OwnershipTracker: A Visual Analytics Approach to Uncovering Historical Book Ownership Patterns

Yiwen Xing, Meilai Ji, Cristina Dondi, and Alfie Abdul-Rahman

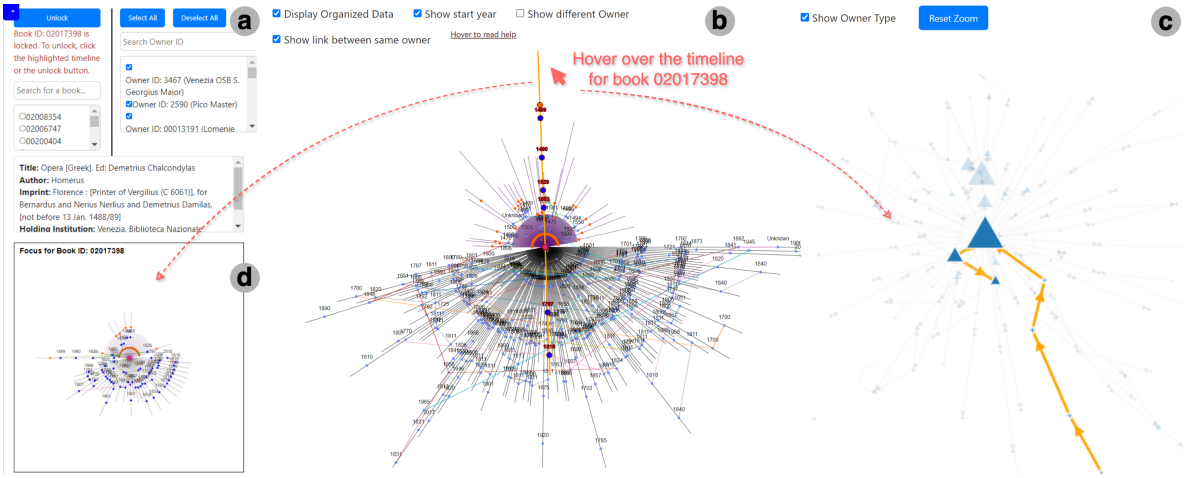

Fig. 1: The interconnected view of OwnershipTracker: (a) control panel includes options to lock the current view, search & select books/owners, and display book/owner details; (b) Spiderweb-Like Diagram as the main exploratory view; (c) linked Node-Link Graph highlights related components when interacting with (b); (d) subview of the spiderweb, displays elements related to a focused book.

Abstract—Ownership relationships of early printed books from the 15^{th} century reveal complex patterns of distribution and possession, offering valuable insights for historical research. This paper presents *OwnershipTracker*, a visual analytics application developed to explore and trace these relationships using data from the Material Evidence in Incunabula (MEI) database. *OwnershipTracker* integrates bibliographic records, copy-specific data, and book provenance and ownership details, enabling users to uncover intricate ownership sequences over time. The application combines several visualization techniques, including network graphs to map connections between owners, timelines for temporal analysis, chord diagrams to quantify transfer patterns, and a distinctive, collaboratively designed spiderweb-like diagram highlighting converging and dispersing ownership transfers through specific owners. Developed iteratively with input from historical book researchers, the application underwent multiple refinements to align with domain research requirements. A summative evaluation with domain experts showcased the tool's ability to address the defined requirements and tasks. The final version of *OwnershipTracker* is deployed and accessible at: https://booktracker.nms.kcl.ac.uk/ownership.

Index Terms—Design study, visualization application, human-centered design

1 Introduction

Historical books are more than vessels of content. They are artifacts that carry rich information about social exchange and historical connection. Analyzing the transfer and possession of these books over time can reveal insights into broader historical dynamics. For instance, following the dissolution of a prominent library may reveal how its books are dispersed across regions. Analyzing the collection patterns of notable figures can reveal shared intellectual interests or alliances among them. These ownership patterns, as documented in historical records, provide valuable insights into the social and cultural dynamics that influenced book circulation.

Visual analytics has the potential to illuminate these complex relationships, providing historians with tools to examine ownership and distribution patterns through an empirical, interactive approach. Prior research has explored historical book movements through spatial visualizations, analyzing provenance data to observe the books' geographic distribution and circulation patterns [39, 41]. This study builds on that foundation by shifting the focus from geographic data to ownership. Instead of examining where books traveled, the emphasis here is on who possessed them – investigating the relationships between individuals and institutions linked by shared book ownership.

In collaboration with domain experts from prior research [39, 41], we conducted a visualization design study, leading to the development of *OwnershipTracker* – a visual analytics tool designed to explore book ownership patterns through distinct and interconnected views from two exploratory angles – ownership relations and book provenance. The development of *OwnershipTracker* went through three main enhancement stages: 1) initiating the design with a node-link graph to represent connections and relationships between owners; 2) driven by the sequential nature of book provenance, proposing a spiderweb-like diagram that illustrates both the sequence of provenance and the associated owner in each provenance; and 3) recognizing the complementary insights provided by the node-link graph and spiderweb diagram, resulting in the creation of two interconnected interfaces, each centered around one of these two visualizations as the main exploratory panel.

In this paper, we present *OwnershipTracker*, which describes its

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Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx

functionalities and how each component addresses specific domain requirements. We describe our iterative design process, highlighting three key development phases shaped by distinct analytical goals and collaborative feedback from domain experts. Finally, we report on a usage scenario in which domain experts gained insight from the tool during the testing phases, and we discuss the summative evaluation results and reflections from this collaborative visualization project. In summary, our main contributions are as follows.

- The development of *OwnershipTracker* to support the analysis of historical book ownership data from multiple perspectives.
- An account of our iterative design process, emphasizing three critical phases and detailing the design rationale.
- Insights from a usage scenario and evaluation, reflecting on the collaborative process with historical book researchers.

2 Related Work

2.1 Historical Book Trade Research and Visualization

Books have long traversed trade routes, spreading knowledge, and changing ownership. Since 2009, the Material Evidence in Incunabula (MEI) database [9] has collected data on 15^{th}-century books, enabling researchers to trace their circulation, trade, and collecting and beyond [15, 16]. The 15cBOOKTRADE Project [14] further enhanced MEI, expanding its utility for provenance studies. Visualization tools have become essential with the growing availability of book provenance data. BookTracker [40] and LiberRoad [27] are tools to facilitate the exploration of temporal-spatial features of book trade data, while Guo et al. [26] focus on temporal networks of book provenance. Broader efforts, such as visualizations of the Republic of Letters [20], illustrate the circulation of correspondence, aligning with historical book trade research.

2.2 Network and Temporal Visualization

Node-link diagrams are a foundational method for visualizing network relationships, valued for their intuitive depiction of entities and connections [32, 36]. Despite their popularity, challenges arise in scaling node-link diagrams to dense networks [24] and incorporating temporal data [31], which adds complexity to the representation. Various strategies have been developed to depict dynamic networks [3, 21, 34]. Animation is a widely used approach, offering an intuitive representation of temporal evolution through frame-by-frame transitions [2]. Static alternatives, such as small multiples [23] and stacked timelines [12], enable users to compare temporal snapshots side by side, improving clarity for cross-time analysis. Interactive exploration further enhances dynamic network analysis by combining multiple techniques. Tools like NodeTrix [28], VisLink [11], GraphTrail [19], and Person&Dataset Visualizers [7] integrate node-link diagrams, adjacency matrices, and hybrid visualizations, allowing users to explore relationships, temporal evolution, and additional features interactively.

