3D Information Visualization for Time Dependent Data on Maps

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Abstract

The visual analysis of time dependent data is an essential task in many application fields. However, visualizing large time dependent data collected within a spatial context is still a challenging task.

In this paper, we therefore describe an approach for visualizing spatio-temporal data on maps. The approach is based on two commonly used concepts: 3D information visualization and information hiding. These concepts are realized by means of novel embeddings of 3D icons into a map display for representing spatio-temporal data, and an integration of event-based methods for reducing the amount of information to be represented. Our approach is capable of visualizing multiple time dependent attributes on maps, and of emphasizing the characteristics constituted by either linear or cyclic temporal dependencies.

1. Introduction

Modern databases are capable of storing large amounts of multivariate time dependent data. Since such data could help understanding natural phenomena or business processes, temporal data analysis is an essential task in many application fields. Besides statistical methods, visualization has proven to be an effective means for analyzing temporal data. A variety of expressive techniques have been developed in recent years (cp. [1], [2]).

In many cases temporal data is collected in a geographic context. This leads to another data dependency – a spatial dependency. Maps have been used for ages to visually represent spatial contexts. Modern Geographic Information Systems (GIS) provide rich facilities to use maps on computers. They also provide interactive techniques for visualizing data on maps. In GIS temporal data is commonly visualized by means of animations, which represent changes in the data. By using animations the evolution of temporal data can be conveyed efficiently.

However, a detailed data analysis is hardly possible when using animations. Moreover, visualizing multivariate data with both temporal and spatial dependencies on maps is still a challenging task. Especially, if very large multivariate datasets have to be visualized on maps current methods reach their limits.

In order to meet this challenge we have developed an approach that integrates two well known concepts, which have proven to be effective in other applications as well:

- 3D information visualization, and
- Information hiding.

The main advantage of using a 3D representation space is the possibility of integrating additional visual information into the representation. In this paper we describe how special 3D icons can be utilized for mapping temporal dependencies, and how such icons can be combined with maps in order to represent spatial dependencies. The proposed 3D icons have been designed not only to be able to represent multiple data attributes, but also to address different types of time (i.e. linear time and cyclic time).

Another challenge when visualizing data with temporal dependencies is coping with large datasets. Disregarding this aspect would result in overcrowded and cluttered displays if the amount of data represented exceeds certain limits. A first approach for alleviating this problem is to integrate concepts such as overview+detail or focus+context. A second possibility to deal with large datasets is to use information hiding concepts. Here the intention is to visualize information relevant to users, and to hide information irrelevant to them. Although we will regard both possibilities, the focus we set in this paper is on information hiding. We utilize an event-based approach allowing users to specify their interests by means of events. In order to hide irrelevant information we visualize detected events rather than the whole dataset. By doing so, overcrowded displays are avoided and only relevant information is displayed.

This paper gives an overview on related work in Section 2. The proposed 3D icons and their combination with a map are described in Section 3.1. Sections 3.2 and 3.3 are dedicated to coping with large datasets by means of event visualization. The paper concludes in Section 4 with a summary of the presented methods and an outlook to future work.

2. Related work

The visualization of time dependent data has been addressed by many researchers. A variety of techniques (cp. [1], [2]) have been developed for different application backgrounds.

When visualizing temporal data it is important to be aware of the type of time constituting the time dependency. In this paper we focus on two common types of time: linear as well as cyclic time with time points as temporal primitives [3]. Linear time can be defined by points on a linear time axis (e.g. 1, 2, 3, seconds). Cyclic time is defined by temporal primitives, which recur cyclically (e.g. seasons or months of a year). If cyclic time is extended by an indication of the number of cyclic passes (e.g. seasons + year), cyclic time can be unrolled to linear time. This is useful since it enables visualization techniques to emphasize either linear or cyclic characteristics of a dataset.

Commonly, time is visually represented by a time axis. The shape of the time axis differs among the techniques known in literature. Mostly, a straight line is used to represent time. This is suitable for conveying linear temporal dependencies (e.g. in many kinds of diagrams). Moreover, utilizing spirals (cp. [4], [5], and [6]) have resulted in expressive time visualizations especially useful for visualizing cyclic time. The temporal dependency is usually represented by aligning data items with the time axis (e.g. plots or simple icons). Since common techniques require large amounts of drawing space, simply embedding them into map displays leads to lot occlusion of map data.

