Making Semantic Data Accessible: A Human-Centered Approach to CIDOC CRM Visualization

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Abstract

Semantic data are gaining increasing relevance within the fields of Cultural Heritage (CH) and Digital Humanities (DH). Despite their considerable promise and potential, however, these technologies currently tend to introduce additional challenges rather than effectively resolving existing ones. A central issue lies in the limited availability of graphical user interfaces that enable individuals with little prior knowledge of semantic data to explore them through clear, accessible, and easily customizable visualizations. To address this challenge and facilitate broader access to the insights embedded in semantic data, this paper presents methods from the field of Human-Computer Interaction (HCI) and applies them to concrete examples from CH and DH. In particular, the study adopts a Human-Centered Design (HCD) approach, systematically examining the target user group and its needs, identifying recurring issues in existing visualizations of the CIDOC Conceptual Reference Model (CIDOC CRM), and deriving the tasks and requirements for a novel user interface (UI). Based on these analyses, the paper introduces a newly designed UI sketch and justifies its design decisions with reference to established principles from Information Visualization (InfoVis).

Keywords

Human-Computer Interaction, Human-Centered Design, Semantic Data Visualization, CIDOC CRM

1. Introduction

Semantic data are becoming increasingly significant within the fields of Cultural Heritage (CH) and Digital Humanities (DH), providing a foundation for generating new insights based on machine-readable data [1, 2, 3, 4, 5]. As a consequence, both the production and the use of semantic data in these domains are steadily expanding, making engagement with such data virtually unavoidable. A central challenge, however, is that semantic data are often not presented in a way that is readily comprehensible to many of the professionals working with them. In particular, researchers and professionals in the fields of galleries, libraries, archives, and museums (GLAM) frequently encounter representations that are difficult to interpret, which significantly complicates their work with semantic data. These groups often operate under considerable infrastructural constraints and typically have only limited personnel and technical resources at their disposal to address them [6, 7, 8]. Existing solutions, many of which rely on the CIDOC Conceptual Reference Model (CIDOC CRM) standard, often fail to adequately address the needs of their intended users. In particular, they rarely provide intuitive visual representations that enable individuals without prior expertise in semantic technologies to meaningfully interpret the data [9, 10]. As a result, such tools offer only limited support in overcoming the underlying challenges. In the worst case, this situation may even lead to the generation of erroneous data and to further assumptions based on these inaccuracies. Preventing such outcomes requires the development of low-threshold visualization solutions that allow GLAM professionals and researchers to keep the rapidly growing body of semantic data accessible, reviewable, and extendable. Within the field of Human-Computer Interaction (HCI), research explicitly focuses on the human use of interactive computer systems [11]. The overarching objective is to design systems that align with the needs of their users and that can be operated in a manner that is both efficient and user-friendly [12]. A central concept within HCI is

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Human-Centered Design (HCD), which places the user at the core of the design process. Accordingly, systems should adapt to human requirements rather than forcing users to adapt to the system [13]. In the application of HCD, the target group, their needs, tasks, and contextual constraints are systematically identified through a series of analytical steps. Based on these insights, the system is then developed iteratively in close collaboration with the intended users. The goals and methodologies of HCI and HCD are highly transferable to current challenges surrounding the visualization of semantic data and offer promising avenues for addressing them. This paper therefore presents the HCD process for the visualization of semantic data within a CIDOC CRM context, illustrated through a concrete use case and a persona developed by the authors. Although the solutions proposed here are still subject to further development, they can already serve as a conceptual reference for current and future CIDOC CRM modeling practices. Accordingly, the results are prepared in a way that enables GLAM professionals and researchers in CH and DH to adopt and adapt them for their own visualization workflows. Importantly, the methods introduced in this paper are not limited to the visualization of semantic data in a single scenario; due to their multidisciplinary adaptability, they can also be applied across a wide range of research contexts.