2.3 Visual Analytics for the Humanities

Over the last decade, scholars have emphasized the need for visualizations tailored to the humanities, where data is often constructed and interpretive, unlike the observer-independent nature of scientific data [4, 6]. Drucker argued that humanities visualizations must provide rich contextualization, accommodating the complexity of layered information [18]. A promising trend is the integration of close and distant reading – detailed analysis of individual texts with large-scale pattern exploration. Tools like Serendip [1] and VarifocalReader [30] bridge these approaches, linking cluster views to close reading for better interpretability. Poemage [33] extends this integration to support detailed textual analysis through interactions.

3 Design Requirements

3.1 Domain Data

The data for this study is sourced from the Material Evidence in Incunabula (MEI) database [9], which documents provenance information for 15^{th}-century printed books, including ownership, binding, annotations, and other copy-specific details. Personal and institutional

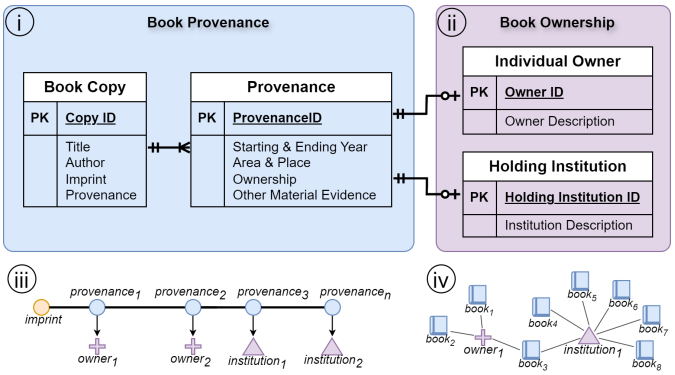

Fig. 2: The data structure of book provenance and ownership. (i) Book Provenance entities, capturing each book's details and its sequential provenance records. (ii) Book Ownership entities, documenting ownership by individuals and institutions. (iii) Sequential representation of a book's life, showing its transitions between owners over time. (iv) Ownership network, illustrating that each owner can hold multiple books, and a single book can be associated with various owners over different periods.

ownership names are collected in the satellite database Owners of Incunabula [10], which includes further bio-bibliographical information and links to all copies owned by the same person or institution, enabling the reconstruction of dispersed collections. The Holding Institutions database [8] lists libraries and institutions associated with the books recorded in MEI, providing additional context for tracing book provenance and explicitly representing the current owners.

The data can be divided into two main components: the book provenance data (Fig. 2 *i*) and the book ownership data (Fig. 2 *ii*). The first component, book provenance, captures the journey of each book copy through various transfer stages. Each printed book copy is associated with one or more provenance records. These provenance entries are sequentially ordered, indicating the chronological flow of the book's journey from one individual owner or holding institution to the next (Fig. 2 *iii*). The second component documents details about individual owners and holding institutions, which are organized within entities related to book ownership. Each provenance record has a one-to-one relationship with an owner, meaning that at any given point in the book's history, a provenance record will be associated with either an individual or an institution.

From the perspective of owners, each individual or institution may hold multiple book copies, highlighting the one-to-many relationship between owners and books (Fig. 2 *iv*). Additionally, a single book copy may be associated with multiple owners over time as it passes from one individual or institution to another. This structure captures both the networked ownership relationships and the temporal progression of book provenance, which are central to the aims of this study.

3.2 Domain Requirements

We worked in close collaboration with a leading domain expert, who is also the third author of this paper. The following set of requirements was derived from our iterative discussions. While requirements were primarily defined during initial meetings, minor adjustments were made during user testing and evaluation with a broader group of experts.

R1 **Insights into Ownership Relationships.** Domain experts seek visual techniques that enable them to observe patterns in the flow of books between holding institutions and individual owners. These visualized "in" and "out" transitions serve as foundational clues, helping experts understand and depict the complex network of ownership relationships across time.

R2 **Integrating Book Provenance Sequence with Ownership Visualization.** Given the sequential nature of provenance data, it is essential that any visualization of ownership also respects the continuity of each book's life journey. While ownership data can be analyzed independently, it remains deeply interconnected with

the provenance sequence, reflecting the natural progression of the book trade. Therefore, the visualization must account for both ownership and provenance data to provide a coherent depiction of each book's historical trajectory.

R3 **Visual Quantification and Pattern Highlighting.** Historical book experts often possess a deep understanding of significant events, gained through years of study, such as how particular events may have influenced the dispersion of books. Visualization should present data to validate these hypotheses and quantify the impact of historical events, such as the redistribution of books after a library's closure. The visualized data should highlight and quantify these patterns, offering empirical support for domain experts' insights.

R4 **Access to Individual Book and Owner Information.** As experts analyze grouped data (such as clusters of books or owners connected by specific relationships or events), they need direct access to individual-level information. This includes specific identifiers, names, and other details about books and their owners, allowing experts to conduct more in-depth investigations through their own resources and databases when exploring particular cases.

3.3 Design Tasks

Design tasks devised to meet the domain requirements are:

T1 **Visualize Ownership Flow & Relationships.** For **R1, R3**. The tool should provide a clear and quantifiable representation of book transfers between owners and the relationships among owners. This allows users to observe patterns that validate their historical hypotheses or support exploratory analysis.

T2 **Combine Provenance Sequence with Ownership.** For **R1, R2**. The tool should integrate the book provenance sequence with ownership information, presenting the life journey of each book as a series of temporally ordered stages linked to specific owners.

T3 **Support Linked Views for Ownership & Provenance Perspectives.** For **R1, R2**. The tool should offer complementary views of ownership (network perspective) and provenance (sequential perspective), with linked interactions that enable users to explore ownership relationships and provenance sequences together.

T4 **Highlight Patterns.** For **R3**. The visualization should enable users to identify patterns and phenomena connected to historical contexts intuitively. During the design of visual representations, special attention should be given to emphasizing data and entities related to these historical phenomena, helping users uncover meaningful insights tied to specific events or trends.

T5 **Provide Access to Detailed Book and Owner Information.** For **R4**. For deeper investigation, the tool should allow users to drill down into detailed information about specific books and owners, including identifiers, names, dates, and locations.

4 OwnershipTracker

4.1 Toolset Description

OwnershipTracker comprises three single views and two interconnected views, enabling multi-perspective data exploration. Built with d3.js [5] and Flask [25], this section details its components.

4.1.1 Node-Link Graph with Timeline View

The Node-Link Graph with Timeline View interactively visualizes book ownership relationships and temporal flows (T1, T2). The node-link graph (Fig. 3 *a*) represents owners – either individuals or institutions – as nodes, where the size of each node corresponds to the total number of books owned by that entity. Links between nodes represent book transfers, with arrows indicating the direction of the transfer, and the width of both link and arrow shows the number of transitions. Node positions reflect interaction frequency – owners with more frequent exchanges are placed closer together, enhancing the clarity of their interconnectedness.

To enhance interpretability, owner types are distinguished by shape: triangles represent institutions, while crosses indicate individual owners (see Fig. 3 *i*). Users can zoom in and out of the view to focus on dense clusters or overlapping connections, enabling detailed network exploration. Interactive features, such as hovering over nodes and links, reveal additional information about the owners and the specific books involved in transfers, including owner names, IDs, and book IDs (Fig. 3 *ii*). A search bar and selection tools (Fig. 3 *b, c*) allow users to isolate specific owners or books (Fig. 3 *iii, iv*), while filters provide further control over the visualization.

