



Visual Analysis of Linked Musicological Data with the *musiXplora*

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Abstract. While digitizing data is the first major step for many digital humanities projects, the visual analysis is of high value for humanists, as it brings a wide range of possibilities to work with data. While rather traditional analysis often concentrates on standalone or sets of information (close reading), global inspections of linked data are also requested by today's researchers and made possible through digital processing. Hence, distance reading approaches are more and more found in humanities projects. Next to such approaches allowing new research questions of quantitative analysis, linking previously separate information on a data level is another way of providing humanists with access to further, previously not reachable, global inspections of faceted datasets.

As a domain with both, faceted data and a rather low level of digitization, musicology is a prime example of how the digital humanities may improve and support the daily workflows of humanists. Despite the generally low level of digitization, multiple projects already build a basis to help in digitizing the field. As an example, the *musiXplora* project collected a vast amount of musicological data throughout the last 16 years and now offers both, a detailed biography of persons, places, objects, events, media, institutions and terms and also the linkage between these kinds of entities to help in giving a user a comprehensible overview in the traditionally fragmented field of musicology. Supported by a set of visualizations, the website of the project allows for visual analysis on close reading and distant reading levels. This does not only help researchers in their daily workflows but also offers users with a more casual nature an interesting view inside the domain of musicology.

Keywords: Computer science · Visualization · Visual analysis · Digital humanities · Musicology

1 Introduction

As a domain for both, theoretical and practical approaches, musicology has a wide set of different subdomains. Each of these domains differs by approaches and goals. Some have specific needs of specialized data, while others need in-depth analysis [16]. Typically known subdomains are namely organology [25] or the instrument restoration. While the former one, as research domain, uses data linked to the *career* of the object to shed light on its history, the latter one, as practical domain, needs information about materials, measurements or temporal aspects to help in preserving or even repairing an instrument. Further, a whole branch of musicology deals with prosopographical research – inspecting or producing biographies of relevant persons, making use of all kinds of metadata and offering different research questions to be answered through data analysis [16].

As a side effect of more than hundred years of work in these different subdomains, today’s musicology is not only a field with vast amounts of (analog) data but also quite fragmented. As a result, whole libraries of musicological related books have been published and preserved, normally specifying on a single facet or narrow range of data. Examples may be given with biographical lexicons often containing only persons of a specific profession (like instrument makers) and sometimes even temporal (e.g. medieval) or geographical (working in a specific city) data. While musicologists learned to work with such a degree of fragmentation, caused by a very limited space in manuscripts and books, today’s research does begin to shift towards trying to get comprehensible overviews of domains [12, 23]. As part of the digital humanities movement, adaptation of digitization, electronically processing, and visual analysis brings distant reading possibilities to the researchers, helping in more global views on the fields and possibilities to work with the growing amount of data [24]. Paired with close reading approaches, more and more projects additionally support their users in daily workflows. Previous work showed this with a focus on musicology and how the digitization of musicological knowledge helped musicologists in generating a comprehensive database of this faceted knowledge [16]. In this publication, we present an extension to the musiXplora tool. Its main goal is to support domain experts in dealing with the fragmented data digitally, aiming to create a more comprehensible musicological knowledge resource. Exemplary, we will present real use cases of our collaborating musicologists, giving insight into the potential a digital knowledge tool with visualizations can offer.

2 Related Work

In the recently published work about the basic concept of the musiXplora [16], the seven facets of musicology are explained in detail. While previous publications of the musiXplora in general focused mainly on the prosopographical aspect [10, 11, 13–16] only a few works had enough data available for in-detail use cases of other entities [19]. While a continual growth of the database could be seen throughout the years of the project, a shift away from the prioritizing of the persons’ data has led to rapid growth in the other facets and especially the linkage between them. In detail, while at the beginning of the year 2020 roundabout 40,000 links existed, half a year later more than 100,000 links between different entities have been added with more to come.

Also non-*musiXplora* related projects in musicology mirror the fragmentation of the field. In a recent survey on visualization in musicology, more than 120 projects from the last twenty years are included and separated by their focused data type [17]. Again, encountered sub-domains include prosopographical research [4, 7, 20–22, 27], inspection of places linked to musicology [5] or temporal aspects [1]. Facets like the musical objects are inspected in works generating three dimensional data [2, 3, 8, 9, 18] and rendered in their volume or surface [26].

2.1 BMLO

A first project trying to link the gaps was started in 2004. The German research project BMLO (short for *Bayrisches Musikerlexikon Online* or *Bavarian Musician Lexicon Online*) [6] began with collecting and digitizing musicological knowledge in a database with lexicon-like web-based access. The project consisted mainly of years of manual work of an editorial team, using different existing online sources or traditional sources like books and magazines and their standardization to fit into a relational database. Due to centuries of research in musicology, an automatic crawling-like process of data is not possible. By far, too few structures can be found within the field. Beginning by missing naming standards and changing definitions – one term having different meanings depending on the temporal context or the same instrument or person having multiple names – [19] and ending by the physical fragmentation of the sources – a division in books specialized on only a small subset of data. Hence, the collection process is especially in need of musicologists and their intellectual knowledge and skills. While in the beginning, the fundamental idea and groundwork for the linkage of the facets were built, the actual process of offering a linked database started with the successor of the BMLO, the *musiXplora*.

2.2 *musiXplora*

Starting in 2014, ten years after the start of the BMLO, the *musiXplora* inherited the whole BMLO database and began to open up its boundaries. While previously, a geographical link to Bavaria was required – to reduce the initial gigantic workload of collecting musicological data –, then, musicological relevant data of a worldwide scope was accepted. Also, during the BMLO time, mainly data of persons and places were included. Up to last year, the *musiXplora* added not only more persons (round about 33,000 today) but also objects (9,000), places (75,000), and institutions (800). While this was already a vast amount of data that took more than 15 years of work, the initial goal of linking facets could still not be met. With the beginning of 2020, the linkage of the facets started. Not only did the editorial team began to include data to all facets but also to include linkage between these types of data entities. For a more detailed description of the *musiXplora*'s data and features, consider Khulusi et al.'s detailed description [16].

3 Data and Linkage

In short, the musiXplora offers seven facets defined by musicologists:

1. MUSICI - Persons
2. CASAE - Institutions
3. LOCI - Places
4. BACCAE - Objects
5. RES - Terms
6. EVENTA - Events
7. CATALOGUS - Media

Table 1 shows a matrix of all facets and which facets are presently reachable through instances of an other facet. Further, the last row shows whether the facet is presently online available for all users¹. As the structure of the data is inherited from the BMLO project (see Sect. 2.1), existing challenges of the data also apply and have to be considered. Exemplary challenges are the work with uncertainties typical for historical data. While a lot of paper-based information is conserved over the centuries, they are neither always correct nor complete. It is not untypical for persons to be missing crucial information needed for visualizations and analysis like date of birth or even the name, making it hardly possible to put them into relation with others. Also, imprecise information like a birth date of *before 1720* or *around 1300* are frequently encountered. With the dependence on historical sources, such imprecision may never be resolved, as the needed sources may never have existed or could not be preserved through history. As for the temporal data, four kinds of information may be of special relevance: the *first mentioned date*, where a person appeared for the first time in a musicological context, hence, the beginning of the person working in a musicological profession. Second, the *last mentioned date*, analog to the former, but the last time a person is explicitly mentioned. Mostly, this is given with the *date of death*, as most persons have been relevant for musicology until they died. Lastly, a *date of birth* may give insight into the living time of the person. Unlike with the *last mentioned date*, a person was not relevant for musicology beginning with its birth. Thus, the span between *first mentioned date* and *last mentioned date* is the period in which the person was relevant for, or active in, the domain. Nevertheless, the birth date may give useful information and even be used to approximate a *first mentioned date* [13]. In numbers, a *date of birth* is missing for 13,193 out of 33,602² persons (39%). Similarly, a *date of death* is not given for 48% of the people. For the *first mentioned date* and *last mentioned date* the missing information is 2.5% and 75%, respectively. This does not include imprecise dates, which do mess with roundabout 14% of the given temporal data. While such uncertainties are known and considered for analysis and visualization inside the musiXplora [16, 17], we will not go into more detail in this paper. Instead, we want to shed a bit more light on the available data in general.

