Interactive Hierarchical Timeline for Collaborative Text Negotiation in Historical Records

Gabriel D. Cantareira, Yiwen Xing, Nicholas Cole, Rita Borgo, and Alfie Abdul-Rahman

Abstract—Visualizing event timelines for collaborative text writing is an important application for navigating and understanding such data, as time passes and the size and complexity of both text and timeline increase. They are often employed by applications such as code repositories and collaborative text editors. In this paper, we present a visualization tool to explore historical records of writing of legislative texts, which were discussed and voted on by an assembly of representatives. Our visualization focuses on event timelines from text documents that involve multiple people and different topics, allowing for observation of different proposed versions of said text or tracking data provenance of given text sections, while highlighting the connections between all elements involved. We also describe the process of designing such a tool alongside domain experts, with three steps of evaluation being conducted to verify the effectiveness of our design.

Index Terms—Digital Humanities, Collaborative Text

1 Introduction

Collaborative text development is an application that can take many forms, from source code management to the building and maintenance of knowledge repositories. Typically, several actors are involved in proposing changes that have different protocols for approval, and navigating the history of these changes may be essential to understanding the current state of a text and how different parts of it came to be. This history is often modeled as event timelines, which can be complex to navigate depending on the domain and associated metadata due to the different types of operations that can be done and relationships that can be formed between authors, metadata objects, and the text itself.

One such domain is historical records in humanities - in particular, the drafting of foundational legal texts in constitutional conventions. The Quill Project [1] is a research initiative that investigates text analysis and data visualization with the aim of providing humanities researchers with tools to help understand such texts. Built on an event-based structure, Quill contains well-organized datasets representing the negotiation of legal texts in negotiation processes that can last for several months or years. As each discussed text is the result of hundreds of amendments proposed by several actors over an extended period of time, visualization methods to navigate such data become a necessity.

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While this domain has much in common with other applications of collaborative text development, it also poses a particular set of challenges that makes it distinct and worthy of investigation: namely, its multiple hierarchical components, encompassing bureaucratic structures, procedural depth between events, and relationships between documents, as well as transforming a very specific set of procedures for proposing, discussing, and enacting changes into visual language.

This paper presents an interactive tool for historical text visualization designed to provide domain experts with a complete timeline of changes to a document, allowing them to quickly grasp important changes, cross-reference appearances of elements such as people and keywords, and identify provenance and details over the history of a given part of a text. We then present usage scenarios for the aforementioned tool and an evaluation with domain experts. In short, our main contributions are as follows:

- An interactive visualization model for representing collaborative text data provenance, displaying timelines and event relationships on three different levels;
- An application of such model in humanities research, discussing design constraints, and domain expert evaluation.

2 Related Work

2.1 Event Timelines

Event timelines refer to one or more sequences of events laid out over a timeframe. Unlike time series data, event timelines are not structured as a consistent number of observations or results over time that can be easily compared, offering varying densities as the number and types of events change over time. Many data sources can be viewed as event timelines, from musical scores to sports matches to robotics planning.

Recent challenges in event timeline data tackled by the research community include viewing timelines through the perspectives of multiple different metadata [2], identifying common topics among multiple simultaneous events [3], [4] finding patterns and detecting anomalies in large event sequences [5], de-noising and summarization [6], among others. Many timeline visualization techniques in literature, however, are focused on tackling specific challenges of specific application domains, such as neural networks and medical data [7], online education [8], or assembly line optimization [9].

Brehmer et al. [10] presented a survey on timeline-based visualization techniques, offering a three-dimensional design space to classify different approaches. Guo et al. [11] presented a survey on

event sequence data visualization, including timelines, using a new design space-based taxonomy. One common defining feature for a timeline visualization is its spatial layout: while many applications employ linear timelines, alternative layouts such as radial [12] are often used. Additionally, certain techniques can optimize the layout itself to convey information [13].

Another relevant topic in event timeline research is the automated generation of events and timelines from raw data such as text [14]. As narrative and storyline visualization methods [15] became more widely known, so did techniques aiming to generate them automatically [16], [17].

2.2 Collaborative Text Development

As our work refers to collaborative text writing, there are other visualization applications that provide parallels, such as source code contributions and shared online documents. These approaches are usually focused either on the text itself or user activity and collaboration network.

Text-focused visualizations display the structure of projects or repositories, changes in different areas of text over time, and actions from different authors. Text is often represented as blocks with changing parts over a series of timestamps; one of the most known techniques for visualizing collaborative text development is History Flow, by Viegas et al. [18], which shows the evolution of text blocks over multiple timestamps in a horizontal timeline. There are other approaches that employ similar concepts but show activity and the connection between text fragments over time in different ways [19], [20]. Other ways to represent text include a graph representation for source code that shows the evolution of structural code elements over multiple updates [21] and the visualization of code changes as an evolution of topics [22].

Visualizations focused on activity history show the interactions between authors and text over time. Examples of such approaches include using different symbols to represent multiple users interacting with a text in different ways [23], allowing authors to use sticky notes to generate narrative nodes to an activity history [24], or representing activity as color maps [25]. Other approaches focus on the controversy between different authors and how their contributions interact with one another over time [26], [27]. Other visualizations may show the network of authors and how it changes over time, as behavior patterns of editing and different topics appear [28].

2.3 Historical Data Visualization

Visualization research for the Digital Humanities (DH) has experienced a steady increase in interest from the visualization research community over the last few years [29]. With the increasing computational capacity of modern systems and the evolution of information visualization techniques, new possibilities arise to extract new insights from data, sometimes centuries old [30].

While digitized historical documents can be explored with regular text visualization methods, specialized tools can provide various benefits to a DH researcher's workflow. Janicke et al. [31] discuss different uses for text visualization tools in humanities, and offer a taxonomy of tasks that are performed with them. History researchers are often interested in relationships between texts, or summarization [32], [33].

Approaches for timeline visualization for DH are often event-based, and process graphs of interconnected elements interact over time [12]. Visualizing relationships between instances such as historical figures over time can often be a complex task, and can sometimes be tackled through indirect information such as event sequences or location [34], [35].

2.4 Related Work Discussion

While the research on each of those fronts is extensive, being at an intersection between all of them provides us with a particular opportunity and challenge: developing a visualization model that can employ cues from the current state of the art, while presenting it in a way that fits the workflow of humanities researchers. The focus on data provenance (i.e, a documented account of the origin of data and its intermediary points up to a present state) that was requested by Quill domain experts is not often tackled in existing approaches; the many hierarchical relationships that connect events and other entities in Quill datasets provide an interesting angle in tracking provenance and observing interactions between data instances.

