

VISUALIZATION SYSTEM OF SPATIAL-TEMPORAL INFORMATION FOR HISTORIC SITES BASED ON GIS

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Abstract: A historic site shows different times in a space by reflecting the social values, economic conditions, and culture of a particular period. However, current paper-based static documents, such as descriptive lists, words, and simple marked maps, for describing the historic sites are lack the capability to depict the meanings and changes of the historic sites in a spatial and temporal manner. When integrated with advanced visualization tools, GIS can become a very effective tool for analyzing and representing complex data. The event-based spatial-temporal data model (ESTDM) that has recently been proposed by Peuquet and Duan (1995) is useful in representing the spatial-temporal database. However, in the ESTDM, each event representation is static and fragmented, even though it must still be captured and integrated in a temporal manner. Therefore, in this paper, we discuss the visualization of spatial-temporal information as a way of describing and representing the past in several historic sites. We focus on improving the so-called "ST-ESTDM" (Smooth-Timing Event-based Spatial-Temporal Data Model) to overcome the disadvantage of ESTDM mentioned above. We develop a GIS-based system prototype for Taiwanese historic sites to exemplify our concepts and methodology.

Keywords: Visualization, Spatial-Temporal Data, Historic Sites, GIS

1 INTRODUCTION

Historic sites are proof of history. A historic site shows different times in a space by reflecting social values, economic conditions, and culture of a particular period. Documenting historic sites is important because it preserves information that allows future generations to learn from the past. A rich architectural and urban heritage may provide designers the solutions to various problems (Koshak and Gross, 1998).

Documentations related to historic sites, in general, describe the sites' spatial structures, characteristics, categories, value of arts, educational meanings, and the consequences of changes in the historic site (Shi, 2000). However, most of the traditional documents take the form of descriptive lists, words, or simple marked maps. These are paper-based static media, even though the information of historic sites belongs to a structure of dynamic spatial-temporal data that dynamically links the place with a specific time. Using the traditional ways of documentation we cannot fully describe the events that have occurred, the reasons for their occurrences, their impact on historic buildings, and the evolution of the historic buildings. In other words, paper-based static methods lack the ability to reflect the meanings and changes of the historic sites in a spatial and temporal manner.

Orford et al. (1999) review recent literature and Internet sources on visualization and discuss four advanced visualization technologies: the World Wide Web (WWW), multimedia, virtual reality (VR) and computer graphics. They also claim that when integrated with advanced visualization tools, Geographic Information Systems (GIS) can become a very effective tool for analyzing and representing complex data. GIS integrated databases with geo-referenced spatial-temporal data are called 'Temporal-GIS'. Worboys (1998) suggests that a temporal information system must include a history of changes in the application world. Peuquet and Duan (1995) propose an event-based spatiotemporal data model (ESTDM) that is based on the TRIAD GIS database framework represented in Peuquet (1994). The ESTDM organizes event changes under an event list that is composed of individual event entries. This model is a raster based model that uses a collection of time-stamped layers to represent temporal information from an event; when an event occurs, changes are discovered and stored in an event map. However, in the ESTDM, each event representation is static and fragmented, even though it still needs to be captured and integrated in continuously in a temporal manner.

In this paper, we discuss the visualization of spatial-temporal information to describe and represent events that have occurred in several specific historic sites. We focus on making the so-called 'ST-ESTDM' (Smooth-Timing Event-based Spatial-Temporal Model) methodology to overcome the shortcomings of the ESTDM mentioned above. To illustrate our concepts and the new methodology, we develop a visualization system prototype for three Taiwanese historic sites to represent the spatial-temporal data using the API (Application Programming Interface) of the ArcView GIS software.

2 Background

2.1 Recent Developments in Visualization

Changes in visualization technology in the past decade have profoundly affected the way in which the sciences are researched and the ways in which studies are communicated (Orford et al., 1999). Interactive, multidimensional, and animated data-representation tools can help improve business process and the bottom line (Adams, 2003). Especially when integrated with advanced visualization tools, GIS can become very effective in the analysis and presentation of complex data such as spatial-temporal information (Orford et al., 1999). The following is a review and summary of recent developments in visualization technologies.