The objectives of this paper are therefore threefold: (1) To demonstrate the applicability of the HCD approach to CIDOC CRM modeling; (2) to highlight current challenges in CIDOC CRM visualizations, using the CIDOC CRM modeling of the Laoöcon case [14] as an example, where insights from HCI principles are not yet sufficiently reflected; and (3) to illustrate a potential solution by applying the HCD process to the Laoöcon case and presenting resulting visualizations that were themselves designed following this methodology.

2. Related Work

The visualization of semantic data is frequently realized through knowledge graphs or comparable visual representations [15]. Within the domains of CH and DH, such visualizations are often implemented using CIDOC CRM [16]. CIDOC CRM is an ontology for information integration and is formally standardized as an ISO model [1, 17]. Its primary objective is to enable domain experts and implementers to integrate information from heterogeneous sources, thereby fostering a shared understanding of CH and DH information [17]. Applications of CIDOC CRM span a wide range of domains, including CH and DH objects, paintings, and many other cultural artifacts [18, 19]. Despite its goal of facilitating a shared understanding of CH information, however, the current ecosystem reveals a significant limitation: while the underlying data structures and exchange formats are machine-readable, the final step emphasized in HCI, the preparation of information for human users through appropriate User Interfaces (UI), is often missing. From an HCI perspective, the resulting systems remain incomplete for end users. Across many existing implementations, one recurring issue becomes apparent. Although the CIDOC CRM models themselves are technically correct and functional for computational processing, the neglect of UI design and User Experience (UX) considerations frequently results in visualizations that are difficult for humans to interpret [9, 20]. For individuals without prior expertise in semantic technologies, existing solutions often present a considerable barrier to effective engagement with such systems [9]. More recent approaches such as ResearchSpace already demonstrate notable improvements in comparison [21, 22]. However, they do not yet represent the culmination of the development process. Among other limitations, overly text-heavy visualizations, as well as data representations and UIs that could be made more visually appealing, indicate further potential for refinement. While WissKI and Wikibase both provide valuable functionalities, their focus differs from the needs addressed in this paper: WissKI is designed for ontology-compliant data management and requires direct engagement with the underlying data structure [23]. Wikibase prioritizes general-purpose structured data entry rather than visual exploration of CH-specific semantic models [24]. Neither system focuses on the low-threshold, visualization-centered access this paper addresses. These observations suggest the need for continued exchange and collaboration in order to enhance usability and further improve such systems. To improve clarity in UIs and enhance UX, HCI research employs methods such as User-Centered

Design (UCD), which can be applied across interdisciplinary contexts. These approaches place particular emphasis on the needs of the direct users of a system [25]. In this paper, however, the broader HCD framework is adopted. Unlike UCD, HCD addresses not only direct system operators but also a wider range of individuals who may explore semantic data through visualizations or encounter them in other contexts [13]. Within the HCD process, two aspects are particularly important when designing or revising UIs: first, the application of design guidelines and methods that support the development of effective interfaces, and second, evaluation methods that assess how the implemented interface affects the overall UX. When designing effective UIs, adherence to widely established design guidelines and principles is essential. These include maintaining consistency in icons, colors, typography, spacing, and visual hierarchy, among other aspects [26]. Additionally, Nielsen's "10 Usability Heuristics" emphasize principles such as minimalism, clear feedback on user interactions and system processes, and effective error prevention [27]. Beyond these general guidelines, a variety of design methodologies exists that support the practical development of UIs. Buxton (2007) introduces a design-oriented approach that combines practical methods such as sketching and prototyping with conceptual design thinking [28]. Within the field of Information Visualization (InfoVis), additional principles specifically address the design of visualization systems. One prominent example is Shneiderman's Mantra, which emphasizes interactive exploration through "Overview first, zoom and filter, then details on demand" [12]. This principle enables users to navigate complex datasets through multiple levels of detail. Complementary visualization heuristics include the use of color for categorization and emphasis, linking and brushing techniques for highlighting selected data points, and a variety of other interaction mechanisms designed to facilitate exploratory analysis [29, 30]. Considering these principles when designing visualization systems can substantially improve the accessibility and usability of semantic data representations. Newly designed or revised UIs can subsequently be evaluated with representatives of the target group, allowing identified weaknesses to be addressed before the system is released to a broader audience. Evaluation does not necessarily occur only at the final stage of the HCD process. It can also be applied to intermediate prototypes in order to iteratively refine the design. During such evaluations, participants are typically asked to complete tasks using the interface integrated into the system. Feedback and empirical data can be collected through a variety of methods, including interviews, standardized questionnaires such as the User Experience Questionnaire (UEQ), and similar evaluation instruments [31]. Both the timing of the evaluation and the choice of evaluation instrument may vary depending on the research design. Particularly for visualization systems intended for the CH and DH communities, such evaluation steps represent a valuable contribution to improving overall UX.