As such, our work is more closely aligned with event timelines and activity history visualizations for collaborative text, focusing on tracking sequences of events containing patterns and making users aware of them. In Brehmer et al. [10] design space, our approach would fit as Linear *representation*, varying between Chronological and Sequential *scales* and offering Unified and Faceted *layouts* in its different components. While the use of bars and stacked symbols to represent different hierarchical abstractions for events in our tool is in line with approaches discussed in 2.1, we needed to develop novel ways of representing these elements and highlighting how they relate to text components to properly address the needs of our domain. Our aim is to enable users to follow threads of activity and interactions between events while still using the text as an anchoring point.

3 Background

3.1 The Quill Platform

The Quill platform [1] is a system designed to store and present historical records related to the negotiation of legislation texts. These negotiations may be described using different types of actors and events, depending on the historical context and political structure of the negotiation in question. Quill's main intended audience is humanities academics, such as researchers and teachers.

Negotiation processes stored in Quill are modeled after official and unofficial journals and minutes, recording proposal texts, details of decisions, and descriptions of speeches made during sessions. Data is structured as events, linked to relevant people and event sequences, building a representation of debates and discussions. Therefore, an analytical tool for Quill may require pulling data from multiple entities in its database to build data instances containing all information relevant to the task at hand.

At the moment of this writing, the Quill platform has three other data views that are relevant to our work: a session explorer, which presents the timeline of events in a session and their details using icons; a convention timeline, showing the distribution of sessions for each committee; and a document relationship viewer, which shows all documents transferred across committees over the entire dataset. The platform also has detail pages to display all information from a given entity: events, people, keywords, sessions, committees.

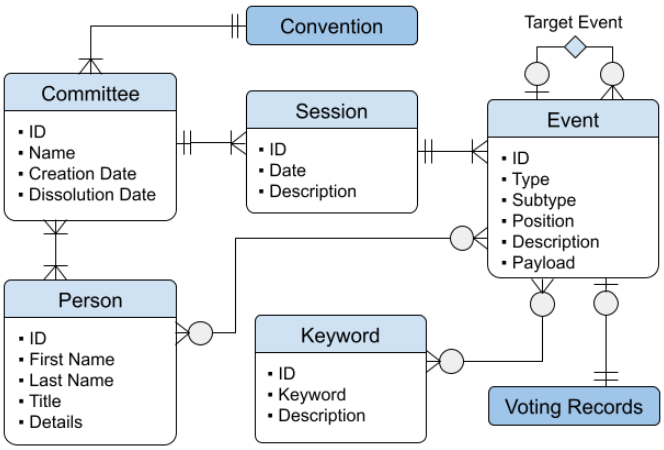

Fig. 1. Database structure for the document timeline workflow displayed in the visualization. A *Convention* dataset contains multiple committees, each with its own timeline of sessions and events, referencing keywords, people, and additional data such as voting records. It is worth noting that the entities and attributes represented here are only a subset of the data contained in Quill databases.

3.2 Data Structure

In the context of this application, there are three layers of hierarchy in Quill datasets (*Conventions*). At the highest level, there are *Committees*, groups of people who conduct multiple meetings over an extended period of time to decide on the writing of one or more documents. Each committee meeting, called a *session*, has its own list of topics and a timeline of *events*. At the lowest level, *events* describe the actions that occur within a session. *People*, *keywords*, and *documents* are other entities relevant to our application, as they can be associated with events. Figure 1 presents an overview of the data structure.

Committees contain timelines, including creation and dissolution dates, a list of sessions conducted, and a list of its members.

Sessions are individual moments within a committee timeline, containing a date, description, and a list of events.

Events are the atomic data instances that directly affect the document's writing, occurring sequentially over the course of a session. They contain type, position, description, a list of people involved, a list of related keywords, and a reference to a target (parent) event. There are several event types, some of which include specific additional data or behavior. The event types relevant to our application are:

- **Document events**: the creation of a document, either from scratch or as an import from another source.
- **Amendment events**: proposals to alter the existing text in some way. Include a payload with the proposed changes.
- **Debate events**: discussion undertaken by participants.
- **Decision events**: details on how the committee decided on a given proposal. May also include voting records.

Event types also include a subtype that further specifies them, such as a decision being of acceptance, rejection, postponement, or referral. References to parent events have different meanings according to type: a document may be created as a result of a decision, an amendment may be a part of a larger proposal, debates and decisions will refer to their subject matter, and so on.

People records contain full name, title, and any description.

Keywords contain the keyword itself and any description.

Documents are not actual entities in Quill databases, being instead referenced by the event of their creation. In this paper, we refer to documents as their own entity for clarity.

In the Quill platform, a *document* refers to a version of a text being discussed under a committee. Documents are modeled as follows: each amendment proposal event includes a payload of alterations to be introduced to the text. The text itself can then be built by enacting changes from a sequence of adopted amendments in chronological order, from the document's creation event up to a given moment in time. Therefore, the platform allows not only the viewing of the full final text from historical documents, but also the exploration of the status of a given text at a certain moment in time, or "what if" scenarios with the resulting text being created from including rejected or pending amendments.

The interconnection between events generates an additional dimension of hierarchical abstraction: as events themselves can occur in response to or following other events, every event relating to a document is part of a tree that originates in the event of that document's creation. Documents themselves can also have hierarchical relationships, as one document can be created as a copy or complement of another. This is further complicated by the fact that referencing between documents can occur between multiple committees, resulting in the interconnection of timelines.

It is worth noting that Quill databases are more complex than what is described in this section, containing many more types of events, entities, attributes, and metadata, not directly relevant to our application and omitted for the sake of clarity and brevity.

4 Design and Requirements

4.1 Requirements

At the start of our design process, we established communication with one of our co-authors, a lead domain expert who would provide information regarding their requirements and goals for a visualization tool. We would then refine these requirements over time as prototyping and further communication took place, as well as obtaining feedback from other platform users in the preliminary evaluation to avoid a single expert bias. As a result, we condensed the information obtained into the following requirements:

R1 Summarize Event Sequences. The visualization should enable users to have an overview of text events over time and quickly understand the overall flow of events in the dataset.

R2 Identify Text Provenance. For a given fragment of the text, users should be able to follow its history and identify when it was proposed, if it has been altered, what other text preceded it, and which people were involved.

R3 Highlight Entity Relationships. The visualization should be able to highlight relationships between texts, events, people, and topics, and identify patterns of elements occurring together.

R4 Integrate into existing system. The visualization needs to integrate seamlessly within a larger platform, becoming part of users' workflow, not disorienting them, and retaining ease of use.

4.2 Design Tasks

After discussing domain requirements, we defined four design tasks that our visualization tool would need to tackle:

T1 Multiple views. For **R1, R2, R3**. Combining effective summarization with the level of detail needed to properly convey provenance and entity relationship information in a single view would result in visual clutter. Therefore, multiple synchronized views would be an effective approach for exploring this data.

