An Interactive Chart of Biography

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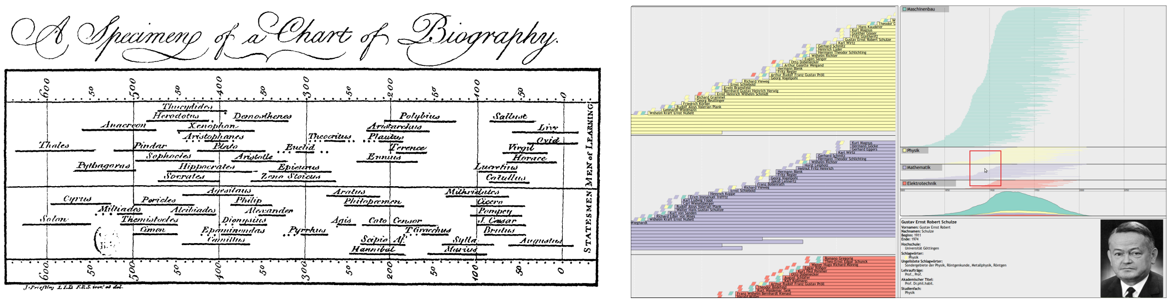

Figure 1: A redacted version of Joseph Priestley's Chart of Biography from 1765 (left) and our Interactive Chart of Biography (right).

Abstract

Joseph Priestley's Chart of Biography is a masterpiece of hand-drawn data visualization. He arranged the lifespans of around 2,000 individuals on a timeline, and the chart obtained great value for teaching purposes. We present a generic, interactive variant of the chart adopting Priestley's basic design principles. Our proposed visualization allows for dynamically defining person groups to be visually compared on different zoom levels. We designed the visualization in cooperation with musicologists having multifaceted research interests on a biographical database of musicians. On the one hand, we enable deriving new relationships between musicians in order to extend the underlying database, and on the other hand, our visualization supports analyzing time-dependent changes of musical institutions. Various usage scenarios outline the benefit of the Interactive Chart of Biography for research in musicology.

1 Introduction

In 1765, Joseph Priestley published "A Chart of Biography" that is known as the first and the most influential timeline chart of the eighteenth century [49]. It provides an overview of the lifespans of around 2,000 famous men who lived between 1200 BC and 1800 AD. They are grouped into the six categories "Statesman and Warriors", "Divines and Metaphysicians", "Mathematicians and Physicians", "Poets and Artists", "Orators and Critics" and "Historians and Antiquarians". Persons with achievements in multiple of those fields were assigned to the category under which their most important work had been done. The lifespan of a person is depicted with a tiny horizontal line from birth to death date. If those information were incomplete or only a single date on the flourishing of a person was given, Priestley drew a straight line estimating the activity time of a person and he placed dots before and/or after this period to indicate this uncertainty. A redacted version of Priestley's timeline illustrating people who lived between 650 BC and 40 AD categorized as "Statesmen" or "Men of Learning" is shown in Figure 1. Priestley was an educator who designed the timeline as an adjunct to his lectures in order to facilitate "the imagination to conceive the course of History in all its parts, and to comprehend what was co-existent and what was successive" [52]. The Chart of Biography was a major reason when Priestley was awarded a Doctor of Law degree by the University of Edinburgh as a reward for his educational accomplishments.

In contemporary terms [7], Priestley's chart is a manually created, static data visualization. On the one hand, it is *data-driven* as it takes a list of individuals with certain features (lifespan and profession) as input. On the other hand, it is *exploratory* as it enables visual data analyses, e.g., the analysis of person groups or the detection of time-dependent relationships among individuals. Despite the indisputable value of Priestley's chart at that time and for future timeline developments, which has been emphasized by Brehmer et al. [9], as a data visualization it suffers from the non-availability of algorithmic methods and means of interaction. First, Priestley was forced to reduce a potentially vast data set to a small number of personalities in order to make it possible to draw the names and lifespans on the available canvas. Second, he displaced names vertically in a frame with a fixed height to avoid occlusions, but a specific ordering strategy is not applied. Thus, potentially related individuals having similar lifespans are not necessarily placed close to each other. For example, in Figure 1 the statesmen Mithridates and Sylla who fought against each other in the Mithridatic Wars are far apart from each other. Instead, Sylla is placed next to Brutus who was eight years old when Sylla died. Third, more specific details on individuals or known relationships among them are not illustrated.

This paper presents an "Interactive Chart of Biography". It is inspired by Priestley's masterpiece and implements his basic idea of plotting the lifespans of all persons contained in a biographical data set in an interactive visual environment. As opposed to a static, hand-drawn chart, our interactive variant takes arbitrary input data, which enables exploring co-existence and succession within diverse person groups. Therefore, we provide a dynamic filtering environment that allows for narrowing down a biographical data set according to the given research question, and for defining features that separate the remaining persons into different categories. The resulting subgroups can be comparatively analyzed on three different levels: (1) an overview that makes global patterns salient, (2) a semantic zoom that focuses on a subset of few hundred persons, and (3) a details-on-demand view showing the characteristics of a single person.

We followed a user-centered design approach when developing the Interactive Chart of Biography in collaboration with musicologists who aimed at extending their database with hitherto unknown

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relations between musicians. Thus, the system required to support this task. Further, musicologists wanted to analyze time-dependent changes of musical institutions. We emphasize the utility of our system by exposing different usage scenarios. In a storytelling style, we show how the proposed visualization supports the exploratory analysis of biographical databases, and how the system helps generating hypotheses about relationships between people that have not been registered in the database and time-dependent developments of professions and institutions. In addition, we report experiences of our interdisciplinary work, including evaluative aspects and limitations due to the nature of humanities data.

2 Related Work

We group works related to ours according to three aspects. First, we look at contemporary visualizations that might have been inspired by historical time-based visualizations, or infographics, respectively. Second, we observe modern timeline visualizations with a prior focus on biographical data. Third, our work is situated in the digital humanities domain from which we outline the most related techniques.

