A Temporal Focus + Context Visualization Model for Handling Valid Time Spatial Information

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I. INTRODUCTION

OVER the last decades we have seen considerable developments in enabling technologies concerning the innumerous tasks associated with information: from acquisition to communication and storage, from processing to presentation and manipulation. Accomplishments in areas such as remote sensing and automated data acquisition, networks and hardware, alphanumeric and spatial database management systems, information and scientific visualization have been pushing forward the requirements of today's information systems for many domains of human activity.

One of these requirements concerns the efficient management of information over time. This is a consequence of the intrinsic temporal nature events, whether they result from natural causes or from human activity. From the perspective of data management, alphanumeric and spatial databases have provided a solid and robust means of keeping track of the most recent state of things for any particular application domain. Consequently, such databases perform a critical role in the management of data in most of today information systems.

However, many applications require that, besides the most recent state, all the previous temporal states are kept. Alphanumeric and spatial databases have pushed the burden of temporal data management to the application layer, due to the lack of proper temporal data types, temporal operators and functions, temporal indexes and temporal query language extensions leading to undesired complexity and performance problems.

The last decade has witnessed the fast development on temporal data management, resulting in approaches for most of the issues above in several temporal database prototype systems with support for *valid time* (Richard T. Snodgrass 1996), and more seldom *transaction time* (R. Snodgrass 1996), continuous change or discrete changes, historic-temporal support or predictive support.

These accomplishments have a direct impact on how information is represented, kept and queried in emerging temporal database management systems (Jensen 2000). Among other application domains, those that handle geographical or geo-spatial information benefit from full temporal database support, allowing efficient representation, management and access of information on evolution of spatial objects. Moreover these new possibilities raise interesting issues regarding the visualization of spatio-temporal information directly supported by database management systems. Datasets resulting from a database query can describe the spatio-temporal evolution for distinct objects, where each object is described through several non-overlaping timestamped rows, each representing a distinct state of evolution for the object. Regarding the visualization of such datasets, a temporally flat visual representation can be very confusing to interpret. On the other hand, a chronological visual representation focuses on one instant[1] at a time and the observer loses the idea of temporal context.

In order to overcome this visualization issue and provide effective support for observation, interactive exploration, analysis and presentation of spatio-temporal information directly gathered from a spatio-temporal database, this paper describes a Temporal Focus + Context (F+C) Visualization Model. The basic idea of the proposed visualization is to calculate a Temporal Degree of Interest (TDOI) for each row, through a function that uses the *valid time* attribute of the row and user semantic criteria, based on predefined analysis, exploration or presentation goals. In the rendering stage of the visualization pipeline, the calculated TDOI for each row is used to control graphical variables, as opacity and colour, or to control more complex rendering properties such as sketch drawing edges or applying other non-photorealistic enhancement techniques.

By carefully defining user scenarios, large amounts of data from distinct periods of time and from several datasets can be compressed onto one dynamic presentation as they are depicted with distinct graphical configurations. Moreover, as the user interactively travels over the temporal scope of the dataset, the TDOI of each row is recalculated and the row attributes are rendered accordingly. To make the display more meaningful, as objects can be described through several temporally non-overlapping rows, the model provides the selection of a key attribute from the dataset structure which helps row sets from a single object to share the same basic graphical property values, before the calculation takes place.

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[1] In the remaining of this document the word *chronon* will be used instead of instant. It corresponds to the smallest amount of time considered for a particular application domain.