The timeline component (Fig. 3 *d, e*) complements the node-link graph by emphasizing the temporal aspect of book transfers. Each entry in the timeline corresponds to a book transfer and is linked to the relevant owners displayed in the graph. The timeline provides a visual summary of ownership changes over time, with distinct color coding specifying different events – imprint or provenance. By hovering over timeline entries, users can access detailed information, such as the owner's name and the book ID, supporting an integrated exploration of relational and chronological data. The timeline (Fig. 3 *d*) can be interpreted as a horizontally flattened version of the polylines shown in Fig. 3 *iii*, offering a more precise representation of time progression. When the node-link graph (Fig. 3 *a*) contains a large number of entities, the timeline can serve as a close reading feature. The selectable book IDs listed in the timeline control panel (Fig. 3 *e*) are synchronized with those selected in the node-link control panel (Fig. 3 *b*), i.e., they correspond to the books currently involved in the node-link graph.

The node-link graph and timeline offer a dual-perspective view, allowing for the simultaneous exploration of ownership relationships and temporal sequences. This integration enables researchers to validate hypotheses and gain new insights into historical book ownership. The design supports intuitive navigation and detailed exploration of both individual transfers and broader ownership networks.

4.1.2 Spiderweb-Like View

The Spiderweb-Like View provides a focused visualization of book provenance and ownership sequences, emphasizing convergence and divergence patterns among multiple books (T2, T4). Each book is represented as a distinct timeline, beginning with its initial imprint and progressing through sequential ownership stages (Fig. 4 *a*). Each timeline comprises nodes corresponding to an individual or institution owner at a specific time. A key feature of this view is its ability to depict shared ownership: timelines converge at a central node when multiple books are held by the same owner, and diverge as books transfer to different owners, illustrating collection dispersal. Colored lines connect nodes belonging to the same owner across timelines, making it easy to trace an owner's involvement with multiple books over time. Nodes may also be color-coded to differentiate between owners, aiding in the interpretation of complex datasets. The first node in each timeline is colored bright orange to mark the imprint, and due to many books being printed in similar years, these nodes form a semi-ring near the center, highlighting temporal clustering. To distinguish segments before and after the central owner, purple and black colors are used for the corresponding portions of each timeline.

To support detailed analysis, the Spiderweb-Like View includes two key interactive functionalities. First, users can lock a specific timeline in the spiderweb visualization, freezing the view for deeper exploration of a particular book (Fig. 4 *b*). This feature enables researchers to focus on a book's provenance and associated ownership transitions without being distracted by other timelines. Second, the view integrates a focused sub-view located in the lower-right corner (Fig. 4 *e*). When a timeline is hovered over or locked, this focused view dynamically updates to display the subset of owners and books (timelines) directly associated with the selected book. This enables researchers to examine ownership relationships within the context of the entire dataset, highlighting how individual books connect owners across the network. Additional interactions are designed to facilitate detailed exploration in both the main and focused spiderweb views. Users can hover over nodes to reveal detailed information about owners or hover over timelines to view book-specific data. Search and selection panels (Fig. 4 *b,*

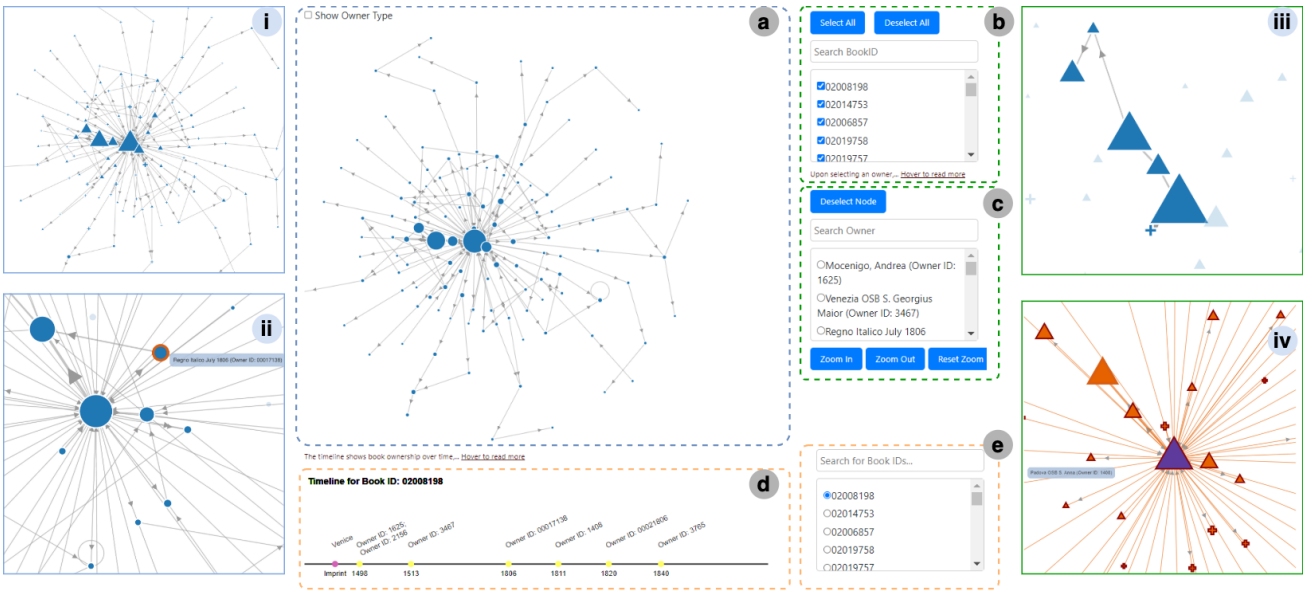

Fig. 3: The Node-Link Graph with Timeline View: (a) the display area for the node-link diagram; (b) and (c) are control panels for searching and selecting books and owners, respectively. (i) shows the result when owner types are displayed; (ii) demonstrates the hover-over text annotation with highlighting, and variations in arrow size and link width to indicate ownership quantity; (iii) displays the zoomed-in view with a selected book; and (iv) presents the result when an owner is selected. (d) shows the timeline display area, presenting owner information aligned in time order, while (e) provides the search and selection panel for the timeline.

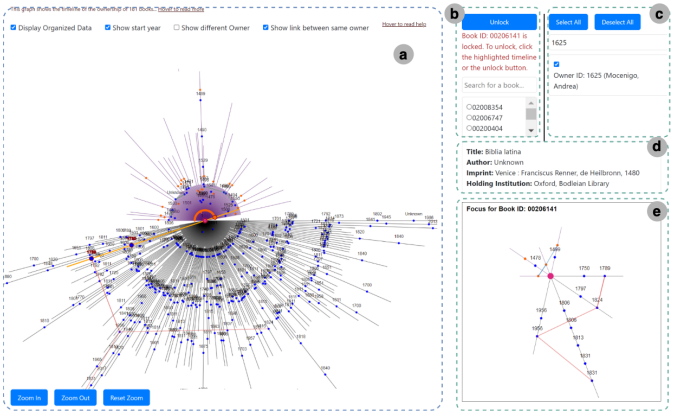

Fig. 4: The Spiderweb-Like Diagram View: (a) the display area for the Spiderweb, with four customizable options on top to adjust the layout; (b) the search & selection panel for books with the freeze function; (c) the search & selection panel for owners; (d) detailed information panel displaying book or owner details; (e) the focused subview showing only the timelines and nodes associated with the selected book.

