not meant to review, but rather to direct towards new hypotheses. Such review, especially verification of suggested facts, has to be performed intellectual with additional knowledge. Nevertheless, the falsification is easily possible by using the visualizations, but this use case underlines again the dependence of calculated and displayed statements on the quality and quantity of the used data points.

6.3 Future Work

The measurement of similarity will be improved e.g. by the consideration of geopolitical information like provinces and countries. Therefore, the aggregation of information from other repositories and a better alignment of the different existing vocabularies is necessary. Also, the derivation of new information out of existing is possible. For example, the database of the musiXplora (Khulusi et al., 2020a) contains over 32.000 persons in the musical context with a variety of information about them, e.g., the denomination of musicians. Hypotheses like the denomination of cities (as mentioned in the first use case in Section 5) could be derived from the denominations of all locally born persons. Further, the system is expandable by e.g. a force-directed graph for the results of the recommendation system. Therefore instruments or musical pieces could be grouped depending on the demand of research questions. A box plot glyph could be evolved to a bean plot (Kampstra et al., 2008) for the better creation of shapes for the matched results. Furthermore, we want to increase the linkage of the different attributes and views e.g. by implementing a time slider for the map, to see the geospatial trends of the two entity classes over time.

7 CONCLUSION

Due to the increasing amount of digital cultural heritage resources, user interfaces that support aggregation, mapping and linkage gain more and more importance. Our project aimed to find relations between musical instruments and historical performances of musical pieces. To encounter this, we cooperated with musicologists, aggregated and linked two digital repositories. In addition, we defined a multi-faceted similarity measure for the likeness of two matching events. To achieve the ability of qualitative close reading and quantitative distant reading of the results, we designed a new timeline metaphor with semantic zoom levels accompanied with a map to review results in a temporal as well as a geographical context. The presented use cases indicate the value of our approach to support new research questions in musicology.

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