

A General Web-based Framework for Spatio-Temporal Exploration and Visualization applied to a Case Study on Cultural Heritage Data

Francesco Cutugno
University of
Naples Federico II
Naples, Italy
cutugno@unina.it

Vincenza Anna Leano
University of Naples Federico II
Naples, Italy
vincenzaanna.leano@unina.it

Francesco Mangiacrapa
ISTI, CNR
Pisa, Italy
francesco.mangiacrapa@isti.cnr
.it

Adriano Peron
University of Naples
Federico II
Naples, Italy
peron@na.infn.it

Abstract

The ability of representing spatio-temporal features plays a crucial role in Cultural Heritage field. Management of thematic contexts, of time domain with qualitative and imprecise references, hierarchical structure of time and spatial and temporal multiple granularities are very important feature in this environment for users aiming at discovering knowledge process. In this paper a framework to manage spatio-temporal cultural heritage data exploration and visualization is presented. This framework allows to develop web applications able to handle spatio-temporal objects, regardless of the specific descriptive nature of data, and relies on a flexible architecture for web applications that shows low coupling among tiers and uses standard files and protocols, like WFS, GML, KML, becoming independent from storage and visualization tools. The Visualization layer is designed to offer spatio-temporal views with a high level of personalization: users can choose different kinds of views and visual metaphors to compare objects on the geobrowser by activating or disabling layers of their interest. A new method aiming at visualizing and exploring the hierarchical and stratified time domain is presented. The user interface is open and extendable to new methods of visualization. Finally, a specific web application, based on the described framework, is shown.

Keywords: : Spatio-Temporal Model, Spatio-Temporal Visualization, Temporal Exploration, Cultural Heritage.

1 Introduction

Studies show that 80% of data stored in a database has a spatial reference [11] and it could be reasonable to think that this proportion holds also for the temporal reference. The current state of art has always highlighted how this two features are “special” [10], defining ad hoc representation models, exploration operators and visualization metaphors to better render them to the user.

Cultural Heritage experts usually partition timeline differently depending on the context (i.e. “History of Naples” or “History of Literature”) and each context may have different granularity levels. Elements of this timeline might not have a precise quantitative temporal dating but only topological relation with other events in the same context. Space is an important feature too: the evolution of space domain over time and the correlation of ancient sources and archaeological artefacts with nowadays space locations are very helpful for users wanting to discover knowledge process.

Theoretically, a spatio-temporal data model has to be designed with the purpose of making all (or a lot of) the possible aspect of spatial, temporal and spatio-temporal feature, offering operators to manipulate and exploit them. Many applications managing spatio-temporal data have been proposed e.g. [2, 17] etc. and often these applications focus on particular aspects of spatio-temporal data, using proprietary tools for the representation or the visualization of data. In this paper we present a framework aiming at merging a spatio-temporal data model in a web-architecture which can be a) compliant with existing standards and b) independent from data storage and visualization tools. The system defines a flexible architecture for web applications that shows low coupling among tiers and uses standard exchange data formats like WFS, KML, GML to guarantee independence from storage and visualization tools. The framework interface allows to interact independently with the three data dimensions, showing an original way to explore spatio-

temporal data and stratified temporal domain.

This paper closes with the presentation of a web application whose interface offers a highly customizable and integrated spatio-temporal visualization and incorporates and synchronizes spatial, temporal, and descriptive views. Users can choose between different kinds of views and visual metaphors to compare objects into the geobrowser and activating or disabling information. By interacting with a map, users can perform spatial queries to obtain information about the referencing objects and their content. This interface also offers a new metaphor to visualize and explore the hierarchical and stratified time domain.

2 Related Work

Several research works have been recently conducted on spatio-temporal data model [24].

