The History of Temporal Data Visualization and a Proposed Event Centric Timeline Visualization Model

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ABSTRACT
Temporal data management has an ancient history. From the earliest days people are using timeline (a way of displaying a list of events in chronological order) to record their transaction data in a log file or table and often those files or tables are used by researchers to understand the events or trends of the transaction. The first attempt to illustrate chronological events graphically was made in 1765 and presently timeline is used ubiquitously. This paper attempts to explain the history and present state of timeline visualization and proposes a timeline visualization model that provides a new perspective on the existing models. We showed the development of timeline visualization of temporal data over decades, evaluated different techniques, connected and presented them in sequential order to justify the importance of our proposed technique. Our study is structured in three parts: First we discussed different methods of management and visualization of temporal data, then we showed the history and current state of timeline visualization and finally we proposed a timeline visualization technique. [1]

General Terms
Data Visualization, Timeline.

Keywords
Timeline Visualization, Temporal Data, Temporal Data Management.

1. INTRODUCTION
The word Timeline states a graphical representation of a chronological sequence of events. We can also state timeline is line that shows what someone has achieved over time. Many researchers have been working on timeline from the past decays and their contributions helped us to understand the importance of timeline.

Back in past, Vannevar Bush's vision of Memory Index (Memex) in 1945 has come across a long way paving numerous fields of applications. Surprising enough was the use of the term memory. A memory of oneself does not go around the time, but along the time, though still erratic when we try to remember them. A lexical definition of Chronology is the science of arranging events in time by their order of occurrence. It was not until 1583 when the modern science of chronology was introduced by Joseph Scaliger [20] in his famous book "De emendatione temporum". However, the visualization of chronology was not in its infancy in those early times. Shoshani and Kawagoe in 1986 [12] described a framework for the management of temporal data. Their work introduced the concept of time sequence for representing the semantics of temporal data. Therefore, they first introduced the idea of time-value pair, basically a two dimensional time sequence array (TSA), stored in the databases were to be extracted, sequenced and represented with the semantics of time. Later, Rotem and Segev [19] proposed a multi-dimensional partitioning scheme in 1987. These works leveraged the necessary frameworks for the organization and management of time-oriented data.

Nowadays famous social networks like twitter, facebook, google plus etc. have introduced new features in the form of timeline that presents all actions of a user on the network in a chronological manner, scrolling from the present day back to his/her birth.

From the above discussion, we can recognize the significance of timeline to represent temporal data. In this research, the first two sections describe the management and visualization of temporal data to understand the importance of timeline to present temporal data. We discussed a brief history of timeline visualization in the following section. Then the subsequent section illustrates the recent researches on timeline and the limitations in existing visualization techniques where our proposed model is introduced. Finally, we presented our proposed data visualization model and timeline visualization technique in the last section. Event centric works are not discussed separately since they essentially come as historical or temporal data in one way or the other.

2. MANAGEMENT OF TEMPORAL DATA
The temporal property of an object has successive meaningful and recorded values [35]. Values of temporal properties are histories, i.e. functions from a finite set of instances observed from certain granularity. They have both temporal and structural domains [8]. Eric Freeman and David Gelernter [24] materialized the organization of user collections in the line of time, having the objects being temporally characterized. The work was first proposed by David Gelernter [18] and described in [3]. This organizational metaphor subsumes many desktop metaphors cumulating in a single application (Figure 1).

[1]This work has been partially done during the PhD thesis research of Hasan K. T. under the title "A User Centric Interface for the Management of Past, Present and Future Events" at the University of Trento, Italy in 2011[45].

The documents are arranged in a time-oriented stream. Features are being fascinated by using colors and animations. The borders of unread documents are made red while the writable ones are being made thicker. Open documents are slid out to left of the stream. Newly created documents are popped from the top pushing back the stream by one document. They used the concept of substreams, virtual directories created upon user search queries that provide an organizational framework for finding information.