The most common and basic method of data visualization is basic charting. Pie, bar, and line charts help the audience quickly identify general upward and downward trends as well as identify groups within the data that are performing differently than other groups. These basic charts are typically used to display the relative performance of key dimensions such as historic events, timelines, and geographic regions. Instead of looking at a tabular list of numbers, the audience can literally see how data relates to other data (Adams, 2003).

Multimedia is the use of more than one medium such as text, still graphics, sound, animation, and video to represent and convey information. It gives users control over the order in which they see or hear this information. In its current use, multimedia always implies the use of a computer and almost always implies interactivity between the computer and users. Lately, researchers also have started using "texture" for data visualization, the rationale being to exploit the sensitivity of the human visual system to texture in order to overcome the limitations inherent in the display of multidimensional data (Rao and Lohse, 1996).

3D Virtual Reality (VR) is a computer-generated artificial environment in which the user is projected into a sensation of 3D spaces. There are two types of 3D VR. The first is the total immersion system where the users wear VR equipment that interacts with special software, giving interactive tactile and multi-sensory feelings that are similar to real world experiences. The second type of 3D VR simulations is used to train pilots or astronauts. Special equipment is not worn but the users place themselves not physically but visually in a 3D virtual computer environment (Deuchar, 2003). An important area of visualization in GIS is the integration of 3D visualization technology. Standard elements of GIS can imply 3D representation, but new techniques in multimedia, 3D modeling and VR now are at the point where they might be embodied within GIS. 3D visualization capabilities can be added to ArcView by using VRML and custom-written Avenue scripts (Orford et al., 1999).

Animation is the production of consecutive images, which, when displayed, convey a feeling of motion. Animated images are almost magical in their ability to capture our imagination. Each individual image, or frame, in the animated sequence must blend seamlessly with the other images to create smooth and continuous motion that flows through time. The most basic computer animation tools automatically generate some of the frames of

animation. Animation tools have also been developed to composite together multiple layers of a scene in much the same way that layers of cells are used in manual animation. Other more powerful techniques make use of algorithms that render an image from a geometric description of the scene. These techniques change the task from drawing sequences of images to using computer tools to specify how those images should change over time (Hodgins et al., 1999).

2.2 Spatial-Temporal Data Models

“Spatial-temporal data is the records of spatial data changes in a period of time. It was process complex phenomenon at the interaction between time and space” (Peuquet, 1994). Spatial-temporal data was increased with time, so we can call “time- sequence object” for every spatial-temporal data. The length of time sequence is the time state, and there are some specific events occurred during the time sequence (Langran and Chrisman, 1988).

A spatial-temporal object is comprised of three components: spatial, temporal, and non spatial-temporal (descriptive) component. To represent a spatial object in a spatial-temporal data model we need to define these three components for each spatial object. This means we would have to identify the “what”, “where” and “when” for each object. All three of these components need to be addressed in order to identify each object in a spatial-temporal data model. The temporal component in a spatial-temporal data model is the most significant of the three components. When examining changes in spatial data, we are essentially examining the non-temporal components of a spatial object, such as geometry, topology and attribute data. However, these attributes and geometric relationships in the data are influenced by time. Time defines the current attributes of a spatial object, the geometric relationships that are present and the changes that have occurred to that object. If time is incorporated as a component of a geographical object, the possibilities of analyzing an object over time and keeping track of the object’s history are greatly increased (Leslie et al. 2001). The following is a review of recent developments in spatial-temporal data models.

