Shapes of Time: Visualizing Set Changes Over Time

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ABSTRACT

In cultural heritage collections, categorization is an important technique used to document historical developments or cultural movements by grouping artifacts with set-typed metadata, like genres, groups, or categories. Visualizations can communicate to casual users how such sets organize a collection - and how they change over time. But existing interfaces fall short a) by not representing an overview of the temporal development of the sets in an integrated, multidimensional view and b) of not representing the set elements, i.e. the cultural objects, but only their aggregations. We developed two integrated, multidimensional visualization techniques - a superimposition and a space-time cube view - to depict the development of sets and their elements over time, and evaluated both approaches.

1 INTRODUCTION

The time of history—as the art historian Kubler noted [10]—stretches like a sea, occupied by innumerable cultural objects, which yet belong to cultural forms of "a finite number of types" (p. 32). Arts and humanities scholars have to reassemble these forms and types, and analyze their evolution and development in larger continuous sequences, to better understand the cultural "shapes of time". With this submission, the development focus is on visualization techniques for set-typed and temporal data in the context of the cultural heritage (CH) domain. After recollecting design requirements and related work, we introduce two visualization techniques for set-typed CH data to support the exploration of set changes over time with consideration for uncertain sets changes in time. We further provide an outlook on first evaluation results and future work in the area of set changes over time.

2 RELATED WORK

Visualization of CH collection data is an area of increasing importance in information visualization [17]. Visualization-based interfaces to galleries, libraries, archives, and museums provide collection overviews, support exploratory browsing, and facilitate the contemplation of details on demand [4]. While a wide spectrum of visualization techniques has already been utilized—such as maps, graphs, trees, charts, or timelines—only a few examples of set-based visualizations have been documented up to now [17], which did not take the temporal dynamics of sets into account. Yet, set-typed, time-varying metadata is omnipresent in the CH domain, due to archival knowledge management strategies given by CH taxonomies, categories, genres, topics, or styles.

In other domains beyond CH, we find a great variety of visualization techniques to represent set-typed data [1, 3, 14], for which the representation of *temporal changes over time* counts as a crucial challenge [1]. In a simplified manner, sets can be described by the number of elements they contain, and their temporal variation can be visualized by line charts, stacked area charts, or variations thereof, such as *ThemeRiver* [9] or *Tag River* [6]. These methods also provide basic options for temporal visualization of sets in CH (e.g., [5]). However, these visualizations build on significant abstractions and do not represent the elements within the set-like categories—which hinders further exploration of single objects. This also holds true for more advanced visualization systems, such as *TimeSets* [13], *KelpFusion* [12], and *VISTopic* [19], or for systems with coordinated multiple views [2, 7, 15], which remain limited with regard to important functions, tasks, and design requirements in the CH domain.

3 DESIGN: SHAPES OF TIME

We layout our design rationales and describe the resulting *Shapes of Time* visualization techniques for time-oriented, set-typed data in the CH realm.[1] We start from the question of how to define and represent sets and their individual elements (sec. 3.1) and then exemplify two methods to represent sets over time (sec 3.2). We introduce the design of a superimposition view and a space-time cube view, as well as interaction techniques to support set-typed data exploration for casual users. With regards to casual users, we identify the below tasks to support exploration with *overview* (T1), *traceability* (T2), and individual object *identification* (T3).

3.1 Representing Cultural Objects and Sets

Sets. A single cultural object (such as an image, sculpture, or artifact) is represented as a single point. Single points are arranged into sets using the temporal and categorical attribute definitions: For a single *set*, using intentional set definition, set members are formed based on a rule. For example, members of set S^1 share the primary genre g^1 independent of the temporal attribute t. Sets are visually represented as circles and the set elements are arranged as points inside the circle. To support the task of *identification* (T3), individual objects can be selected, previewed and detailed information can be retrieved.