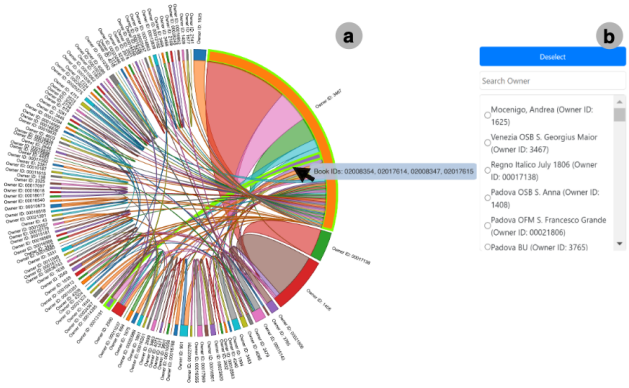

Fig. 5: The Chord Diagram View: (a) the chord diagram with one highlighted transfer; (b) the control panel for owner searching and filtering.

c) allow for quick identification of specific books or ow. In contrast, detailed information about selected books is displayed in the information panel (Fig. 4 *d*). Zooming capabilities allow users to adjust the level of detail in the visualization to suit their analytical needs.

This view excels at uncovering patterns of ownership and provenance, particularly in historical contexts. By highlighting convergence and divergence points, researchers can identify key figures or institutions central to book circulation and examine how books moved between successive owners. Integrating the focused view and lock functionality further enriches the analysis, offering a detailed approach to understanding the interconnected histories of books and their owners.

4.1.3 Chord Diagram View

The Chord Diagram View offers a streamlined visualization of book transfers, focusing on the quantity and flow of ownership transitions between entities (T1). In this circular layout, each segment of the outer circle represents an owner, while the chords connecting the segments illustrate book exchanges (Fig. 5 a). The thickness of each chord reflects the volume of books transferred, with thicker chords indicating larger quantities. Additionally, chord color encodes directionality: each chord is rendered in the same color as the outer edge of its destination owner segment. This visual mapping enables users to identify the recipient of each transfer, even in cases where the chord overlaps with others or spans a long distance across the circle. Interactive features support exploration by allowing users to hover over chords to view detailed information about the books involved. Search and filtering options (Fig. 5 b) highlight owners' segments, revealing all associated transfers.

Compared to the Node-Link Graph, which emphasizes the relational network of ownership transitions, the Chord Diagram highlights the magnitude of transitions, making it easier to compare the quantity of exchanges between different owners.

4.1.4 Interconnected Views with Example Cases

The previously introduced views are designed to explore the dataset through a specific lens. But what if users want to explore the data from multiple angles simultaneously? Below, we describe two interconnected views that link the Node-Link Graph and the Spiderweb-Like

Diagram to support a more holistic observation of the dataset.

Spiderweb-Like Diagram as the Main View. The Spiderweb-Like Diagram is the primary view in the interconnected visualization framework, focusing on the temporal and relational aspects of book provenance and ownership. This view emphasizes convergence and divergence patterns among multiple books, highlighting shared ownership points and subsequent dispersals. In the interconnected setup, the Spiderweb-Like Diagram is tightly linked with the Node-Link Graph, enabling researchers to explore relationships between books and owners from multiple perspectives. When users interact with the Spiderweb-Like Diagram by locking a timeline or hovering over a specific book, the corresponding data in the Node-Link Graph is dynamically highlighted. This highlights the type, relational proximity, and sequence of owners associated with the selected book.

The example in Fig. 1 demonstrates how these interconnected views function. When *Book 02017398* is hovered over and locked for exploration (a), the Spiderweb-Like Diagram (b) reveals that this book underwent seven ownership transfers, including its passage through the library of San Giorgio Maggiore of Venice, the focal library positioned at the center of the spiderweb. The focused subview (d) shows that a significant number of books share ownership with the selected book, excluding the library of San Giorgio Maggiore. Simultaneously, the Node-Link Graph (c) highlights the related owners. From the graph's layout, we can observe that individual owners initially held the book, gradually transitioning to major libraries within the dataset. The first four owners are individuals positioned far apart, indicating minimal book transfers between them. In contrast, the latter three owners are libraries positioned closer together, suggesting frequent exchanges of books among them.

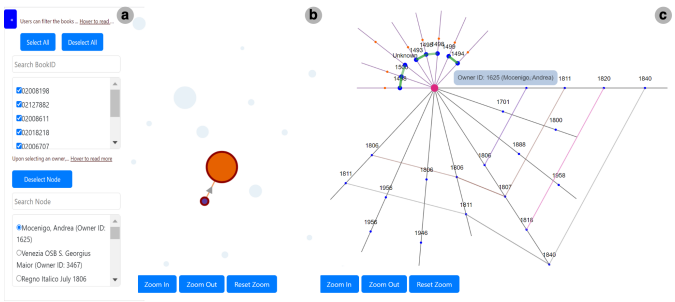

Fig. 6: The interconnected view with the Node-Link Graph as the main view: (a) the control panel for searching and selecting books/owners; (b) the Node-Link Graph, where one owner is selected (in purple), with the related owner (in orange); (c) the linked Spiderweb-Like Diagram, displaying all book timelines associated with the selected owner.

Node-Link Graph as the Main View. When using the Node-Link Graph as the primary view for exploration, the starting point shifts to the owners rather than the book's provenance timeline. As previously mentioned, this graph represents owners as nodes and book transfers as directed links, with node size reflecting the total number of books owned and spatial proximity indicating the frequency of exchanges between owners. In the interconnected setup, the Node-Link Graph is linked with the Spiderweb-Like Diagram to enable exploration from both network and temporal perspectives. When users interact with the Node-Link Graph by selecting an owner or hovering over a link between nodes, the Spiderweb-Like Diagram updates to display the book timelines and the shared ownership links associated with the selected elements. This interactivity highlights book details while preserving their connections within the broader network of ownership.

The example in Fig. 6 illustrates this functionality. When a specific owner, *Andrea Mocenigo (ID: 1625)*, is selected from the owner selection panel (a), the point is highlighted in purple as the focal owner in the Node-Link Graph (b). Related owner nodes are also highlighted, and in this case, only one large orange node is visible, indicating that Mocenigo's private collection in this dataset was entirely transferred to the library of San Giorgio Maggiore of Venice. To explore the temporal aspect further, the linked Spiderweb-Like Diagram (c) reveals that eight books are involved. Initially owned by Mocenigo, these books were transferred to San Giorgio Maggiore's library between 1493 and 1500 and then dispersed to various owners after 1700. Observing these subsequent owners, the crossing lines in distinct colors indicate significant overlap, suggesting shared ownership connections. Using the Node-Link Graph as the main view allows researchers to focus on identifying key owners, analyzing high activity, and tracing broader relational trends in ownership transfers. This perspective adds depth to the analysis, particularly regarding ownership relationships.

4.2 Design Iterations

This section describes the iterative design process undertaken with the leading domain expert and the rationale behind the visualization designs. Guided by the 'Nine-Stage Framework' [38], the development of *OwnershipTracker* progressed through three main stages.