2.1 Historical Time-based Visualizations

Edward Tufte's "The Visual Display of Quantitative Information" [56] and "Cartographies of Time" by Rosenberg and Grafton [49] are recommended sources containing a large variety of historical time-based representations of data. Some of those have a rather declarative nature as they illustrate facts using conventional charts. William Playfair is considered as the founder of graphical methods of statistics [19], including a time-dependent line chart to illustrate the increase of Britain's national debt due to colonial wars (1786). In 1879, Luigi Perozzo designed a three-dimensional chart to visualize Sweden's population increase according to the Swedish Census from 1750 to 1875. Another example is given by Antonio Gabaglio's "Casse Postali di Risparmio Italiane" (1888) that illustrates the monthly development of the number of postal savings books and the average size of deposits for the first time in a cyclic form. Such charts are the means of choice for communicating statistical information nowadays, but their fundamental design principles also resurface in visualization research. For example, the cyclic arrangement of temporal data [4] aids analyzing seasonal climate changes [55] and seasonal developments on the stock market [59]. At Chicago World's Fair 1893, the tree rings of a cross section of the Mark Twain Tree that was cut in 1891 were annotated to illustrate historical developments since 550 AD. EMDialog [26] uses the same metaphor to arrange statements about the Canadian artist and writer Emily Carr in a cyclic fashion. In "Rise and Progress of Christianity and Mahometanism" (1832), John Warner Barber illustrates the changing ratio of both religions with stacked area charts—one chart per political unit. A similar design is used for visualizing multiple time series comparing the developments of stocks with the Horizon Graph [45, 47]. CloudLines [35] are similar as they visualize the time-dependent popularity of persons in news articles and the resultant streams are stacked in order to enable comparative analyses. The last example is John Sparks' "Histomap" (1932) that visualizes the changing relative power of contemporary states, nations and empires over the course of 4,000 years. Similarly, ThemeRiver [22] and Stacked Graphs [11] convey theme changes over time. As Sparks, Shi et al. [53] fill whitespaces of the streams with tags scaled according to its importance.

While it is likely that designers of time-based visualizations or infographics in the past and nowadays develop similar ideas to visualize multifaceted data sets, and that a historical data visualization was not necessarily fundamental for a contemporary work, in our case, we deliberately chose Priestley's biography chart as a source of inspiration. This enabled for revitalizing an established visual representation of biographical data on the one hand, and for improving and extending the design for an interactive, versatile access to multifaceted information on the other hand.

2.2 Modern Time-based Visualizations

Time-based visualizations have been subject of many works in our domain. While Aigner et al. [4] provide an overview of the large variety of sophisticated interactive time-based visualization techniques, Bach et al. [6] discuss time-based visualizations in the context of space-time cubes. Our proposed biographical timeline visualization is based on a cultural heritage collection, and time-based visualizations are often used to display inherent temporal information [29]. For example, Hinrichs et al. [25] use a time-based bar chart for the exploration of commodity trading, and Cho et al. [13] use a stacked time graph for analyzing events in Roman history. A typical task that is enabled by time-based visualizations is the visual analysis of evolving topics over time in news corpora. Examples are given by RoseRiver [17] and TextFlow [16] both representing major topics as color-coded streams over time that merge and split. Other notable works are Parallel Tag Clouds [14] that support the analysis of terminology usage over time, and MultiStream [15] for the exploration of hierarchical time-based stream graphs.

Our biography visualization presented in this paper is a typical timeline. TimeSlice [59] is a similar visualization as it can be used for exploring engineers, scientists, philosophers and politicians that can be arranged in different person groups to support comparative analyses. However, TimeSlice is not designed to visualize uncertain information and relationships among individuals. Furthermore, it does not provide perspectives from various zoom levels necessary for insight-oriented research in digital humanities. Continuum [5] presents a timeline for composers alongside with their works, but the design favors a small number of persons to be displayed. One of the early works is LifeLines [46] that visualize events related to a single person's life on a timeline. Timeline representations for events in news corpora are LeadLine [18] that use small multiples of time graphs to support the comparative analysis of different topics in news and social media data, and EventRiver [37] that uses bubbles with different shapes and sizes for event representation. StoryFlow [36] is a timeline visualization that intuitively illustrates the story lines of movies or novels. For a more detailed overview of timeline visualizations and timeline design we refer the reader to Brehmer et al. [9] who propose a design space for timelines derived from related visualizations and infographics.

2.3 Biographical Data Visualizations

Many works dealing with biographical databases propose social network visualizations. Weaver embeds an attribute relationship graph in a visual analytics framework to visualize the relationships between movie actors [57]. Perer et al. [44] visualizes large social networks focusing on navigation and interaction means. The design of such visualizations is especially important for exploring online social networks [21, 23]. HistoGraph [43] is an interactive graph that serves, among others, for visualizing the social networks of politicians. The given relationship information is extracted from historical social multimedia collections. Likewise, Networks of Names [34] support the visual exploration of social networks derived from newspaper articles, and likewise to our approach, support extending the data set by semi-automatic tagging.

A common task is visualizing relationships among characters extracted from literary works. Euler diagrams [48] can be used to visualize clusters in social networks while also showing relations among them. GeneaQuilts [8] is a genealogy visualization used to express familial relations, e.g., the family trees of the Bible or the European Royalty from many countries. Klein illustrates Thomas Jefferson's social relationships in the form of an arc diagram using the thickness of a line to indicate relationship strengths [33]. Chen et al. [12] introduced tapestries—a matrix visualization that illustrates the importance of characters throughout a story—as visual means to explore emotions and the roles of characters in slave narratives. MusikerProfiling [28] is a visual analytics interface to enable the discovery of musicians with similar careers. It offers stream graphs, maps and social networks for exploratory purposes. Windhager discusses the value of space-time cube visualizations for biographical databases [58] as biographical information often relate to space and time. An example is given by Schich et al. [50] who explore geospatial-temporal developments in a database with 150,000 notable individuals by analyzing birth and death locations. Typical linked views systems to explore diverse biographical characteristics have been presented for musicians [32] and engineers [39].

3 User-centered Design

When developing the Interactive Chart of Biography, we applied a user-centered design approach [3, 24, 41] leading to an intense interdisciplinary collaboration between computer scientists and humanities scholars. We wanted to ensure developing a beneficial, powerful tool for the targeted user group that supports investigating the domain-specific research tasks. Gibbs and Owens pointed out that this is especially important for interdisciplinary collaborations in digital humanities projects where visualization scholars "generally [neglect] the typical humanities user in their design" [20]. We took the experiences of visualization researchers [29] who worked together with humanities scholars into account in order to avoid such pitfalls. What followed was an iterative development yielding a number of prototypes that prepared the ground for the proposed visual analysis system. In this section, we outline several design aspects referring to Munzner's nested model [41].