¹ Due to the work-in-progress-nature of the project and some facets not having a – for the musicologists – satisfying scope, some facets are only available after logging in. Access to these facets may be requested by email.

² As of July 2020.

Table 1. Showing connected facets and if they are online available at the moment. A cell is green, when at least one entity links towards the other facet. As example, the person facet is linked to the places facet through naming of places like the place of birth of Beethoven *Bonn*. A click on the *Bonn* label redirects the user to the loci result page of the city. Also, public available facets are marked as green in the last row.

	MUSICI	CASAE	LOCI	BACCAE	RES	EVENTA	CATALOGUS
Type	Persons	Institutions	Places	Objects	Terms	Events	Media
MUSICI	YES	YES	YES	YES	NO	YES	YES
CASAE	YES	NO	YES	YES	NO	YES	NO
LOCI	YES	YES	YES	YES	NO	YES	NO
BACCAE	YES	NO	NO	YES	YES	YES	YES
RES	NO	NO	NO	YES	YES	NO	YES
EVENTA	YES	NO	YES	YES	NO	NO	NO
CATALOGUS	NO	NO	NO	YES	NO	YES	YES
Public Yet	YES	YES	YES	YES	NO	NO	YES

3.1 Musici: Persons

For the set of persons m_1, m_2, \dots, m_n , with $n = 33,602$, each m_i may have:

1. m_i^{Name} – Naming variants of the person. This may include given and surname, pseudonyms or maiden name
2. m_i^{Date} – Temporal Data as seen above: Life and work years in a range of [0,2020] A.D.
3. $m_i^{Confession}$ – List of Confession(s)
4. m_i^{Gender} – Gender(s)
5. $m_i^{MusicalProfessions}$ – List of musical professions
6. $m_i^{OtherProfessions}$ – List of non-musical professions
7. m_i^{Branch} – List of types of employer. Examples may be concert, court, orchestra or military
8. m_i^r – Lists of relations leading to other facets. A green cell in Table 1 indicates that from this facet an instance of the other facet is included/named.³
9. m_i^{IDs} – List of IDs used in related repositories of musicological knowledge [VIAF, GND, Q, ...]
10. m_i^{Links} – List of links using the IDs to reference other resources containing important data of the person (highlighted in red)

³ E.g. a person having worked in the institution *Bayerische Staatsoper* has a list of the to him connected institutions and one entry is the *Bayerische Staatsoper*. A click on the label redirects to the result page of the selected institution in another facet.

3.2 Casae: Institutions

The round about 800 institutions – containing operas, courts and conservatories – may list data of:

1. c_i^m – Members m_j, \dots, m_k
2. c_i^{Name} – The name
3. c_i^{Date} – Dates of opening and closing
4. m_i^r – Lists of relations leading to other facets. A green cell in Table 1 indicates that from this facet an instance of the other facet is included/named (See Footnote 3).

Compared to the other facets, this list of data is rather short. Nevertheless, the linkage between institutions and persons is of high value and already showed great distant reading analysis in previous works [13].

3.3 Loci: Places

Geographical locations, as places a person was born or worked in or as site an institution was located, are of further interest for musicologists. Mainly, they are linked in other facets' entities and bear useful and interesting results. Already shown examples include the analysis of cities in pre-industrial eras, where specific places were known to be centers of agglomerations. For use cases shedding light on this, consider Khulusi et al.'s paper [16].

Like the prior repositories, given information includes names, links, IDs, and different relations to other facets (See Footnote 3). Further, topological information is given hierarchically, linking e.g. l_i Germany to l_x Europe as a parent and to the German states l_y, \dots, l_z as children. More information is given with e.g. longitude and latitude coordinates.

3.4 Baccae: Objects

Objects to generate music are, of course, a further important part of musicological research. This includes mainly instruments and lists different (hierarchical) types, images, sound samples, properties, relations, labels, and internal and external links. Later, in Sect. 5.4, a more detailed description will be found.

3.5 Res: Terms

The repository *Res* includes different terms in musicology. While normally, dictionaries exist that help in understanding terms and offering descriptions, musicology has the unique issue that a lot of terms are uncertain, leading to challenges for automated processing [17, 19]. This ranges from changes in the meaning of a single term in different centuries to almost no endeavors to standardize terminology. For example, the number of strings of a string instrument may have changed due to general changes in music throughout the years. Still, the same term may be used for both types of instruments with a different number of strings. Hence, while using the term, a temporal context may

now also change the to be expected features of the object. Especially automated processing encounters difficult challenges due to this lack of standardization. In this facet, terms, and descriptions of musicological labels are collected and described, helping in letting the users get important context information. For this purpose, r , as the set of r_1, \dots, r_n , contains $r_i^{Variants}$ – labels (in different languages) or synonyms for the term –, describing elements $r_i^{Description}$ for the concept behind the term, and again links and relations to other facets (See Footnote 3) like media containing definitions of it or lists of objects of this term.

3.6 Catalogus: Media and Titles

While *Baccae* contains the physical objects itself, the digital representations of objects (metadata of books, 3D data of objects or contents on CDs) are collected in the *Catalogus* facet. With the piano roll use case (see Sect. 5.4) we will describe in more detail the included data.

3.7 Eventa: Events

The event facet mainly links other facets and can be considered as a kind of interface. Each event has a type, two to be linked IDs and sometimes further to be connected entities like associated persons, temporal context, locations, or more.

4 Connecting Facets

In current work, the *musiXplora*'s editorial team began to include data to link up the different facets and subdomains. While a high coverage of the single facets is mandatory for a useful research tool, the linking of the facets is the heart of the project, offering unique possibilities available through its digital nature.

In general, two kinds of linkage exist. (1) An entity may be linked with a special and internal generated *musiXplora* ID (mXpID). This ID allows a glance at the type of entity. A mXpID for a person is beginning with the first letter of the surname of the person, followed by a four-digit number combination. The numbers are auto-incremented and do not have a semantic value (as example b1316 for Ludwig van Beethoven). For the other facets, mXpIDs consist of seven-digit combinations, giving more possibilities to help in not running out of combinations. Each of these IDs starts with the facet's index. Hence, all objects have IDs starting with 4, while all terms start with 2. Thus, it is quite easy to know to which facet an ID belongs to. (2) A second way of representation of entities exists for places and terms. While they also have (1) mXpIDs, they also have a *Vorzugsansetzung* (preferred name). This unique name – like *Frankfurt/Oder* or *Frankfurt/Main* – is mainly motivated through the internal editorial work. Some entities have vast lists of data. Additional, the work with digit IDs is prone to errors. Hence, terms and places are internally also linked by their *Vorzugsansetzung*. To illustrate the motivation, Fig. 1 shows the pianist Axel Zwingenberger and his exhaustive list of places he worked at. Maintaining – correcting or adding places to – such a list through digit identifiers has proven to be problematic for the human worker.