GIS stands for Geographic Information Systems, a method of managing, analyzing, and displaying geographic information on easily understood, computer-generated maps. Many GIS data models have been proposed to incorporate temporal information into spatial databases. Their general frameworks, with little considerations of data needs for spatial-temporal modelling, use a set of geometry-based spatial objects to represent reality. A rigorous data model must anticipate spatiotemporal queries and analytical methods that are to be performed in the temporal GIS. Information about temporal constructs must be represented by data objects defined in data models to be stored or retrieved for analysis in a GIS (Segev and Shoshani, 1993). Computer scientists have proposed methods to incorporate temporal information into a relational database by time-stamping a relation (Yuan, M., 1996).

Another important model is the snapshot model. In this model every layer is a collection of temporally homogeneous units of one theme (Figure 1). The model shows the states of a geographic distribution at different times without revealing the explicit temporal relations among layers. Time intervals between any two layers may vary and there is no implication for whether changes occur within the time lag of any two layers. The Temporal Map Sets (TMS) model can be seen as extensions of the snapshot model. The design of TMS purports to model geographic events in a defined area (Figure 2). Events are defined as binary TMSs, specifying whether each cell is inside or outside of the event. These snapshot approaches always result in a large amount of data duplication with unchanged properties in space and time. The major drawback is data redundancy and the risk of data inconsistency (Yuan, 1996).

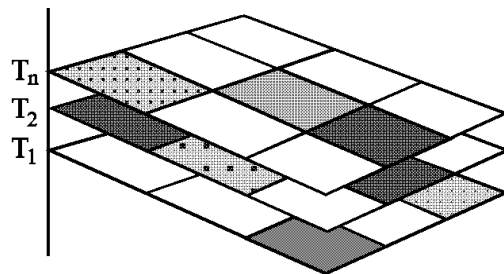


Figure 1: An example of the snapshot model

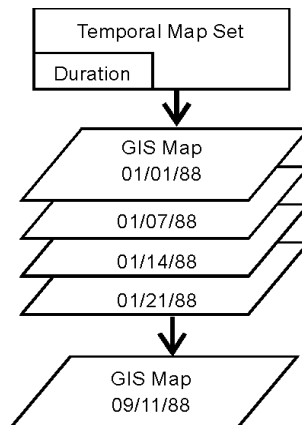


Figure 2: An example of a TMS model

ESTDM (Event-based Spatial-Temporal Data Model) model, like TMS, is a raster based model that uses a collection of time-stamped layer to represent temporal information from an event. Peuquet and Duan (1995) propose an ESTDM (Figure 3) that is based on the TRIAD GIS database framework presented in Peuquet (1994). The ESTDM organizes the changes under an event list that is composed of individual event entries. Each event entry has a

time stamp and consists of a set of components. A component stores the new value of all grid cells that experienced changes of a specific attribute from $t(i-1)$ to $t(i)$ and the locations of grid cells that changed to the new value. Run-length encoding is employed to store the locations of grid cells with changing values as token arrays in order to reduce the storage space requirement. Each grid cell is equivalent to the smallest spatial feature stored in the space-time composite model that permits the storage of its change history. The ESTDM also includes a header file with a time stamp of $t(0)$ pointing to the base raster layer of the initial state of the entire study area. This design allows the ESTDM to record only amendments with respect to the initial and previous states.

