Characterizing Visual Exploration Techniques for Temporal Data

Rafael Henkin*
giCentre
City University London

Aidan Slingsby*
giCentre
City University London

Jason Dykes*
giCentre
City University London

ABSTRACT

Designing visualizations for exploration of temporal data requires several choices based on aspects of time and visual representation. Previous taxonomies have described existing visualizations based on these aspects without relating the visual representations. We propose to characterize existing visualization techniques based on both semantic aspects of time and visual representations. Our design space helps to identify how these different visual representations relate and give the possibility to combine attributes of representation from different techniques. We compare two examples of visualizations from the literature based on our taxonomy.

1 INTRODUCTION

Exploratory analysis of temporal data includes various choices regarding design of visualizations. For instance, polar layouts may highlight the cyclical aspects of data aggregated by month, allowing the seasonality or trends in the data to be observed at that granularity. Breaking down data into days of month might show a smoother pattern, which may also be more difficult to be observed in a radial chart. A linear arrangement, such as in a line chart, may be more suitable in this case.

We propose a design space of visualization techniques for temporal data based on visual representation and temporal aspects, as a first step to design a framework for reconfigurable hierarchical visualizations, extending the HiVE framework [8] to support visual exploration of time. By describing this design space, we aim to allow the exploration of different techniques in it by investigating the transitions between them, combining them in a dynamic hierarchical approach.

2 RELATED WORK

Various taxonomies and frameworks of time-oriented visualizations exist in the literature. Aigner et al. [1], Muller and Schumann [6] and Silva and Catarci [7] classify visualization methods based on how the temporal dimension is used in the visualization technique. In terms of visual representation, they classify techniques either as static or animated and 2D or 3D. Bach et al. [3] also present a complex taxonomy mapping space-time cube operations to visual representations of temporal data. Interaction is discussed as a mean of applying the operations and, thus, transforming the data. No characteristics of visual representation are considered in this model. We propose to go further by identifying the capabilities of visual representations for time and other dimensions and relating to the semantic aspects of time, in order to facilitate the design of new techniques.

3 CLASSIFICATION CRITERIA

The classification is a preliminary step for finding out similarities between the various attributes that allow different configurations to be changed dynamically, maintaining some attributes of choice when transforming between visualizations.

*e-mail: {rafael.henkin.1,aidan.slingsby.1,j.dykes}@city.ac.uk

Table 1: Permutations and examples of Cartesian 2D layouts

Dimensions	Space	Time	Characteristics
Space	map	-	-
Time	-	calendar	timeline
Characteristics	-	timeline	scatterplot

3.1 Semantic aspects of time

For the temporal dimension, we consider the following aspects, based on [1]:

Temporal structure Due to the periodic organization of time in quarters, months, weeks and days, data can be arranged either in a *linear* way from the earliest date to the latest, or in *cycles* in the referred units. A cyclic arrangement means that there's no starting point in the set of times used.

Temporal primitive Objects or events can be referred by an *instant* point, an *interval* with initial and ending points or an unanchored *duration* (i.e. an event that lasts for a certain duration of time units without an initial or ending point in the temporal domain).

Granularity level Visual representations can show a *single* granularity level, such as time series based on days, or *multiple* granularities, like in a calendar with days and months. This classification is not concerned with multiple-view systems where more than one granularity is shown through the different views, but rather with a monolithic visualization (and respective interactions within).

3.2 Aspects of visual representation

For representation, we separate layout, shape and size of visual marks, the ordering used to position the visual marks and what variable is used to color visual marks.

Layout The layout of visualizations is described according to how visual marks are either positioned or formed by permutations of three possible sets of attributes (space, time and characteristics, following Andrienko and Andrienko [2], as well as the dimensionality (1 or 2 dimensions). The layout does not specify the function of used to position marks, but serves as a way of separating the three sets of attributes due to the different interactions needed and the semantics of the sets. A description of the same attribute being used on both coordinates does not imply different or same units. For example, *day of month* can be used to position visual marks across both dimensions of the 2D space. This arrangement over the 2D space is defined by the order attribute. The possible combinations and some examples of known/valid visualizations are listed in table 1.

Size, shape and color Visual marks can be described in terms of how their size is defined. *Fixed* size means that the size for each mark is not dependent on any attribute of the data. The actual method used to fix the size is not part of the description, but can vary from a percentage of available space or number of elements. When size is not fixed, we consider it to be calculated from an *attribute*, either directly from individual items or functions resulting from aggregation.