Many approaches on modeling spatio-temporal data adopt the triad model (spatial, temporal and descriptive) [25]. Several different forms of spatio-temporal data types and applications are available in real world and the current state of art offers many ways to classify them [4, 15 19, 26]. In [25] a comparative overview of some of such existing models is provided. In [8] authors extend the ODMG model including classes and literal types in order to model time and space introducing spatial and temporal granularities. Both space and time are partitioned in granules (i.e.: day, week, year for time; m, dm, km for space). Granules are related by the “finer-than” relation (and its inverse “coarser-than” relation). Other works aim at modelling spatio-temporal data from a database point of view, proposing Spatio-Temporal Database Management System (STDBMS). In [18] authors present a model based on five database tables based on three access levels. This model does not distinguish among objects, storing all the descriptive attributes in a single table. In [13] authors present a web architecture based on OGC standards in order to offer a web service for spatio-temporal data. However this solution is

based on a proprietary STDBMS, only moving-objects are managed and it does not offer many facilities, limiting the user to a superficial temporal exploration. In [16] an OO model for STDBMS based on time versioning is proposed: time is treated as an attribute of the spatial objects and this limits the temporal representation and exploration. In [5] authors combines OGC standards and SVG SMIL to produce animated maps for moving objects data. From the architectural point of view, the Open Geospatial Consortium (OGC) suggests best practice for a Web-GIS architecture, defining four loosely coupled tiers architecture [20]. OGC has defined standard Web Services (OWS) responsible for handling the different kinds of operation on geospatial data like Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS).

3 Proposed Framework

The existing works on spatio-temporal data so far examined, focus on two distinct aspects:

1. defining expressive data model,
2. providing applications relying on architectures which make use of proprietary tools for visualization, data storage and/or spatio-temporal exploration.

The here proposed idea is to offer a simple and general spatio-temporal data-model, based on existing standards for the spatial dimension and on a revisited model for the hierarchical and stratified temporal domain. At the same time a better organized classification model for the spatio-temporal data together with a web-oriented architecture exploiting the existing standard will be introduced. This allows the framework to be independent from both data storage and visualization tools.

3.1 The Temporal Model

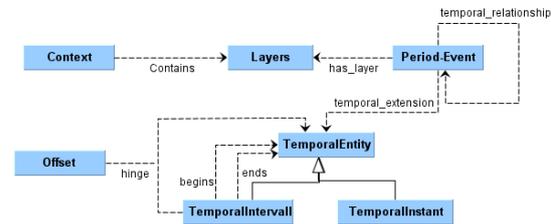
The temporal model here presented merges the qualitative and quantitative aspects of time references using the de facto standard model [9] with the granularity concepts studied in theoretical works [6], making it possible to partition the temporal domain in thematic contexts, each of them with its granularity, and to make quantitative and qualitative temporal references.

The temporal domain can be partitioned in thematic *Contexts* defined by user, for example in the developed case study there are three *Contexts*: “*History of Campi Flegrei*”, “*History Events*” and “*Authors Life*”. Users can define temporal granularity in *Context* creating a finite number of *Layers*, e.g the *Context* “*History Events*” has five granularity *Layer*: “*Epoch*”, “*Ages*”, “*Empire/Domination*”, “*Political and Historical Events*”, “*Important Events*”.

Each *Layer* contains *Period-Events*, expressing the Temporal Reference of an object. If the Temporal Reference is *quantitative*, then the *Period-Event* has a *temporal_extension* property that refers to a *Temporal-Entity* object. A *Temporal-Entity* can be a *Temporal-Instant* or a *Temporal-Interval*. A *Temporal-Interval* can begin and/or end with a precise dating or with other *Temporal-Entities*, or can be an *Offset* hinging on another *Temporal-Entity* (e.g “*Ulysses’ Homecoming*” happen 20 years after “*Trojan War*”). If the Temporal Reference is *qualitative*, then the

Period-Event object has a *temporal_relationship* property (see [1]) that refers to another *Period-Event* object in the same *Context*. Figure 1 shows the adopted time model structure.

Figure 1: Temporal Model.