Stage 1: Initial Prototyping With the provided data and the primary design goal of visualizing ownership relationships, while incorporating the temporal nature of book transfers, we began with simple but intuitive prototypes. We presented the domain expert with several network-based visualizations, including a temporal network [13] – a visualization we considered capable of representing both temporal progression and relationships among entities – as well as a force-directed graph enhanced with edge bundling to reduce visual clutter [29]. However, from the domain expert's perspective, the temporal network did not clearly convey the progression of time, and the bundled links made the force-directed graph difficult to interpret. She referred to our previous work [41] in which the provenance and temporal features were handled through a separate timeline, allowing linked interaction and coordination between views. Therefore, in the initial prototype, a node-link graph was used to represent network relationships between owners, while a timeline depicted the trading history of individual books. Although the link width in the node-link graph provided a rough indication of flow quantity, it lacked sufficient clarity for direct comparison. The chord diagram is introduced to address this limitation, offering a more straightforward method for quantifying book transfers. Informal user testing during this stage facilitated discussions on design refinements, such as using arrows instead of gradient colors to indicate direction, replacing color with shape to differentiate ownership types, as color was already used for other purposes in the interface, adjusting highlighting colors, and improving control and filter functionalities.

Stage 2: Introducing the Spiderweb-Like Diagram Inspired by the initial prototype, the domain expert proposed a new visualization concept through hand-drawn sketches, leading to the creation of the Spiderweb-Like Diagram. Her design emphasized a specific domain insight: within the data, certain libraries held significant historical importance as central points through which many books passed. While the initial prototype could identify several major libraries, it was unable to effectively convey the pattern of books converging at and subsequently dispersing from these libraries. The domain expert sought a visualization highlighting this historical context, emphasizing the impact of key events and the number of books influenced. To achieve this, she positioned the most influential library at the center of the spiderweb, with timelines for individual books radiating outward. This design reflects convergence and divergence patterns, with lines connecting nodes to represent books shared by the same owner across different timelines. While the visualization resembles a spiderweb, it is fundamentally distinct from radar charts, commonly referred to as spiderweb charts. When the visualization expert implemented this prototype, the domain expert particularly appreciated how clearly the central convergence of book movements was depicted, especially around one pivotal library. However, visualization researchers found the output less intuitive to navigate from a usability perspective. Through continued discussions with the domain expert, we agreed to retain the overall layout while introducing additional customizable interactive features. These included a freeze view function, a simplified subview for close inspection, and options for highlighting specific books or owners and providing hover-over explanatory text. To further reduce the visual

clutter caused by intersecting lines representing shared ownership, we applied the Apriori algorithm [17] to cluster the raw data. This enabled timelines with more shared owners to be positioned closer together, making ownership connections more visually discernible. During this stage, the domain expert's insights shaped the design to suit the needs of historical research.

Stage 3: Interconnected Views for Complex Analysis After finalizing the previous prototypes, the domain was preferred for both designs, noting that each contributed to different aspects of data exploration. Desired for a more integrated perspective combining insights from ownership relationships and book provenance. This feedback led to the development of two interconnected views, enabling seamless data exploration from multiple perspectives. The interaction design focused on linking panels to support dynamic updates and synchronized exploration between ownership-focused and temporal-focused visualizations. The design rationale behind the two interconnected views involved splitting the interface into two parts: the visualizations on the left serve as the primary exploration area, where users interact with components and initiate data queries, while the visualizations on the right are synchronized with these queries, highlighting related data from a different analytical perspective. We linked the *Node-Link Graph with the Timeline View* and the *Spiderweb-Like View*, alternately assigning them as the main or secondary panels. This resulted in two interconnected views, allowing users to choose their preferred entry point based on their focus.

When the two interconnected views were implemented, we sought the domain expert's feedback by comparing them with the previously developed individual views. We aimed to understand whether the interconnected views are a substitute for the standalone ones. However, the domain expert preferred to retain all five views in the tool, emphasizing the value of offering users multiple options. She noted that the individual views, with more screen space dedicated to each visualization, were better suited to present data to others. In contrast, the interconnected views provided more substantial analytical support and were more appropriate for in-depth exploration. Based on this feedback, we implemented all five views in the tool, accessible through different tabs.

5 Usage Scenarios

In addition to the earlier examples, we present two expert use cases.

Exploring Ownership Transfers During the Napoleonic Era: The first scenario focuses on the historical context of the Napoleonic era, during which religious institutions across Europe, including San Giorgio Maggiore, were systematically suppressed and their assets confiscated. Books from these institutions were seized as cultural artifacts and relocated to repositories such as Paris's Bibliothèque nationale de France (BnF).

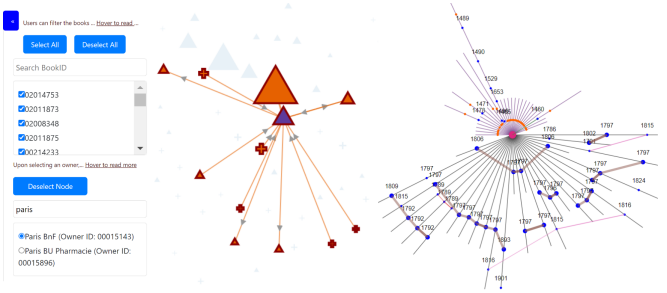

Fig. 7: A screenshot of the interconnected view during user testing, with the Node-Link Graph as the main view and the Spiderweb-Like Diagram linked for contextual exploration.

To investigate this historical event, the domain expert uses the interconnected view to explore the dataset, starting with libraries in Paris. Utilizing the search and selection panel, she entered *"Paris"* and selected the Bibliothèque nationale de France (BnF) as the focal point, as shown in Fig. 7. The selected data is visualized simultaneously in the Node-Link Graph and the Spiderweb-Like Diagram. By interacting with the Node-Link Graph, hovering over nodes, and zooming in, the expert observed that Paris BnF received books from several sources, including three libraries from Venice and individual owners. Among these, San Giorgio Maggiore in Venice was identified as the largest contributor. Its node, represented as a large triangle, was positioned closest to Paris BnF, and the connecting link was the thickest, indicating the highest volume of transfers.

Switching to the linked Spiderweb-Like Diagram, the expert quantified the number of books in the dataset held by the Paris BnF and confirmed that most of them were transferred directly from San Giorgio Maggiore. By hovering over ownership points along the timelines, they accessed detailed information about each owner involved in the transfers. This visualization provided empirical support for historical records, echoing known historical events. The domain expert praised the interconnected views for their ability to clearly present and quantify these transfers, showcasing the historical impact of Napoleon's expropriation policies.

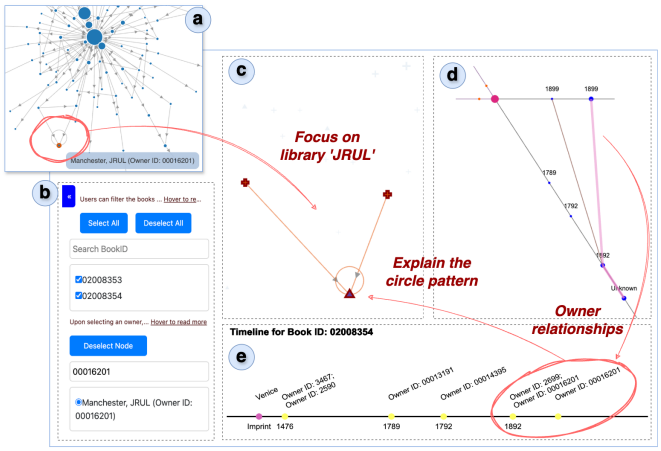

Fig. 8: Screenshots from the second use case: (a) Node-Link Graph with circular patterns; (b) control panel filtered by selection; (c) focused owner node (JRUL); (d) Spiderweb Diagram showing related two books; (e) timeline view indicating joint possession in 1892.