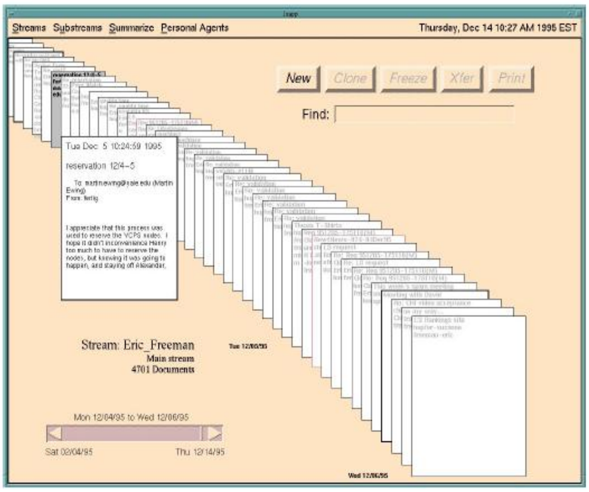

Fig 1: Lifestream interface (organizational metaphor)

Rekimoto's work in [7] went another step toward a time-centric approach for the information environment. This work leads to the concept of time machine computing (TMC) that allows user visit past and future state of computing through the time dimension. The system, called TimeScape Desktop (Figure 2), is a combination of temporal calendar and timeline for automatically archived user content by their temporal properties.

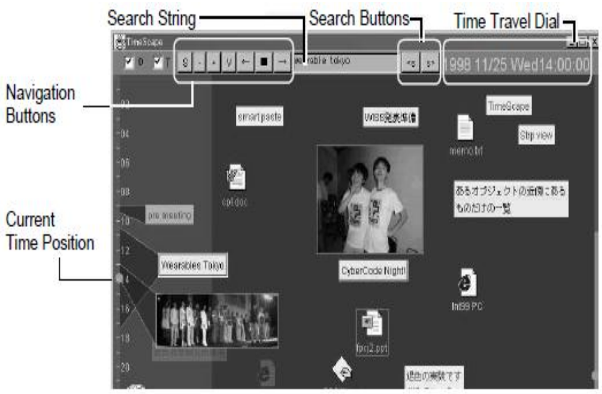

Fig 2: TimeScape desktop interface.

On the other hand, MyLifeBits [28], a project from Microsoft research aimed to fulfill Memex vision in total terms by adopting four principal. It is one step forward to digital mechanism that Bush did not foresee. However, annotations and links, the two fundamental features, were not overlooked by Bush. Hierarchical organizations are too constraining and allow no reference to other forms of query [1] [24]. As an extension from Bush's trail, they argued the use of user constructed story that is laid out in time and space. Apart from aspect, they argued for multi-faceted organization of contents by user annotations.

Events are basically time-oriented happenings or historical data that includes other contextual information. There are other structural domains that describe the events. We examine different cases of time-oriented information visualizations as they provide the foundation of interaction framework in a user centric application. We have dedicated one separate section for timeline visualization that inspired our work in adopting and advancing the best paradigm.

3. VISUALIZATION OF TEMPORAL DATA

There are many visualization techniques proposed in the applications domain like clinical data [9], geographic data [16], hydrometric data [6] and personal history [14]. The visualization techniques differ in two fundamental ways: Timeline View and Calendar View. Therefore, the navigation is exploited in either way provided by the visualization framework.

While calendar is conventionally and extensively used in many applications for accessing temporal information, J. Mackinlay et al [2] proposed a 3D spiral calendar view for temporal data visualization with interactive animations. Time relationships among the schedules of groups are supported through the use of time lattice. A planar spiral technique has been used in [29] for the visualization of periodic patterns of serial data (Figure.3).

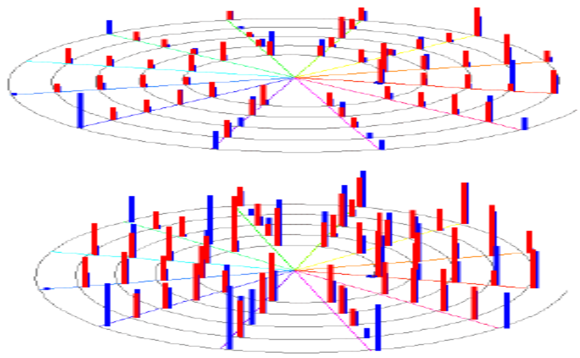

Fig 3: Spiral visualization of serial data.

Likewise, Daniel A. Keim proposed pixel-oriented arrangements in circle segments for visualizing large amount of data on multi-dimension scale [32]. This technique used value to screen pixel corresponding for the visualization (Figure 4).