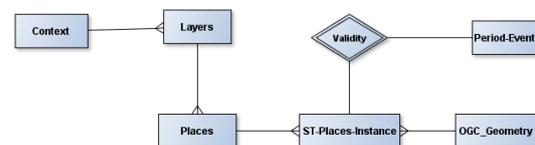
3.2 Spatial Model

The spatial model (see Figure 2) aims at managing two aspects of spatial entities:

1. places that evolve in time (i.e. for name or shape);
2. hierarchical and stratified spatial domains, i.e thematic contexts with a stratified granular structure similar to the temporal dimension.

We consider the entity *Place* as an abstract entity with only semantic meaning, having an Id, a name and a description. A *Place* can change its spatial extension over time, i.e. it can change its boundaries. In order to manage this *ChangeShape* object we introduce the entity “*ST-Place-Instance*”, having the *Place* as external reference, the *Period-Event* of validity and a reference to the *OGC Geometry* by means of which it is spatially represented. Users can organize the spatial domain with different semantic meaning e.g. with thematic maps. Similarly to the temporal dimension, also the spatial domains are organized in thematic contexts. Each *Context* has a spatial domain partitioned into *Layers*.

Figure 2: Spatial Model



3.3 Spatio-Temporal Integration

A rigorous data model must be able to manage and foresee any required spatio-temporal query and analytical method [30]. The proposed classification, inspired by previous works [4, 15, 19], considers the temporal dimension to be dynamic and based on two binary dimensions:

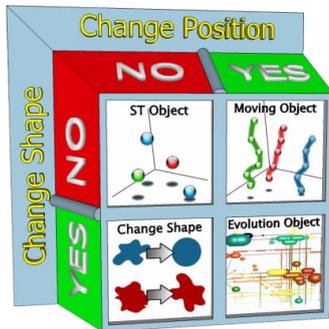
- *Spatial Position*: the object spatial location changes over time.
- *Spatial Extension*: the object shape (geometry) changes over time.

From this two dimension four classes of spatio-temporal object are obtained (Figure 3):

- *ST-Event*: objects that do not change neither their position nor shape over time but that could change their descriptive component.
- *Moving-Object*: objects that change their position but not their shape over time.

- *Change-Shape*: objects that can change their shape (geometry) but not their position.
- *Evolution-Object*: objects changing their shape and position over time.

Figure 3: Spatio-Temporal Classification.



A model implementing this classification should cover all the spatio-temporal aspects of data to be managed, and should be used by all the spatio-temporal application described in [10]. Formally speaking, in the presented model an object is uniquely identified by a couple $\langle IdObject, Type \rangle$, where *Type* is a meta-data pointer to the set of object's descriptive attributes (i.e. the name of the class, the table on the DB, etc). A Spatio-Temporal reference is identified by a couple $\langle TemporalReference, SpatialReference \rangle$ where:

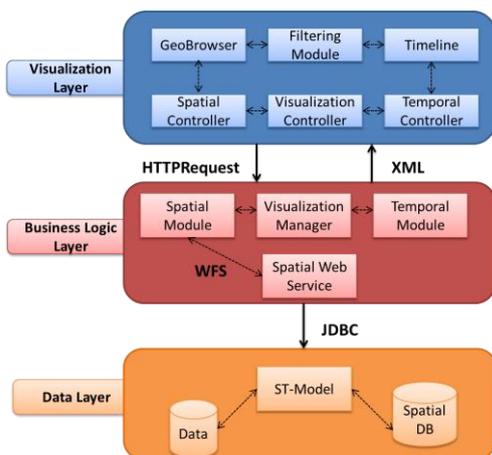
- *TemporalReference* is a pointer to the *Period-Event* id.
- *Spatial Reference* is a *Geometry* in the OGC model [29] (*Point, Line, Polygon, MultiGeometry* etc) that can represent a position or a shape.

This model is implemented using a DB view for each type of ST-Object.