3.1 Domain Situation

This research bears on musicology, a field of the humanities that observes musicians and their achievements. Although a *composition* is seen as the fruit of a musical process, not only composers are of interest to the musicologists but also instrument makers, conductors, singers, instrumentalists, music publishers, etc. In order to enable quantitative analyses on musicological data, musicologists initiated the digital humanities project Bavarian Musicians Encyclopedia Online (BMLO) [1] in 2004 with the goal to create a database that combines a multitude of biographical information about musicians of various professions that has been searched, collected and digitized from a vast number of documents related to music history. While the BMLO only considers musicians, their works and associated places, the successor project MusiXplora composes a universal database on musicology that also includes information on musical institutions, instruments, events, etc. The MusiXplora is an ongoing project—a research team steadily expands, corrects and refines the database. Thus, the MusiXplora will never contain *all* musicians of human history, and, considering the inhomogeneous state of research in musicology, it will also always be only a snapshot of this inhomogenity. However, due to the manifold information stored, the MusiXplora is one of the prior digital resources for musicologists.

Only a subset of information were required for this project. Collaborating musicologists were predominantly interested in investigating the developments of musical professions and the staff of musical institutions, in particular, the following research questions were posed:

- How did musical professions change over time?
- How did ensembles of musical institutions evolve?
- Who were the important links between musical institutions?
- Are means of visualization capable of triggering hypotheses on unregistered personal relationships between musicians?

In order to address these research questions, information on musicians and their personal relationships were required on the one hand. The MusiXplora contains multifaceted biographical information about around 30,000 musicians including lifetime data, places of activity, professions, divisions and denominations. Furthermore, for each musician a list of relationships including relationship types to other musicians in the database is provided. On the other hand, information on musical institutions (224) and the employments of musicians in musical institutions (about 9,500) were required.

3.2 Data & Task Abstraction

3.2.1 Data Abstraction

Although stored in a relational database, taking all information on musicians and their relationships to be analyzed constitutes a directed (social network) graph $G = (V, E)$ with musicians being the nodes $V = v_1, \ldots, v_n$, and the aggregate of all personal relations being a set of directed edges $E = e_1, \ldots, e_m$ with $e_i = (u, w)$ $(u, w \in V)$. The database contains $n = 31,003$ musicians and $m = 33,466$ directed relations. In order to support analyzing the social network or to compare clusters of the graph with visual means, subgraphs $S_1, \ldots, S_k (S_i \subseteq G)$ of musicians can be dynamically defined, priority according to professions and musical institutions.

Professions of a musician Professions are provided in a list and they are separated between musical and non-musical professions. For each musician, at least one musical profession is provided, e.g., composer, conductor, musicologist, etc. Musical professions are hierarchically structured, e.g., violinists and double bass players are strings instrumentalists that are instrumentalists. Basically, each class in that hierarchy can be chosen as category defining a subgraph of the social network. Also, non-musical professions like teacher, judge or soldier can be used for clustering purposes.

Institutional relations Some research questions are directed towards the composition of musical institutions and employments of musicians in these institutions. Also, it is likely that musicians who worked during a similar time range in the same institution having the same musical profession knew each other although no relationship information is registered. For each musician, a list of musical institutions he or she worked for is provided. Although only 7,731 musicians are assigned to at least one musical institution, categorizing according to musical institution was a mandatory requirement to define individual subgraphs.

Denominations or divisions of musicians as well as the places they worked can be likewise taken into account when defining subgraphs. Dependent on the chosen categories, musicians may be excluded from the analysis, or they might belong to up to k subgraphs. Relationships are divided into intra-subgraph relations that will always be shown, and inter-subgraph relations shown on demand. Of specific importance for visualizing and analyzing purposes was the definition of a life span $t = \{t_s, t_e\}$ for each musician based on the given lifetime information.

Defining the life span of a musician The database provides up to four different dates per musician: birth/baptism, death/funeral, first and last mentioned dates in official documents. If available, the first mentioned date seen as the beginning of a musician's career is chosen as t_s. Such a date is given for 22,818 musicians (73%). If it is not provided, t_s is approximated by date of birth plus 20 years, which increases the number of musicians that can be represented to 27,563 (89%). As musicians are ordered according to t_s, the remaining musicians are discarded from the visualization. t_e is set according to the date of death as this marks the end of musician's career. It is provided for 14,214 musicians (46%). Taking last mentioned dates increases the number to 20,686 musicians (67%) having a complete life span in the form $t = \{t_s, t_e\}$. If neither the date of death nor the last mentioned date is provided, we chose $t = \{t_s, \emptyset\}$ for representation purposes. Further problems of the lifetime data are uncertain datings. Approximately 14% of all provided dates are uncertain marked by *before* (4.8%), *after* (1.9%) or *around* (7.7%). These information are not taken into account when defining t, but are kept for visual representation purposes.

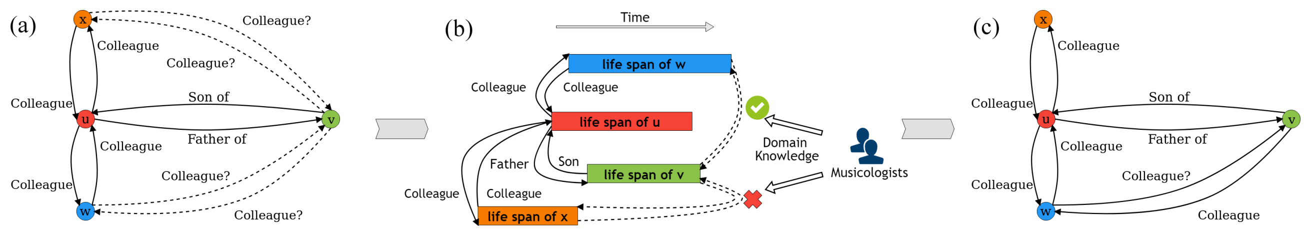

Figure 2: Deriving new relationships between musicians. (a) For musician *u*, a familial relationship to *v* and collegial relationships to *x* and *w* are documented—is it possible to derive collegial relationships between *v/w* and/or *v/x*? Hypothetical relationships are indicated by dotted lines. (b) The *meso reading* view organizes the observed musicians' life spans in a temporal frame. The hypothetical relation *v/x* is impossible as both persons' life spans do not overlap. The hypothetical relation *v/w* is possible due to overlapping life spans. With domain knowledge, the relation *v/w* was assessed as very likely and had been registered in the database. (c) The resultant social network graph.

3.2.2 Task Abstraction

The structure and quality of the data calls for visual means to analyze and to extend the database. Although temporal and institutional data are provided, there is no relation between both. It is not registered when a musician started or stopped working for an institution. Thus, for visualization purposes entire life spans of musicians are used. Taking musicological background knowledge of the domain experts into account when observing the visual output only enables for detecting time-dependent patterns or deriving hitherto unknown relations among musicians, and cannot be adequately replaced by mere database requests. Following Munzner's task taxonomy [42] and the question of *why* the Interactive Chart of Biography is used by domain experts, the actions to be supported are listed below.