A Pattern-Driven Discovery of Potential Co-Ownership: In the second scenario, the domain expert began by inspecting the whole dataset using the Node-Link Graph (Fig. 8 a). She was intrigued by the circular patterns among the connections. Clicking on one of the nodes revealed an owner entity labeled *JRUL* (ID: 00016201) (Fig. 8 c). This triggered updates in the linked panels. In the control panel (Fig. 8 b), only the IDs of the selected owner and two related books (book 02008353 and book 02008354) were retained. The linked Spiderweb Diagram (Fig. 8 d) filtered to display only these two books. While the possession of the focal owner *JRUL* was highlighted in pink, a brown connecting line indicated that another owner also possessed both books at a certain point. This suggested a possible relationship between the two owners. Motivated by this observation, the domain expert hypothesized that the two owners might have a historical connection. The timeline component also updated accordingly, listing the two selected book IDs in its control panel. By clicking on each entry, the expert explored the provenance sequences (Fig. 8 e), and noticed a pattern in book 02008354: in the 1892 record, the book appeared to be jointly owned by *JRUL* and Enriqueta Augustina Tennant (ID: 2699). Further inspection confirmed that Tennant was the owner indicated by the brown line in the Spiderweb. The co-ownership prompted the expert to investigate whether this reflected a meaningful historical relationship or a possible data entry error.

Upon checking archival sources, the expert discovered that Enriqueta Augustina Rylands, originally born as Enriqueta Augustina Tennant, was the founder of JRUL (John Rylands University Library). Following the death of her husband, industrialist John Rylands, she established the library in his name and transferred many of their collected books

into its holdings. The co-ownership pattern observed in the dataset thus reflects this historical transition. This scenario demonstrates how *OwnershipTracker* can support hypothesis generation, guide source verification, and facilitate historical insight through visual exploration.

6 Evaluation

To evaluate the usefulness and usability of *OwnershipTracker* in meeting domain-specific tasks, we conducted a two-phase evaluation comprising a domain user survey and in-depth expert interviews.

6.1 Domain User Survey

6.1.1 Methodology

The domain user survey was conducted to evaluate the usability and functionality of the pilot version of *OwnershipTracker* before its deployment among researchers specializing in historical book studies. The survey was distributed via the online platform Qualtrics [37] and explicitly targeted the intended user group. To reach this niche group, an expert sampling [22] approach was employed, with the leading domain expert collaborating on the project and distributing the survey link to colleagues and relevant professionals in the field. During the distribution process, the leading domain expert was already familiar with the tool and was a liaison, introducing tool features to the participants and addressing any questions they had. To help participants become familiar with the tool more quickly, the questionnaire was designed to incorporate demonstration videos for each feature, accompanied by detailed descriptions and annotated screenshots. The survey was launched on June 28, 2024, and received a total of 23 responses.

The survey design included the following key components:

- **User Background**: Questions were aimed at gathering participants' general demographic information, familiarity with visualization techniques, and prior experience with visualization tools.
- **Evaluation of Each Views**: Separate sections of each of *OwnershipTracker*'s views, including Node-Link Graph view, Spiderweb-Like Diagram view, Chord Diagram view, and the two interconnected views. Participants evaluated the usability and usefulness of the tools' functionalities and components, focusing on metrics such as learnability, understandability, ease of use, and the helpfulness and effectiveness of the designed features in supporting domain tasks.
- **Recruitment for Further Studies**: Participants were invited to volunteer for future in-depth evaluations at the end of the survey.

The survey combined Likert-scale questions for quantitative feedback with open-ended questions for qualitative insights, supported by screenshots and demo videos showcasing the tool's features.

6.1.2 Results

Participants' Background The survey responses indicated diverse levels of familiarity with visualization tools among participants. Regarding their visualization knowledge, **26%** rated their expertise as very poor or poor, **26%** as neutral, and **48%** as good or above. When asked about prior experience with visualization tools, **57%** of respondents indicated they had used such tools before, while **43%** reported no previous experience.

Feedback on Individual Views The survey results highlighted several strengths and areas for improvement in *OwnershipTracker*, particularly its usability and functionality. Respondents found *OwnershipTracker* generally effective in visualizing ownership relationships and book provenance. The Node-Link Graph and Spiderweb-Like Diagram were praised for their intuitive design and representation of complex relationships. However, some participants suggested that providing more guidance on interpretation could improve the Chord Diagram.

The ***Node-Link Graph with Timeline View*** received positive feedback for its effectiveness in visualizing ownership networks, particularly in identifying major ownership hubs and highlighting transfer flows. Quantitative analysis of Likert-scale responses revealed that **69%** of participants rated node size to represent the number of books held as moderately or highly effective, while **59%** found the proximity of nodes to visualize transaction frequency useful. Similarly, directional arrows to indicate book flow between owners were rated positively by **77%** of respondents, and **73%** appreciated the use of different shapes to distinguish owner types. However, only 50% of participants found the encoding of transaction frequency via link thickness effective. In response, we refined the underlying calculation slightly to improve the perceptual distinction. However, as most transfers involve only a single book, the limited variance in the data restricts visual differentiation. Low-weight links dominate the view, giving the overall visual impression a uniform appearance. However, the effect improves when filters reduce the number of displayed links.Interactive functionalities were particularly well-received. Features such as highlighting selected components, color encoding for distinguishing elements, and the search and selection panel were rated as either somewhat useful or extremely useful by over **85%** of respondents. Among these, the owner selection panel was identified as the most appreciated feature, with **96%** of participants highlighting its utility for centralizing and interacting with a selected owner (as shown in Fig. 3 *iv*). Participants suggested minor refinements, such as improving node labels to include both owner IDs and names for easier identification.

The ***Spiderweb-Like Diagram View*** was praised for its innovative approach to visualizing book provenance timelines, particularly for its ability to show convergence and divergence patterns among books. The responses exceeded our expectations regarding the learnability of this non-traditional visualization. We anticipated challenges for users unfamiliar with this visualization, yet **57%** of participants found the spiderweb-like diagram somewhat or extremely clear and easy to understand, **10%** rated it neutral. In contrast, **29%** found it somewhat unclear, and **5%** rated it extremely unclear. Annotations on the spiderweb were also well-received. **77%** of participants preferred displaying the year on the radial timelines, highlighting the importance of clear temporal markers. From a visualization research perspective, we were concerned that the dense layout of the spiderweb might hinder users' ability to analyze the data effectively. To address this, we implemented a zoom functionality to reduce visual clutter. When asked about the ease of navigating and understanding the charts, particularly in data-intensive areas, **81%** of participants rated the diagram as moderately or above moderately easy to navigate and understand. However, one ended response noted: "*Too many lines overlapping with each other, lines too dense in the middle.*" This feedback underscores the need for further refinement in handling data-dense areas. Interestingly, 35% of participants found displaying year information by the nodes only slightly or not at all useful. As full-text annotations increase visual density, we retained this feature as optional, allowing users to toggle it based on their preference. Participants praised the interactivity integrated into the visualization. When asked about features such as mouse hovering, highlighting, and the control and information display panel design, **88%** agreed these features were helpful. Nevertheless, a few users suggested adding interactive filtering options to isolate specific ownership relationships, enabling more in-depth data exploration.