3.4 Web Architecture

The proposed architecture relies on a three-tier architecture, composed by a data storage at the back end, a business logic layer, and a visualization layer at the front end (Figure 4). As suggested by the OGC, to achieve modularization, all the communication among or intra modules are carried out through standard open protocols for exchanging data formats.

Figure 4: System Architecture



3.4.1 Data Layer (DL)

This component is responsible of storing the application data and making it persistent. It is composed by a standard DMBS and a Spatial DBMS (in our case Oracle Spatial [22]) implementing the DB view of the model. This layer communicates with the upper one by means of JDBC.

3.4.2 Business Logic Layer (BL)

The layer executes the operations required by the user and integrating data belonging to the heterogeneous data sources in a single data structure, to be fed to the *Visualization Layer*. This tier makes use of OGC-compliant web-services for computing spatial operation and it is composed of four main modules:

- *VisualizationManager*: it is responsible for interprets and manages the operations received by the *Visualization Tier*. It dispatches the spatial and temporal requests to the respective module and merges the results, completing them with the descriptive information produced by the heterogeneous DB queries that feeds the upper layer.
- *SpatialModule*: it performs the spatial query requested by the user invoking a *SpatialWebService* through WFS.
- *TimelineModule*: it implements all of the temporal operators defined in [1]. It is responsible for performing the requested temporal query and returns the results to the *VisualizationManager*.
- *SpatialWebService*; it implements the OGC compliant web services (WFS, WCS, WMS), and works with standard protocol like HTTP, SOAP etc (in our case this component is carried out by GeoServer [23]).

3.4.3 Visualization Layer (VL)

The main goal of this layer is to present spatial, temporal, textual and multimedia information merged together and offered to the users. The visualization layer has also the responsibility to notify the underlying layers about the queries and the requests issued by users. *VL* exploits a Geobrowser and a Timeline visual component in order to allow independently spatial and temporal explorations. The descriptive data dimension is represented on the Geobrowser or/and in the descriptive component.

This Layer is composed by four components:

- *VisualizationController (VC)*: it is responsible for handling events on the user interface and for notifying the Logic Tier about the operation the user wants to do. The extra-tier communication uses the HTTP/XML protocol, the intra-tier one uses an XML data format; as a response the VC receives XML data to refresh its visual components.
- *SpatialController*: it is able to both render user selected information onto a map and interpret and notify the spatial query to the VC.
- *TimelineController*: it implements the visual metaphor allows an easy navigation and interaction with the hierarchal and stratified time dimension.
- *FilteringModule*: it is responsible of applying the

descriptive filters given by the user, to notify the user operations to the underlying layer and to display the descriptive dimension of data.

The *SpatialController* was implemented using OpenLayers [21], the *TimelineController* was implemented extending the Simile Timeline [12], and all the components are managed and synchronized with JQuery [4] and AJAX technologies.

3.4.4 Exchange protocol

The user interaction is handled by the *Visualization Layer* (VL), which interprets and intercepts the user query and notifies the *Business Logic Layer* (BL) performing an *HTTPRequest*. At this point the BL switches the request to the specific component. In particular, the spatial manager invokes a *SpatialWebService* using the WMS standard protocol receiving a KML file as response. The BL invokes the data layer too in order to retrieve the descriptive data information from the DBMS using a JDBC connection. This response is merged with the KML from the spatial component and with the response from the temporal component building a new XML file. This XML is given as response to the VL. Filtering operations on the descriptive dimension are made using XQuery [7] on the merged XML file.

4 Web Application

The proposed framework here has been implemented in a web-based prototype. With respect to the classification proposed in section 3.3, the web application manages two types of spatio-temporal objects: *ST-Events* and *Moving Objects*. The case study presented in this paper documents a joint work with Latin philologists and describes a deliverable of the project named TRACCIA. The aim of the project is to give public access to the literary and historical evidences of typical agricultural *Products* in an area in the neighborhoods. The proposed application allows the representation of *Products*, *Literary Excerpts* and *Authors* in a common framework enhancing their temporal and spatial dimensions and allows the user to query data in different manners. The application itself also manages the *Biographic Notes* on *Authors*.