Analyze When starting the project, musicologists remarked that they desire to see the social network in a visual form, and not in the form of lists determined after database requests. Thus, a major purpose of our system is to enable to *consume* the data. This further enables domain experts inexperienced with querying databases access to the data. The visualization is designed to support the *discover*y of patterns and trends, but it also aids in *present*ing and discussing findings between musicologists. A mandatory task to be enabled by the system was to be able to *derive* relationships among musicians that are not registered in the database. Focusing on user-defined subgraphs that lead to grouping potentially related musicians and placing them closely in a temporally aligned area supports this task. Still, domain knowledge is required to extend the database with personal relationships derived from our system. An illustrative overview of this task is depicted in Figure 2.

Search Our system needed to support all four ways of searching. *Lookup* tasks require profound domain knowledge, so that users can navigate to the desired musician (target) in the corresponding subgraph (location). If the location is not known, the user can *browse* a certain subgraph (e.g., the musical institution Bayerische Staatsoper) and find out, e.g., the first or last listed musician(s), or groups of musicians in a certain time range. *Locate* tasks are supported by entering the name of a musician in a search box, and the visualization will automatically navigate to the corresponding position that will show the musician in a time- and subgraph-dependent context. A major value of the system is that it enables to *explore* the visualized data at hand, without forcing the musicologist to formulate a specific query allowing for a casual access to the data.

Query The design was required to support all low-level user goals. First, once a target is found, it is possible to *identify* it, in other words, to investigate different biographical characteristics of a musician. Life spans of different musicians can be *compare*d, and the aggregate of all musicians' life spans allows to *summarize* information. This not only allows to generate hypotheses on a certain subgraph, but also to analyze and compare the social networks of juxtaposed subgraphs or groups of musicians.

3.3 Visual Encoding & Interaction Idiom

The collaborating musicologists brought diverse research questions to our initial meetings that required a flexible composition of the subgraphs $S_1,\dots,S_k$ of G. After defining appropriate filters, the subgraphs can be comparatively analyzed in a linked views system.

3.3.1 Filtering

Dependent on the research question at hand, different filter operations can be applied to manipulate the visual output. As a first step, a number of filters applied to the entire database can be applied. Choosing a musical institution, e.g., "Bayerische Staatsoper" disregards all musicians who were not associated to it, and would allow for analyzing employment structures within the selected institution. Denominational research questions could be investigated by first filtering for followers of a specific religion. This way, a limited set of musicians to be further clustered can be defined.

The musicologist is then asked to select the main biographical feature to be used to categorize the remaining data. For example, when categories are derived from musical professions, each subgraph will then contain only musicians practicing the same musical profession. But musicologists are usually only interested in comparatively analyzing a subset of possible attributes of a chosen category. Therefore, after selecting the main category, a list shows the various attributes entered in the database sorted by the decreasing amount of musicians having these attributes. The selected k attributes define $S_1,\dots,S_k$. Using musical professions as main category, "keyboard instrument player", "string instrument player" and "singer" might be the chosen attributes defining the subgraphs S_1, S_2 and S_3.

With the mentioned filtering mechanisms, the musicologist is able to compare groups of musicians with the same profession that were all employed at the same musical institution. Several linked views are offered for a detailed analysis of the resultant subgraphs.

3.3.2 Linked Views

Many related projects in the digital humanities implement Shneiderman's *Visual Information-Seeking Mantra* "Overview first, filter and zoom, then details-on-demand" [54] to support a multifaceted visual analysis of the data at hand. With the increasing amount of digitized data it has been shown that means to dynamically navigate through the data are indispensable [29]. As opposed to Shneiderman's terminology, the digital humanities community established other terms. *Distant reading* [40] or macro view refer to "Overview first" as they process certain features into visual representation giving manifold perspectives to the underlying data. The traditional term *close reading* or micro view refer to "details-on-demand" as information on an individual data item or a very limited set of entities are provided. Also, digital humanities has come to recognize that close and distant approaches are combinable and perhaps exist more as a continuum than a binary, or more as complementary than an exclusive methodology [51]. This introduced *meso reading* [30] and zooming [31]

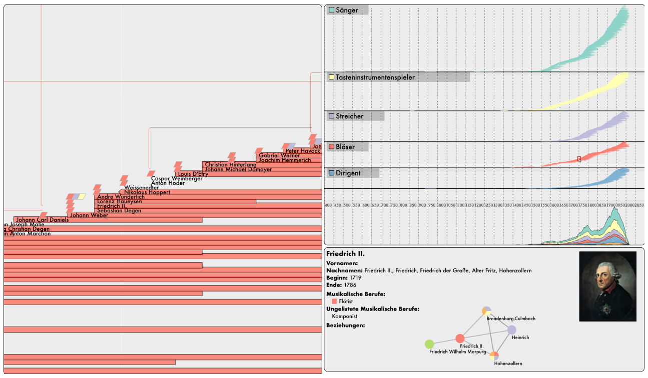

Figure 3: Screenshot of the Interactive Chart of Biography

that refer to "filter and zoom" yielding manifold perspectives onto differently-sized subsets of the observed data.

To support the tasks listed in the previous subsection, we implemented Shneiderman's mantra in a visual system consistent of three linked views for which we use the domain-related terms distant, meso and close reading. Figure 3 depicts a screenshot of the final Web-based application. It shows the *distant reading* view on the upper right side, the *meso reading* view on the left side and the *close reading* view on the lower right side. To make it easy to visually distinguish entities belonging to different subgraphs $S_1, \ldots, S_k$—and the number k is usually small—in the different views, we applied a qualitative color scheme using the ColorBrewer [10].

Distant Reading Two overview visualizations are provided for distant analyses. Both views support time-dependent analyses of the observed data. A stacked graph [11] illustrates quantitative information about $S_1, \ldots, S_k$. The life spans of all musicians belonging to a certain subgraph are aggregated to an area graph, and stacking k graphs supports comparing quantitative changes and developments of $S_1, \ldots, S_k$. Inspired by Priestley's Chart of Biography, a timeline visualization gives a more detailed view on the life spans of musicians. Each subgraph receives a horizontal section of the timeline dependent on the number of musicians assigned to it. Each musician's life span is drawn as a thin horizontal line that stretches between t_s and t_e. In order to make it possible to detect time-dependent patterns, life spans are stacked and sorted by t_s, which differs from Priestley's timeline chart. If the number of musicians exceeds the number of available pixels, in other words, the height of the section assigned to the corresponding subgraph, life spans with similar values for t_s occlude. Using transparent colors, these occlusions get visible. Collaborating musicologists stated this is not a notable drawback for the distant view, as the distant timeline view is merely used as an entry point for a more detailed analysis in the meso reading timeline view. Hovering the mouse over the timeline navigates the meso reading view accordingly, and clicking freezes the currently selected viewport.