The ***Chord Diagram View*** was well-received for its ability to quantify book transfers, with **82%** of participants strongly or somewhat agreeing that the chord diagram effectively represents exchanges between different owners through intuitive visual strings. Regarding interactivity and annotations, **95%** agreed it is easy to trace nodes to chords for transactions and that the table aids in linking owner names to IDs. In open-ended comments, a few participants mentioned that the visualization was very new to them, and the circular layout was somewhat confusing. They suggested adding a brief hint or explanation on how to read the visualization directly on the page.

The ***Interconnected Views*** were described as standout features enabling seamless dataset exploration from multiple perspectives. For the Spiderweb-Like Diagram as the main view, **91%** of participants indicated a moderate or higher level of effectiveness in identifying related owners and understanding a book's circulation path when hovering over a radial timeline and observing the highlighted components in the Node-Link Graph. For the Node-Link Graph as the main view, **86%** of participants strongly or somewhat agreed that it is easy to see the corresponding highlights on the Spiderweb-Like Diagram when

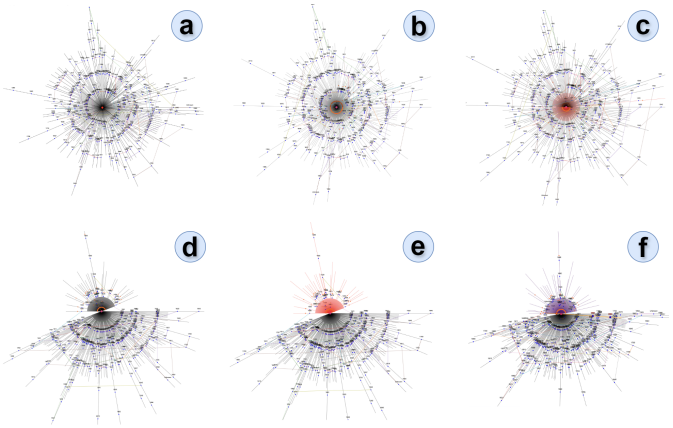

Fig. 9: Six designs: (a) original; (b) starting point highlighted in orange; (c) starting point & prior line segments in orange; (d) spatial segmentation with starting point in orange; (e) spatial segmentation with starting points & prior lines in orange; (f) spatial segmentation with starting point & prior lines in distinct colors.

selecting a node in the graph. Across both interconnected views, **91%** of participants found the linking feature very or extremely effective in helping them understand the relationships between book owners.

Refinements: Survey results prompted a key refinement to *OwnershipTracker*: modifying the dense radial timelines to enhance readability by distinguishing provenance before and after the critical library, with four alternative designs proposed (Fig. 9 b-e). After discussing these designs with the lead domain expert, we implemented the version that increased the gap between the two sections, dividing the circular layout into upper and lower sectors and using different segment colors (Fig. 9 e) to enhance clarity. Additional enhancements include adjusting the transparency of unselected nodes to highlight selected elements and displaying detailed owner information when hovered over.

6.2 Expert Interview

6.2.1 Methodology

Three domain experts, recruited from the previous survey, volunteered to participate in in-depth interviews to evaluate the refined version of *OwnershipTracker*. All three experts have extensive experience working on the 15cBookTrade Project [14], are familiar with the MEI dataset, and represent potential tool users. The interviews were conducted via MS Teams as online meetings and followed a semi-structured format. A think-aloud protocol was applied during user testing activities. The procedure and the duration of activities are outlined in Table 1. The leading domain expert involved in the iterative design stages was also present and served as a facilitator during the interviews.

Each session started with a brief introduction to the evaluation settings and procedures. The visualization researcher then shared their screen to guide participants through the visualizations, highlighting enhancements. Participants shared their screens and engaged in user testing while thinking aloud. During the think-aloud sessions, participants were first encouraged to interact with the tool freely, exploring its features in an unguided "Test in the Wild" phase. This allowed us to observe the tool's use without explicit direction and gather insights into their natural workflows. Subsequently, participants were asked to perform specific tasks derived from the pre-defined domain requirements and design tasks. These tasks were grouped by visualization view and designed to test the functionality and usability of each component in the tool. The sessions concluded with a reflective discussion on the usability of *OwnershipTracker*, focusing on how well it addressed domain requirements. Participants also provided feedback on potential improvements to the tool.

6.2.2 Results

Overall, the refined tool's usability was rated positively. Improved features, such as making unfocused components transparent, significantly enhanced the clarity of visualizations. Additionally, the inclusion of hover-over annotations with domain-related identifiers received favorable feedback. As in previous evaluations, as noted by all three participants, the zooming feature was highly praised for its utility in detailed data observation, particularly in the Node-Link Graph and Spiderweb-Like Diagram. Referring to the usability indicators proposed by Nielsen [35], participants' feedback and performance indicated good levels of *satisfaction*, *efficiency*, and *low error rates*. Regarding *learnability*, participants were able to understand and utilize most of the features quickly. However, it should be noted that they were already somewhat familiar with the tool, as shown by screenshots and demo videos during the previous survey.

Table 1: Evaluation Procedure and Duration.

Order of Procedure	Activities	Duration
Preliminary Preparation	1) Warming-up 2) Tool demonstration	30 min
Think-aloud Evaluation	1) Test in the wild 2) Test via predefined tasks	40 min
Reflective Discussions	1) Reflection on the tool 2) Future direction	20 min

While the improved Spiderweb-Like Diagram was commended for its enhanced clarity, further refinements were suggested to represent imprint points better. As one participant noted: "*Although I appreciate the improvement made to partition the spiderweb, which makes it easier to distinguish the periods before and after San Giorgio, the place of printing should be clearly marked as the starting point. This should be followed by the book's journey to San Giorgio and its subsequent path to its current state. Can we make the imprint point more visible, as it represents the beginning of each timeline?*" In response to this feedback, we decided to use a single distinct color to represent imprint nodes and to differentiate line segment colors for the periods before and after the intersection point. This adjustment transformed the Spiderweb-Like Diagram from Fig. 9 *e* to *f*, where imprint points are now displayed in bright orange, while blue and black line segments represent the paths before and after intersection, respectively.

The tool's usefulness was assessed based on how well it supports achieving domain requirements. From the interview transcripts, all participants found *OwnershipTracker* highly effective in providing insights and visual clues into ownership relationships, as well as in integrating provenance sequences with ownership data (**R1, R2**). The ***Node-Link Graph with Timeline View*** was praised for its ability to visualize ownership relationships and quantify the number of books possessed by each owner (**R3**), helping to identify influential ownerships. The timeline served as a helpful auxiliary visualization, allowing participants to examine a book's provenance in conjunction with its relationships with other owners. The ***Spiderweb-Like Diagram View*** was recognized for its innovative design in combining provenance sequences with ownership relationships (**R2**). Participants noted that the final visualization effectively represented a historical phenomenon and provided a comprehensive view of book ownership transitions (**R3**). The ***Chord Diagram View*** was highlighted for its effectiveness in quantifying ownership transitions between owners (**R3**). However, participants tended to spend less time on this view, noting that while it provided straightforward information, its scope was more limited compared to the other views. The ***Interconnected Views*** were described as a standout feature, enabling participants to explore ownership and provenance from complementary perspectives and enhancing the analytical capabilities of the tool. One participant remarked: "*When I'm focusing on single views, for example, the spiderweb, I start to think about ownership relations, [...], being able to use the owner selection from the Node-Link Graph in parallel provides more information...*". While testing the Interconnected View with the Node-Link Graph as the main view, one participant provided a use case tied to a specific historical context, as discussed in Section 5.