Figure 5: Web Interface a) Active Filter Panel, b) Spatial Component, c) Timeline



The web interface consists of three synchronized areas (see Figure 5): the *Timeline* (Figure 5c) that implements the visualization metaphor proposed in 4.1, the *GeoBrowser* (Figure 5b) that allows user to make spatial queries and visualize the spatial referenced object and the *Active Layers*

Panel (Figure 5a) that allows the selection of the information layer to be visualized on the map. Each component will be described separately in the following subsections.

4.1 Temporal Visualization Component

The defined temporal model allows users to navigate information by thematic *Context*, granularities *Layers* and *Period-Events* (see Figure 6). The proposed temporal visualization metaphor uses a tab for each context listed in the dataset, allowing users to select the context they are interested into. In the presented case of study there are three tab for the three thematic context “*History Events*”, “*Campi Flegrei’s History*”, “*Authors’ Life*” (Figure 6a). The bottom panel, called *General Timeline Panel* (Figure 6c), shows an overview of the dataset entire time, displaying it as a bar.

Users can create a temporal window to be analyzed by dragging the mouse on this bar is displayed in the upper panel (*Selected Interval Panel*, see Figure 6b). This panel shows a bar for each *Layer* present in the chosen *Context* and displays the *Period-Event* distribution over the selected temporal window. Users can interact with this panel by selecting a *Period-Event* or by selecting an interval of interest dragging the mouse over this panel and visualizing the corresponding objects on the map. This operation filters the objects showed on the map. Timeline structure allows an easy understanding of temporal relationship [1] like before, after, etc., making also immediate to recognize the overlaps among *Period-Event* belonging to different layers.

4.2 Spatial Visualization Component

Visualization of the spatial dimension is delegated to the *Geobrowser*. Objects are displayed according to their spatial extension and to their (spatio-temporal) type. For each spatio-temporal data type, several visualization metaphors have been proposed in the literature. We choose a spatial metaphor for each kind of ST-Object inspired by [3] where it is suggested the appropriate visualization according to the spatial nature of data. In our case study we have two kinds of ST-Objects:

- *ST-Events: (the Literary Passage)* they are displayed on the map according to the *Place* they mention, using different icons according to their descriptive type (*Product*, *Literary Source*, *Author*). The spatial reference for this kind of object is not very accurate: we have more than one *Literary Excerpts* speaking about the same *Place*. In order to avoid the overlaps of a lot of placemark in the same *Place* on the map, we grouped objects having the same spatial reference in the same placemark icon, according to the descriptive filter selected in the *Active Filter Panel*. By clicking on a place mark on the map a balloon containing a text with the list of the *Literary Excerpts* in that place (see Figure 7) will appear.
- *Moving Object (Author’s Biographic Notes)*: this objects represent biographic moves of authors; they are represented by a line that joins places ordered by time. So the map shows the path of an Author life.

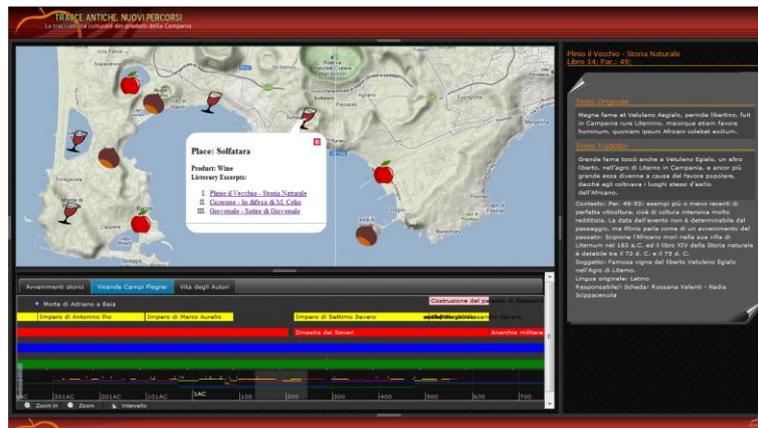
4.3 Descriptive Visualization Component

The descriptive visual component is represented by two panels. The first one is the *Active Filters Panel* (see Figure