Contemporary Title „Boogie-Woogie-Pianist“

Branch Ensemble, Festival, Jazz, Konzert, Medien, Rundfunk/Fernsehen

Place of Activity Hamburg, Aachen, Aalen, Abidjan, Accra, Agypten, Ahrensburg, Aleppo, Alexandria, Algerien, Algier, Almelo, Alsdorf, Amberg, Amerang, Amman, Ammersbäk, Ampfinghau, Amsterdam, Amstetten, Ann Arbor, Anney, Ansbach, Antwerpen, Anifels, Arnstadt, Arnstein, Arosa, Ascona, Aspach, Asunción, Augsburg, Baabe, Bad Abbding, Bad Aussee, Bad Homburg, Bad Ischl, Bad Kreuznach, Bad Oldesloe, Bad Säckingen, Bad Tölz, Bad Vilbel, Bad Wildungen, Bad Wörishofen, Baden-Baden, Baden/Wien, Bandung, Bangalore, Bangla Deah, Bangui, Baniko, Barcelona, Bargtheide, Basdorf, Basel, Beanne, Bellingries, Beint, Belfast, Bergen, Berlin, Bern, Bevoren en Auge, Bielefeld, Bieilgheim-Bissingen, Binz, Bludenz, Bochum, Bognar Regis, Bolivien, Bonn, Boppard, Bozen, Braunsau/Inn, Braunschweig, Brecon, Bregenz, Bremen, Bremehaven, Bresewitz, Brüssel, Buchholz/Nordheide, Budapest, Bukarest, Burgdorf, Burghausen, Burkina Faso, Burnley, Bussum, Calcutta, Coimbra, Caminha, Campo Basso, Casablanca, Chaumont, Chemnitz, Chennai, Chiba, Chicago, Chichester, China, Cincinnati, Clermont Ferrand, Cleveland, Colombo, Crawley, Dacca, Dakar, Darmstadt, Deggendorf, Dessau, Detroit, Differdingen, Dijon, Dorsten, Dormund, Douala, Douglas, Dreieich, Dresden, Düren, Düsseldorf, Eastleigh, Ecuasstenes, Eisenstadt, Ellenwinküste, Elnaz, Enden, Enns, Erding, Erkrath, Erlangen, Erlangen, Ertlingen, Farnham, Feldkirch, Feldkirchen, Feme, Fischlham, Frankfurt/Main, Freiburg/Breisgau, Freyung, Friedrichshafen, Fürstenfeldbruck, Furth, Gaggenau, Garching, Gävle, Gelsenkirchen, Genf, Gent, Germaring, Gernshaim, Ghana, Gleisdorf, Gmunden, Grafenegg, Graz, Great Bardfield, Griechenland, Gütersloh, Hagenbach, Haiger, Hainburg/Donau, Hallein, Hamamatsu, Hamm, Hannover, Harfen/Niederlande, Heide, Heidelberg, Heilbronn, Heiligenhaus, Hell, Herford, Herisau, Hildesheim, Hirschberg, Hongkong, Houston, Huzou, Hyannisport, Hyderabad, Iking, Igi, Imolo, Imst, Indonesien, Innsbruck, Inverness, Isernhagen, Islamabad, Isle of Man, Itzehoe, Jena, Jordanien, Kairo, Kältern, Kamen, Kannewur, Karatschi, Kassel, Kathmandu, Kiel, Kirchheim/Teck, Kitakami, Kitzbühel, Klagenfurt, Knokke, Koblenz, Köln, Kopenhagen, Krens, Kreuztal, Kuala Lumpur, Kufstein, Kötlingborn, Künzelsau, La Chaux de Fonds, La Paz, La Rocheberou, Lagos, Lahore, Lamspringe, Langenszersdorf, Larsen, Lauchham, Leer, Leiden, Leingarten, Leipzig, Leoben, Leukirch, Leverkusen, Libanon, Liechtenstein, Lillge, Lille, Limoges, Lindau, Linz/Donau, Linz/Rhein, Lisboa, Liverpool, Lloer de Vista Alegre, Lomé, London, Los Angeles, Louisville, Lübeck, Lüchow, Luckenwalde, Ludwigshafen, Lugano, Luxemburg, Lyme Regis, Lyon, Madrid, Magdeburg, Maison-Laffite, Malaysia, Malilla, Manchester, Manila, Mannheim, Mantua, Maribo, Marlborough, Marokko, Meinerzhagen, Meiningen, Melk/Donau, Milton Keynes, Minden, Möding, Molede, Monaco, Monte Carlo, Mragowo, Mühlhofen/Inn, Mühlheim/Rahr, Mumbai, München, Münster, Murau, Müzzschüßing, Nagoya, Naimé, Nepal, Neuburg/Donau, Neuchâtel, Neuzßel, New Delhi, New York City, Newcastle upon Tyne, Nigeria, Niigata, Nizza, Nocera, Norderstedt, Norwegen, Nürnberg, Næstved, Oberstufen, Oberhulba, Oldenburg, Oostende, Osaka, Osznabrück, Österreich, Ottersberg, Ouagadougou, Pakistan, Paraguay, Paris, Passau, Peine, Penang, Perchtoldsdorf, Pfäding, Pinneberg, Porto, Prag, Preston, Pune, Rabat, Radstedt, Regensburg, Kied/Innkreis, Ris Orangis, Rochester, Rom, Rosenheim, Roth, Rothenburg/Tauber, Rotterdam, Rügheim, Ruialeda, Rüschkon, Saarbrücken, Salzburg, Santa Cruz, Sargans, Schaau, Schönberg, Schwarzenau, Schwaz, Schweinfurt, Seosan, Sells, Sella, Semarang, Senegal, Seoul, Siegen, Simbach/Inn, Simmarath, Slowaki, Sofia, Southport, Spakonoo, Sri Lanka, St. Johann/Tirol, St. Pölten, St. Veit/Glan, St. Wolfgang, Starnberg, Stein an der Traun, Steinegg, Steyr, Straßburg, Sturmminster Newton, Stuttgart, SP Maria da Feira, Südkorea, Surabaya, Syrien, Tanger, Tegernbach, Terrazzo, Thun, Timmendorfer Strand, Töging, Togo, Tokio, Toulouse, Travers City, Trebel, Tripolis, Trittau, Trostberg, Tunis, Uelzen, Ulm, Unna, Utrecht, Valburg, Vannes, Vilach, Villingen-Schwenningen, Vilshofen, Vöcklabruck, Vorchdorf, Waidhofen/Thaya, Waidhofen/Ybbs, Wätkung, Weiden, Weiheim, Weinstadt, Weiz, Wels, Wendelstein, Werheim, Westerland, Wetzlar, Wien, Wiener Neustadt, Wilhelmshaven, Wimborne Minster, Winsen/Luhe, Winterthur, Wolfberg, Worswede, Würsiedel, Yaoundé, Yogyakarta, Zallweg, Zeuthen, Zingst, Zürich, Zwingenberg ◀ less

Venue Aachen, Aalen, Abidjan, Accra, Agypten, Ahrensburg, Aleppo, Alexandria, Algerien, Algier, Almelo, Alsdorf, Amberg, Amerang, Amman, Ammersbäk, Ampfinghau, Amsterdam, Amstetten, Ann Arbor, Anney, Ansbach, Antwerpen, Anifels, Arnstadt, Arnstein, Arosa, Ascona, Aspach, Asunción, Augsburg, Baabe, Bad Abbding, Bad Aussee, Bad Homburg, Bad Ischl, Bad Kreuznach, Bad Oldesloe, Bad Säckingen, Bad Tölz, Bad Vilbel, Bad Wildungen, Bad Wörishofen, Baden-Baden,



Fig. 1. Snipped showing Axel Zwingenberger’s places to illustrate problematic amount of data.

With this in mind, we can have a look at an entity. For the user, the vastness of information is presented with visualizations, helping in grasping and working with even such long lists. The snippet of the musician Axel Zwingenberger’s result page (Figs. 1 and 2) shows already multiple links to the other facets, also. Each named place or visualization representative (as long as it is already included in the database) can be clicked, resulting in a call to the places facet and result page of the clicked place. This is indicated by a coloring of the label on mouseover in the facets’ color. As the database does not include all places ever mentioned in documentation, not every place is linked. Each place that could not be linked is logged and counted as missing in the database. Hence, the most required missing entities will be the first to be added to the database every month. The linking and logging also apply for all other facets, as seen in Table 1.