Therefore, spatio-temporal data is often visualized by means of animated maps [7]. These are created by rendering a map for each time step in the data to a frame of an animation. Usually, color coding is used to represent the data in each frame. As such, animations are useful for comprehending the evolution of time dependent data within a spatial context. Due to the limitations of the human brain, however, an exact analysis of certain time steps of a large dataset can be hardly realized by means of animations. Even to achieve simple comparison of different time steps users would be compelled to browse through the animation over and over again.

Especially if the amount of data to be visualized is very large, more sophisticated techniques are required to create expressive visualizations. In recent years this issue has been addressed by several researchers. Their efforts have resulted in the development of the following concepts:

- Overview+detail,
- Focus+context, and
- Information hiding.

Overview+detail and focus+context are widely used concepts for interactively (i.e. user interaction is required) dealing with heavily loaded graphics. Overview+detail techniques provide a coarse representation of the data in an overview and allow zooming in upon user request for a detailed data analysis [8]. Since detailed views are represented separately from the overview, additional perceptual efforts are required for comprehending the data. Therefore, focus+context techniques try to combine overview and detailed view within a common display [9]. Lens techniques for instance realize this by applying distortions to an underlying visualization technique. As such, lens techniques can be understood as second order visualizations [10].

Besides applying overview+detail or focus+context concepts, an automatic limitation of the amount of information rendered to the display could alleviate the problem of overloaded and cluttered displays. Therefore, the goal of information hiding is to only visualize information relevant to certain users and omit irrelevant or less important information. The visualization of events of interest is one possibility for achieving this goal.

Recently, several publications followed an event-oriented approach. Matković et al. describe in [11] how events (i.e. exceeding of thresholds) can be utilized to provide virtual monitoring instruments at different levels of detail. In [12] it is described how events can be visualized in time and space by using a space-time cube. While in [11] only quite simple threshold exceedances are detected as events, the events visualized in [12] are even given only a priori. This lack of generality infers a requirement of methods for describing and detecting arbitrary events of interest to be accounted by the visualization.

Therefore, we have introduced in [13] an event-based approach which addresses these issues. The basic idea is to let users specify their interests by means of events, detect these events on the data, and consider occurred events when creating a visual representation of the data. The event specification is formally based on predicate logic formulas. In order to address differently experienced users, events can be specified either by directly writing a formula, by parameterizing formula templates, or by simply choosing from a collection of domain specific predefined formulas. In the event detection step the defined formulas are evaluated regarding the dataset to be visualized. This can be realized by utilizing the capabilities of modern database management systems. Once events are detected, there are two basic possibilities to represent the occurred events. On the one hand a given visualization technique can be parameterized to visually emphasize the event occurrences (i.e. implicit event representation). On the other hand events can be represented separately rather than visualizing the whole dataset (i.e. explicit event representation).

While in [13] we have focused on implicit event representation, in this paper we will utilize explicit event representation in order to realize information hiding.

3. A concept for visualizing time dependent data on maps

In this section we will describe a concept for visualizing data depending on linear or cyclic time in their spatial context. The basic idea is to utilize a 3D space for representing the data, and to integrate an event-based approach for focusing on relevant information. The following subsections will detail on both aspects.

3.1. Using 3D icons for visualizing spatio-temporal data

In order to address the challenge of visualizing spatio-temporal data on maps, we introduce in this section novel embeddings of 3D icons representing either linear or cyclic time into a sophisticated map display.

As basis for our approach we are given a hierarchically structured 2D map, which is subdivided based on administrative subdivisions of geographical regions (i.e. federal state, country, zip code regions). Hence, different levels of spatial detail can be provided upon user request. This allows users to get an overview of the map and zoom in details on demand.

Additionally, the focus+context approach is supported by means of a cartographic fisheye lens that has been realized as a vertex shader for the graphics hardware, and therefore, allows zooming in small areas of the map in real time. By interactively moving the lens, users can analyze details of the represented data without loosing the overview of the map.

