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Illustrative visualization of time-varying features in spatio-temporal data☆

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ABSTRACT

Identifying and analyzing the time-varying features is important for understanding the spatio-temporal datasets. While there are numerous studies on illustrative visualization, existing solutions can hardly show subtle variations in a temporal dataset. This paper introduces a novel illustrative visualization scheme that employs temporal filtering techniques to disclose desired tiny features, which are further enhanced by an adaptive temporal illustration technique. The unconcerned context can be suppressed in a similar fashion. We develop a visual exploration system that empowers users to interactively manipulate and analyze temporal features. The experimental results on a mobile calling data demonstrate the effectivity and usefulness of our method.

1. Introduction

Exploring and analyzing features in the highly complex datasets is still a significant challenge in visualization. It becomes more difficult and complicated when dealing with spatio-temporal data, due to the need for analysis across time steps to present the temporal evolution of the patterns. These hidden temporal patterns often convey important cues for data understanding and decision making. Visual presentation of the temporal data is an important tool for revealing such patterns.

Over the past decades, many visualization methods have been developed to depict the evolution of spatio-temporal data [1]. Traditionally these methods could be roughly divided into two categories: animations or snapshots of individual time steps. Animation offers viewers an intuitive and overall feeling of time-varying phenomena, alleviating the trouble of limited screen space. Snapshots facilitate observers to simultaneously track multiple features and compare the features in detail. Defining, detecting, and analyzing these features are core tasks in these techniques and lots of these methods have performed well in many applications. However, all these techniques have a limited spatio-temporal sensitivity and thereby are not qualified for dealing with many patterns whose intensity fall below this capacity. For example, it has been disclosed [2] that the human mobility shows strong periodic spatio-temporal patterns at a large scale. However, city managers may want to understand the mobility of a specific group in a small region to plan urban service facilities more rationally. For another example, the department of environmental protection hopes to find out the source of local air pollution accurately in order to deal with pollution more quickly and reduce complaints from residents. These spatio-temporal patterns are subtle and may occur at different spatio-temporal frequency scales. We need a novel mechanism like a microscope to magnify and reveal these invisible structures while leaving the surrounding large structure unchanged.

Illustrative visualization has attracted much attention due to its capability of enhancing visual expressiveness [3]. Different from traditional photo-realistic rendering, these methods aim to convey the characteristics of the datasets through exploiting artistic abstractions and highlighting the features of interest in focus while compressing the unconcerned context. A variety of illustrative techniques have also been developed for time-varying data, such as motion blur, strobe silhouettes [4], faded representations of older positions, speedlines, flow ribbons [5], temporal style transfer functions (TSTF) [6], and so on. They are designed mainly for indicating histories and evolution of the data. Although these advances in illustrative visualization have resulted in techniques capable of efficiently extracting the temporal patterns, the problems of efficient abstraction and display of subtle temporal patterns are still remaining, for none of these techniques are targeted to subtle temporal cues and cannot successfully isolate and identify these subtle patterns from their surroundings.

Inspired by the work of Wu et al. [7], we present a novel illustrative visualization method based on an adaptive feature identification and

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magnification scheme for spatiotemporal data. In our method, the patterns evolving at some desired temporal frequencies are detected after a filtering in the frequency domain, then enhanced by an adaptive modulation scheme. Our method is best suited to reveal small temporal patterns in regions with low spatial frequency. We have also designed an interactive visualization system to facilitate users to analyze spatiotemporal data with our algorithm. With the assist of the system, users can easily locate one or multiple regions of interest in the data by simple interactions. The ratio of magnification for various temporal frequencies and various regions can also be simply set through an interface similar to transfer function.

Our method can be considered as a new temporal illustrative technique in spatiotemporal data and provides a new analytical means for experts in spatiotemporal data analysis and other domains. To the best of our knowledge, we are the first to study the detection of the subtle patterns in spatiotemporal visualization by the techniques of signal filtering and magnification. We anticipate potential applications of our system ranging from engineering diagnosis or mechanism discovery to social security analysis and decision making. Our contributions include:

- A novel illustrative visualization scheme that enhances and reveals subtle temporal evolutions of the spatiotemporal in an adaptive fashion.
- A visual exploration system that allows for preview, specification, and modulation of temporally illustrative visualization for spatiotemporal data.

We begin the paper by summarizing related work in Section 2. Section 3 gives the overview and fundamental design requirements of our system, Section 4 describes the underlying algorithms used to magnify and reveal patterns in the spatiotemporal field, while Section 5 presents a visual exploration system. Section 6 states the evaluation of our approach and some directions for future work are discussed in Section 7. Finally, The paper is concluded in Section 8.