With the availability of linked facets, a user may now be able to both, inspecting entities in its facet with all relevant information and also to quickly navigate to other facets. An example and very simple use case may be having a look at a specific person. While we can get a quick overview of the musicological career, like working time, places worked at or professions, the latter one may list *string instrument maker*. Under *Events* we may now see events of this person including the instruments that were built. A click on one of these instruments leads to the objects’ facet, showing us detailed information of the instrument, including its type, images, career – especially relevant for organologists –, measurements – for instrument makers and conservators – and more. Hence, the combination of presenting data in its faceted view and still linking them allows the users both, inspecting an entity in its specific subdomain or general context of the musicological knowledge.



Fig. 2. Map visualization to give an overview of Zwingenberger's places.

4.1 Subsets

Next to this, the collaborating musicologists wanted to also include a more or less traditional view on the data, mirroring the book-like information range. *Teilmengen* (subsets) of specific, relevant entities are predefined. They only include a subset of both, facets and entities within. One subset called *NOVY KINSKY* only contains instrument makers, while another has a geographical range, including only persons who were active in Bavaria (*BMLO*). While the subsets of persons are not disjoint, for objects we see only two disjoint subsets. *MIMUL.OBJECTS* with all objects located in the Musical Instrument Museum of Leipzig University and *FUNDUS* with the objects outside.

While it may seem to be a backward step from a facet containing all available information – especially considering the quantitative global nature of digital humanities inquiries. For musicologists, including of such subsets is highly motivated. Firstly, as discussed in Sect. 6.5 and works by Khulusi et al. [17] and Kusnick et al. [19], musicology's missing standards in terms and definitions lead to quite inhomogeneous data. This inhomogeneity is increased by the described problems of historical data, like uncertainty and imprecision. This makes it hard to reach a global high level of quality within a facet. Using homogeneous subsections allows especially the editorial team to focus on specific aspects of data. Further, like our collaborating musicologists explained, a musicologist, as user, is provided with a tool to work in a similar manner to their traditionally known way. It was stressed as follows: Imagine a user, who already knows analog lexica of information and wants to get information about a lute maker. Such a person wants improvement to the printed media, hence, a digital lexicon showing only the required data and not unnecessarily much information, with also a lower level of quality. Hence, a subset of the whole facet with guaranteed quality is required. This can be offered for typically requested parts of the data through such subsets. Lastly, a practical motivation lies within the funding of humanities projects. Especially state-funding is often limited to the digitization of only a small set of data. The State of Bavaria for

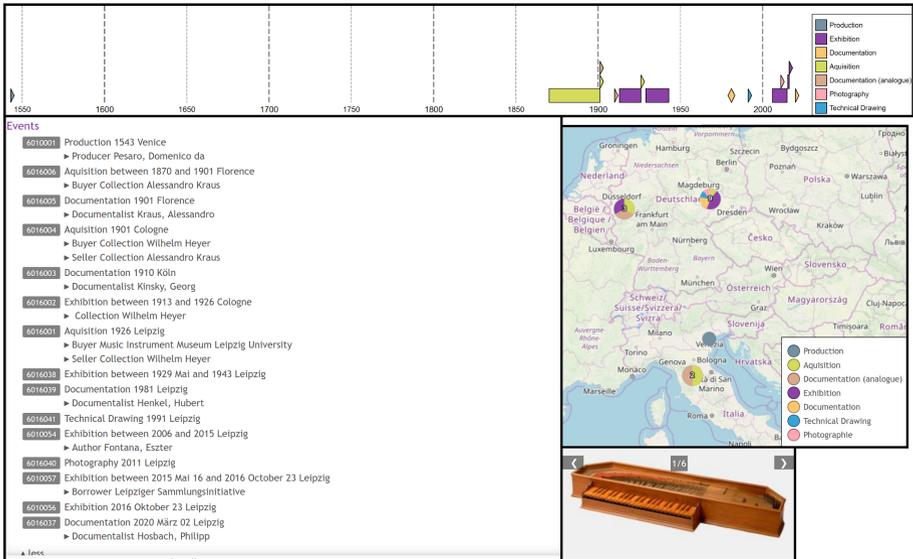


Fig. 3. View on the world oldest clavichord with visualizations of temporal data and geographical data next to a list of all events shaping the career as well as an image browser.

example is funding the digitization of musicians working in its area. Hence, additional manpower may be available, but only to work on the persons within the *BMLO* subset, thus giving the need to separate a facet into different subsets.

5 Use Cases

As a project heavily motivated by musicology and being done in close collaboration, we would like to include further use cases of how our collaborating musicologists work with the tool, to highlight its possibilities and value. Previous works already show a broad spectrum of use cases of mainly the persons' facet (like temporal changes in typical relations found in musicology, time frames of the lute instrument starting to be included in Europe's court, the movement of historicism and the changes on instrument production centers due to globalization) [13–16]. Also, different works using the *musiXplora* database itself, without the tool, highlight the usefulness of the data [10, 11, 19]. With this range of already published use cases, we want to complement the use cases with four newly possible views on the data.

5.1 The Oldest Still Preserved Clavichord

In 1543, Domenico Pisarenensis, a famous instrument maker, produced the instrument, which is known as the oldest still preserved clavichord. Not only the date of production makes this instrument unique for today's musicology, but also the fact that it consists of mostly original parts, highly uncommon for such old instruments. Figure 3 shows the entry in the *musiXplora*'s web interface, representing the instrument in question.

Next to the images of the instrument, we can also see 15 documented events, shaping the career of the instrument. After its production in the city of Venice, in this time a centre of culture in Europe, it was added to the collection of the wealthy collector Alessandro Kraus in Florence (1870–1900). This collection is known to be one of the earlier collections of music instruments. As part of this collection, it was documented for the first time, by collecting images, measurements and descriptions. In 1901, Wilhelm Heyer bought the whole collection and moved the instruments to Cologne, where it was documented again by Georg Kinsky and then exhibited for 13 years. As of today, the last owner change was the acquisition by the Musikinstrumentenmuseum of Leipzig University in 1926, followed again by being exhibited (1929–1943 and from 2006 onwards). Today, it is placed right at the entrance to the museum’s exhibition. Besides this list of events, visualizations can be seen, showing the career of the instrument in time-centered and in geographical context, letting the user get a grasp of not only the geographical space this object travelled but also the time-frame in which it was preserved. Also especially important for musicologists are further references offered by other websites that hold valuable and detailed information about the object, an example being the MIMO (Musical Instrument Museums Online), a shared database of different museums. Here, we can find measurements and descriptive data like the inscription “DOMINICVS PISAVRENSIS MDXXXIII”, which informs on the producer and the year of production. All information on the object’s result site is linked to other repositories of the *musiXplora*. This way, the user can use this page as a starting point for an in-depth research by accessing more detailed information on different points of interest (e.g. related locations, producers or restaurators).