Meso Reading The meso reading is a semantic zoom providing a more detailed view on the life spans of musicians in the current viewport of the distant reading timeline. Next to the musicians' names, occlusions prevalent in the distant reading timeline are resolved, and a horizontal bar is drawn for each musician. The left and right borders of the bars are shaped according to occurring uncertainties of life span information. Straight vertical lines are used for precise datings. Triangles pointing to the left (◁) mark *before* datings, triangles pointing to the right (▷) are used to illustrate *after* datings, and vertical zigzag lines are used to indicate *around* datings. To the left of each bar, a series of parallelogram icons informs on the categories or subgraphs a musician belongs to. For example, when filtering for musicians belonging to a specific musical institution and choosing musical profession as main feature, this allows to indicate musicians with similar profession profiles in a similar time frame. Mandatory for the musicologists for analyzing social networks, relationships among musicians belonging to the same subgraph are displayed using the category's color. On demand, relationships among musicians belonging to different subgraphs can be shown (in black). Hypothetical relations can also be shown on demand. The confidence of a hypothetical relation is indicated by the thickness of the dotted line. In the meso reading view, a certain musician can be focused. Clicking a bar grays out all relations not belonging to the corresponding musician, making it easier to follow edges especially for wider time spans and for data sets containing lots of relations. More detailed information on the chosen musician can be inspected in the close reading view.

Close Reading This view is a typical details-on-demand visualization. It lists a musician's biographical information including the registered life span t, musical professions and musical institutions. If provided, a portrait of the selected musician is displayed—an important function desired by musicologists as it reminds them on the vividness of the underlying data. In addition, a force-directed drawing of the social network of the selected musician and all related musicians is shown. It aids at exploring the types of relationships, e.g., familial or educational. This specifically aids in generating hypotheses on hitherto unknown relations between musicians.

3.4 Algorithm

Our work prioritized turning Priesley's static chart into an interactive visual design. Computational aspects were not central to our development. As opposed to Priestley, we order life spans of musicians by increasing t_s, which takes $\Theta(n \cdot \log n)$ time for a subgraph with n nodes. A further consideration was pre-calculating all distant and meso reading views beforehand in order to allow a smooth and fluent visual analysis without delays.

4 Validation

The Interactive Chart of Biography is the result of a *problem-driven* work. As Munzner remarks, "the problem can be [often] solved using existing visual encoding and interaction idioms rather than designing new ones" [42]. In our scenario, Priesley's work aided as a source of inspiration, and we revised some design considerations and developed interaction idioms required to tackle the given tasks. Our experiences on the four levels of validation are listed below.

Domain Situation Given the cooperation between visualization scholars and musicologists, our project is situated in the digital humanities domain. Other visualization scholars reported that traditional research workflows benefit from integrating means of visualization to generate new perspectives on historical data sets [2,29,38]. As we already worked together in a couple of past interdisciplinary digital humanities projects, the important "get-together" [27] with the goal of finding a common basis and to speaking the same language was not decisive for the success of the project. It rather helped us visualization scholars to quickly understand the musicologists' excitement concerning the research questions to be analyzed, and to discuss their needs concerning the visualization to be implemented. Already in the early stages of the project, we discussed the potential value of an interactive version of Priestley's chart.

Data & Task Abstraction Not all user tasks were specified at project start, some desires arose when engaging with intermediate prototypes. Most importantly, in the initial versions of the system a comparative view among various subgraphs was not provided. This user task was defined in the course of the project and also affected data abstractions. Adopting Priestley's idea, we offered multiple timelines reflecting the musicians belonging to multiple subgraphs $S_1, \ldots, S_k$. Whereas Priestley was required to strictly divide by profession, our data model allows to choose attributes of interest according to the given research question. At that time, research interests were directed towards comparing musical professions and institutions. As 203 different musical professions are possible but hardly comparatively analyzable, musicologists superimposed a hierarchy of musical professions—e.g., ”tenor“ and ”soprano“ were grouped together in a ”singer“ category—to support multifaceted analyses. A hierarchy for institutions was not necessary as related research questions only included a very small number of institutions in a comparative view. Disregarding the musicology use case, we implemented a generic interface in order to enable straightforward adaptions of the system to other data. This includes not only other biographical databases, but also very diverse scenarios, in which data items are to be represented in the form of a time span, e.g., the number of days movies are shown in cinemas, the length of wars, the duration of empires, etc.

Visual Encoding & Interaction Idiom While Priestley was not able to apply a singular vertical ordering of lifelines due to place restrictions, musicologists quickly recognized the value of this strategy although taking minor occlusions in the distant reading view into account. As opposed to Priestley, in our case, the life spans of all persons of a category or subgraph are comparable supporting hypothesis generation regarding unknown relationships. We offered various ordering strategies in the first place, and the musicologists reviewed the ”ordering-by-t_s” variant as particularly effective for most research questions. The desire to compare different subgraphs to each other lead to including a color coding scheme. In the distant reading view, we integrated the stacked area graph as musicologists wanted to observe quantitative changes within the given subgraphs.

Algorithm In the early development stages, we worked with rather small data sets containing few hundred musicians. The meso reading view was drawn on mouse move according to position of the mouse pointer with neglectable loading times. With the increasing amount of data to be displayed, mouse move interactions triggered iterations over a larger amount of data items, and more and more visual elements were required to added to the HTML DOM. This lead to delays especially for very large data sets. Pre-calculating the meso reading view ensured smooth interactions at the expense of a short page loading time at the beginning of an analysis. This was seen as a considerable improvement by the musicologists and it motivated them to further engage with the visualization.

Expert Feedback The development of our biography visualization brought forth eight prototypes that were iteratively evaluated by the musicologists in interdisciplinary meetings. Each session lead to modifications of the design and computational foundations. For example, the musicologists suggested biographical information to be taken into account when automatically determining the probability of unknown relationships. Also, observing how musicologists worked with the tool provided valuable information, e.g., the wish to align life spans by their beginnings, or the necessity to attach life spans in the meso reading view with category lists. Finally, the usage scenarios offered by musicologists working with the tool underpin its value for musicological research. One musicologist remarked: ”The temporal overview that the tool provides is new to our field. Up to now, we only worked with textual representations of data neglecting distant reading tools. This system shows the importance and the potential of visualization for our research field.”