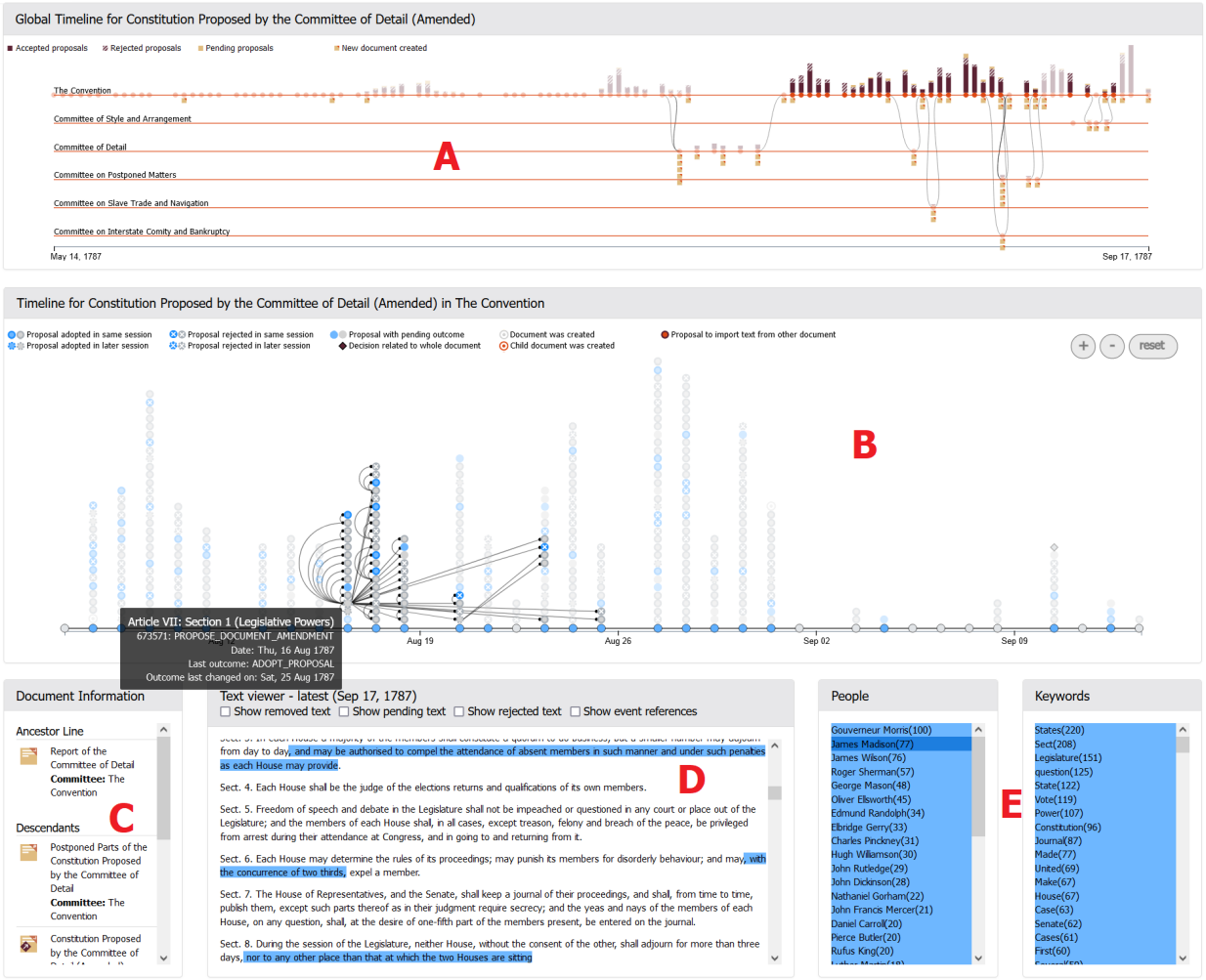

Fig. 2. The document visualization tool's interface shows user interaction with timeline and selection panes. The upper area Document Path Overview timeline (A) shows activity pertaining to the current document in the context of other related documents in the dataset. This view can be hidden to better allow using the two remaining panels as a dashboard. The Single Document Timeline, in the middle, shows events stacked according to the dates on which they occur (B). Events have their own hierarchy, which is displayed alongside a description box when the cursor hovers over one of the event symbols in the timeline. Clicking on one of the events will draw the connected paths that are related to the event. The lower area shows other documents related to the one being analyzed (C), the text under discussion (D), and panels for the people and keywords involved (E). Clicking on a segment of the text, a person's name, or a keyword will highlight all events related to the clicked object in blue.

T2 Interactive timeline. For **R1, R2, R3**. An efficient timeline allows for an overview of events while showing the most important details and further relevant information on demand.

T3 Select and highlight data. For **R2, R3**. As part of interactivity options, users should be able to select elements of interest and other elements connected by provenance should be highlighted.

T4 Context on demand. For **R1, R2, R3, R4**. As the data involved is inherently complex, further investigation of elements in the visualization may be necessary. This information should be made easily accessible. Additionally, the visualization should link to other specialized interfaces for exploring events, sessions, people, and keywords in Quill whenever relevant.

5 Tool Description

The tool described in this paper consists of a visual interface presented as a web page as part of the Quill platform, implemented using primarily using d3.js [36]. Fig. 2 provides an overview of the interface: The visualization tool consists of three components, an document path overview panel (A), which shows a timeline of the entire negotiation dataset and how the selected document fits into it; a single document timeline panel (B), containing a timeline of events relating to a document's composition over the course of all sessions from a committee; and a text panel, which contains related documents (C), an interactive version of the text itself (D), and lists of involved people and keywords (E). The visualization can be made to show either the entire timeline of a document or the state of the document at a given point in time, in which case the timeline after that point will be grayed out and text, people, and keyword panels will be limited to events before it.

5.1 Document Path Overview

The transfer of documents from one committee to another is a common occurrence, either for a more specific discussion of certain elements or for referral. As each document in Quill represents a given version being discussed by a committee, this transfer is represented in the system as the creation of a new document that carries information from the previous one. The creation of child documents that either contain parts of the parent document or are line-by-line revisions of the parent document is

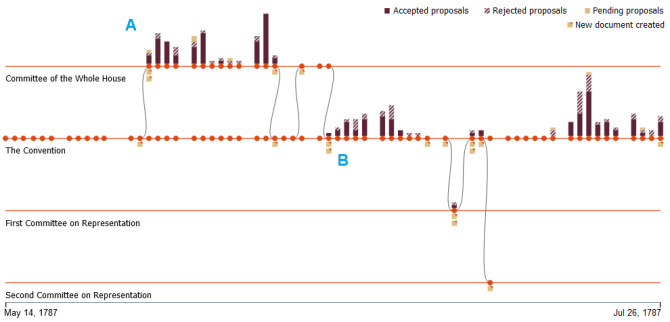

Fig. 3. Document Path Overview representation for the dataset. It is possible to see a document being referred to a different committee and discussed there (A), and then brought back to its original committee as part of a larger document (B). Hovering over each document icon will further highlight which sessions discussed each document.