5.2 Jazz Musicians

While scenarios of the *musiXplora* often refer to historical data [13, 16], some current research projects focus on more contemporary aspects like 20th century jazz, rock and folk musicians in the USA, recently added to the *musiXplora*. Figure 4 shows a social network graph of banjo players generated by the *musiXplora* with color-coded relationship types. The musicologist working with these data reported that the different genres of music can be easily seen here. In part A, the folk music genre can be found, centred around Pete Seeger, an essential folk musician. Area B consists of musicians belonging to the country and blue grass genres, who are more connected to each other and less centralized. This is caused by them often playing together in ensembles. The centre of the graph is formed by pop musicians and centered around famous artists like Bob Dylan or Paul Simon. A last genre is given with modern and experimental jazz (D). Here, Tom Waits is a musician to be named and, especially in comparison to the other genres, green edges are dominant, showing that these musicians have mainly worked together as colleagues. A further point of interest is the connection between these sub graphs. The dark nodes are for persons that are inside the result set, hence, banjo players. The lighter ones are their first level neighbours. While for the country musicians, connectivity between dark nodes can be seen (again, caused by their tendency to playing together in performances), the other genres mainly have lighter nodes building connections inside the sub graphs and towards other genres. These are influential people networking as part of their job or by a high level of interest in collaboration. Between folk and country music, a

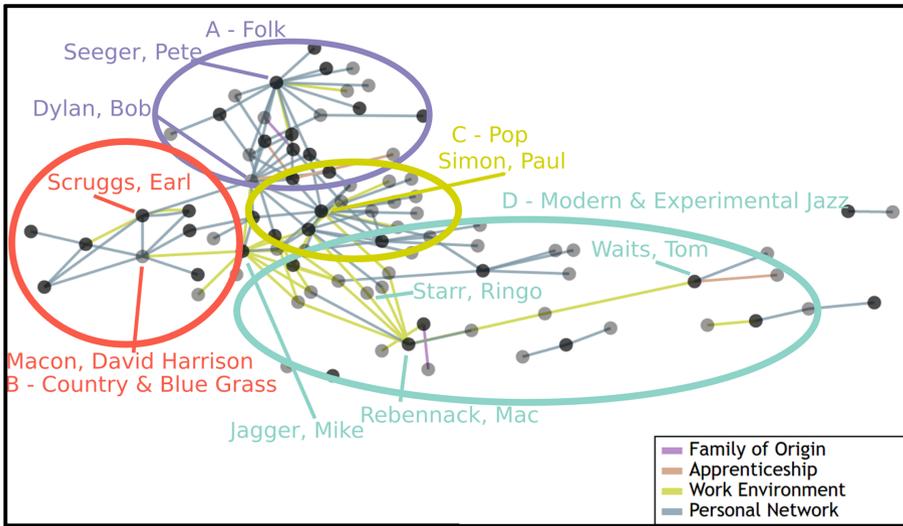


Fig. 4. Network graph of all banjo players currently in the database. Annotated with findings and classifications of the musicologist and prominent musicians.

noticeable connecting node is Bob Dylan, but folk musicians of the 1960s are bridges to country music in general, as we were told by the musicologist. For pop and country music, we can see lesser connecting nodes, indicating less common concepts. The links still found between these subsets relate to studio musicians from the 1950s and 1960s country scene and by people of music research as central nodes. The cluster of modern and experimental jazz shows again a large amount of light nodes connecting to, e.g., the pop genre. Linking musicians in this case are highly connected musicians like Ringo Starr or Mick Jagger, who played in different ensembles. Another view on the data is shown in Fig. 5.

With the help of these pie charts we get an overview of different biographical characteristics. For example, the ratio of female banjo players was very small (A1). As comparison, the ratio for the singer profession was much higher (A2, 32%). The musicologist that we talked to, was quite interested in non-musical professions (C1), showing that the banjo players mainly originated from a lower income class and a creative setting. A background of creative jobs was expected, but the rather high percentage of soldiers in this group surprised him. While this does not mean that these genres are promoted inside these classes, it does highlight the influence of the genre in communities belonging to three specific classes: military, church and agriculture. In the following, he compared them to blues musicians. Here, the non-musical professions indicate a rather low income group (C2). Blues musicians typically had agricultural professions and, especially, a high amount of pastors is shown. This highlights the important role of the church for the rural African American communities in southern states of the United States, typically found for this genre in this time era, and also more rural than creative background in general. Further, the denominations of banjo players were mixed, having a Jewish and Baptist majority (B1), and blues musicians typically had a baptist belief (B2). For a more general

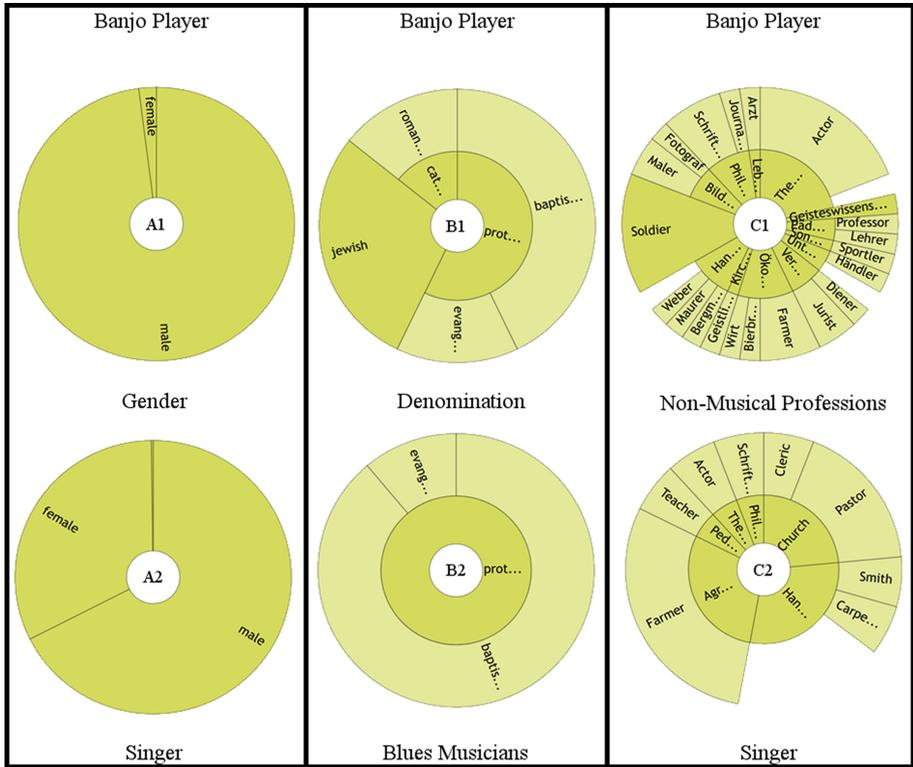


Fig. 5. Pie chart match up of banjo players, singer and blues musicians with their gender, denomination and non-musical profession distribution.

profession like singer, a majority of Roman Catholic musicians can be found, highlighting the specifics of the denominational compositions of sub genres of jazz. Some of these different characteristics are even mirrored in the lyrics of the songs showing their importance for the jazz genres.

5.3 Organological Inspection of a Viola d’amore

Organologists try to shed light on the career of instruments. Figure 6 (B) shows a Viola d’amore, which does not have a typical signature of its builder and is also delivered anonymously. Hence, it is neither known when, nor where, nor who manufactured this instrument. Still, musicologists are interested in knowing the origin of the instrument and its production data. Of course, the *musiXplora* will not be able to give a guaranteed answer (it cannot recreate lost knowledge), but it may give strong hints and indications on the origin, helping in both, narrowing down the possible answers and directing towards secondary sources where useful information may be hidden/found.