Shapes can be *circles*, *lines* (or polylines), *polygons* or *complex* shapes, such as glyphs or geographical entities such as shapes depicting countries. For polar coordinates, we also define *sectors* as the area delimited by two radii in sectors from polar area charts or shaded areas in a spiral representing intervals, drawn between two angles. Finally, color is defined by the attribute(s) used in a color scale and how that attribute is ordered (ascending or descending).

Ordering Ordering defines the position of visual marks along one axis, for one-dimensional visualizations, or across both axes. For temporal and spatial ordering, the reference (e.g. longitude) and the sorting direction (ascending for left to right or top to bottom) are used. For characteristics, order can be defined in an *arbitrary* way (e.g. days of the week) or by the type of data (*ordinal* or *linear*), with sorting direction also being used. The order for one-dimensional visualizations is also classified as *horizontal* or *vertical*.

3.3 Example

We compare two examples from the literature and how they fit this classification, also showing how the taxonomy is flexible for transformation. The first example is the heatmap in Flowstrates [4] (see figure 1), used to show migration patterns for countries over the years. Time is arranged in a linear fashion, with data items referring to instant points and a single granularity being shown. In a non-hierarchical approach, the heatmap can be considered a 2D cartesian layout composed of time and characteristics of objects. Elements from the data space are mapped to *fixed*-size polygons, with lightness mapped to the *magnitude* of the attribute for each year and object. The temporal axis is ordered *ascending* from the earliest to the latest year, left-to-right. In the vertical axis, elements are ordered arbitrarily by an ordinal scale (side-by-side). As Flowstrates was designed as an interactive tool, the actual attribute used for ordering is not essential for objective of the representation.

In contrast with this visualization, there is CircleView [5] (see figure 2), which also shows data indexed by time, but with a different coordinate system. The layout is polar with angle mapped to an ordinal attribute, ordered arbitrarily, and the length of the radius mapped to year, in an ascending ordinal fashion. This configuration results in sectors ordered outwards from the center of the circle. Like in Flowstrates' row ordering, the inwards or outwards sorting is not an essential aspect of the visualization - though it considerably changes the distance between sectors early or late in the timeline. The size of the sectors is fixed in relation to the data, like in Flowstrates, and color is also mapped to a *magnitude* of an attribute. Time is arranged linearly, with years as instant points in time and a single granularity shown.

The fundamental difference between these visualizations is the layout used, which in turn affects the shape of the representation and, ultimately, perception. In relation to the framework we intend to develop, switching between the layouts would maintain consistency between all other attributes except for shape. However, as sectors are not linked to the data in this example (as size is fixed for both visualizations), we can consider shapes in both examples as equivalent representations even though the areas of the shapes change in the circle.

4 Conclusion

We have proposed a description of visualization techniques for temporal data exploration. The aim is to support a framework for reconfigurable hierarchical visualization, by finding similarities and differences between existing techniques and applications that allow them to be combined and dynamically reconfigured.

We have described two examples in the literature with similarities and differences and how they can be described by our taxonomy. The next steps are to design the framework based on this classification, finding out groups of similarities and differences that

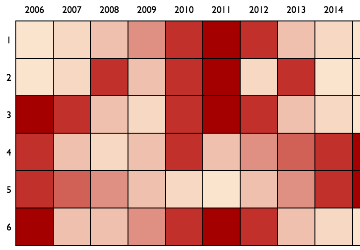

Figure 1: Heatmap example from Flowstrates, with years ordered from left to right, and objects from top to bottom. Generated by the authors.

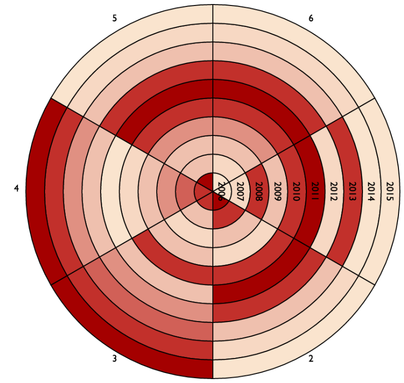

Figure 2: CircleView example with the same dataset. Objects are ordered clockwise, with years from the center of the circle to the edge. Generated by the authors.

allow these visualizations to be transformed, following the semantic aspects of time and aspects of visual representation.

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