After having introduced the map display we will now detail on the:

1. Construction of expressive 3D icons, and the
2. Efficient embedding of the icons into a 3D map display.

For the construction of 3D icons it is first necessary to consider what type of time constitutes the temporal dependency, and hence, should be conveyed by the visualization. The second aspect that must be taken into account is how to make the icons capable for visualizing multiple data attributes. Addressing both aspects, we utilize two kinds of 3D icons: pencil icons for representing linear time and helix icons for representing cyclic time.

Pencil icons: Since everybody is familiar with the shape of a pencil, it is a very useful visual metaphor. This is corroborated by the fact that visualizations based on pencils have been successfully used in other applications (e.g. [14]). The natural shape of a pencil provides multiple faces, which evolve from a common tip. This shape excellently serves as a 3D icon for visualizing multiple data attributes with dependencies on linear time. For mapping data onto a pencil icon, linear time is encoded along the pencil's faces starting from the common tip. Each face of a pencil can then be used to color code an attribute of a dataset (cp. Figure 1(a)). The number of faces of a pencil can be adjusted according to the number of attributes to be visualized.

Helix icons: If temporal dependencies have cyclic characteristics this should be conveyed by the visual representation as well. A spiral helix provides a geometric shape that allows an emphasis of the cyclic character of a dataset (cp. [4], [5], and [6]). In order to construct a helix icon, a ribbon is created. For each time step the ribbon extends in angle and height depending on the number of temporal primitives per cycle and the number of cyclic passes. Again color coding is used to encode data values along the ribbon (cp. Figure 1(b)). In order to be able to represent multiple data attributes the ribbon can be subdivided into narrower sub-ribbons.

The fact that the icons will be embedded into a 3D map display implies that perspective distortions will occur in the final visual representations. Mapping data values onto any geometric parameter (e.g. width, height, angle, etc.) could therefore lead to misinterpretations and false conclusions. As a solution to this problem, both kinds of icons make use of color coding to visualize data values. To fully exploit the capabilities of the human visual system we integrated an enhanced color coding scheme [15]. By doing so, we not only enhance the visual exploration, but we also support comparison tasks essential in visualization.

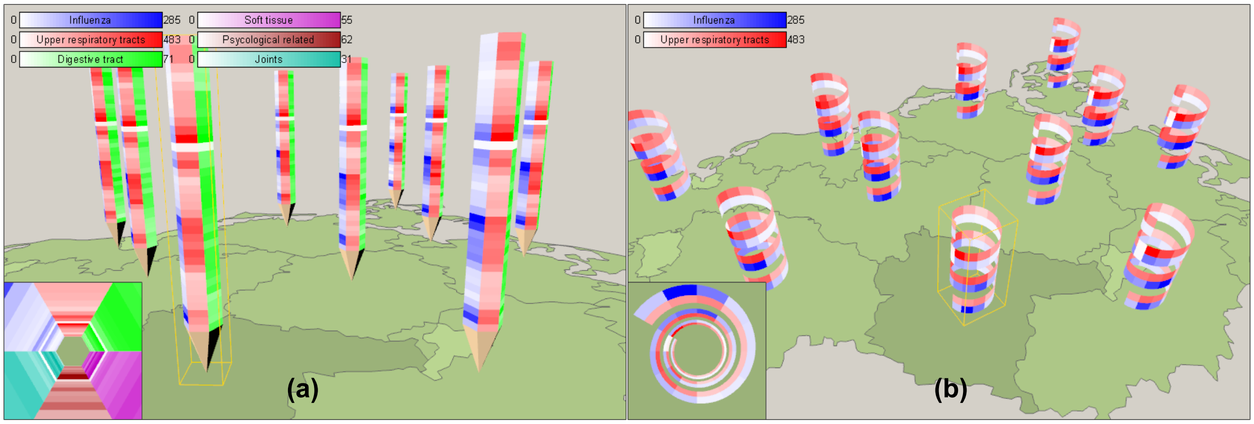

Figure 1. Visualizing monthly health data by means of 3D icons on a map: (a) Pencil icons representing cases of 6 diseases, some diseases show a certain pattern over time; (b) Helix icons clearly reveal the cyclic characteristic of 2 selected diseases. Additional "tunnel views" mitigate the problem of hidden information for a selected icon.