4.1 Limitations

The overall concept is limited by the user’s available screen size. In the distant view, too less vertical space leads to overlapping lifelines, and it further restricts the maximum number of subgraphs to be laid out. Although both aspects were not considered obstructive by the musicologists, this limits the flexibility of our approach. However, a restricted number of subgraphs eased defining appropriate color maps for our approach.

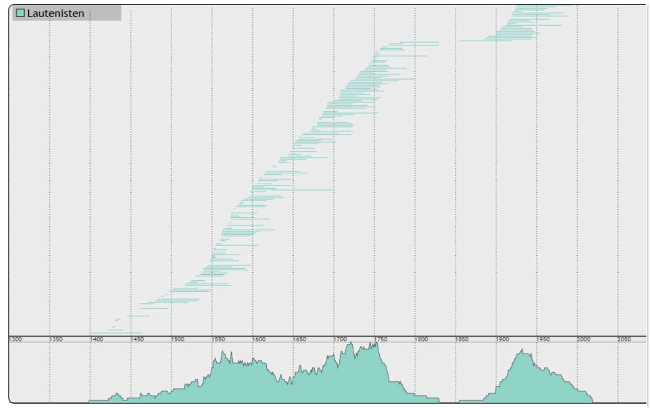

Figure 4: Development of the lutenist profession

Furthermore, we had to decide if musicians should belong to only one or to multiple subgraphs. As opposed to Priestley, who took an individual decision for each person, in our case, no machine readable criteria could be exploited to determine any preferences. Thus, duplicating musicians was the only sustainable solution, but it further exacerbated the space issue.

Finally, it has to be said that the data itself limits the capability of the system. In case of the MusiXplora, the database lacks information on the time ranges a person was employed in diverse institutions. For example, it is possible that two musicians have the same life spans, and that they worked for the same institutions, but it cannot be concluded if they were actually related. On the other hand, this limitation provides a reasoning on the necessity of the presented design. As will be shown in the next section, the system supports hypothesis generation, but it requires domain knowledge to derive valuable information.

5 Use cases

This section anecdotically outlines how musicologists use the Interactive Graph of Biography for their daily research. While one example serves as a paragon of how the system is used to derive new relationships among musicians, other use cases illustrate the capability of the system to generate hypotheses on the changing musical society, i.e., in the development of musical professions and institutions. Finally, we present a usage scenario on the basis of an engineers database to highlight the genericity of our approach.

Analyzing the lutenist profession Our system can be used to validate already existing hypotheses. One musicologist studied the highs and lows of the lutenist profession, and he initially suspected three influential eras. The distant reading view gives aggregate views on the life spans of 232 lutenists, and the area graph confirms the musicologist’s assumption. The first two peaks correspond to distributing the lute across the courts in middle Europe. During the second half of the 18$^{\text{th}}$ century the lute was replaced by modern string instruments like the guitar, which lead to the a decreasing number of lutenists. More remarkable is the increase at the beginning of the 20$^{\text{th}}$ century. This rise is not caused by the instrument regaining influence, but by the rising of historism that turns towards bygone things. Although the full capability of the system was not used, this was an important use case when the first prototypes were evaluated by musicologists. The verified hypothesis helped to build trust in our approach, and it further engaged musicologists in working with the system.

Evolution of musical institutions in the 19$^{\text{th}}$ century In the early modern age, Germany had many court orchestras due many principalities and duchies. Each residence hosted a court orchestra

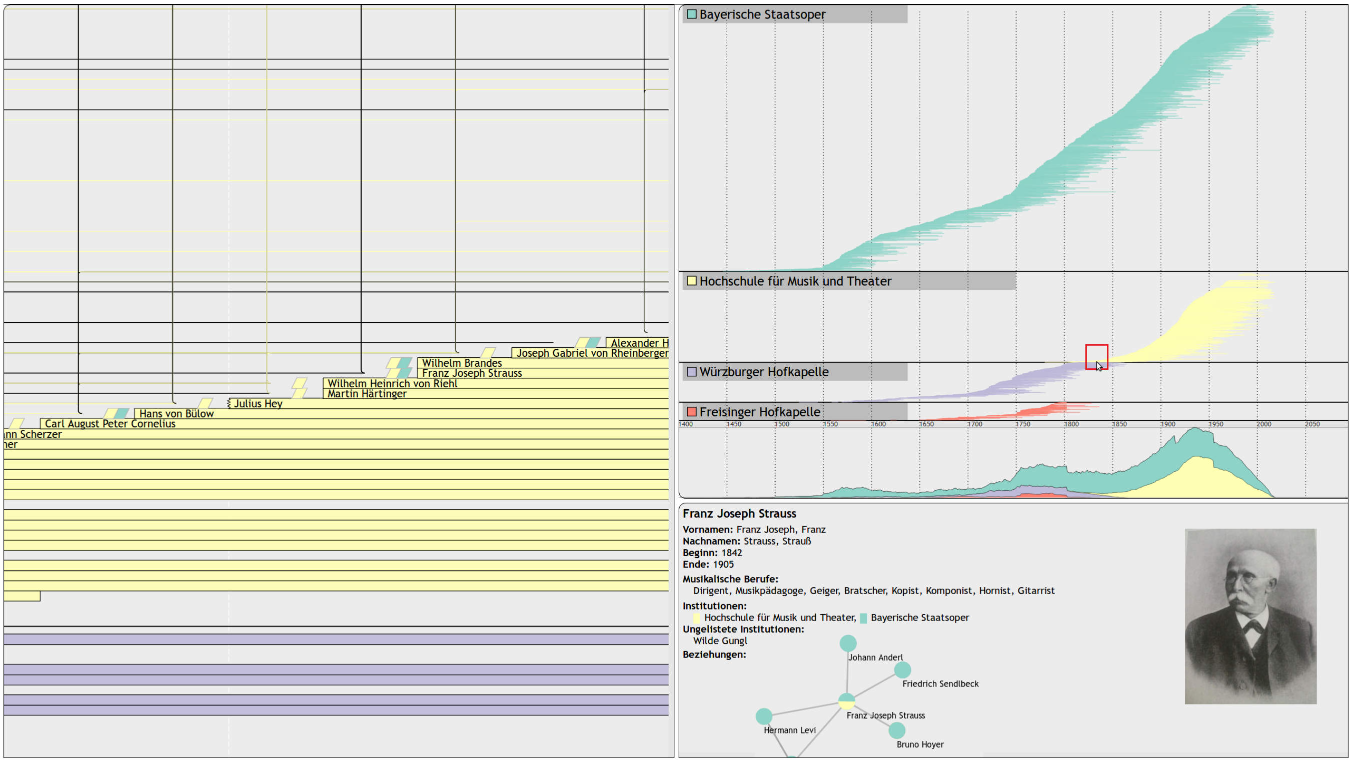

Figure 5: Overview over the 3,856 persons working at Bayerische Staatsoper (2,573), Hochschule für Musik und Theater München (879), Würzburger Hofkapelle (385) and Freisinger Hofkapelle (176) (right) and musicians' relations between the *Bayerische Staatsoper* and the *Hochschule für Musik und Theater* (left). Colored edges are intra-institutional, black edges are inter-institutional. The colored boxes show the affiliations of musicians to different institutions.