II. INFORMATION VISUALIZATION TECHNIQUES FOR TIME-DEPENDENT DATA

Over the last two decades a vast number of techniques regarding visual analysis of time-dependent information have been developed. For abstract data, several taxonomies for time-dependent information visualization have been suggested, such as based on the number of variables or based on the representation (Müller and Schumann 2003). *Time Series Graph* (Harris 1999) or *Parallel Coordinates* are examples of univariate static representations, while *ThemeRiver* (Havre, Hetzler et al. 2000), *Spiral Graph* (Carlis and Konstan 1998), the *Calendar View* (van Wijk and van Selow 1999), the *Lexis Pencils* (Keiding 1990; Brian and Pritchard 1997), the *SpiraClock* (Dragicevic and Huot 2002), and *The Time-Wheel* (Tominski, Abello et al. 2004), address multi-variate static representations. Regarding dynamic representation of time-dependent abstract data the most natural approach has been to map the temporal aspects of the data directly onto the time control of a dynamic representation, where the data elements' representation changes over the time (Müller and Schumann 2003). Examples are (Thrower 1961; Tobler 1970; Gould, DiBiase et al. 1990; Dorling and Openshaw 1992; Johnson 2004; Johnson 2005).

For time-dependent geospatial data, the Geo Visualization community has been developing new techniques to graphically depict time-dependent abstract data integrated in physically-based data, such as in geospatial information dynamic representations. Concepts are often brought from research areas such as Information Visualization, Scientific Visualization and Cartography (Rhyne, MacEachren et al. 2006). In this context, GeoVisualization has addressed new possibilities to visually represent information through the use of animation, such as observations, walkthroughs and simulated flights through 2D/3D landscapes or cityscapes, all performed in real-time or in differed time (Peterson 1994; Johnson 2005; Tominski, Schulze-Wollgast et al. 2005). Further visual stimulation involved in animation has been achieved though dynamic variables such as display time, duration, frequency, order, rate of change and synchronization (Kraak 1994).

III. PROBLEM DEFINITION

Currently, temporal information systems support much more than simple data time stamping and therefore provides working grounds for the development of new visualization techniques support for features such as upward compatibility and temporal upward compatibility (Steiner 1998), sequenced semantics and non-sequenced semantics and the use of temporal functions and operators (F.Allen 1983) requires the visualization of query results to capture the semantics of time and to help answering questions such as those suggested by MacEachren (Maceachren 2004), namely related to temporal existence, temporal location, temporal interval, temporal texture, rate of change, sequence and synchronization. Temporally flat visualization, where the temporal focus and context are the same, is not satisfactory in providing effective answers to most of these questions. This happens because of: (a) excessive high compression of data onto the same visualization (all times draw onto one display); (b) visual spatio-temporal inconsistencies such as spatial co-occupation of two distinct objects that exist in non-overlapping periods or the depiction of same object in two distinct places at the same time; (c) undifferentiated rendering of data, regarding data temporal features. On the other hand, plain animations are also not appropriate to provide answers for the above questions since they narrow the focus extent to a single constantly moving instant of time and always hide temporal context. Consequently, rendered objects appear/disappear very abruptly with no smooth transitions. It may be expected that the representation does not limit itself to show/hide data elements, but is also able to render differently data elements merely intersecting the boundaries of the period focus. Moreover Questions regarding temporal interval, such as *how long is the time span from the beginning to the end on the data element?*, rate of change and sequence are left unanswered. Finally, both these traditional visualization techniques fail to easily depict information about synchronization, such as *which data elements exist together for a certain period?*

IV. THE TEMPORAL F+C VISUALIZATION MODEL

In order to answer the issues presented in the previous section, we suggest a visualization model that is developed taking into account ideas from on the Fisheye concept (Furnas 1986). This is a Distorting of Information Visualization technique based on what Card later defined as F+C Visualization (Card, Mackinlay et al. 1999). However, the distinction between F+C Fisheye and the suggested visualization model is that the transformation and mapping is done with respect to the temporal dimension. In our visualization model, regarding Card's F+C three premises, *Context* is the full spatio-temporal extent of the dataset; *Focus* is the part of the dataset that has been *temporally focused* (Monmonier 1990). *Focus* and *context* are rendered with distinct amounts of information and graphical representation, and combined onto the same display. Regarding the Fisheye concept, in our model, the distortion used in the visualization of information is based on the calculation of a TDOI for every row in the dataset. This value is then used in the rendering of the graphical representation of the row attribute values and can control of one or more of the graphical variables. For instance, the TDOI calculated for a row can be used to influence the overall color, size, texture, opacity, scale, etc of a 3D representation of a geospatial value for that row.