In summary, the usability and usefulness of all the designed visualization views were positively evaluated. The designed views effectively addressed domain requirements with analytical purposes (**R1, R2, R3**). Although the Interconnected View was highly praised for supporting complex analysis, the three single views were retained for their ad-

vantages in providing larger, clear, full-screen layouts. Additionally, interactions such as hover-over functionality with detailed information on individual books and own to support **R4** effectively.

7 Discussion and Limitations

While we have previously collaborated with historical book researchers on several projects, this is the first time we transitioned from focusing on provenance and mapping trajectories to exploring ownership relationships. This shift introduced both challenges and opportunities, requiring us to rethink how data and relationships could be visualized to address domain research questions. For a discipline like history, where visualization and data science have traditionally been less integrated, domain experts often approach these methods with caution and varying levels of familiarity. Our user survey reflected this, with **26%** of domain researchers rating their knowledge of visualization as poor or very poor. Therefore, in the project's early stages before the second design iteration, the visualization team proposed and demonstrated different chart types and potential solutions, helping domain experts explore data presentation and analysis options. Showcasing a variety of visualization types and discussing user preferences from the domain were essential. These activities supported the development of shared understanding and improved domain experts' visualization literacy, enhancing collaboration and informing subsequent design discussions.

7.1 Visualization Tailored to Domain Context

A highlight came during the second design iteration. The Spiderweb-Like Diagram originated as a sketch by a domain expert inspired by her understanding of historical facts. Specifically, the library of San Giorgio Maggiore played a pivotal role in the dataset, with nearly every book copy passing through this library at some point. The design emphasized the convergence of book provenance lines at San Giorgio and their subsequent dispersal, visually representing the library's historical significance. This design was valuable evidence for presenting the library's impact and highlighted the strength of interdisciplinary collaboration, where domain knowledge directly informed visualization design. This outcome highlights the strength of interdisciplinary collaboration, where domain expertise directly shaped the visualization. Such a design would have been difficult to arrive at without the expert's historical knowledge, reinforcing the value of a collaborative design over a traditional client-developer model. A key challenge was assessing how non-traditional users perceived the Spiderweb-Like Diagram, which drew extensive feedback for iterative improvements.

7.2 Debates and Compromises in Spiderweb Design

One area of debate during the Spiderweb-Like Diagram's development was the alignment of year annotations along the timelines. The domain expert envisioned a convergence of book provenance lines at the San Giorgio library, shaped by common movement patterns. However, provenance lines inherently have a temporal aspect, as the library held each book at different times. From a visualization perspective, aligning the timelines by location while ignoring temporal order introduced inconsistencies, since the diagram used a temporal layout to convey geographical aggregation. Attempts to align timelines by actual years weakened the visual emphasis on convergence and dispersal – central to the diagram's purpose. This compromise led us to adopt an alternative approach: using sequential order as the basis for the provenance timelines, where each line represents the order in which a book transitioned between owners. The year information was included as annotated text adjacent to the points. While this preserved the historical patterns of convergence and divergence, it raises an open question: how can we better balance the emphasis on convergence with a more accurate representation of time? This remains a topic worth further exploration.

7.3 Tailored Solutions May Fall Short in Scalability

From the visualization researchers' perspective, the design of the Spiderweb-Like Diagram is highly tailored to the specific characteristics of the domain case. The design process was participative, primarily driven by the leading domain expert's hand-drawn sketches and contextual insights. While the domain experts appreciated the final outcome, particularly for its ability to emphasize the importance of the central library more effectively than other visual solutions we explored, it is important to acknowledge its potential limitations in terms of scalability. The Spiderweb-Like Diagram performs well for the current case, which includes 181 book copies. This number aligns with the typical working scale of domain experts using the MEI dataset, who often focus on 100-200 book copies at a time. However, as the number of books increases, the visualization can become visually cluttered, with overlapping features and diminished readability. Future work could explore grouping techniques, such as clustering by provenance patterns or owner types, together with layered layouts that allow users to toggle between summary and detail. Progressive disclosure mechanisms and scalable alternatives, such as edge bundling or Sankey-inspired flows, may further support the visualization of large-scale ownership transitions while preserving key convergence and divergence patterns.

In addition, the solution is tightly coupled to a specific structural pattern in the dataset – namely, the presence of a dominant library that creates a visible convergence-and-divergence flow. The design was proposed because the domain expert is already familiar with the data and its historical context. The current design would require substantial adaptation for datasets with multiple important libraries or those without a clear central institution. A promising direction for future work is to adapt the radial layout to support multiple focal points, with each key owner acting as a local center of convergence. This could involve a small multiples approach, showing several spiderweb subviews in parallel, or a hybrid layout that clusters books around multiple hubs while preserving temporal order. An interactive pivot mechanism, allowing users to re-center the view on different owners, may further improve flexibility in multi-centric datasets. Developing visual encodings that maintain provenance clarity while enabling cross-center comparison remains an open challenge.

These reflections on scalability raise broader questions about the nature of domain-specific design studies. When the domain problem is highly contextual, and the users are a small, specialized group with deep subject expertise, the definition of a "good" visualization can diverge from general-purpose design principles. For visualization researchers involved in such projects, determining how much to prioritize scalability – versus addressing the nuanced needs of the domain – can be a complex decision. While we are satisfied that we have developed a solution the domain expert found genuinely helpful for her analytical context, the extent to which such a tailored design contributes to the broader visualization research community remains an open and ongoing discussion within the field of domain visualization design.

7.4 Generalizability and Broader Applicability

Although the Spiderweb-Like Diagram was tailored to a specific dataset structure, its core design principles – visualizing convergence and divergence in sequential flows, and highlighting shared ownership – may extend to other domains. Similar patterns occur in contexts such as tracing the transfer of artworks among collectors and galleries, the movement of archival materials between institutions, or the reuse of scientific datasets across research projects. By abstracting away from book provenance, the diagram could support analyses involving temporal transitions and intersecting entities. While currently bound to the MEI dataset's scale and structure, improvements in scalability could enable its adaptation to larger and more complex datasets, thereby opening up possibilities for broader applications.

8 Conclusion

In this work, we introduced *OwnershipTracker*, a visual analytics application designed to support domain experts in exploring book ownership relationships and temporal provenance. The application was developed in close collaboration with domain experts, involving multiple iterative refinements and a summative evaluation. Beyond the tool itself, we reflected on our co-design experience and shared lessons learned from working in a humanities context. We hope this work contributes to the field of visualization design studies, particularly in digital humanities settings.

Acknowledgements

This work was partly supported by the King's-China Scholarships Council PhD Scholarship programme (K-CSC) and the King's Undergraduate Research Fellowships (KURF). We would like to thank all the participants who took part in the survey and interviews for their time and valuable contributions.

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