that represented its musical skills, and it consisted of eight (in the early days) to 20 (towards 1800 AD) musicians. At the beginning of the 19$^{\text{th}}$ century—the rise of nationalism—many of those small political entities were united, e.g., the Bavaria kingdom was founded in 1806. Already 20 court orchestras were situated in Bavaria at that time. As each country normally hosted only a single court orchestra, it was not necessary to maintain all of them. At the same time, countries began to monopolize education. Until the beginning of the 19$^{\text{th}}$ century, music was rather seen as an art, but it was meant to be educated. These circumstances lead to secularization processes of education and the foundation of musical tertiary institutions like the *Hochschule für Musik und Theater München* (University of Music and Performing Arts Munich) on the one hand, and to vanishing traditional court orchestras on the other hand. This scenario was explored with our system. Figure 5 shows the *distant reading view* for four selected institutions constituting $S_1,\ldots,S_4$ on the right side. Next to the *Hochschule für Musik und Theater*, representative for a state institution, the three largest court orchestras are shown: *Würzburger Hofkapelle* (Würzburg Court Orchestra), *Freisinger Hofkapelle* (Freisinger Court Orchestra) and *Bayerische Staatsoper* (Bavarian State Opera). As opposed to the latter institution, the former two court orchestras were not maintained, they both disappeared around 1850—visible in both distant views. The *Bayerische Staatsoper* was the only courtly institution that was maintained for the whole Bavarian region. Figure 5 also suggests flowing transition between the *Würzburger Hofkapelle* and *Freisinger Hofkapelle* to the *Hochschule für Musik und Theater*, hypothesizing that musicians from the closing court orchestras were taken over by the *Hochschule für Musik und Theater*. A closer inspection of the time frame between 1800 and 1850 in the meso reading view further strengthens this hypothesis. But after observing relations and employments using the meso and close reading views, this hypothesis was rejected as neither musicians from the two traditional orchestras were employed at the university, nor significant relations between both person groups were found. Although only showing a small amount of institutions is discussed (displaying all 20 court orchestras is not supported by the system), the musicologists extracted valuable information and summarized a general decline of the number of musicians at this time caused by the reduced number of musical institutions. The musicologists further discovered a high amount of inter-institutional relations between musicians from the *Bayerische Staatsoper* and the *Hochschule für Musik und Theater* since its foundation in 1846. In the meso reading view to be found on the left side in Figure 5, multiple colored parallelograms highlight persons employed in multiple institutions, and a series of black edges indicate inter-institutional relations. Using the *close reading view*, the musicologists discovered a typical career path for musicians working at the *Bayerische Staatsoper*, who often changed their workplace to the *Hochschule für Musik und Theater*. Thus, they became professors and changed from performing to teaching a musical profession.

Changing Ensemble of the Bayreuther Festspiele One musicologist used our system to investigate the changing ensemble of the *Bayreuther Festspiele*. Figure 6 marks anomalies indicating significant changes for the first time visible in the distant reading view in the form of straight vertical borders. Either a lot of musicians joined (A, B, E and G) or left (D, F and I) the Festspiele in a single year. This conclusion can be drawn as for many musicians who were employed at the Bayreuther Festspiele, not the living dates but the times of employment—extracted from playbills—are known to the musicologists. Meso and close reading views accompanied with profound domain knowledge aided in analyzing these events

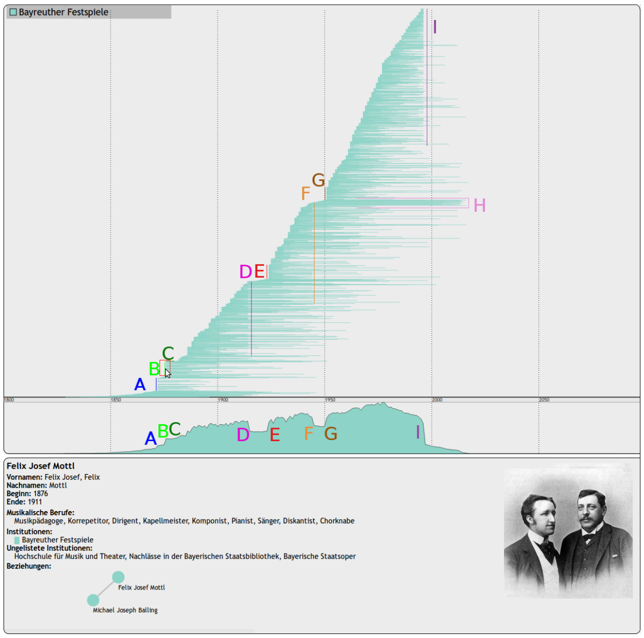

Figure 6: Significant changes in the development of the Bayreuther Festspiele. The close reading shows Felix Josef Mottl.

Figure 7: Deriving relations between musicians.

interactively. A group of musicians typically left when the Festspiele were not held yearly, like in the years of World War I and World War II. Many musicians joined the ensemble after such periods, or when new operas were introduced. For example, the meso reading view was used to analyze the employment of 92 musicians in 1876 (B). One of the musicians was Felix Josef Mottl (selected in the close reading view) who had been invited to the Bayreuther Festspiele and who conducted more than 60 performances, including the premiere of *Tristan and Isolde* and *Ring of the Nibelungs*. Additionally, the relation to his student and successor Michael Joseph Balling pops out, who later spread Richard Wagner's works in Great Britain, Spain, Austria and New Zealand. Marker H points to a group of 13 musicians having an uncommonly long employment at the Bayreuther Festspiele. The reason for this anomaly is yet to be investigated.

Deriving New Relations The latter usage scenario highlights the need of a visual analysis system to derive unregistered relations among musicians. For some musicians, the life spans denote their employment at the Bayreuther Festspiele. Thus, overlapping life spans suggest relationships that are even more likely when musical professions are similar. But, as life spans may stand for the actual life times of musicians, the domain expert needs to decide case-by-case. A computational approach would lead to numerous false positives. In a more complex scenario, a musicologist used the system to explore musicians of the *Bayerische Staatsoper* between 1870 and 1880, and he extracted more than 200 new *colleague* relations that were not documented in the data. A sample is given in Figure 7. Yvo de Vento and Antonius Goswino were colleagues, what is shown in the meso reading view by the yellow connection. Both musicians had similar musical professions like Caspar Glaner, who also worked at Bayerische Staatsoper in a very short time frame. With a lookup in secondary literature, the suggested colleague relations between Caspar Glaner and Antonius Goswino (as well as Caspar Glaner and Yvo de Vento) could be derived, although the computed confidence was rather low (17.4%). This highlights the need of a musicological knowledge to validate hypothetical relations.