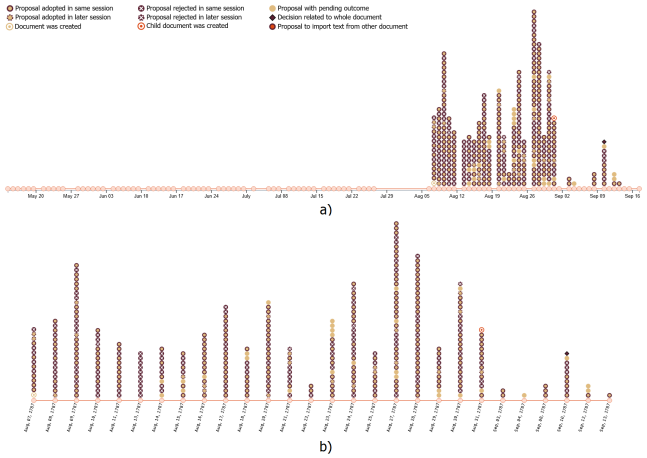

Fig. 4. Comparison between full length view (a) and collapsed list form (b) for the Single Document Timeline. The collapsed list allows for better spatial organization of activity unevenly distributed over time.

also common. Additionally, documents can be imported or exported, being incorporated into other documents as amendments. Therefore, the final version of a document is often the product of many other document instances. To make users aware of how the selected document fits into a larger timeline for a negotiation (**T1, T2**), we developed the Document Path Overview.

The Overview consists of multiple timelines arranged vertically, one for each committee in the negotiation. Sessions are shown as orange dots (a common representation in other Quill interfaces) and arranged horizontally for each committee according to time. A summary of activity for each session is displayed as a stacked bar chart. The stacked bar chart contains the number of accepted proposals, rejected proposals, and unresolved proposals made in that session.

The bar charts are complemented by small document icons on the underside of the timeline dot, indicating that a new document has been created in that session. Documents can be created as copies or extensions of existing documents, and connections to documents in different committees are displayed as curved lines connecting the session in which the decision to refer the document was made to the session in which the new document was created. The visualization optimizes the vertical space used by each committee timeline as to minimize the space wasted with committees with low activity, while retaining enough space to display bar charts and document creation icons.

Different settings can be applied to the Overview; by default, all sessions that did not include references to the selected document are shown in reduced opacity, to highlight the parts of the timeline that the current document occupies. The transparency will also change when a cursor is hovered over objects in the Overview: hovering over a session or one of its stacked bars will show it in full opacity, while hovering over a document icon will show all sessions related to it in full opacity. In a similar manner, the Overview only shows activity for other documents that are related to the selected document, being part of its ancestor or descendant line, but it can be set to show activity for all documents in the dataset. The Overview can also be hidden to focus the visualization on the Single Document Timeline and not interfere with its dashboard layout. Figure 3 shows an example of the Document Path Overview.

5.2 Single Document Timeline

The event sequence for the document to be visualized is structured as a two-layer hierarchical timeline (**T2**, Figure 2-B). Each session from the document's committee is laid out along a horizontal line, and the sequence of events in each session is displayed vertically. This representation was chosen due to its readability and ease of use [37], as well as being well-suited to our dashboard layout. Additionally, this horizontal/vertical hierarchical structure is currently employed in other Quill interfaces, which contributes to consistency as well as familiarity (**R4**).

Each session is displayed as an orange dot, similarly to the Overview, over which symbols representing text-altering events are stacked according to their temporal sequence, from bottom to top. Horizontal layout can either display the timeline in full length, scaled by time, or in collapsed form, showing only sessions containing amendments from the selected document equally spaced as a list. Figure 4 shows an example of both methods.

5.2.1 *Event representation*

One challenge in displaying the timeline in this manner is that sessions may contain a large number of events, which could make drawing the timeline impractical. Additionally, even if we could display all of them, these events may not be immediately relevant to the document at hand and result in unnecessary clutter. To tackle this issue, we first filter the event list, removing all events that do not reference the document being visualized, and also events not directly related to document composition, (e.g. motions, session procedures, events referring to people). To further optimize the timeline layout, we then apply a symbol system that condenses multiple events into one semantically consistent symbol.

The symbol system is focused on amendment proposal events, which can be then followed by other events such as approval, rejection, or further discussion. We condense this sequence of events into a single symbol, prioritizing three aspects: the type of amendment, whether it was accepted or rejected, and how long it took for this decision to be reached. Amendment proposals are therefore shown as circles, in which type is described by a color: general amendments are shown in yellow, while red is used to highlight amendments imported from other documents or committees. If a decision is reached for an amendment, a purple outline is applied. The outline is dotted if the decision was reached at a later date. Finally, an "x" symbol is applied to rejected proposals. Fig. 5 illustrates this process.

The color and shapes of symbols were chosen to retain consistency and familiarity with other icons in Quill timelines and,

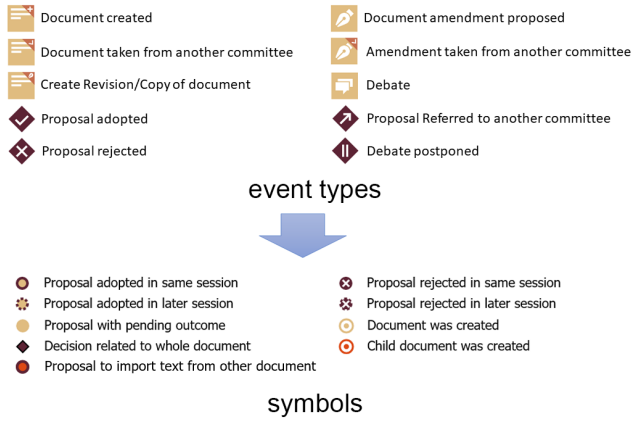

Fig. 5. Conversion from original Quill icons to timeline symbols. A symbol is obtained from a sequence of one or more events. While certain events (such as debates) are omitted from symbols, they are still available for interaction logic and descriptions.

at the same time, be compact enough in size to be stacked while maintaining scalability. In addition to amendment proposals, other types of events are shown with different symbols. A dotted circle is used to represent document creation, which could describe either the observed document itself (yellow circle) or a child document that copies some of the observed document's text (red). Finally, a purple diamond is used to represent decisions related to the whole document (e.g., if it was reported to another committee, or if its inclusion in another document is adopted). These representations were developed alongside domain experts, ensuring that the most relevant information would be retained.