Previous dendochronological inspections of the instrument already pointed on a creation around 1721 in the northern area of the Alps. With this information, a col-

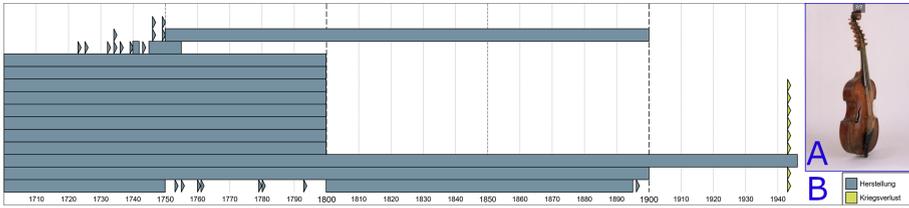


Fig. 6. (A) Timeline showing events of all Viola d’amores. Blue are events of production, yellow events of instruments being lost due to war. (B) Image of a Viola d’amore from the 18th century, as presented in the musiXplora. (Color figure online)

laborating musicologist accessed different available information of comparable situations. (1) In the object facet, he searched for instruments documented through museum or research context and of this baroque and courtly type. Filtered again by their time of production being between 1701 and 1741, resulting in about 20 instruments (see Fig. 6 (A)). Next to the access to each of these objects and their information, a similar search is started for persons. (2) He filtered by the profession of *String Instrument Maker* who worked in the time between 1701 and 1741. While the information of building string instruments does not necessarily only include persons that produced Viola d’amores, the present state of the musiXplora does not allow for a more detailed filter – which is quite difficult in musicology in general, as e.g. persons who produced string instruments are mostly named as *Violin Makers*, independent of them ever producing a violin. Presently a whole set of portfolios – areas of specialization for persons – is being collected and created by musicologists, but could not be put online, yet. Nevertheless, we already have access to the almost 20 instruments that are produced in the relevant period. Through the linkage of the events of the objects, we can directly access the specific instrument makers that could not be reached through the single facet. Hence, through the linkage of the facets, even not yet available, specialized data and functions can be used, which makes us hope that the tool may be used in even more situations than we can imagine (yet). While this lead to an increase in precision in the result set (compared to searching by profession of string instrument maker), the downside is, of course, a low recall, as we only got the rather small set of Viola d’amore builder who’s instrument(s) are still preserved/included in the database.

The last step in this use case is now the intellectual work of the musicologist. With access to different relevant instrument makers (2) and instruments (1) similar to the unknown Viola d’amore, he can now use the interactive tool to inspect single data entities in more detail or make use of the various visualizations for visual analytics of the related instruments, giving insight into e.g. single production places or centers typical in the timeline. For this, Fig. 6 shows all Viola d’amores produced in the period of question. Next to the production (blue) events, we can also see a couple of war damage events (yellow). These events describe a loss of the instrument during the Second World War. Therefore, these instruments can be excluded as exactly fitting candidates for the instrument that is still preserved, but can be useful for comparison. With the help of the

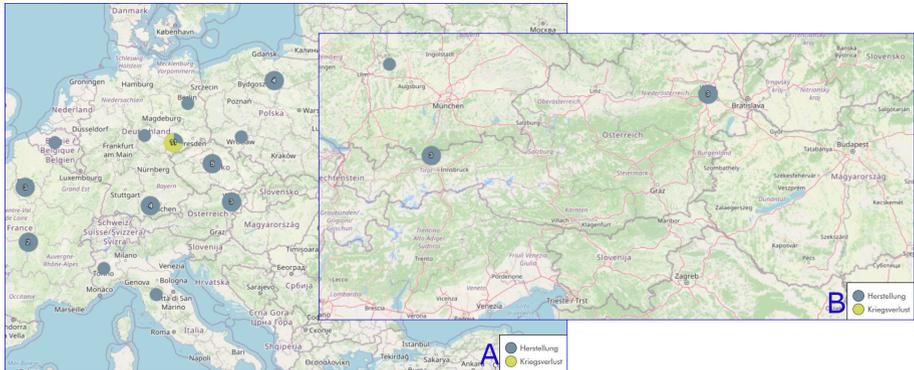


Fig. 7. Maps showing distribution of production places (blue) and war damages (yellow). (A) Overview of middle Europe and (B) locations in the northern Alp region (Mittenwald and Vienna). (Color figure online)

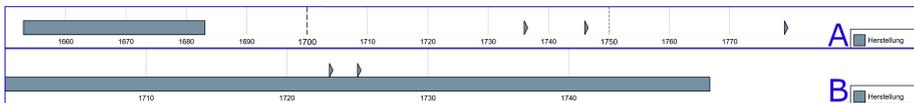


Fig. 8. Timeline showing all Viola d'amores produced in the northern Alp area. (A) The city of Vienna, (B) the city of Mittenwald.

map visualization (Fig. 7) we can see the geographical aspects of the production events. With a zoom on the northern Alp region we find two productions centers of interest: Mittenwald in the lower Bavarian region and Austria's capital Vienna. A match up of both sets of instruments, seen in Fig. 8, shows that only one of the instruments produced in Vienna fits into the temporal scope, while the Mittenwald ones seem all to be promising candidates. With this exemplary delivering of information we conclude this use case. Now, the musicologist would start a more detailed analysis, using information like images and description of the found instruments.

5.4 Piano Rolls: A Special Case

As an entity, piano rolls are a special case in the *musiXplora*. Normally, an entity can be effortlessly put into one of the seven facets. A piano roll is a long piece of paper (with easily 50 m). Holes indicate sounds to be played and handwritten annotation may be found throughout the roll. These holed papers can be used to recreate musical pieces. In musicology, these objects are known as early ways to document and recreate interpretations. While a typical music notation on paper is by far older, they show a kind of blueprint of a piece and how it should be played. In contrast, piano rolls may be produced as *recorded piano rolls*. These have been recorded in a specialized recording procedure, were – mostly famous – pianists played on a special recording piano. Live, holes were punched into the paper. The difference to musical notations is that here,

we can actually see how a person interpreted – played – a song, which may be quite different from its blueprint version. Parts where the rhythm is not followed directly, fingerprint-like and typical keystroke patterns, or parts where the pianist improvised can be found. Thus, a piano roll is a very early way of recording and gives us today access to data and ways how famous persons played piano. For the database, a piano roll is both, an object to create music with (like an instrument, having paper and wood components) and a media to transfer information like a book or note sheet. Hence, it can be put into either the *BACCAE* or the *CATALOGUS* facet. We decided to split the piano rolls to fit well into the categorization. This leads to the physical object and its data like measurements to be put into *BACCAE* and the content like titles into *CATALOGUS*.

In the following, we will have a look at an exemplary piano roll, helping in research questions like “Which musical pieces are often recorded?”, “From which pianist do we have preserved techniques?” and “How do different interpretations of the same song differ by the pianist recorded?”. Figure 9 shows the Object facet’s entry for the piano roll, here we can find different kinds of data:

- A – Name and different properties like interfaces, equipment, damage (e.g. a discoloration of the paper seen in the image) or weights and measurements
- B – The linked data within the musiXplora, like events of the piano roll (production and documentation), Terms (general piano roll and the subcategory), institutions linked to the object and media entries.
- C – musiXplora external and internal links. In this case, a hyperlink to the subset of objects in the collection of the Musical Instrument Museum of Leipzig University (*MIMUL_OBJECTS*), where the piano roll is located.
- D – Different kinds of visualization like a scan of the object, a map, and a timeline shaping its career.
- E – Further information like identifiers (only one for this object), a shortcut to give feedback, and information about citing this page.

With a click on the *MIMUL NR6731* label, we move to the media facet entry of the piano roll shown in Fig. 10. While here no visualizations are included (yet), we find again similar entries, more focused on the content of the roll:

- A – Name of the media and different title variants including specification of the key in the – for the production time typical – languages German, French and English, and the specification of the tempo.
- B – List of musiXplora internal links, similar to the Object facet.
- C – List of musiXplora external links, in this case to the German National Library’s dataset of the musical piece recorded on this piano roll.
- E – Analog to the Object facet

Like with the clicking on the *MIMUL NR6731* label, all other named labels are linked within the musiXplora as seen in Table 1. Hence, we could also get more information about the composer of the musical piece – Beethoven –, the artist whose musical handwriting is preserved with this piano roll – Pembauer – or general information about the producing firm or project which documented the roll.