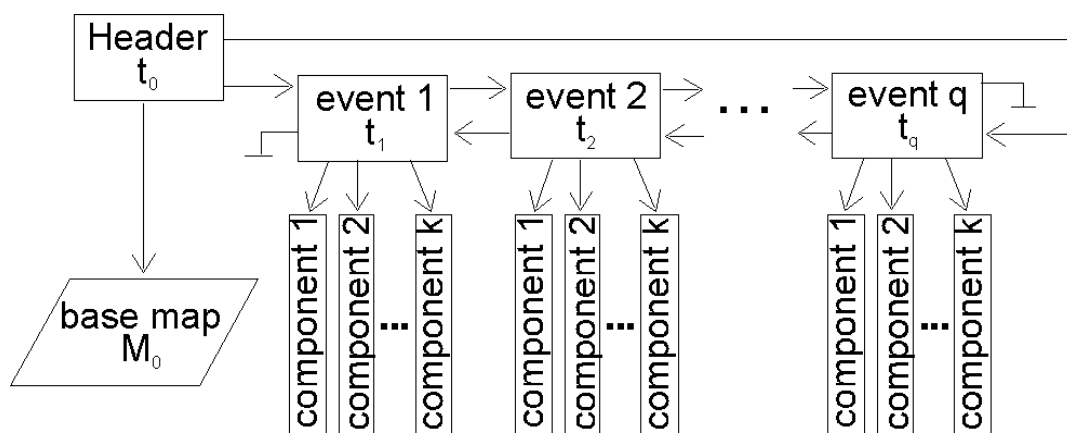


Figure 3: Primary elements and the pointer structure of an ESTDM (Peuquet and Duan, 1995)

The ESTDM was designed to facilitate analysis of temporal relationships and patterns of change over time. It was not designed solely to address the problem of modelling changes of historic sites, but it can apply to this problem because it is a spatial-temporal model. It enables queries which retrieve locations that have changed to a given value at a given time, queries to retrieve events that changed to a given value over a given time interval. Although the ESTDM, like the snapshot model, still uses time-stamped layers, its advantages over the snapshot model include the ability to perform temporal manipulations on data and the ability to compare temporal data in a sequential manner. The ESTDM also reduces the storage of redundant data because it does not repeatedly store data that has not changed (Peuquet et al., 1995). Shortcomings of the ESTDM include difficulties in modelling changes to topology or spatial information and the model's limitation to using raster or point data versus vector data. In addition, there is the problem of retrieving historical data (Yuan, 1996).

3 Methodology

3.1 Enhancing the ESTDM: ST-ESTDM

The concepts described above about the ESTDM model are generally useful in the design and implementation of our spatial-temporal data model. However, the ESTDM model represents the components of events with static mode; when each event changes, it changes suddenly like the traffic light so that it is impossible to know when the light will change. The result of representing historic information of an entity or process will be fragmented when changes occur, and the temporal data cannot be exactly represented for each historic event.

To solve this problem, we improve the existing ESTDM and we call it “ST-ESTDM” (Smooth-Timing Event-based Spatial-Temporal Data Model). Figure 4 shows the concept of the ST-ESTDM.