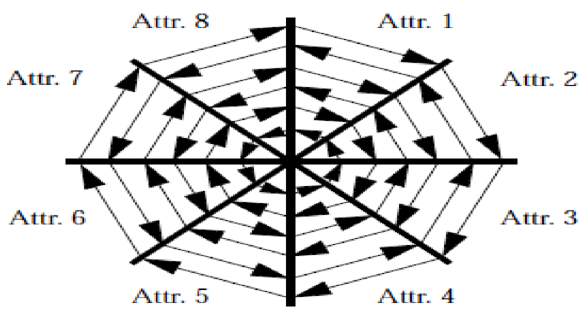

Fig 4: Circle segmented techniques for multi-dimension data visualization.

Kullberg [37] proposed a 3D timeline visualization technique for history photo visualization. TimeSlider, a time navigation technique used for specifying time points in non-linear time scale is a different approach [44].It was an early version for time machine computing developed in NEC, while the TMC [7] was later developed in Sony Corp.

The visual display of time-oriented patient data in [40] addressed two fundamental issues: Granularity problem and Calendar mapping problem. It is incredibly different from LifeStream [24] which was not characterized with these issues. Patient's events are laid out on timeline facilitating the operations - slice, filter, overlay, new and add. They also have provided a formal definition of timeline that would hold the events by offsetting from a null event. Scale, align and mark are seen to be very prominent features in the visualization scheme. Similar work had been done in LifeLines [14] by using the concept of stream lining the access details where the data are presented in multi-timeline.

However, most of the proposed solutions [4], [43], [14], [39], as we found, are timeline visualization of temporal data. This is more natural and intuitive for human to apprehend. From the Chronopsychological point of view, our mental action is not instantaneous but requires a finite state of time [21] and its behavior stays tuned to sequential contingencies afforded by its environment [5]. In many ways we seem to perceive time, though we don't have a genuine sense of time and this gave rise to the question, what exactly we call the perception of time [26]. We have considered this cognitive approach of the perception of time in developing our visualization scheme with the concept of arranging events in the line of time as a series of sequences. Therefore, we move into more detail on timeline visualization in the following section.

4. BRIEF HISTORY OF TIMELINE VISUALIZATION

Cartography, by definition, is the study and practice of making maps. Though initially it meant to be spatial data, later it found its way out to the representation of historical data dated back from 1450. Joseph Priestly in 1765 [8] developed the idea of describing the life span of famous people (1200 BC to 1750 AD) by using horizontal lines along the time scale detailed in the Chart of Biography (Figure 5). This was a very similar work to modern horizontal bar type timeline charts.

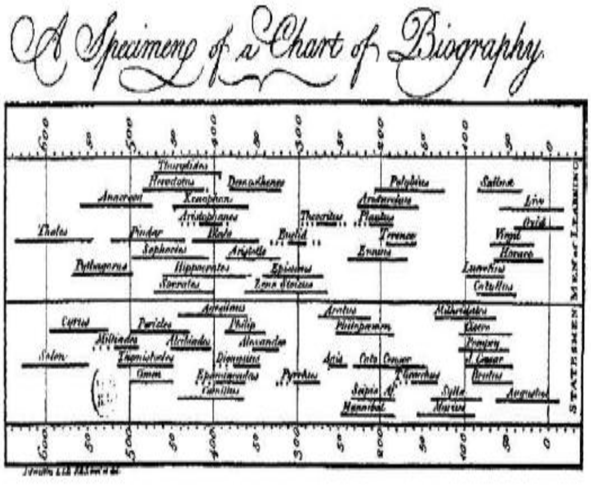

Fig 5: Timeline cartography in Chart of Biography. Source: Priestly, 1765 [31].

However, this is apparent that Playfair's introduction of time series charts and bar charts were influenced by the work of Priestly [25]. Playfair's creation of the chart of trade between England and Ireland from 1700 to 1800 is still a classic historical example (Figure 6). The data was not only temporally aligned, but also the trade volume was shown.

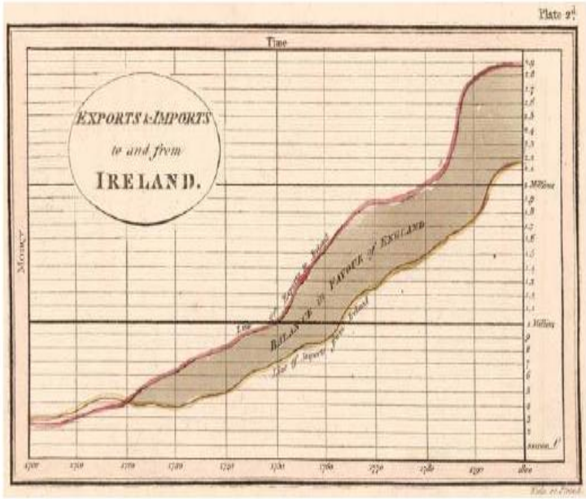

Fig 6: The trade between England and Ireland from 1700 to 1800. Source: Antony Unwin [11].