In summary, with the availability of piano rolls, a use case may be to inspect different kinds of interpretations and playing techniques by famous pianists from which no

Piano Roll 4036731

A **Properties**

- ▶ Interfaces
- ▶ Equipment
- ▶ Damages
- ▶ Weight
- ▶ Cabinet Measurements

B **Events (3)**

6031094 Production 1922 Leipzig

- Composer Beethoven, Ludwig van
- Artist Pembaur, Josef
- Producer Hupfeld AG
- Piano Roll
- MIMUL NR6731

6039094 Cataloguing 2018 Leipzig

- Cataloger TASTEN-Project
- Piano Roll

▼ more

Terms (3)

Hupfeld Phonola 17924

2002522 Piano Roll

▼ more

Institutions (2)

3030119 Hupfeld AG

3000335 Music Instrument Museum of Leipzig University

Media (1)

5018094 MIMUL NR6731

C **Archives, Museum, Collections (1)**

MIMUL Objects

D **Visualizations**

Tempo 50-60

E **Identifier** musiXplora 4036731  

Questions and Corrections 

How to Cite MusiXplora, Hg. Josef Focht, <https://home.uni-leipzig.de/mim/dev1/mxp/4036731> (Version vom 29. Mai 2020)

Fig. 9. Single Result Page of the Piano Roll in the Object facet with different properties (A), linkages within the musiXplora (B), outside the musiXplora (C), visualizations (D) and further information (E).

live recordings are preserved otherwise. For this, a musical piece like the *Mondscheinsonate* from Beethoven – from which the musiXplora has 23 different recordings by pianists like Josef Pembaur and Harold Bauer – can be searched for. The found recordings can then be analysed in depth.

For further and future inspections, we presently work on including the whole scans of all piano rolls (1–5 GB per piano roll) next to the already included first part (showing labels and stamps typical on the first few hand-lengths of the paper). Further, sound samples of the musical piece being played through a MIDI interface will be added soon. This will not only allow hearing the exact interpretation but also to choose the instrument on which it is played out of different digitized historical and unique objects

<p>MIMUL NR6731</p> <p>Sonate Op. 27, No. 2 Mondschein cis – ut dièçe – c# Presto agitato</p>		<p style="font-size: 2em; color: blue;">A</p>	
<p>Events (2)</p> <p>6031094 Production 1922 Leipzig</p> <ul style="list-style-type: none"> • Composer Beethoven, Ludwig van • Artist Pembaur, Josef • Producer Hupfeld AG • Piano Roll • MIMUL NR6731 <p>6043094 Documentation 2019 Leipzig</p> <ul style="list-style-type: none"> • Documenter TASTEN-Project • Piano Roll • MIMUL NR6731 		<p style="font-size: 2em; color: blue;">B</p>	
<p>Terms (1)</p> <p>2002522 Piano Roll</p>			
<p>Objects (1)</p> <p>4036731 Piano Roll</p>			
<p>Institutions (2)</p> <p>3030119 Hupfeld AG</p> <p>3000335 Music Instrument Museum of Leipzig University</p>			
<p>Library Catalogues</p> <p>German National Library</p>		<p style="font-size: 2em; color: blue;">C</p>	
<p>Identifier musiXplora 5018094 </p> <p>Questions and Corrections </p> <p>How to Cite MusiXplora, Hg. Josef Focht, https://home.uni-leipzig.de/mim/dev1/mxp/5018094 (Version vom 7. April 2020)</p>			<p style="font-size: 2em; color: blue;">E</p>

Fig. 10. Single Result Page of the Piano Roll in the Media facet with different titles (A), link-ages within the musiXplora (B), outside the musiXplora (C), no visualizations yet, and further information (E).

which a user may never be able to hear from the physical object, due to damages and protections of these instruments.

6 Future Planning

As a longtime project, a lot of effort and time has been put into the planning. While a full list of still open plans would bust the scope of this paper, we would like to include near-future and already being worked on extensions.

6.1 Facets Availability

As seen in Table 1, two facets are still not available for the open public. Mostly, this is caused by a low level of completeness inside this facet’s entities’ data. An example is given with the newly published facet of institutions and its most important data type of

member lists. A lot of institutions only show zero to five persons, which is not representative. Due to working with historical data, it may not be able to extend these data further, as there is just no more detailed information preserved. The editorial team is currently still able to fill the lists of many institutions, but will not be able to deliver a full list for all institutions. Therefore, the facet was put online now, although many entities only have a low level of detail. For the terms, events, and media the situation is different. These three facets are quite new. Existing entities are quite well documented, but the number of entries is rather low. With the focus on these facets now, we expect to be able to put the terms and events online soon, while the media facet has been published together with the institutions facet.

6.2 Connectivity

Table 1 also shows that some connections are not included. For example, the institutions' facet only links to two other facets. With the extending of data in other facets and, hence, the collection of data to be linked, we expect to be able to increase the level of linkage to be able to link all facets. To be added data may be different media about institutions (e.g. books describing an institution), which will create a linkage between media and institutions.

6.3 Complexity

Presently, the *musiXplora* allows browsing within a facet on a single page and within multiple facets by changing of the page. With the increasing level of complexity, more and more inter-facet ranging questions are arising, leading the musicologists to ask us about ways of visually linking single facets. This directly leads to the visualization subsection.

6.4 Integrating Visualizations

One of the core features of the web-interface is the deploying of visualizations to help users in a distant and close reading of data. While the facets of persons, objects, and places have a whole set of refined visualizations, some of the other facets are missing both, basic visualizations like pie charts, for getting a general overview over sets of data, and specialized visualizations helping in specific analysis approaches. An example of such specialized visualizations are namely the *Musicians Profiling* tool [11], presently available as a stand-alone tool helping in finding similar musicians to a given one by user-chosen and weighted properties. While this is presently accessible through a red link (*musiXplora* external link) on the person's page, it is planned and allowed to be directly included in the website. Another example is the including of the *Interactive Chart of Biographie* [13], giving the user the possibility to match up groups of persons divided by properties (profession, membership in an institution, confession, ...) and having a look at intra- and inter-group relations and cooperation as well as distributions of properties. Through the persons being positioned on a timeline, it also gives insight into temporal tendencies and time-typical abnormalities of these groups. While these

two visualization projects were already included in the persons and institution facets, there is still planning and potential for other visualization tools dedicated to specific research questions.

6.5 Localization

A major future step needed for the tool to be of high value for musicology is the translation to other languages. While the present state only offers the German language (as one of the main languages in musicological research), at least an English translation is desired. Besides the issue of translating a work-in-progress and the high amount of maintenance arising with it, the translation itself is a rather difficult task. With the low level of standardization in musicology, even within a single language, a term may be quite ambiguous. Kusnick et al. tried to deal with a matching of terms between only two different sources and described even this for only a small set of terms in a single language as issue [19]. Nevertheless, localization, as a cooperation project with other universities, is already being planned. The planned localization includes Mandarin, Russian, Arabic and English, although the extent of the intellectual work of multilingual musicologists is still unknown.

6.6 Musicological Motivated Extensions

Next to specific potential, possibilities and ToDos to extend the musiXplora, the close collaboration in which the tool is growing leads to iterative development and evaluation. During these different iterations, more and more aspects of interest for the musicologists showed. Often, these were research questions that were not possible to answer in the musiXplora, at that time. An example has been seen in the organological use case in Sect. 5. While we were still able to get a result with high precision by going through the object facet to instrument makers, we actually want to find specialized instrument makers through the search functionality in the person facet. Due to such needs, the portfolio property of persons is in work, presently. Also, more and more subsets for specialized projects (see Sect. 4.1) are currently evolving through different research projects (*TASTEN* – German for keys –, *KONTRABASS KARTEI* – double bass index – and more).