3. Human-Centered design using semantic data visualizations as an example

This chapter applies the HCD approach to the case of visualizations based on CIDOC CRM and the corresponding input formats used to generate them. As the current challenges associated with CIDOC CRM have already been extensively documented, conducting an initial workshop to identify these issues during the early stages of the conceptual design process is not strictly necessary [32]. Instead, broadly transferable assumptions regarding typical knowledge levels and skill sets related to CIDOC CRM are used as the basis for constructing personas that represent the intended target group. The visualizations developed through the applied design methods (Section 4) nevertheless provide an opportunity for subsequent evaluation with members of the target group and for further refinement in future work (Section 5). The following subsections outline the analytical procedures used to determine the needs of the target group (Section 3.1), to identify current challenges (Section 3.2), and to define the tasks that the proposed system should support (Section 3.3). The sequence of analyses presented here is particularly well suited to the use case discussed in this paper. For other application contexts, however, the order of these analytical steps may be adapted to better align with the specific requirements of the respective domain.

3.1. Target Group Analysis

Within the HCD framework, addressing the needs of the target group constitutes the highest priority, as only a system that aligns with user requirements can enable effective and successful interaction [13]. Consequently, identifying the target group and understanding its needs is a crucial step, as all subsequent analyses and design decisions build upon the insights derived from the target group analysis. As highlighted in both the Introduction (Section 1) and the Related Work section (Section 2), CIDOC CRM is not used exclusively by computer scientists trained in semantic technologies. Instead, it is also employed by GLAM professionals and researchers who often possess little to no prior experience with this ontology or with semantic technologies in general [32]. Notably, this group represents a substantial portion of the potential end users who are intended to benefit from improved visualization solutions [6]. The needs of these user groups differ significantly. However, these differences do not constitute a conflict in the design process. On the contrary, addressing them appropriately can ultimately create added value for all involved stakeholders. To systematically capture these requirements, the needs of the identified target group were translated into a persona developed by the authors. This persona represents a GLAM curator working in a museum, responsible for collection management and provenance research, who has no prior experience with semantic technologies. For this persona, several requirements emerge as particularly relevant. **First**, alternative forms of representation are necessary to facilitate a clearer understanding of relationships between objects and related entities. **Second**, the persona requires the ability to perform targeted queries on selected data within a dataset and to temporarily hide or display less relevant information through filtering mechanisms, thereby improving clarity and enabling a stronger focus on the topic currently under investigation. **Third**, intuitive system interaction is essential to ensure efficient and satisfactory use of the available functionalities. Beyond the interpretation of existing visualizations of semantic data, additional requirements arise regarding data management within the system. **Fourth**, the persona needs the capability to add new data to the system. To support this process, a **fifth** requirement is the provision of an input interface that remains comprehensible without prior knowledge of semantic technologies and that automatically translates user input into functional code. Finally, **sixth**, the persona must also be able to edit existing data in order to incorporate newly discovered information or correct potential errors identified within the visualizations.