V. TEMPORAL DEGREE OF INTEREST

In the following, a database row *r* is assumed to contain a tuple with several alphanumeric or spatial attributes plus a special attribute containing the row *valid time* (*vt*). A TDOI is calculated for each row *r* based on the following TDOI function, which contains semantic criteria:

$$TDOI = f(P, FP, vt, FC)$$

Where:

- P is the time period the user is interested on, corresponding to an interval $[i_{start}, i_{stop}[$. This interval can assume the value of a user defined single *chronon* or a span with several *chronons*;

- *FP* is a user defined function (semantic criteria) that describes the temporal degree of interest for every *chronon* in time period *P*; this is the most important argument for providing visualization distortion.
- *vt* is a period expressing the *valid time* of row *r* from the dataset, for which the TDOI is being calculated;
- *FC* is another user defined function (semantic criteria) strictly dependent on the application domain for which results are being calculated. It defines what is temporally relevant to be considered in calculations, regarding each row *valid time* period, namely. For instance row TDOIs can be calculated based on a single *chronon* (*start*, *middle*, *stop, period*) or the *valid time* period itself.

For each row, *r*, the *TDOI* calculation starts by applying function *FC* to the row *valid time* (*vt*)*,* filtering the relevant *chronons* according to function *FC* and providing the *filtered valid time* of the row *r* (*fvt*). For instance, the following expression provides *fvt* equal to the *start chronon* of *vt*:

$$\forall vt = \left[i_{r.start}, i_{r.stop} \right[, i_{r.start} \in N, i_{r.stop}$$

$$\in N, i_{r.start} < i_{r.stop} :$$

$$fvt = start(vt) = \left[i_{r.start}, i_{r.start} + 1 \right[$$

Next the *TDOI* calculation determines the *row* period of interest (*PI*), by intersecting the previously determined *fvt* with the user period of interest, *P*:

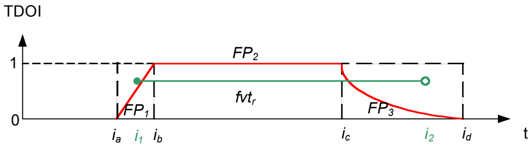
$$PI = fvt \cap P$$

The following expression calculates the final value of *TDOI* for row *r*:

$$\forall PI \neq \varnothing \wedge P \neq \varnothing$$

$$TDOI = \begin{cases} PI_{r.stop} - PI_{r.start} = 1, FP(PI_{r.start}) \\ PI_{r.stop} - PI_{r.start} > 1, \dfrac{\int_{i=PI_{r.start}}^{PI_{r.stop}} FP(i)}{\int_{j=P_{start}}^{P_{stop}} FP(j)} \end{cases}$$

In the previous expression, the greatest *TDOI* corresponds to rows whose *PI* is matched in span and location to the user's period of interest, *P*. Other rows have values of *TDOI*, calculated relatively to the overall behaviour of *FP* throughout the entire span of the *P*. Rows where $PI = \varnothing$ get zero *TDOI.* Moreover, the TDOI calculation for a row can involve multiple TDOI functions (Carvalho 2008), each function defined for a distinct *P*, as shown in the following picture.



Picture 1: the representation of a tupple valid time that is intersected by three TDOI functions.

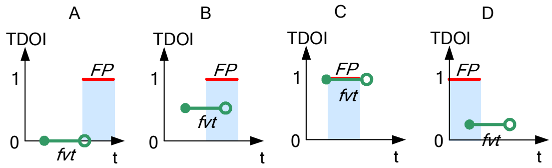
Here, the choice of FP_1 and FP_2 control the increase/decrease of the TDOI as intersection between interval [i_a ; i_d[and *fvt* increase/decrease, respectively, but does not touch the focus interval [i_b ; i_c[.