Ordering of elements within sets. The order in which sets and set elements are arranged can depict patterns and relationships in collections and can help users gain an *overview* (T1). Set members are ordered based on their temporal attributes, with earliest points placed in the middle of the circle and latest points placed on the edge of the circle respectively (see fig. 1a). Elements are distributed according to the shape of an Archimedian spiral, which minimizes overlays and occlusion of data points while generating a simple

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[1] For an interactive version of the visualization techniques see `https://bigdata-vis.github.io/polycube/shapeoftime.html`

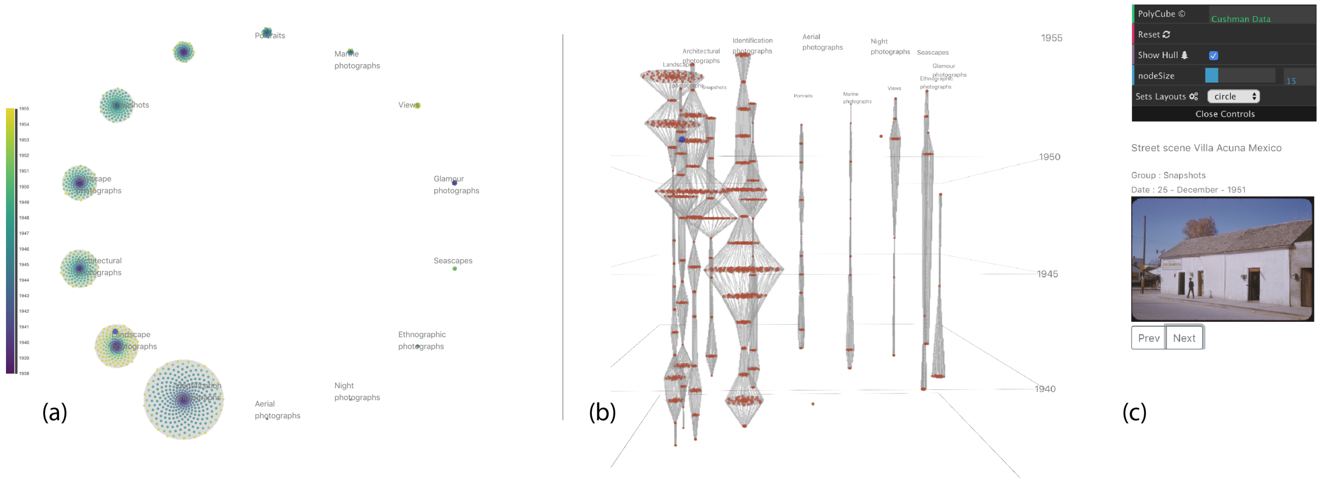

Figure 1: Visualizing set changes over time in the Cushman photography collection: (a) superimposition view, (b) space-time cube view with set changes connected by a "hull", and (c) preview of an individual object.

abstract spiral layout. The radius of each circle gives an *overview* (T1) of the number of objects in that given set. A grey circle in the background shows the overall size of each set and encapsulates the individual points belonging to the set.

3.2 Visualizing Sets over Time

To support the analysis of *temporal* set-typed data, we introduce *subsets* (see fig. 1b). In each subset, the temporal and categorical attributes of the elements are the same. For example, ss^1 is a subset of S^1, whose members are formed based on the rule genre g^1 and time t^1 being the same. To visually represent a set over time, objects are arranged as points inside a subset and then over time to form a single set consistently across multiple views.

To support *traceabiltiy* (T2) and provide an *overview* (T1) on the temporal dynamics of set-typed data two visualization techniques for time-oriented, set-typed data were implemented, superimposition and space-time-cube. While the superimposition view (see sec. 3.2.1) encodes the temporal origin of the objects by the utilization of a color scale, the space-time-cube (sec. 3.2.2) splits up the individual time-segments and arranges them one above the other in multiple layers in three-dimensional space.