3.2. Problem Analysis

Problems in UIs and interactive systems frequently arise when the needs of the intended users are not adequately considered. In order to illustrate the consequences of unmet requirements and neglected design guidelines, the current shortcomings are examined through a concrete example. For this purpose, a visualization from the CIDOC CRM Laoöcon example (Figure 1) was selected [16, 14]. The example is analyzed from the perspective of the persona introduced in the Target Group Analysis (Section 3.1) and evaluated against the needs identified there. This perspective reveals a considerable mismatch between the current forms of presentation and the requirements of the intended user group. The example presented in Figure 1 represents an initial attempt to render semantic data more accessible through visualization. Nevertheless, several design weaknesses remain evident. The chosen color scheme lacks coherence and does not clearly support the interpretation of the displayed information. In addition, the arrangement of content appears somewhat arbitrary, and there are no visual cues indicating potential uncertainties in the data. The visualization also presents an excessive amount of information simultaneously. Furthermore, not all functions listed in the legend are actually represented within the example itself. Collectively, these aspects contribute to a representation that appears unnecessarily complex and difficult to interpret. Given that even the visualization itself is already difficult for the representative persona to comprehend, tasks such as entering new data or modifying existing data through code-based input are effectively inaccessible. Performing such operations requires knowledge of semantic coding expertise that neither our persona nor a large portion of the broader target group can be expected to possess.