J. G. L. Mozart and the "Correspodirende Societät der musikalischen Wissenschaften" Johann Georg Leopold Mozart—father of Wolfgang Amadeus Mozart—was known for being a person of great curiosity, openness to novelty and willingness to communicate. This example juxtaposes the two institutions he was assigned to, the Correspodirende Societät der musikalischen Wissenschaften (Corresponding Societa of the Musical Sciences) and the Salzburger Hofkapelle. The former was a scholar's network that was geographically centred in Leipzig and denominationally associated with the protestant church music. The latter was as an Austrian court orchestra associated to the Roman-catholic denomination. Figure 8 shows a comparative of both institutions. The distant view conveys their temporal existence ranging from the 16th century to the 19th century. These centuries were marked by religious unrest caused by the rise of the Protestantism, and inter-confessional cooperation were unlikely at that time. Looking up Mozart in the meso reading view reveals closely connected social networks within each institution, but Mozart being the link between them. He is the only musician having worked in both institutions, bypassing the confessional borders typical for this time. Inter-institutional relations appear in the form of black edges. The close reading view shows that these relations range across different types (predecessor, students, colleagues and his son Wolfgang Amadeus Mozart).

Database of German Engineers In order to evolve a generic data model and to evaluate the system's genericity, we visualized the prosopographical database of German engineers, provided by the University Stuttgart[1], with our system. It contains biographical information about 4,176 engineers who were employed at educational institutions (mostly universities and technical colleges) between 1825 and 1970. Various information can be used to generate $S_1, \ldots, S_k$, a comparison of engineers who taught the most common subjects is shown in Figure 1 (right).

6 Conclusion

In recent years, musicologists invested a lot of time in collecting manifold information on music history, and making them digitally accessible through queryable databases. A major drawback is the inhomogeneous state of research concerning the relationships among musicians, and a system was required that hypothesizes new, data-

[1]http://www.uni-stuttgart.de/hi/gnt/pdm/index.html

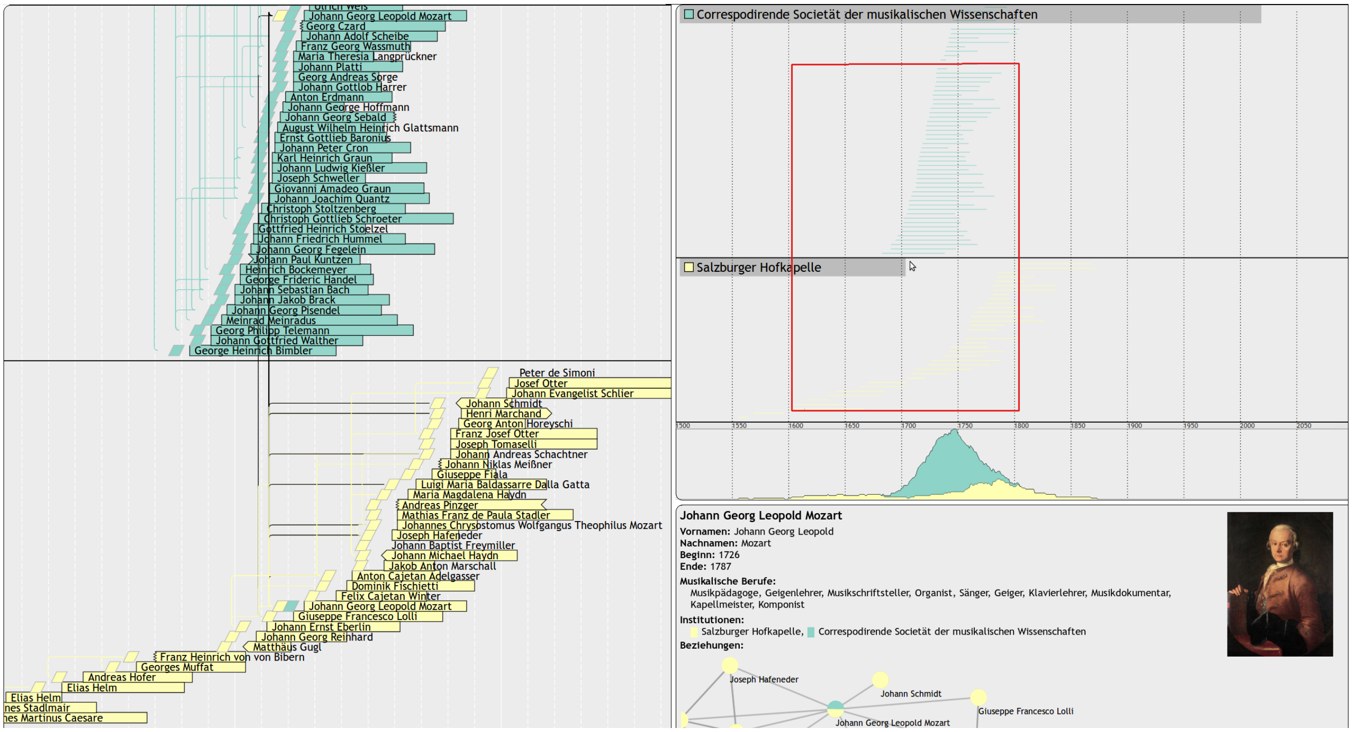

Figure 8: A comparison of the Correspodirende Societät der musikalischen Wissenschaften (turquoise) and the Salzburger Hofkapelle (yellow) with details on Johann Georg Leopold Mozart.

driven relationships. Our Interactive Chart of Biography—inspired by Joseph Priestley's famous Chart of Biography—arranges the lifelines of musicians on a timeline in dependency on specific biographical features, e.g., musical professions, so that potentially related musicians are grouped closely on the screen. Further taking information on employments of musicians in musical institutions into account increases the chance of detecting unregistered relations.

During the development, we closely collaborated with musicologists, who state that the resultant Interactive Chart of Biography is a valuable analysis instrument that serves a novel type of research interest and provokes new research questions on how musical institutions' ensembles changed over time and on how specific musicians connected seemingly unrelated musical societies. We designed the visualization the way that it can easily be adapted to other (historical) groups of people.

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