VI. RESULTS

The proposed model has been developed for interactive dynamic presentations, where the user sequentially or randomly slides the period of interest *P*. Every change in *P* requires the recalculation of the TDOI for every row where $PI \neq \varnothing$.

Flat visualization is achieved by setting P to the temporal extent of the dataset. In this case, each *TDOI* equals the ratio between the span of *PI* and the span of *P*, provided a constant *FP* (no distortion). A visualization showing temporal evolution, similar to ttraditional animation, is achieved by setting the span of *P* to a single *chronon* and by providing temporal displacements, normally in the same temporal direction. Depending on the purpose of the animation, temporal displacements can be constant, providing visualization of linear evolutions, or non-linear, whereas time can be compressed or expanded. Calculated TDOI values for traditional animations vary between the maximum and minimum values of the TDOI scale without assuming intermediate values. The reason lies on the fact that the *valid time* of geospatial object either contains the *chronon* P or it doesn't.

Other visualization configurations, where the user defines a manageable period *P,* allow the compression of information temporally touching *P* to make it coexist visually. However, the coexistence importance depends on how *P* touches *fvt*, on the span of *P* and on the span *fvt*. Consider the following case, illustrated in Picture 2, where the value of TDOI is represented for a row with *valid time vt, FC* provides *fvt=vt* and the period of interest, *P*, is changing.

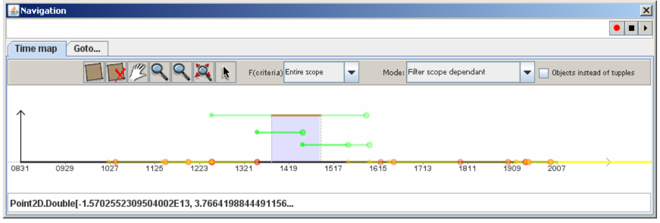


Picture 2: example of TDOI calculation for a row with *fvt*, in a scenario where *P* is sliding from future to past.

In situation A, the filtered valid time for the row (*fvt*) is disjoint from the period of interest *P*, and therefore *TDOI*=0. As we move our interest to the past, *P* overlaps *fvt* and the TDOI increases (situation B) eventually reaching a maximum when *P* is overlapped by *fvt* (situation C). If our interest goes further to the past the TDOI decreases again (situation D). The constant function *FP=1* is used in this example to provide a ceiling for the TDOI. More elaborated *FP* functions can provide local enhancement of the resulting TDOI values and support distortion visualization of results as in the Fisheye model. The proposed model is appropriate for visualizing the answers to queries related to temporal existence, temporal location and temporal interval, and also provides the tools to visualize the results of temporal synchronization questions, such as *which data elements exist together for a certain period*? Sequence questions can also be answered graphically. For such purpose we have extended the TDOI concept to be calculated with multiple TDOI functions, each defined for a distinct interval. In this case, for each row, knowledge of the calculated TDOI value and of which intervals intersect *fvt*, provide the grounds for rendering data with distinct amount of information and looks (Carvalho 2008)

VII. APPLICATION

The proposed Temporal F+C Visualization Model has been prototyped in two application domains namely “Political History of Europe” and “Urban Management”, both with spatio-temporal requirements. The illustrations below are demonstrations in a system based on the model. Picture 3 shows a time window in the prototype, displaying in green and yellow horizontal segments the *fvt* of a dataset for the evolution of the borders of 4 european countries.