2. Related works

Our work is closely related to temporal data visualization and illustrative visualization.

2.1. Temporal data visualization

Temporal data has been strongly investigated in both scientific and information visualization. Aigner et al. [1] have systematically surveyed representative works in this area.

Features in scientific visualization have been defined and abstracted by several means. One strategy is to model changes in value over time directly, just like Time Activity Curve (TAC), which collects the time series data at each sample point. Fang et al. [8] used TACs to detect regions of interest and classified data in the spatial domain. Lee et al. [9] presented a TAC-based distance field for probing the evolution of features. Statistical summaries can be considered as another important feature of the time-varying datasets. Guided by Time Histogram, Akiba et al. [10] presented an importance-driven approach to automatically focus on features within a time-varying volume. A notable recent effort in temporal data visualization is to select salient time steps from the datasets. Tong et al. [11] proposed a technique for finding representative time steps using a global optimization scheme. In addition to the above-mentioned techniques, interface and techniques from visualization could be beneficial for identifying data relationships over time. Gu and Wang [12] developed a graph-based user interface to capture some transition properties over time. Frey and Ertl [13] adaptively select time steps based on the optimization of the coverage of the complete data. Streamstory [14] combined machine learning techniques and graph-based visualization to explore multivariate time series.

Recently, techniques for analyzing relationships among spatio-temporal data was much concerned. Multiple coordinated views were often employed in this process. Jern and Franzen [15] adopted a parallel coordinate as a time axis, together with a succession of heatmaps to show evolution over time. Ivanov et al. [16] presented a system which connected a timeline view to a map and a camera view, for efficient monitoring data collected from surveillance cameras. Some authors visualized the spatial and temporal information in an integrated view. One of the most popular methods is the 3D space-time cube [17], which expresses space as a 2D map and time as the third dimension. In Storygraph [18,19] two vertical axes represent the latitude and longitude of the location while the horizontal axis represents time. Sometimes, integrated spatio-temporal views will be further hybridized with multiple views to provide users supplementary information, leading to a hybrid-views based visualization [20–22].

The data in information visualization can be divided into two categories: linear time data or cyclic time ones. Line chart and its variations [23–25] are the most popular techniques for visualizing linear time series, which encode time and value with positions. Another commonly-used technique for visualizing time-series is stacked graph, such as ThemeRiver [26], which describes thematic variations over time within a set of documents. In some scenarios(e.g., for decision making), branching time visualization [27] is needed, where more than one timelines branch out, which enables us to depict and compare the alternative scenarios. Our paper focuses on identifying some cyclic patterns evolving in some specific frequency bands. The Spiral Graph [28] is a well-known technique to analyze cyclic structures with a spirally shaped time axis. By interactively adjusting the length of per unit time in this axis, the explorer can easily find cyclic cues in the data. Growth Ring Maps [29] is another similar circular structure for detecting cyclic events in time-series data. In addition, other data structures and display tools, such as 2D data array [30], have been developed to explore these recurrent patterns.

2.2. Illustrative visualization

Illustrative visualization has been proven useful in visual abstraction due to its ability to emphasize important features while hiding irrelevant details.

Researchers have adapted various visual cues to enhance the perception of features and details. The common techniques are as follows.

- **Color:** Representatives for color-based illustrations include changing hue [31,32], modulation of saturation [33], adjustment of opacity [34,35], and so on. Color can be often employed to convey changes over time, e.g. indicating regions of rapid change with warm color [36].
- **Texture:** Texture is very suitable for describing the structure of the surface. It was often developed for displaying layered information [37], expressing the shape of surfaces [38], conveying the distance between structures [39] and visualizing multiple data fields on the same surface [40].
- **Depth:** Often, halos [41] are employed to convey depth information for the opaque object. Recently, Zheng et al. [42] enhanced depth perception by comprehensive consideration of multiple quantities including depth, transparency, and faithfulness measures.
- **Artistic techniques:** Artistic style methods, such as line drawing [43,44], stippling [45], hatching [31], are important in illustrative visualization, for they use relatively small number of pixels, thus alleviating the problem of occluding inner structures. Some other techniques, for instance, speedlines, ribbons and strobe silhouettes [5] are proved stronger indicators of variation over time in the time-varying datasets.
- **Deformation:** Deformation [46,47] can resolve the occlusion problem through dissections, cuts and other forms of manipulations. It