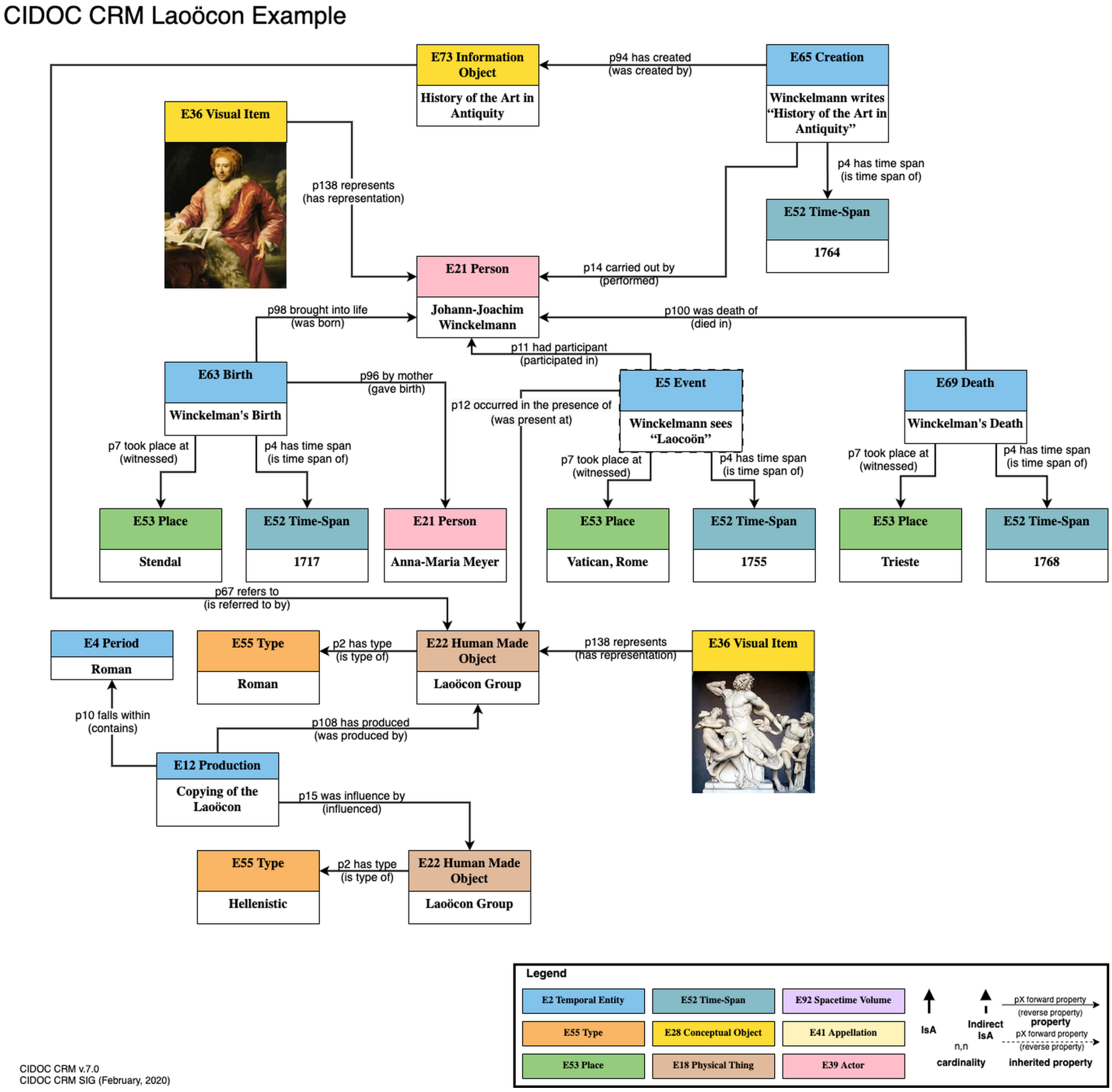

Figure 1: CIDOC CRM Laoöcon Example [14]

3.3. Task Analysis

Based on the insights derived from the previous analyses and the tasks associated with the target group, a set of requirements for the proposed UI can be formulated. In addition to addressing immediate usability concerns, a key design priority is the long-term reusability of the interface for the target community. Consequently, all design decisions must be made with careful consideration in order to provide a sustainable system that remains usable and extensible over time [20]. A central requirement for improving the comprehensibility of semantic data visualizations is the reduction of visual complexity. The amount of displayed information should therefore be limited to a manageable minimum in order to reduce users' cognitive load, while still preserving the elements that are essential for understanding the data [33]. At the same time, users should be able to adapt the visualization flexibly and without complex operations [30]. One way to achieve this is through the implementation of multiple levels of detail: an initial overview that provides a general orientation, followed by more detailed views that can be accessed on demand through search and filtering functions for targeted exploration [34]. Mechanisms like linking and brushing that highlight relationships between values and their associated entities can further support users in navigating and analyzing relevant data [29]. To further enhance orientation within the visualization, the spatial arrangement of interface elements should follow a clear and consistent structure. Likewise, the color scheme should be carefully coordinated so that visual distinctions between objects support interpretation rather than introducing additional ambiguity [26]. In addition the process of entering new data must also become more accessible for direct users of the system. Current approaches to data entry in CIDOC CRM-based systems typically require direct interaction with formal ontological representations such as RDF serialization formats, unlike platforms such as Wikidata, where an abstraction layer hides the underlying data model [24]. A more suitable alternative would therefore involve a visually oriented input method through a graphical interface. In such an approach, users construct the desired representation directly within the interface, while the system automatically translates this visual structure into the underlying semantic model. The system requirements derived from aspects (4)-(6) in Section 3.1 are not further addressed in the sketch presented in Section 4, as their implementation would necessitate a dedicated UI. Nevertheless, it remains important to explicitly acknowledge these tasks and to address them in future work. From a design perspective, a layout similar to that shown in Figure 2 appears suitable: the upper-left area could allow users to add existing data or create new datasets, while the right-hand side would provide a graphical representation of these data. Within this visual space, users could edit information or add new objects and properties without requiring knowledge of semantic code. Based on the resulting visualization, functional code could then be automatically generated, displayed in the lower-left area, and made available for export. On the basis of these requirements, Section 4 outlines the development of a UI sketch designed to address the identified needs and to provide a more accessible means of interacting with semantic data.