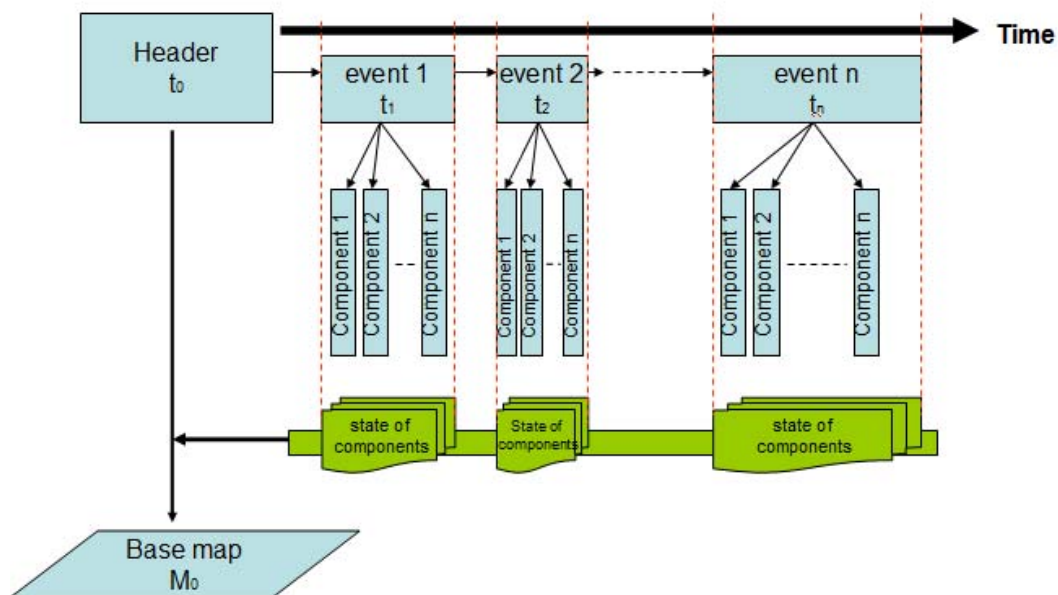


Figure 4: Smooth-Timing ESTDM (ST-ESTDM)

In the ST-ESTDM, each component of an event is considered as spatial-temporal data, each of which has its own time attribute. ST-ESTDM deals with the state of component to indicate when changes have occurred in the event. ST-ESTDM can show the time range and the current situation of the component. Therefore, when an event occurs, each component is represented in the dynamic mode so that any changes can clearly and smoothly represent a period of time. The quality of smooth timing depends on the time unit. If the time unit is small enough, the representation of spatial-temporal data will more detailed and smooth.

3.2 Spatial-Temporal Database of Historic Sites

The history of a historic site needs to be tracked and analyzed in order to correlate changes with carbon storage. As mentioned before, a spatial-temporal object consists of three components: spatial, temporal and descriptive. Therefore, for a historic site, the data can be separated into three components. Figure 5 shows an ER (Entity Relationship) model of the three components of the spatial-temporal database for a historic site.

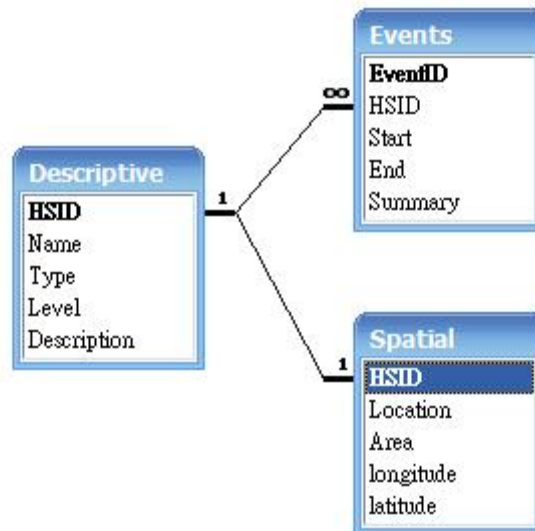


Figure 5: ER-model of spatial-temporal database of historic sites

The spatial component consists of the location and architecture of historical site. It shows the realism of the historic site. In general, pictures or 3D modelling of historic buildings and base maps are used to display the location and information of historic sites. The temporal component consists of the events that have occurred in historic sites, which are related to specific times. This information can be implemented by time slider bars, charts, and animation to depict information of temporal data of historic sites. Finally, the descriptive component of historic sites is information such as the name, type, class, address, and date of creation. Any attributes that do not relate to spatial or temporal data belong here. The spatial-temporal data of historic sites resides in a relational database, which means that if a value of field is changed, other data tables that relate to this value of field will change automatically. This can avoid the inaccurate processing of data.

4 Prototype Implementation

4.1 System Framework

Our system is divided into four parts: a database module, a snapshot module, a ST-ESTDM module, and a graphical user interface (GUI) module. Figure 6 shows the framework of our system.