5.2.2 *Event depth*

Events are structured in such a way that each amendment proposal is part of a hierarchical tree whose root is the event for the document's creation. For instance, there is an amendment proposal for each paragraph in a text, and in order to discuss the specifics of certain sentences in a paragraph, new amendments are proposed under the first. This tree provides one more channel for the visualization to identify amendments that share a larger theme and refer to similar parts of the text. *Event Depth*, therefore, refers to the distance from the tree in which each amendment is located.

Fig. 6 illustrates the event depth of amendment proposals in a document timeline. To show this information without overloading the visualization, we opted to display it as a cursor hover effect: when hovering over a symbol, it will display lines connecting itself to its parent and child amendments, as well as the entire branch of the amendment tree, with a dot in the child amendment's end to indicate direction. If parent and child amendments occur in the same section, they are linked using an arc; otherwise, they are linked using a straight line. The opacity of non-connected amendments is reduced to provide further focus on the connected amendments, as shown in Fig. 7b.

While visualizing hierarchical connections between amendments can become unwieldy when session and event density is too large, the ability to zoom in on the visualization when necessary offsets this issue when a user takes a particular interest in observing a given set of connections.

5.2.3 *Selection mode*

The Single Document Timeline allows for elements to be selected and highlighted (more details in Section 5.4). When this happens,

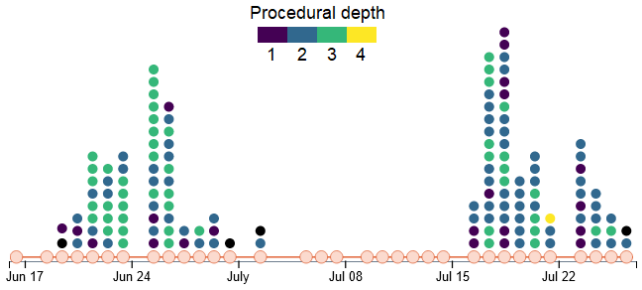

Fig. 6. Different levels of procedural depth in the amendment event tree.

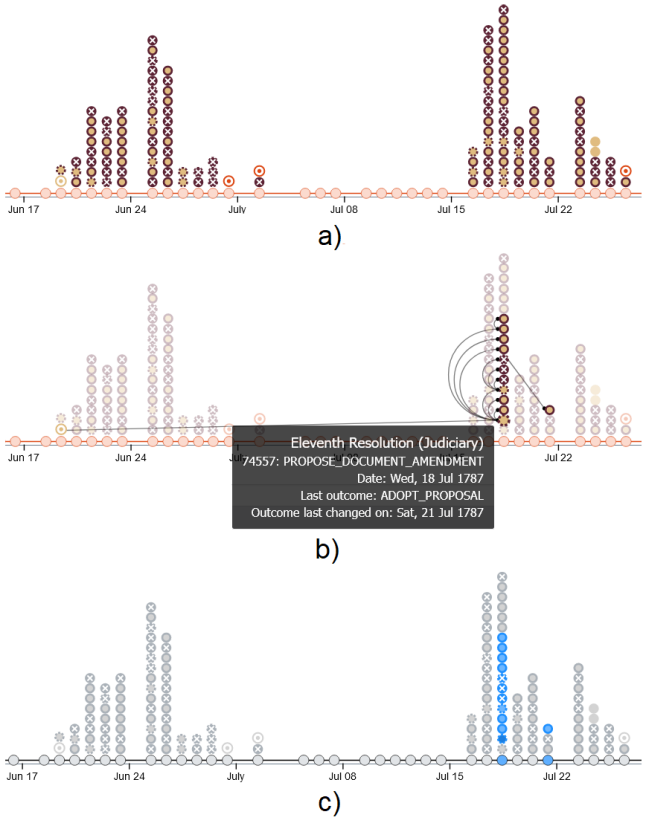

Fig. 7. Timeline interaction: the timeline is displayed in its default colors (a). When the cursor hovers over one of the symbols, its connections to other symbols will be highlighted, all other symbols will lose opacity, and a description box with details will appear (b). If the symbol is clicked, the visualization enters *selection mode* and will highlight relevant symbols in blue, while all others are colored in gray.

the visualization's color scheme changes, displaying non-selected symbols in grey while selected symbols attain shades of blue. This is done to maintain our goal of displaying multiple types of event relationships at the same time, using different visual channels for event depth and events connected by a user-defined filter (**T3**). Fig. 7c illustrates the timeline's response to a selection.

5.3 Text Panels

These panels allow for directly interacting with the text, selecting specific words, or accessing information on related documents.

5.3.1 *Text viewer*

The text viewer (Fig. 2-D) is the central component of the lower part of the visualization tool. Beyond the full text of the document at a given point in time, it also provides extra information

accessible by four toggleable filters: the first is to display text fragments that were removed resulting from adopted amendments; the second is to display text fragments from amendments that were still pending decision at the time; the third is to display text from rejected amendments; finally, the fourth option is to display the event IDs of the amendment proposals corresponding to each text fragment, for use in different interfaces of the platform. The removed text is shown with a red background and struck through, the pending text is shown with a yellow background, and the rejected text is shown with a brown background.

5.3.2 Related Documents panel

This panel (Fig. 2-C) contains information on other documents that interact with the visualized document. The Related Documents Panel shows a list of all ancestors and children of the current document, including immediately relevant information such as which committee they belong to and when they were created. Alongside ancestors and descendants, this panel also displays imported documents and outcomes, which refer to decisions regarding the use of the document (approved as a permanent asset, referred to another committee, and so on). The panel is used to redirect users toward other documents that may be of relevance.

5.3.3 People and Keyword panels

These panels (Fig. 2-E) contain lists of all people and keywords that appear in events related to the document. They can be ordered alphabetically or by the number of appearances, which are also displayed alongside each person's name or keyword. These lists are used to filter and highlight different elements in the visualization, as well as offer context menus to explore people and keywords in other interfaces in the Quill platform.

5.4 Interactivity

The tool offers different methods of interactivity. The first is a selection: by clicking on an event symbol, session symbol, text fragment, person name, or keyword, the visualization will change all of its components to highlight elements related to it. The second is for context menus, which appear when the user right-clicks elements of the interface. There are also navigation and cursor hovering options for the single document timeline and overview. Fig. 2 shows an overview of selection, hovering, and linked-views.