4. A new UI sketch based on the Laoöcon example

Following the approach advocated by Buxton, the design process did not rely on a single initial concept. Instead, numerous ideas were explored and refined through an iterative process, gradually improving promising approaches over multiple iterations [28]. This process resulted in several potential visualization concepts, one of which is presented and explained in the following sketch (Figure 2). The designed UI can be broadly divided into three main components, which together create a clear and structured layout. Consistency in the visual design, such as the spacing between interface elements, further strengthens this clarity and contributes to an overall coherent appearance [26]. The component located in the upper left allows users to select the dataset that should be visualized within the interface. For the example dataset shown in the interface, the design draws on the Laoöcon modeling example presented by Bruseker [14]. As with all areas of the interface, only the elements and information necessary for the current task are displayed. This deliberate reduction directs users' attention toward the most relevant content and avoids unnecessary visual clutter [27, 30]. The lower-left component provides functionality for searching and filtering objects within the selected dataset. Once a dataset has been chosen, users can employ the search function to efficiently locate specific objects. The search bar allows users to query both objects, such as those displayed on the right-hand side, and object filter settings, which in the example are located directly below the search bar. When an object is selected from the search results, the visualization on the right updates accordingly, bringing the selected element into focus. The filtering functionality enables users to temporarily reduce the visible data to those elements that are most relevant to their current investigative focus, thereby supporting a more targeted and comprehensible analysis [34]. In the depicted figure, several filters have already been selected as examples, resulting in a noticeably reduced number of displayed objects compared to Figure 1. The right-hand side of the interface displays the visualization of the selected dataset, taking into account the filters currently applied. A zoom control in the upper-right corner allows users to adjust the desired level of detail, enabling a transition from an initial overview to progressively more detailed information, following the principle of overview first, details on demand [34]. When zooming out, relationships associated with an object are aggregated, whereas zooming in reveals them in greater detail, thereby