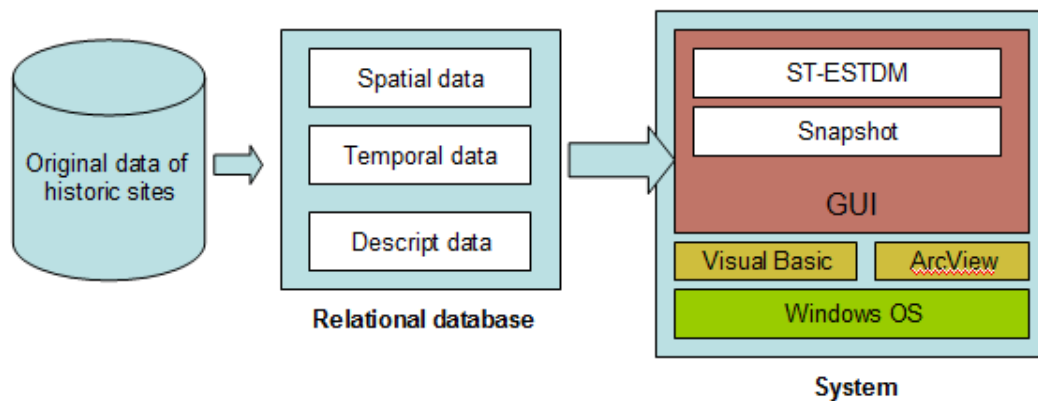


Figure 6: Framework of the Spatial-Temporal Information System for Historic Sites

In order to gather the information of historic sites, the domain expert was interviewed and a literature review was conducted. The information is separated into three parts: spatial, temporal and descriptive, and stored in a relational database, Access software.

We used the ArcObjects software components that comes with ArcView (from ESRI) software to build a prototype implementation of the proposed system framework. ArcView is desktop GIS software that provides geographic data visualization, mapping, management, and analysis. The ArcView software also offers the ActiveX for Visual Basic, thus the Visual Basic can readily use the ArcView's features to develop our application.

4.2 System Interface

The GUI (Figure 7) of our system includes three parts: (A) Visualization of historic sites on the map; (B) 3D Model of historic sites; and (C) Chart of events of historic sites. The three parts are described below in detail.

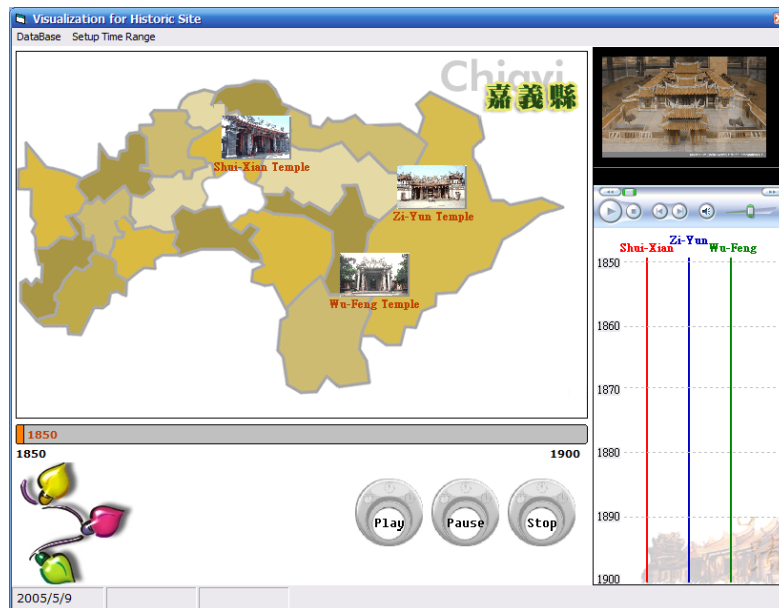


Figure 7: Prototype system interface

A user can start with the first phase, historic sites on the map (part A). When the user inputs the start and the end date (e.g., from 1850 to 1900) and hits the 'play' button, the system displays the information of historic sites to represent the spatial-temporal data. As the time passes, the system checks the historic events of the sites and displays the information on the map (Figure 8). The information includes the picture, name, the spatial location, and historic events for each site. Since every event has its own time range and current state, the interface can represent and compare the spatial-temporal information with other historic sites much more clearly.