The described pencil and helix icons can now be combined with a 3D map display. First, either pencil icons or helix icons are created for a user determined selection of geographic areas. These icons are then embedded into the map display. This can be realized by positioning each 3D icon at the centroid of its respective area and aligning it with the z-axis of the 3D presentation space. By doing so, the representation of the temporal dependencies is shifted from the map to a dedicated dimension in the 3D representation space. However, the embedding in 3D involves new problems compared to a 2D representation:

- Undesired changes of the icon view upon user interaction, and
- Loss of information due to icon occlusion and hidden surfaces.

Applying all interactions allowed in the 3D presentation space (i.e. rotation, translation, scaling) to both the map and the icons is disadvantageous. Though such behavior is common in 3D applications, it implies visual inconsistencies during the visual analysis. If for instance users rotate the map while analyzing attributes represented on a pencil icon, the faces of the pencil are undesirably rotated as well, i.e. the view of data attributes changes. An alternative is to unlink map interactions and icon interactions upon user request. This can be achieved by aligning the icons not simply with the z-axis, but by aligning them with respect to the user's current view point into the 3D scene. By doing so, it is ensured that while navigating the map, the icon view remains the same. In order to allow users to change the icon view whenever required, it is necessary to provide a possibility for rotating the icons. In the common case all icons can be simultaneously rotated. However, for detailed data analysis it is also possible to rotate each icon separately.

The second problem that must be addressed when using 3D visualizations is loss of information. Such loss can occur if 3D icons occlude each other, and on hidden surfaces of the 3D icons.

A first step to alleviate this problem is to improve the crude procedure of positioning icons at the areas' centroids. An aspired method must consider the users viewpoint in addition to the area centroids. Since the viewpoint can be changed interactively, the icon positioning algorithm must be able to calculate new icon positions multiple times per second. This implies that a complete resolution of all icon occlusions by a global algorithm cannot be achieved. Conversely, an iterative approach that calculates occlusion conflicts, and alters the positions of the icons locally can help to reduce occlusion. Our algorithm is started on each change to the viewpoint and runs until no conflicts occur, no further improvements are possible, or the maximum number of alterations has been exceeded. By doing so, on the one hand significantly enhanced icon positions can be achieved, and on the other hand interactive frame rates are ensured.

A second extension regards the problems imposed by information loss on hidden surfaces. Although using 3D allows a high degree of interaction with, and navigation through the data, a certain amount of possibly important information is always hidden. To mitigate this disadvantage, we provide the possibility to switch to special viewpoints designated for each icon. The special viewpoints are located directly underneath each icon and the view directions are aligned with the icons' axes. Switching to one of these viewpoints results in a "tunnel view" that reveals all data values represented by the respective 3D icon. As such this "tunnel view" can be understood as a realization of the overview+detail concept. Figure 1 shows how a "tunnel view" supports visual analysis in a 3D presentation space.

These enhanced viewing and interaction techniques in combination with the mentioned geographic lens and the common 3D interactions provide a rich basis for a visual exploration of multiple, time and space dependent attributes. Furthermore, it is possible to emphasize linear or cyclic characteristics of data by using dedicated 3D pencil or helix icons, respectively.

3.2. Events of interest

When visualizing very large datasets it is necessary to automatically limit the amount of represented information. Focusing on user-chosen events of interests is a possibility to achieve this aim.

When analyzing temporal data, events regarding the evolution of the attributes are certainly of interest. The simplest event would be for instance the exceeding of a certain threshold ($attr_t > thres$). Another example could be the exceeding of a certain increase δ of attribute values from one time step to another ($\delta = attr_t - attr_{t-1} > thres$).

		Time	
		local	global
Space	local	Simple threshold events	Temporal pattern events
Space	global	Spatial pattern events	Complex spatio-temporal pattern events

Figure 2. Categorization of possible events.