Figure 6: Temporal Visual Component a) Context Menu, b) Select Interval Window c) Overview Panel



Figure 7: Object distribution on the map and Detail Panel



5a): it helps users to focus on the descriptive dimension by selecting the information layer to be visualized on the map. They can choose the type of the object to visualize (Author’ s *Biographic Notes*, *Literary Excerpts*), and they can filter them by some feature (*Author*, *Literary Source*, *Product*) by activating and disabling layers, allowing an easily data crossing. It allows also users querying data by textual search and to remove selected spatial and temporal filter. Activating a filter on this panel automatically updates the spatial component (map) according to the selected temporal filter.

The second one is the *Detail Panel* (see right side of Figure 7) it is showed on demand by clicking on an object on the map; it contains detailed information on the object selected and, if present, it shows multimedia content (video, photos etc.).

5 Conclusion and Future Works

In this paper we have presented a framework that merges a spatio-temporal data model in a web-architecture compliant with existing standards and that aims to be independent from data storage and visualization tools. A new method to model hierarchical and stratified temporal domain has been proposed. This model is implemented using OO and Relational Database technologies. Furthermore an innovative visualization metaphor to explore this kind of temporal domain has been presented.

The proposed interface allow users to navigate among the spatial, temporal and descriptive dimensions independently in a synchronized way. The web application representing the case of study we implemented to test our model is fully

deployed and is currently under testing. We are currently extending the visualization modules with spatial and spatio-temporal visualization metaphors like tag-maps, tag-cloud [28], tree-maps [27] and thematic maps. In particular, we are working to provide visualization metaphors for handling stratified granularities in the spatial domain.

6 Acknowledgment

Authors wish to thanks Francesco Cerasuolo for his support in the design and development of the prototype proposed in this paper.

References

- [1] James F Allen, "Time and Time Again: The Many Ways to Represent Time," *Journal of Intelligent Systems*, vol. 6, pp. 341--355, jul 1991.
- [2] Natalia Andrienko, Gennady Andrienko, and Peter Gatalsky, "Exploratory spatio-temporal visualization: an analytical review," *Journal of Visual Languages & Computing*, vol. 14, pp. 503--541, December 2003.
- [3] Gennady Andrienko, Natalia Andrienko, and Stefan Wrobel, "Visual analytics tools for analysis of movement data," *SIGKDD Explor. Newsl.*, vol. 9, no. 2, pp. 38--46, December 2007.
- [4] Viveca Asproth, Anita HÅÿkansson, and Peter RÅÿvay,