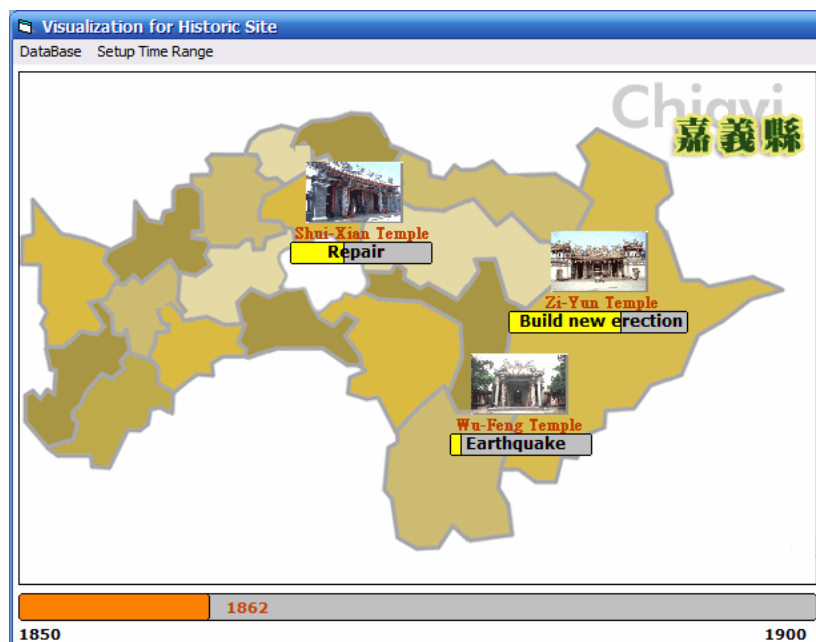


Figure 8: Visualization of historic sites on the map

The 3D model of historic sites (part B) is designed to represent the appearance of historic sites with 360 degree vision. When the user clicks the picture of historic site on the map, it shows the 3D model (Figure 9) of the selected building in the given area. The user can scroll the bar to decide the viewpoint manually or just by clicking on the 'play' button for looping presentation.



Figure 9: 3D model of a historic site

Each historic site has a vertical timeline (chart) representing events (part C). When the event occurred, a square adds on the timeline to represent the information of event. It shows the summary of event between historic sites, and also shows the record of events occurred at historic sites (Figure 10).

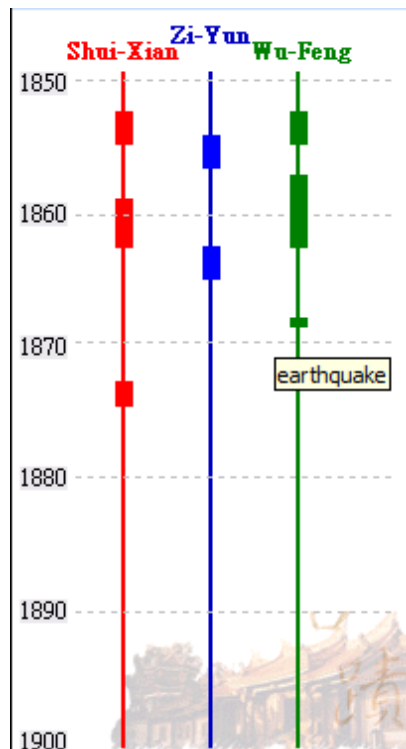


Figure 10: Chart of events of historic sites

5 Conclusion

In this paper we describe visualization of spatial-temporal information to represent the event that occurred in the historic sites. We also suggest a methodology for improving the so-called ST-ESTDM to compensate for the disadvantages of the ESTDM. This new tool can dynamically and smoothly represent the spatial-temporal data. It is a promising application for the visualization of historic sites because the system can give the user more detailed information of spatial-temporal data of historic sites so that, for both educational and commercial applications, the user can understand the changes in the historical sites clearly and quickly. It is also a good analytical tool for the maintainer of historic sites because the system can offer the current state and past records for maintaining of each historic site so that the administrator can more efficiently determine the maintenance schedule.

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