However, considering temporal data with a spatial context raises the question about what events to detect. An issue to pay attention to is whether events should be detected globally or locally. With respect to the temporal aspect this means whether we should detect events for a single time step only, or in the whole temporal domain. Conversely, for the spatial context this means whether we should detect events regarding only a single area, or throughout all areas of the map. Combining both considerations result in a categorization of possible events to be detected. The categories are shown in Figure 2 along with a color coding of the efforts required for specifying and detecting events of a respective category. If events are detected locally regarding both time and space (i.e. event formulas are evaluated regarding a single time step and a single area), only simple threshold events are possible. Such events can be specified and detected quite easily.

If either time or space are considered globally (i.e. event formulas are evaluated regarding the whole respective domain), more complex events are possible. If for instance time is considered globally, temporal predicates like *before*, *starts*, *during*, etc. (cp. [3]) could be used to detect temporal pattern like "value increases over a certain period of time". Conversely, considering space globally allows an integration of spatial relationships (i.e. predicates). This allows events that describe spatial pattern like "all neighbors of an area show lower data values than the area itself". Apparently, a combination of temporal and spatial predicates allows a detection of complex spatial-temporal patterns. However, these require lot more efforts by the user (or a domain expert) in specifying them, and by algorithms in detecting them in the data.

In the next section we will describe how such complex spatio-temporal pattern events can be visualized on a 3D map display.

3.3. Space-time paths for representing events

In the following we will demonstrate how event-based visualization can be used to analyze spatio-temporal data. In our case the goal has been to analyze human health data with respect to the spread of certain diseases. A reasonable approach to achieve this goal is to examine where in time and space maximum data values (i.e. number of cases of a certain disease) occur. In our event-based manner, this means that we detect for each time step the area with the highest data value.

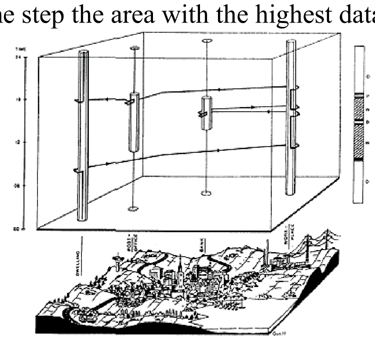

Figure 3. Space-time path (Source: [16]).

For representing the detected maxima values we take on the idea of space-time paths described in [16]. Originally developed for representing human activities (cp. Figure 3), today space-time paths can be found in a variety of cartography related visualizations (e.g. [17]). A space-time path connects points in a 3D presentation space, which consists of one temporal and two spatial dimensions. Hence, it can be used for visualizing maximum events detected on health data.

For creating a representation of the detected maximum events, we first create special 3D icons for each area on the map. Depending on whether linear or cyclic time shall be conveyed the icons provide a respectively shaped time axis. During the event detection the icons are built up by adding a small sphere to each icon for each time step in the data. This sphere is colored red if the maximum event occurred for the respective area, and is colored blue if the maximum event did not occur. By doing so, event occurrences can be clearly detected from the visual representation. Finally, successive event occurrences are connected by a space-time path. In order to guide the user to relevant information only, icons of areas, for which no event occurred (i.e. no red sphere has been added to the icon), are faded out.

For now, we have considered all areas of the map in connection with one certain temporal granularity. However, it also makes sense to consider sub sets of areas of interest. Then it is possible to calculate space-time paths that visualize which areas contribute to the maxima detected for the areas of interest. The visual representation can be further enriched with additional information on how the space-time path looks like for a temporal granularity (e.g. days) finer than the temporal granularity currently displayed (e.g. week). This allows insight into a finer temporal resolution without completely recalculating the whole visualization.

Figure 4 shows an example of space-time path visualization. It can be seen how the visualization focuses users to relevant events within the data. Furthermore, it becomes clear that the space-time path helps to understand how maximum values evolve over time and space.

Though we have focused on maximum value events in our description, it must be mentioned that this implies some questions as well. If for instance data values differ only slightly from one time step to another, it is possible that the space-time path oscillates between two regions. In such cases it would be better to consider an epsilon environment around the maximum before switching it from one area to another.

A second question regards the expressivity of maximum events for visualizing spreads of diseases. For the scenario of human health data it is also possible to consider maximum value increases or decreases from one time step to another as indicators for the evolution of a disease. Since such events are similar to ordinary maximum value events they can be visualized using our methods as well. The decision what events are most expressive, however, must be left to the expertise of physicians. The same applies to other application domains, where surely different events will be required for expressively analyzing spatio-temporal data from that domain.