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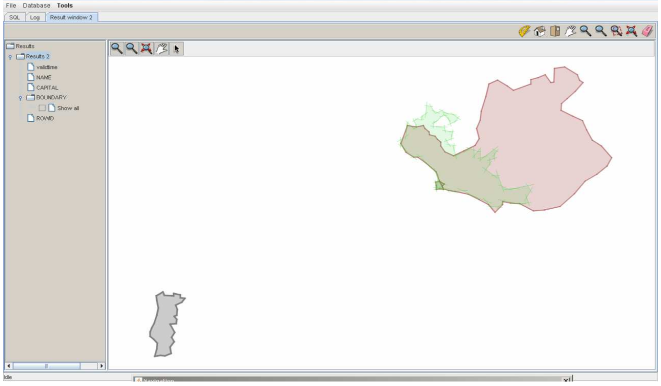
Point2D.Double[-1.5702552309504002E13, 3.7664198844491156...
```

Picture 3: The time window of the prototype application displaying the *fvt* of several rows (green and yellow segments) and a TDOI function.

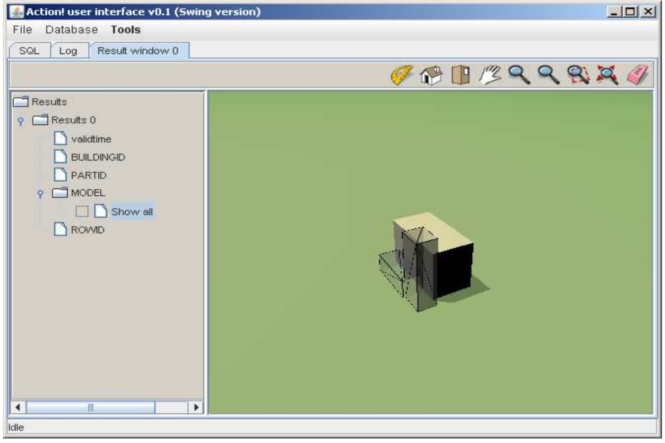
P is shown as a blue rectangle and *FP* is a constant function of value 1 (red segment on top of blue rectangle). *FC* makes *fvt*=*vt*. Green segments correspond to rows where $PI \neq \varnothing$.

In Picture 4, the value of *TDOI* has been used to control opacity and the *interval* resulting from interactively sliding *P* has been mapped to pseudo-color.



Picture 4: Screenshot of a test scennario. Colors and opacity are based on TDOI calculation and variation of TDOI based on user sliding *P*.

Green corresponds to P entering *fvt* resulting in positive variation of *TDOI*, red corresponds to *P* leaving *fvt* resulting in negative variation of *TDOI*, and gray corresponds to variation of *TDOI*. Picture 5 shows a simplified representation of buildings. Here, the *TDOI* values have been mapped to opacity and *wireframe* rendering where *TDOI* < 1.



Picture 5: Screenshot of another test scenario. Opacity are *wireframe* rendering/flat shading is based on TDOI calculation.

VIII. CONCLUSIONS

The changes in paradigm on the management of spatio-temporal information in database systems provide the challenges for developing new visualization techniques, allowing a better representation of the temporal semantics related to datasets that result from queries. Traditional visualization techniques such as temporally flat visualization and animation provide limited support for visually answering questions about the temporal aspects of data. In order to overcome these limitations we suggest a temporal F+C visualization model based on the calculation of a Temporal Degree of Interest (TDOI) for each row in the dataset. The calculation is based on user-specified semantic criteria, which, according to application domains, allow the specification of distinct behaviours for simultaneous Focus and Context visualization. The model also provides distortion visualization, through user-selected functions, to graphically enhance certain temporal features of data. The calculation of TDOI filters the elements to be rendered and, for those elements that appear in the visualization, provides control of the graphical properties in order to enrich the original data with information about time. In interactive scenarios, variation of *TDOI* between *P* displacements can also be used along with *TDOI* values to express rate of change. Finally, this model keeps the possibility of traditional flat and animation visualizations while allowing other, more manageable visualization modes by changing the TDOI functions, and can provide more data compressed onto the same visualization.

The model has been prototyped in an application that deals with two test scenarios: “Political History of Europe” and “Urban Data Management”, both having the data repository in a full-fledged spatio-temporal database information system (Carvalho, Ribeiro et al. 2006). We consider this visualization model very promising for a large range of application domains requiring visualization methods for the temporal aspects of discrete 2D/3D temporal multivariate data.

Future work will encompass dealing with *transaction time* simultaneously as *valid time* and identifying issues that result from the application for the model in moving-object databases.

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