- "Dynamic information in GIS systems," *Computers, Environment and Urban Systems*, vol. 19, pp. 107 - 115, 1995.
- [5] T. Becker, B. Köbben, and C. A. Block, "TimeMapper: Visualizing Moving Object Data using WMS Time and SVG SMIL Interactive Animations," in *SVGOpen 2009: 7th international conference on scalable vector graphics*, vol. 13, 2009.
- [6] C. Bettini, X. S. Wang, and S. Jajodia, "A general framework and reasoning models for time granularity," in *Proceedings of Third International Workshop on Temporal Representation and Reasoning (TIME '96)*, 1996, pp. 104-111.
- [7] Scott Boag et al., *XQuery 1.0: An XML Query Language*, 2005.
- [8] Elena Camossi, Michela Bertolotto, Elisa Bertino, and Giovanna Guerrini, "A multigranular spatiotemporal data model," , 2003, pp. 94--101.
- [9] Martin Doerr, Athina Kritsotaki, and Stephen Stead, "Which Period is it? A Methodology to Create Thesauri of Historical Periods," , 2004.
- [10] Max J Egenhofer, "Whats special about spatial?: database requirements for vehicle navigation in geographic space," *SIGMOD Rec.*, vol. 22, no. 2, pp. 398--402, June 1993.
- [11] Carl Franklin, "An introduction to geographic information systems: linking maps to databases," *Database*, vol. 15, no. 2, pp. 12--21, April 1992.
- [12] D Huynh, *SimileTimeline*, 2006.
- [13] Markus Innerebner, Michael Böhlen, and Igor Timko, "A web-enabled extension of a spatio-temporal DBMS," , 2007, pp. 34:1--34:8.
- [14] JQuery. (2011) JQuery. [Online]. <http://jquery.com/>
- [15] Slava Kisilevich, Florian Mansmann, Mirco Nanni, and Salvatore Rinzivillo, "Spatio-temporal clustering," pp. 855-874, 2010.
- [16] Alex Lohfink, Duncan McPhee, and Mark Ware, "A UML-based Representation of Spatio-Temporal Evolution in Road Network Data," *Transactions in GIS*, vol. 14, pp. 853--872, 2010.
- [17] Alan M MacEachren et al., "Geovisualization for Knowledge Construction and Decision Support," *IEEE Comput. Graph. Appl.*, vol. 24, no. 1, pp. 13--17, January 2004.
- [18] S. Nadi and M. R. Delavar, "Toward a General Spatio-Temporal Database Structure," in *Proceedings of the International Symposium on Spatio-temporal Modeling, Spatial Reasoning, Analysis, Data Mining and Data Fusion*, Peking University, China, 2005.
- [19] S. Nadi and R. D. Mahmoud, "Spatio-Temporal Modeling of Dynamic Phenomena in GIS," in *ScanGIS'2003 - The 9th Scandinavian Research Conference on Geographical Information Science, 4-6 June 2003- Proceedings*, Espoo, Finland , 2003, pp. 215-225.
- [20] OGC, "OpenGIS web services architecture description," 2005.
- [21] OpenLayers. (2011) OpenLayers. [Online]. <http://openlayers.org/>
- [22] Oracle. (2011) Oracle Spatial and Oracle Locator. [Online]. <http://www.oracle.com/it/products/database/options/spatial/index.html>
- [23] OSGeo. (2011) Geoserver. [Online]. <http://geoserver.org>
- [24] Nikos Pelekis, Babis Theodoulidis, Ioannis Kopanakis, and Yannis Theodoridis, "Literature review of spatio-temporal database models," *Knowl. Eng. Rev.*, vol. 19, no. 3, pp. 235--274, September 2004.
- [25] D. J. Peuquet, "Its About Time - a Conceptual-Framework for the Representation of Temporal Dynamics in Geographic Information-Systems," *Annals of the Association of American Geographers*, vol. 84, no. 3, pp. 441-461, 1994.
- [26] Dieter Pfoser and Nectaria Tryfona, "Requirements, definitions, and notations for spatiotemporal application environments," , 1998, pp. 124--130.
- [27] Aidan Slingsby, Jason Dykes, and Jo Wood, "Using treemaps for variable selection in spatio-temporal visualisation," *Information Visualization*, vol. 7, no. 3, pp. 210--224, June 2008.
- [28] Aidan Slingsby, Jason Dykes, Jo Wood, and Keith Clarke, "Interactive Tag Maps and Tag Clouds for the Multiscale Exploration of Large Spatio-temporal Datasets," , 2007, pp. 497--504.
- [29] Main Street, "The OpenGIS Abstract Specification Topic 1 : Feature Geometry (ISO 19107 Spatial Schema)," *Open GIS Consortium Inc*, vol. 5, 2001, pages=703--708.
- [30] M. Yuan, "Temporal GIS and Spatio-Temporal Modeling," in *Proceedings of Third International Conference on Integrating GIS and Environmental Modeling*, Santa Fe, New Mexico, Usa, 1996.