4. Conclusion and future work

In this paper we have described an approach for visualizing temporal data on maps. Our approach is based on the two commonly used concepts: 3D information visualization and information hiding.

We have described intuitive 3D pencil and helix icons capable of both visualizing multiple time dependent data attributes and emphasizing the type of the underlying temporal dependency (i.e. linear or cyclic time). Moreover, we have considered implications of embedding these icons into a 3D map display. These considerations have resulted in enhanced viewing and interactions facilities for the 3D representations space.

In order to address the problem of visualizing large spatio-temporal datasets we followed the information hiding concept. For doing so, we advanced an event-based approach that allows the focusing on events of interest detected in a dataset. This enables to visually guide the users' attention to relevant information (i.e. the events of interest) and to hide irrelevant information. In order to backup our event-based concept, we have demonstrated how maximum events detected in human health data can be visualized by means of space-time paths.

Since we think event-based visualization bears much potential, we will focus on generalizing the concept of explicit event visualization in the future. This will go along with advancing the formalism of event-based visualization and the development of further techniques for visualizing events explicitly. For doing so, it is planned to cooperate with domain experts to determine the efficiency of our methods.

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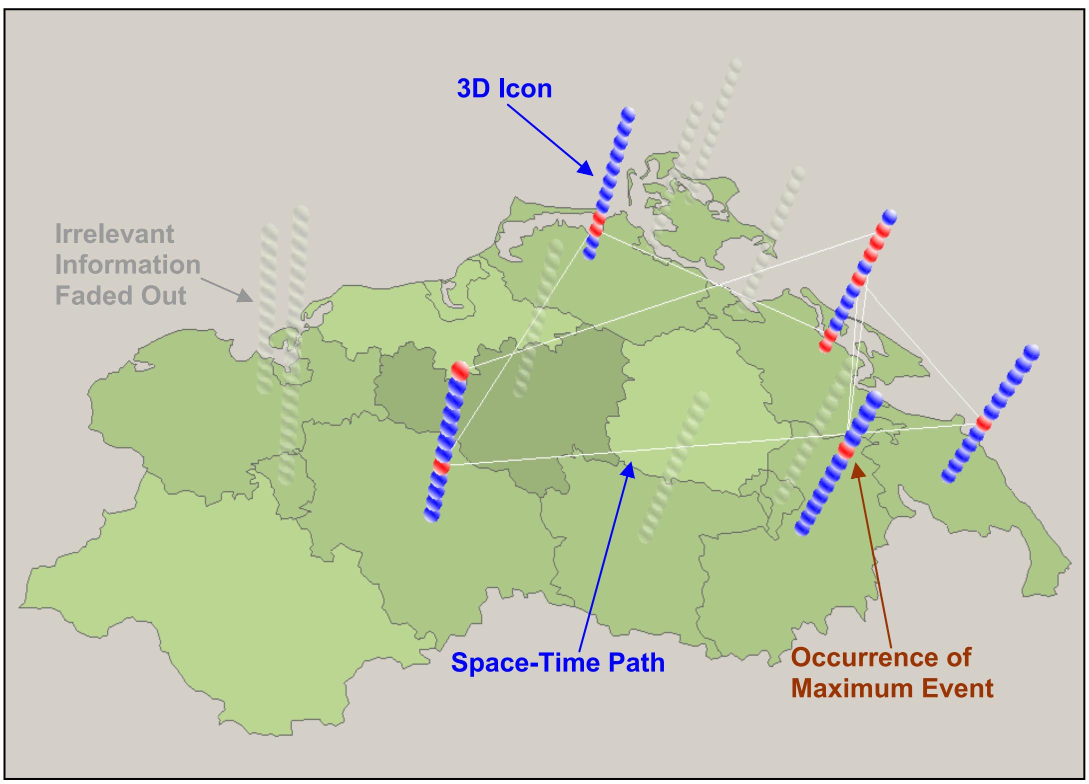

Figure 4. Representing maximum events by means of 3D icons and a space-time path.