Selection works somewhat similarly to *brushing and linking* [38]: whenever an object is clicked, a list of events L_{ev} is produced, containing all occurrences of the clicked object. In the case of people and keywords, L_{ev} contains all events associated with them (as described in Section 3); in the case of a text fragment, L_{ev} contains all events referring to amendment proposals discussing that fragment; in the case of a session (column) in the timeline, L_{ev} contains all events that occurred in that day; in the case of a symbol in the timeline, L_{ev} contains all events following that event's branch in the event tree. Then all the visualization components will display elements connected to events in L_{ev} in blue, while everything else is displayed in gray. The result is that the visualization highlights all elements connected to what was selected: for instance, selecting a person's name will highlight the amendment proposals that the person was involved with in the document timeline, the parts of the text they participated in discussing in the text viewer, other people that appeared in the same events as them in the people tab, and keywords that appear in the same events as them in the keyword tab. L_{ev} takes into account all events related to amendments, including debates or speeches, although they are visually omitted in the document timeline. Clicking on an empty space or the same element will cancel the selection and return the visualization to its default colors. An example of selection is shown in Fig. 7.

The context menus are specific to each element and designed mainly to offer access to different interfaces from other modules in the Quill platform that show other entities in detail (**T4**). The context menu for single document timeline symbols offers two options: a link to the proposal's event detail page in Quill, and the option to view the state of the document up to that point in time.

Single Document Timeline navigation is done by either zooming and panning or using navigation buttons. If users are not using the collapsed view of the timeline, navigation can be particularly effective due to the uneven distribution of events in certain documents. Since symbols are not scaled, zooming applies to the horizontal axis only. Hovering the cursor over symbols will show a description box containing relevant information such as event date, description, outcome (last decision), and outcome date.

Interactivity in the Overview is given by hovering actions, which will highlight certain elements as discussed in 4.2, as well as show a description box containing the date, number of proposals, names of documents discussed, created, and exported. Right-clicking will open context menus for viewing sessions or documents individually, and clicking document icons will refresh the visualization to display that document in the Single Document Timeline and Selection Panels.

5.5 Visual Scalability

5.5.1 Number of events

While the size of each event symbol is relatively small (retaining readability with as little as six pixels in diameter) and our filtering removes a considerable amount of events, as the number of events in a singular session increases, more vertical space is needed for displaying this information. This problem can get particularly troublesome if a single session contains a very large amount of events and others do not, as it can result in requiring a large amount of screen space in the upper regions of the visualization that would be mostly empty with the exception of that session. While the datasets explored during development did not contain particularly extreme examples of this issue, there are solutions that can be employed: the simplest one would be to use multiple columns per session, which works well (especially with the collapsed representation) if the spacing between columns of the same session is kept smaller than the spacing between sessions.

5.5.2 Number of sessions

Similarly, depending on screen resolution, the total number of sessions in a dataset can also become too large to be displayed all at once in the Single Document Timeline. This issue is mostly solved by the combination of the Overview and the ability to collapse the timeline: the collapsible timeline will ensure users can see a reasonable amount of sessions even if it does need to be scrolled while removing empty zones in the visualization. On the other hand, the Overview keeps users aware of context while navigating the Single Document Timeline, even if it is not shown in collapsed form. As a more extreme solution, multiple sessions could be concatenated if necessary; the session dot would be displayed after the last symbol of the previous session.

As for the Overview, each session bar and dot can be displayed and identified clearly with as little as four pixels, which results in close to 500 sessions being able to be displayed on a 1920x1080 screen. However, the bar chart representation allows for combining the events from multiple sessions, which would render the maximum amount of sessions in the Overview virtually limitless.

5.5.3 Multiple committees

Multiple committees are shown only in the Overview, as the Single Document Timeline is always locked to activity in a single committee - while that could be changed in future work, the way Quill structures its events makes it not as relevant for domain researchers. Domain experts did not consider the number of different committees in Quill datasets large enough to become a problem for the Overview, although the option to hide the Overview after examining it would work as a measure to keep it from interfering with the rest of the interface in extreme cases.

6 Usage Scenario

This section contains two examples of usage scenarios for our tool. Both involve exploring the text and timeline to obtain insights into how the text reached its final state, by investigating contributions from people and tracking text provenance.

In one example, a history student is investigating the Committee of the Whole House from the United States Constitutional Convention of 1787, aiming to find points of contention or controversial speeches and proposals, as they could provide insight into political alignment and behavior of the people involved. When visualizing records from a version of the Resolutions of the Committee of the Whole House, they notice that the proposal for the Ninth Resolution contains a considerably large amount of subproposals, and many of them were rejected.

As this indicates a longer and possibly contrived discussion, considering their previous knowledge on the Committee, the student examines the involved proposals, aiming to look at who might appear in them. They notice that rejected proposals tend to highlight more people than adopted ones - by looking into event records, rejected proposals generally have more debates associated with them, providing more opportunities for people to appear as references. When exploring people connected to the Ninth Resolution, the student decides to click on the name of Roger Sherman, as he was involved with events related to the Ninth Resolution. The student notices that this person is often involved with rejected proposals.

The student wonders how expressive Sherman's role in debates - either defending adopting or rejecting proposals. Looking further into the details of this person and their activity in other Quill interfaces will provide further answers to this investigation.

A more advanced scenario involves a more expert researcher trying to evaluate two related aspects of a process of political debate. Qualitative, sometimes impressionistic analysis of processes such as the US Constitutional Convention of 1787 frequently divides periods of discussion into sections, and describes in narrative form how shifting alliances influence final outcomes. In this scenario, the researcher will want to compare discrete periods of the timeline, and be able to visualize a number of related aspects of the evidence.

Firstly, to what extent it is true that alliances have shifted—does the data support a particular interpretation? If so, then to what extent and in what ways. Secondly, to what extent is this sense of shifting alliances dependent on a few key decisions that were made. In processes that are not dominated by hyper-partisanship, where all votes taken fall along party lines, distinguishing the most critical decisions within a process of decision-making, from the point of view of establishing important alliances, can be difficult.

In exploring different hypotheses, a researcher requires a set of tools that allow them to move easily between insights that can be generated from a quantitative analysis of available data, especially comparing discrete regions of the timeline, assistance identifying within extended runs of data points of particular interest (especially those points that might otherwise have been overlooked, such as a vote that suggests an unusual alliance at a particular moment but which does not attract significant comment in the surviving records), and an ability to move to a screen that display the relevant sources and context for more detailed historical work.

7 Evaluation

In this section, we discuss the evaluation process conducted with domain users throughout the tool's design and development. Regular meetings with the leading domain expert were held to ensure that the tool was in line with domain requirements. Additionally, three evaluation sessions were held with domain users from the Quill Oxford Team to collect feedback and refine the tool. The first two sessions, described in Sections 7.1 and 7.2, focused on the interface during its early development stage, encompassing the Single Document ***Timeline*** and its interaction with the ***Text panels***. The third evaluation session, detailed in Section 7.3, was conducted at a later time, incorporating the Document Path ***Overview*** and aiming at gathering feedback on the latest changes.