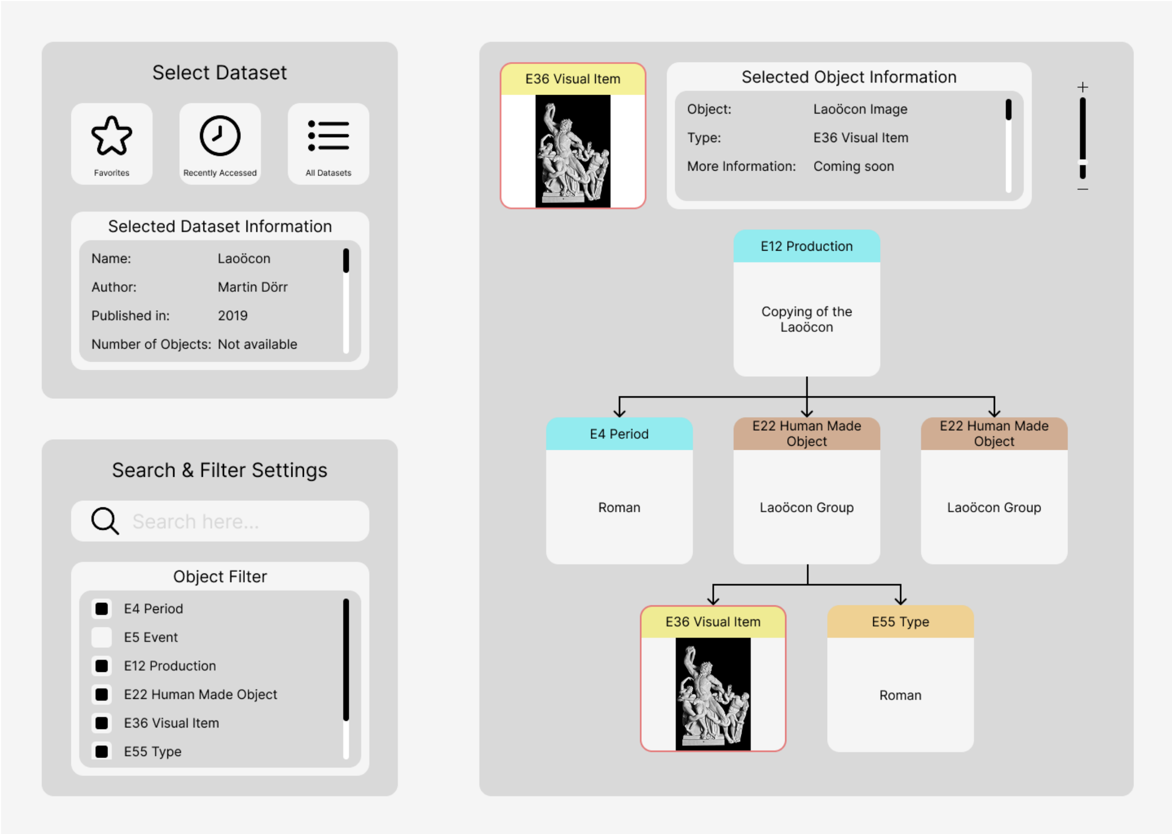

Figure 2: New UI sketch (first iteration/version) for visualizing semantic data using Laoöcon as an example

preserving readability across all levels of detail. Through the use of linking and brushing, selected objects within the visualization are highlighted, while additional information about the selected element is displayed above the visualization [29]. Relationships that were previously indicated through arrows between objects can instead be incorporated into the information panel of the selected object, improving interpretability through a more structured presentation. To further enhance clarity when displaying semantic data, the interface follows a clear hierarchy and structural organization. The visualization is divided into multiple levels, within which entities are arranged according to their identifiers in ascending order from left to right. This structured layout supports orientation within the dataset and contributes to a more intuitive understanding of the relationships represented in the visualization [26]. For reasons of recognizability, the color scheme from Figure 1 was retained, with only a slight reduction in saturation to achieve a less visually intense appearance. At this stage of the design process, however, no fixed color scheme is defined. Instead, the interface relies primarily on gradations of white, grey, and black to create sufficient visual separation between elements. This approach ensures that color schemes can be introduced at a later stage without negatively affecting usability [35].

5. Conclusion

This paper introduced methods from the field of HCI and demonstrated their applicability to the domains of CH and DH. Using the HCD approach and the CIDOC CRM Laoöcon example, the work highlighted the considerable potential for closer collaboration between these research areas. Through this process, a new visualization tailored to the needs of the target group was developed. The design process followed a structured sequence of analyses consisting of a Target Group Analysis, Problem Analysis, and Task Analysis. The goal of this step-by-step approach was to make semantic data more accessible to the identified user group, primarily GLAM professionals and researchers, by systematically translating the insights gained from these analyses into concrete design decisions. In doing so, the proposed interface addresses the needs of the target group while adhering to established design guidelines and methods from HCI and InfoVis. At the same time, the visualization presented in this paper does not represent the final stage of the HCD process. Rather, it should be understood as an intermediate design outcome. The logical next step would involve evaluating the developed UIs with representatives of the target group. To this end, an evaluation based on a within-subjects study design comparing different UI design variants would be a suitable approach. This could be further extended by incorporating a between-subjects design to account for differences across user groups, thereby enabling the identification of both the most effective interface design and group-specific characteristics. For measurement, established instruments such as the UEQ and the System Usability Scale (SUS) may be employed [31, 36]. Based on the insights gained from such evaluations, subsequent iterations of the design would refine and adjust the proposed solutions. This iterative cycle of evaluation and redesign would continue until the resulting interfaces can be validated by the intended users and demonstrably support their interaction with semantic data. The integration of controlled vocabularies and ontologies is likewise a valuable consideration for future development. An iterative approach is likewise appropriate in this context, involving continuous consultation with the target group in order to adequately account for both technical and linguistic considerations throughout the development process.

Declaration on Generative AI

During the preparation of this work, the author(s) did not use any GenAI tools or services.

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