Charles Minard in 1869 published the map of Nepolian's advance and retreat from Moscow during 1812-1813 campaign (Figure 7). The map reflected several variables of the campaign laid on 2D image, e.g., spatial distribution of army along the campaign, the size of the army as it progressed through time and space and variations in temperature [22]. Though scale of time is compromised, the map is termed as gem of information graphics and was nominated as the World's Champion Graph by Howard Wainer [27].

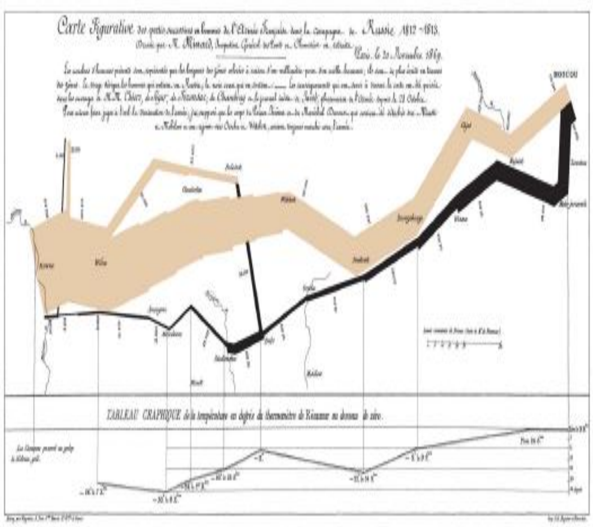

Fig 7: Nepolian's Russian campaign during 1812 to 1813 presented by Minard. Source: Internet

Emma Willard in 1846 published the famous Temple of Time in [23], rendering a three dimensional representation of events with respect to space and time (Figure 8). The relations with other constituents provide a full context of knowledge for any given point of time.

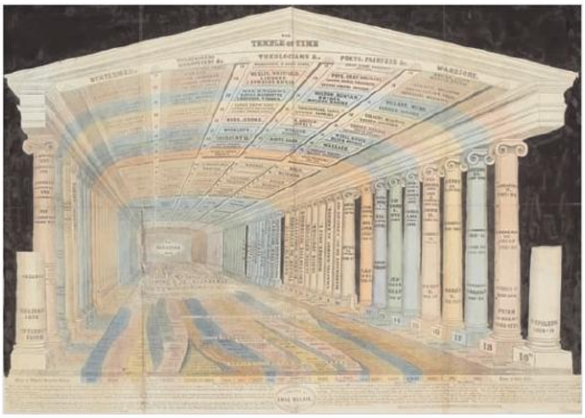

Fig 8: Temple of Time by Emma Willard. Source: Internet.

5. CURRENT STATE OF TIMELINE VISUALIZATION

Several works have already been discussed in the previous section where timeline bars as visualization elements have been used, e.g., [14], [7]. A survey by Silva and Catarci [41] described a detailed account of visualization of linear time oriented data. They tried to address the gap between visual techniques and historical data that includes 2D and 3D representations. Plaisant et al further extended their work of LifeLInes again using timeline visualization technique [13]. Thus, this is agreed [38] that timelines are best understood in the context of other timelines and essentially events are better represented with timelines for their temporal ordering.

However, SIMILE Timeline, a Web based widget is now available for the use of event management and visualization [42]. SIMILE is a joint project conducted by the MIT Libraries and MIT Computer Science and Artificial Intelligence Laboratory. As the project objective described in [36], it seeks to enhance interoperability among digital assets, schemata/vocabularies/ontology, metadata and services. SIMILE Timeline provides the interface (Figure 9) as well as the event management framework. It has drawn much of the researcher's attention and is being used in many state of the art works for chronological data in different applications. Omar Alonso et al used SIMILE Timelines for exploratory search [34], and timeline visualization for search results [33]. The interface is the same as presented in Figure 9.