7.1 Sessions 1: Hands-on Workshop

7.1.1 Methodology

This workshop, held in-person with four domain users, focused on evaluating the visualization's effectiveness and gathering insights into user needs and preferences. We also sought feedback on specific design decisions, such as symbols, colors, representations, navigation, selection mechanics, and metaphors for document and amendment relationships. In addition, we asked participants about their opinions on the usefulness of different additional tasks that the visualization could be developed to perform with complementary data. The workshop began with an introduction outlining the current development status and goals, followed by a demonstration of the tool in use. Participants were invited to engage with the tool and ask questions. Discussions were structured around a questionnaire focusing on the tool's effectiveness, design choices, and possible improvements. Feedback was collected via a post-workshop survey using Likert scale items and open-ended questions, with all observations and responses recorded.

7.1.2 Results

Based on the data collected from the questionnaire and observations during the workshop, we concluded that domain users gave positive feedback on the tool's design - they thought the tool was intuitive, easy to use, and effectively addressed domain needs. We investigated the effectiveness of the tool in meeting the four summarized domain requirements, as shown in Table 1. Users believed that the tool effectively displayed relationships between documents and other related entities, such as people and keywords,

TABLE 1
Feedback from four participants of the first post-workshop survey on tool effectiveness and usefulness of possible additional domain tasks.

Tool Effectiveness (%)	**L**	**M**	**H**
R1 Summarize the history of a document	0	4	0
R2 Show the history of a selected section of text	0	3	1
R3 Show document-entities connections over time	0	1	3
R4 Interact or be integrated with other Quill pages	0	1	3
Potential Tasks (%)	**L**	**M**	**H**
See details of events related to proposals	1	2	1
View document session activity summary	2	2	0
View summary of text changes per session	1	0	3
View session topics/keywords evolution	0	1	3
See the ancestors/children from documents	0	0	4

as well as the development and provenance of the text (**R3**). Users also provided positive feedback on the integration and connection of the tool with other Quill tools (**R4**).

Feedback on the design of symbols was positive: *"I really like the choice of icons, especially those that indicate whether a particular proposal is decided upon in the same session."*, *"The use of color to highlight what is happening is clear and consistent with elsewhere in Quill."* In terms of summarizing the historical development of the document (**R1**), domain experts appreciated the interactive timeline format but suggested changes in colors and highlighting. When explaining the provenance of the text (**R2**), domain experts thought that the strong connection between various entities and the document effectively illustrated the provenance and development of the text. Relationships between events in the ***Timeline*** were clearly displayed using arrows, but experts found arcs and connecting arrows on highly related event clusters to be too cluttered: *"When you click an event, lines are drawn between different events, but particularly if these appear close together on the timeline, they are difficult to interpret."*,*"The visualization shows relationships between amendments in the same document in a really interesting way. It would be clearer if the icons did not overlap at busy points in the timeline."*

On gathering additional information on user needs and preferences to refine requirements and tasks, we found that participants were interested in viewing a summary of session activity, as well as more details on the evolution of topics discussed per session. In particular, all participants expressed a desire to visualize the complete lineage of ancestors and descendants for documents.

7.2 Session 2: Expert Interviews

As a result of the feedback obtained from the first workshop, refinements and enhancements were made to the tool. We added more options to the selection and reset functionalities to make it more convenient for users; The color schema and highlighting design were revised to make elements more distinguishable, and textual explanations were added to the ***Timeline***; We improved zoom and pan functionalities in the ***Timeline*** and tweaked the visual metaphor for connections to improve clarity on dense areas. Finally, the ***Related Documents*** Panel was added to display ancestor and descendant documents and was integrated with the tool. The tool was further evaluated through expert interviews combined with the think-aloud protocol.

7.2.1 Methodology

We interviewed four domain experts P1 – P4, who had previously attended the workshop. Their background is summarized in Table 2. The remote interview session of each participant lasted between 30 and 60 minutes, following a set of procedures as shown in Table 3. The sessions began with a preliminary preparation, featuring a tool overview to introduce the primary panels and their functions, along with a short tutorial using an example document to demonstrate essential interactions and use cases. During the session of task scenarios, participants were encouraged to think aloud, share their screens, and explore a document that they were familiar with using the tool. Tasks included exploring the ***Timeline***, investigating text provenance, examining individuals' contributions, and navigating related documents. The concluding post-test discussion focused on users' experiences with specific aspects of the tool, such as primary panels, interaction techniques, and integration with other Quill components. We sought participants' overall impressions of the tool, and gathered suggestions for enhancing usefulness and usability.

TABLE 2
Summary of interview participants' background.

User	**Expertise**	**Role**
P1	1 year	Quill user & documentary editor
P2	2 years	Quill user & data entry operator
P3	1.5 years	Quill user & documentary editor
P4	5 years	Quill user & data entry operator

TABLE 3
Interview Procedure and Duration.

Order of Procedure	**Activities**	**Duration**
Preliminary Preparation	1) Introductory questioning 2) Tool walkthrough	10 min
Task Scenarios	1) Test via predefined tasks	20 min
Reflective Discussions	1) Reflection on the tool 2) Future direction	20 min

7.2.2 Results

Building on the prior workshop's knowledge and the preparatory introduction of the tool, participants were able to quickly and effectively learn and comprehend the purposes of various panels within the interface. All participants expressed considerable interest and satisfaction in the newly improved ***Timeline*** panel and ***Related Documents*** panel.

Timeline. The improved *Timeline* was considered powerful by all participants, not only for providing a highly summarized representation of the chronological development of document-related events but also for offering users the freedom to make selections according to their needs. All participants mentioned that the zooming functionality was highly useful in helping them grasp the details of the interconnections between events more clearly. Furthermore, the variety of selection options for event points within the *Timeline* panel addresses the cross-session referencing limitations mentioned in previous workshops.

Selection panels with seamless connectivity. Based on participants' interactions with the tool, they were able to comprehend the benefits of the high level of customization and the tight connections between data related to the document from various aspects within individual panels. Furthermore, they could seamlessly use these selections to achieve their specific research objectives. Both P2 and P3 gave positive evaluations for the usefulness of the

People panel: "*The ability to click on a person and see their involvement in proposals and debates is really useful.*" and "*The tool is valuable for presenting a lot of information about changes and their authors, which would otherwise take time to compile.*" The *Text Viewer* also received positive feedback for displaying document text provenance and development: "*The tool was a significant addition to the existing features, as none of the other views in Quill offered the ability to see the life of a document in detail.*" The newly added *Related Documents* panel displays ancestors and children from the document, effectively satisfying users' desires for a comprehensive view of the document's development over time. Regarding the *Keywords* panel, P4 stated "*The Keywords panel was good in theory*" but questioned its implementation, as keywords were often not relevant. We believe this to be mainly due to the keywords currently available in Quill being still under development and not representative for many of its datasets.