Due to these real needs of the musicologists towards the tool – arising over time with the work and increasing familiarity –, the actual scope of possible future functions is unknown today. As a user-centred, iterative project, we expected the tool to grow. Nevertheless, we take the actual level of feedback and communication of needs as an indicator for a continued successful collaboration and an, already taken, big step towards a useful tool.

7 Conclusion

Digitizing information on cultural heritage is the first major step in many digital humanities research projects encountered today. This leads not only to a vast amount of data available, bearing a lot of potential for gaining new insights but also to difficulties working with the data [24]. With the rise of the digital humanities, distant reading methods

began to revolutionize digital research projects in utilizing the newly found range of data, supporting new kinds of research questions [23]. Musicology has more or less not been a part of this development for the last two decades [17], leading to a rather low quantity of digitized data. Further, in this domain, we encountered unique and general issues related to the fragmentation of the field concerning both, data and the state of research. As part of the new research questions arising with the digital humanities [12], a complete and comprehensive overview of the field began to be of high interest for musicologists. With only few unfragmented data sets being available, offering such a comprehensive overview requires numerous efforts to even be considered. In this paper, we presented the *musiXplora* project that, including its predecessor, the BMLO, is running since more than 15 years and offers ground building work: Beginning with the editorial work by musicologists, planning and standardizing by digital humanists and providing intuitive access to the data through visualization by computer scientists. These three groups worked hand-in-hand to achieve a general research tool for musicological information. The current state exceeds previous publications of the project [15, 16] by focusing on the newly included linkage between data facets and refined level of data available e.g. musical objects. While the different functions and types of possible use cases were discussed in depth in the conference paper [16], here, we provided more insight into musicological motivated usage scenarios of the *musiXplora*. One case illustrates how an anonymous instrument, for which only a dendrochronological inspection has been conducted, can be categorized by reviewing information on related instruments and instrument makers. Another scenario provides a look at piano rolls which are part of a current digitization project in the Musical Instrument Museum of Leipzig University, delivering not only descriptive metadata but also high-resolution scans and sound samples, digitally available through the *musiXplora*.

References

1. André, P., Wilson, M.L., Russell, A., Smith, D.A., Owens, A., Schraefel, M.: Continuum: designing timelines for hierarchies, relationships and scale. In: Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology, UIST 2007, pp. 101–110. ACM, New York (2007)
2. Borman, T., Stoel, B.: Review of the uses of computed tomography for analyzing instruments of the violin family with a focus on the future. *J. Violin Soc. Am.: VSA Papers* **22**(1), 1–12 (2009)
3. den Bulcke, J.V., Loo, D.V., Dierick, M., Masschaele, B., Hoorebeke, L.V., Acker, J.V.: Nondestructive research on wooden musical instruments: from macro- to microscale imaging with lab-based X-ray CT systems. *J. Cult. Heritage* **27**, 78–87 (2017). *Wooden Musical Instruments Special Issue*
4. Crauwels, K., Crauwels, D.: *Musicmap: The Genealogy and History of Popular Music Genres from Origin till Present (1870–2016)* (2018). <https://musicmap.info/>. Accessed 24 June 2019
5. Doi, C.: Connecting music and place: exploring library collection data using geo-visualizations. *Evid. Based Libr. Inf. Pract.* **12**(2), 36–52 (2017)
6. Focht, J.: *Bayerisches Musiker-Lexikon Online* (2006). www.bmlo.lmu.de/. Accessed 10 Dec 2019

7. Gleich, M.D., Zhukov, L., Lang, K.: The world of music: SDP layout of high dimensional data. In: *Info Vis 2005*, vol. 100 (2005)
8. Heller, V.: Methoden zur Untersuchung und Dokumentation der Geigen am Museum für Musikinstrumente der Universität Leipzig; Dissertation (2017). <http://nbn-resolving.de/urn:nbn:de:bsz:15-qucosa2-172136>
9. Hopfner, R.: *Violinforensic* (2018). <http://www.violinforensic.com>. Accessed 24 June 2019
10. Jänicke, S., Focht, J.: Untangling the social network of musicians. In: *DH* (2017)
11. Jänicke, S., Focht, J., Scheuermann, G.: Interactive visual profiling of musicians. *IEEE Trans. Vis. Comput. Graph.* **22**(1), 200–209 (2016)
12. Jänicke, S., Franzini, G., Cheema, M.F., Scheuermann, G.: On close and distant reading in digital humanities: a survey and future challenges. In: *EuroVis (STARs)*, pp. 83–103 (2015)
13. Khulusi, R., Kusnick, J., Focht, J., Jänicke, S.: An interactive chart of biography. In: *2019 IEEE Pacific Visualization Symposium (PacificVis)*, pp. 257–266, April 2019. <https://doi.org/10.1109/PacificVis.2019.00038>
14. Khulusi, R., Focht, J., Jänicke, S.: Visual exploration of musicians and institutions. In: *Data in Digital Humanities 2018: Conference Abstracts, 2018 EADH* (2018)
15. Khulusi, R., Jänicke, S.: On the distant reading of musicians' biographies. In: *Digital Humanities 2016: Conference Abstracts*. Jagiellonian University & Pedagogical University, Kraków, pp. 818–820 (2016)
16. Khulusi, R., Kusnick, J., Focht, J., Jänicke, S.: MusiXplora: visual analysis of a musicological encyclopedia. In: *15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, VISIGRAPP 2020*, pp. 76–87. SCITEPRESS Digital Library (2020)
17. Khulusi, R., Kusnick, J., Meinecke, C., Gillmann, C., Focht, J., Jänicke, S.: A survey on visualizations for musical data. In: *Computer Graphics Forum* (2020)
18. Konopka, D., Schmidt, B., Kaliske, M., Ehricht, S.: Structural assessment of wooden musical instruments by simulation: models, validation, applicability. In: *Proceedings of the 4th Annual Conference COST FP1302 WoodMusICK - Preservation of Wooden Musical Instruments Ethics, Practice and Assessment* (2017)
19. Kusnick, J., Khulusi, R., Focht, J., Jänicke, S.: A timeline metaphor for analyzing the relationships between musical instruments and musical pieces. In: *Proceedings of the 11th International Conference on Information Visualization Theory and Applications (IVAPP)* (2020)
20. Leskinen, P., Hyvönen, E., Tuominen, J., et al.: Analyzing and visualizing prosopographical linked data based on biographies. In: *BD*, pp. 39–44 (2017)
21. Lu, S., Akred, J.: History of Rock in 100 Songs (2018). <https://svds.com/rockandroll/#thebeatles>. Accessed 24 June 2019
22. Miller, M., Walloch, J., Pattuelli, M.C.: Visualizing linked jazz: a web-based tool for social network analysis and exploration. *Proc. Am. Soc. Inf. Sci. Technol.* **49**(1), 1–3 (2012)
23. Moretti, F.: *Graphs, maps, trees: abstract models for a literary history*. Verso (2005)
24. Saito, S., Ohno, S., Inaba, M.: A platform for cultural information visualization using schematic expressions of cube. In: *DH*, pp. 365–367 (2010)
25. Tresch, J., Dolan, E.I.: Toward a new organology: instruments of music and science. *Osiris* **28**(1), 278–298 (2013). <https://doi.org/10.1086/671381>
26. Tuniz, C., Bernardini, F., Turk, I., Dimkaroski, L., Mancini, L., Dreossi, D.: Did neanderthals play music? X-ray computed micro-tomography of the DIVJE BABE 'Flute'. *Archaeometry* **54**(3), 581–590 (2012)
27. Vavrille, F.: *LivePlasma* (2017). <http://www.liveplasma.com/>. Accessed 24 June 2019