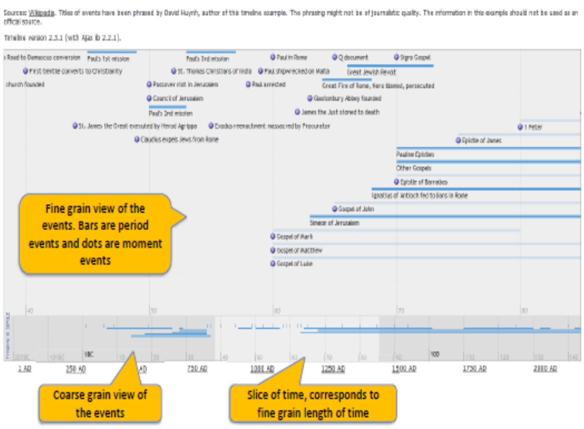

Fig 9: History of Christianity, SIMILE Timeline. Source: SIMILE online Timeline example.

Moreover, a recent work Continuum, [35] addressed the interrelation issues between the events and proposed a coherent user interface facilitating the visualization and the interaction for end users (Figure 10).

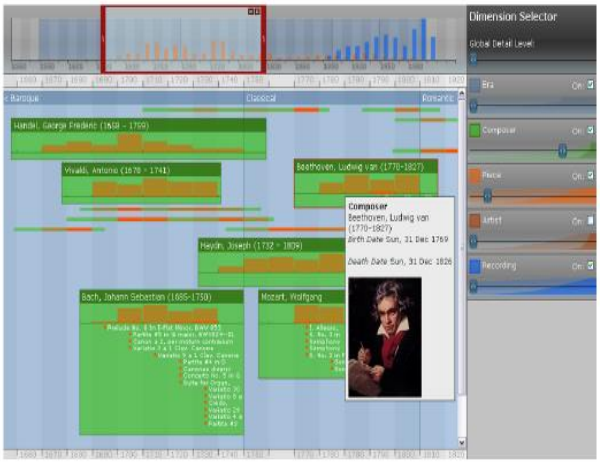

Fig 10: Continuum, a timeline visualization tool for interrelated faceted temporal data.

This work has some interesting features like sub-events, e.g. battles of a war, and being presented as collection of interrelated events maintaining their discrete form in the line of time. Continuum, as it is being termed, enables hierarchical relationship between temporal data. Another intuitive use of timeline visualization for public transport schedule was presented in HCIR 2011[45].

Again, in the year of 2011, R B Allen put forward the issues of causation in history in [10] and provided the schema for visualization. Though with much limitation, he tried to focus on the tapestry of historical events (Figure 11) where associated geo-spatial view is also supported by the interface.

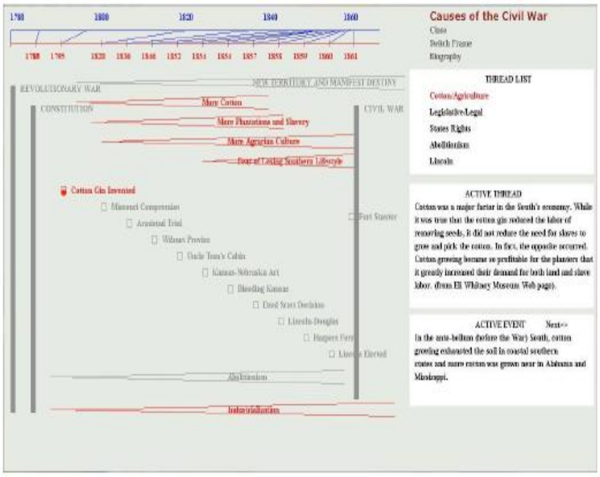

Fig 11: Causes of the American Civil War illustrated in the initial prototype.

This is, however, not an indigenous point where we started our quest for understanding the events in life, instead we tried to make a philosophical inquiry on the subject first, then logically proceeded toward the understanding of events that are amenable to life. Therefore, in the following section, we tried to design a basic visualization model where different levels of events are presented in different bands with specialized symbol for each type of information.

6. PROPOSED TIMELINE VISUALIZATION MODEL

Information visualization is a graphical representation of data meant to reveal complex information at a glance. Successful visualizations are beautiful not only for their aesthetic design, but also the elegant layers of detail that efficiently cumulate insight and new understanding [48]. Chi [47] proposed data state reference model which is taxonomy for information visualization. Previous attempts by the researchers provided solutions which are fairly difficult for the implementers (how to apply them). Chi proposed the visualization process in four steps, e.g., data, point of view on data, visualization space and point of view on visualization space. Chi's work contributed a data to view transformation process which is highly flexible in nature.