The overall impressions of the tool were favorable, as participants found it to be valuable and efficient for their work or research, aligning well with the summarized domain requirements. The hierarchical timeline effectively provided a summary and overview of document-related events and their relationships, and participants could explore the document text's provenance and associated stakeholders through the interactive and linked panels.

They also suggested areas for improvement and potential future directions. Taking into account users who may have limited prior knowledge of the interface, even though it is well-integrated with the Quill platform, participants recommended incorporating a brief tutorial or introductory explanation to facilitate a better understanding. Moreover, they suggested that displaying actual changes made to the document directly on the *Timeline* could be advantageous, which could be a future step involving a separate interface for the *Timeline*. Exploring various facets of a document's lifecycle within committees, enhancing differentiation among committees, and providing an overview of how the document's text changes within individual sessions or groups of sessions were identified as subjects for future investigation.

7.3 Session 3: Final Workshop

Based on feedback from domain experts, we further refined the tool by integrating the Document Path ***Overview*** panel, and adding the list view mode to the ***Timeline***.

7.3.1 Methodology

This workshop was conducted with three domain users P1–P3 along with a Quill UI expert. We aimed to collect feedback on the last changes in the prototype, as well as thoughts on the effectiveness of the ***Overview***in addressing domain requirements, and gain insights into user needs and preferences to refine the tool. We also sought feedback on specific design decisions and metaphors for document and amendment relationships. The workshop followed a similar process to the first workshop.

7.3.2 Results

The feedback collected from respondents regarding the ***Overview*** underscores unanimous anticipation of a positive impact on their workflow. In response to the question about its impact, participants provided insights into how this feature would enhance their productivity. They highlighted the potential for significant time savings, particularly during the proofreading and tracking of document details within a project. The visualization showed promise in streamlining these tasks, making errors more noticeable and, in turn, improving overall efficiency. Users also emphasized how it would enhance their ability to track documents, maintain accuracy, and identify errors effectively. The advantages of faster editing and more precise document tracking across committees were underscored, citing benefits in terms of document flow, version accuracy, and committee assignments.

Combining insights from this workshop and the two previous evaluation sessions, there was no clear consensus on the preferred presentation format for the visualization with all proposed amendments – whether it should be a timeline with spacing accurately reflecting time or equally spaced as a list. Some users expressed a desire for both styles to be available, recognizing the unique advantages of each. Some users leaned towards the timeline version, emphasizing its importance in providing vital temporal context for robust data analysis. This format enabled users to discern patterns in document activity across different dates and meetings, facilitating a more comprehensive understanding. Conversely, others preferred the equally spaced list version due to its enhanced readability when eliminating empty spaces. As a result, we kept both of the designs in the final prototype using a toggle.

Usability feedback for both the new features and the overall toolset has been consistently positive. Participants found the color and symbol choices in the visualization aligned well with Quill's conventions, with the distinctions in opacity tiers and colors receiving praise. Although one participant suggested larger symbols in the lower visualization, this was attributed to device limitations. Component clarity was generally strong, with only a minor initial hesitation about darker lines, which was quickly clarified. The connection between different visualizations was considered clear.

8 Discussion

In this section, we discuss significant findings from the interaction with users, limitations, and future directions.

Utility in Dataset Construction. An interesting point of feedback that we obtained from users is that the tool also seemed useful for dataset construction, namely debugging and validation. As documents and records are scanned and entered into the system, a visualization of the document history in progress would help editorial users confirm the status of recently processed data and identify potential problems.

Cross-domain Applicability. While our tool was designed for visualizing historical texts, most of the elements described here can be applied to other domains - e.g., *amendments, debates, child documents* have similar counterparts in *commits, tickets, branches* in the context of source code management. The feedback described in our evaluation can also be used as guidance in designing applications in other domains.

Balancing Consistency and Innovation. The colors and shapes of the symbols displayed in the interface were carefully chosen to maintain consistency and familiarity with other icons on the Quill platform. This decision received positive feedback in all evaluation sessions regarding consistency and integration into the Quill platform. As the tool's potential users are already familiar with the Quill platform, maintaining design consistency enhances the comprehensibility and learnability of the new tool. However, one participant (P3) mentioned during an interview that, although

the design was consistent and engaging, they personally did not particularly like some of the existing icon colors and shapes and hoped for more effective symbols in a new tool. This remark made us reconsider the tradeoff between maintaining consistency and fostering innovation. While we believe that consistency currently maximizes the efficiency of newly integrated tools, we will consider alternative new icon designs and further deviating from the Quill platform's constraints in future research.

Limitations. Our methods have certain limitations: the first is that scalability issues may arise in datasets with outlier behavior (e.g. very few active sessions with a very large amount of amendment proposals, documents that have small amounts of activity but bounce very often between multiple committees, and so on). Another limitation is that the visualization does not show all possible details for document events, and, while we were guided by domain experts in defining what to display, certain data may require examining events in further depth. Finally, while designed to be effective in general terms, the semantic logic for selection operations may not be the most efficient for all occasions (e.g., highlighting only proposal authors instead of all people involved in an amendment proposal).

In opposition to the *cross-domain applicability* discussion in the previous section, it is also important to highlight elements that are in fact intrinsically attached to this particular domain and platform, and would need adaptation for different contexts. Most of our timeline symbol design was developed specifically for Quill, its particular event sequencing, and its existing symbols, and may not fit other types of workflow. Branching and merging in other applications will also likely not operate under the same constraints as the referencing between multiple committees in Quill. Finally, our evaluation itself was focused on Quill researchers and their needs, which are likely different from collaborative writing users in other domains. In addition, it follows that users not familiar with the domain (or visualization techniques in general) may have a considerably steeper learning curve when using such a tool, with some level of training or onboarding process being required.

It is worth noting that this visualization is focused on summarization and provenance tracking in event sequences, and Quill's event detail page displays text comparison for amendment proposal events. However, users did express interest in further observing summaries of text changes, which we are investigating as a future research direction. Users also expressed interest in visualizing how discussed topics change over time; adapting and building upon state-of-the-art techniques in those areas to fit the context of this application will also be investigated as future work.

9 Conclusion

In this paper, we presented a visualization tool to explore timelines for collaborative text negotiation in historical records, organized into multilevel relationships and hierarchical structures. We discuss our design choices and implementation and how we navigated the constraints of the domain, the existing platform, and the expectations of domain expert users, ensuring that the tool would be both effective and fit in the scope of a larger environment.

Overall, the tool received positive feedback in our evaluation sessions, and domain experts were effective in providing insights for development, as well as suggestions that could lead to future work, namely, relationships between different timelines and how each of the involved elements' involvement with the text evolve over time as the texts change.

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