3.2.1 Sets in the Superimposition View

Superimposition (SI) is one of the views offered by our framework for temporal CH data exploration. The subsets in the SI view are not directly visible, as they are arranged in a seamless, ring-like manner (see 1a). Regarding the temporal order, data points arrangement remain consistent with STC view. For user guidance, labels next to each individual set annotate the corresponding genre.

In addition, we utilize the Viridis color scale to encode the time of origin of each object (see fig. 1a). Differences in the color scale provide users with an *overview* (T1) on the temporal extension of the subsets, the internal temporal distribution of each set, as well as temporal differences between multiple sets.

3.2.2 Sets in the Space-Time Cube View

Secondly, we offer a space-time cube (STC) view for the time-oriented exploration of CH data. The STC was first developed and utilized in human geography to support the visual analysis of human movement patterns and the spatial diffusion of innovation [8]. Based on the strength of STC as highlighted by [16] for temporal data exploration of larger datasets, the STC offers an effective solution to visualize the temporal dynamics of sets and their subsets as intuitive *visual shapes of time*.

We extended the STC to visualize set-typed data with a focus on the arrangement of multiple sets. To provide an *overview* (T1) on the temporal development of the individual sets over time, users can activate a "hull" structure (see fig. 1b), which connects the geometrical vertices of each subset to its neighboring subsets over time. The shape of this hull allows users to *trace* (T2) the development or dynamics of sets over time. The hull between each subset denotes basic flow patterns of set dynamics, such as emergence, growth, diminution and decline [18].

3.2.3 Encoding Uncertain Sets

Part of the objectives of visualizing set changes over time is to highlight uncertain data, such as missing information or objects with uncertain set assignments. For the use case of the Cushman collection, the hull structure was improved to make gaps in sets over time more salient [11] (as seen in Fig. 2).

Another challenging aspect of set-type data is an object belonging to multiple groups. This is prevalent in the Cushman data, where many objects have a primary and a secondary classification. We used the primary to define the default set group of each object, and a filtering option to view the secondary classification.

4 Evaluation and Conclusion

We presented 2 approaches to the visualization of sets changes over time (STC and SI view). An evaluation of these approaches with 4 casual users showed that both have their strength and weaknesses and require further improvement. Results indicate that the space-time cube view performed better for traceability tasks compared to the superimposition view, but individual preferences for the views highly differ between users and are task-dependent.

A specific challenge is the visualization of uncertainty in sets (in general), but more specifically when it comes to time. We presented visual and interactive solutions for two kinds of uncertainties, but further developments are needed to be able to represent also other kinds of uncertainties in sets (e.g. fusion or differentiation of sets.)

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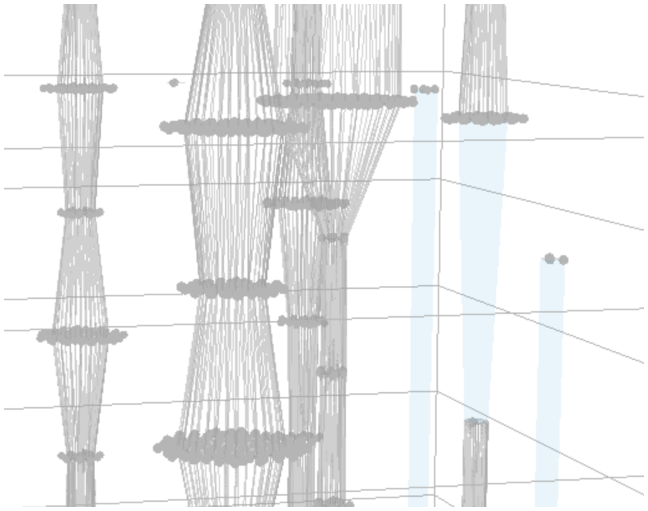

Figure 2: A visualization of gaps between set changes over time highlighting missing information.

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