We have used similar technique in our visualization model with extra considerations. Though in both cases, data are dynamic, but our interface holds subset of a set/subset for different viewpoints at different granularity, such as events and event clusters. Hence, we have extended the temporal data visualization model as shown in Figure 12.

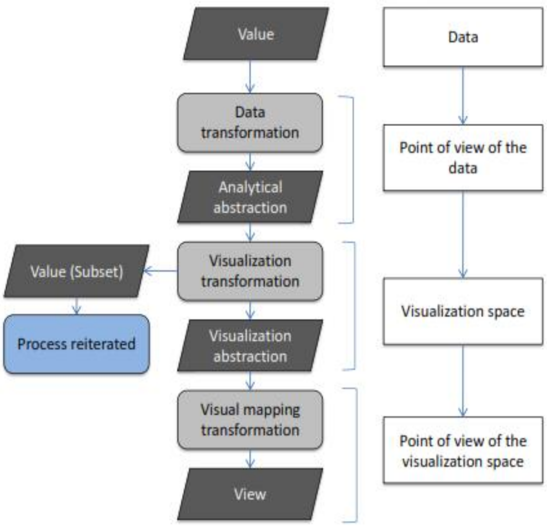

Fig 12: Data visualization model allowing data subset from the time slice of coarse grain view to corresponding fine grain view.

For our work, we have considered laying out event as spots (for moment events) and horizontal bars (for intervals) on a linear absolute time scale i.e. timeline visualization. To facilitate quick navigation, the granularity of the scale is divided in three bands. The lower band is a coarse grain time scale that contains mostly clusters of events, the middle band is a semi-fine grain that contains series of events and the upper band is the fine grain that contains events showing the interior of the events where all bands are zoomable.

Moreover, a calendar view is also available for quick selection and navigation of a bigger to smaller time frame accommodating the user experience with calendars. This option replaces the coarse grain timeline in the lower band. The proposed visualization is illustrated in Figure 13 at different zoom levels.

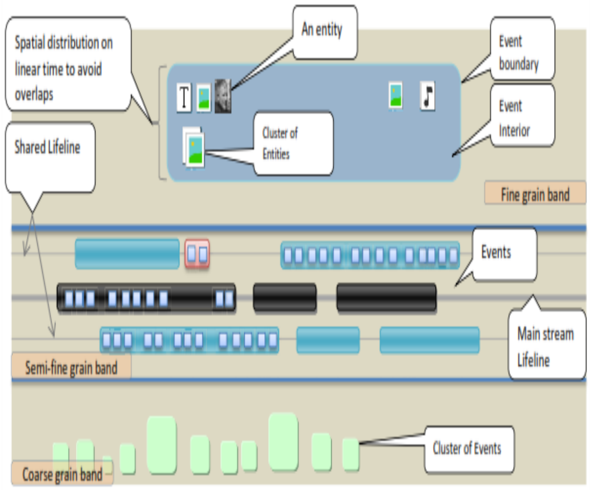

Fig 13: The basic visualization of elements.

The top element to be visualized on Timeline is event aligned along a single lifeline and anything else goes in it. The user's own life events are discretionally colored black, the color of authority. The level of zoom determines if the contents are displayed, clustered or discrete and of course it will depend on the algorithm and its granularity being set.

Here, the cluster of events is visualized on a single horizontal level with temporal distribution. At minimum zoom level, events are rounded rectangles with a fixed height and variable length. Finally at this level, event contents and content groups are shown as small rectangles that hold their temporal and content type property.

7. CONCLUSIONS AND FUTURE WORK

Considering the researches, we have discussed in this paper, it is very clear that visualization of temporal data is not a new idea. People are using timeline visualization techniques for a long period of time. Our study covered timeline visualization models from ancient time to the recent work. We analyzed, compared, evaluated different models, made relation among them and finally we presented them chronologically in this paper.

Nevertheless, the existing models most of the cases focused on philosophical or graphic theme rather than logically proceeding towards the understanding of events considering the temporal data. Therefore, we modified an existing data visualization model and using the modified model, we proposed a basic timeline visualization technique where bands of events and symbolic representation of different types of data were introduced. This technique essentially handles the granularity problems of large temporal data set.

In future we have planned to improve our timeline visualization model where events of user's life will be automatically tagged with a very low interaction with the user.

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