AN INTEGRATED FRAMEWORK FOR SPATIO-TEMPORAL DATA MANAGEMENT: THE PROJECT BRISEIDE – BRIDGING SERVICES INFORMATION AND DATA FOR EUROPE

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ABSTRACT:

The world of Geographic Information (GI) Science has changed. Today, many of the elements of Digital Earth, meaning as a multiresolution, three-dimensional representation of the planet, are not only available but also used daily by hundreds of millions of people worldwide thanks to innovative ways to organize and present the data and rapid technological advancements. 3D Geobrowsers can provide higher usability and interactivity that can facilitate exchange and dissemination of spatial information among stakeholders and government agencies. However providing access to harmonized data is only a first step towards providing adequate support to environmental management, which requires development of analysis and spatio-temporal data models functionalities. Many environmental analyses, e.g. monitoring a sequence of earthquakes epicentres, a storm, a forest fire, spread of pollutant etc., cannot be performed without considering the evolution, over time, of geographic features. Additionally today's sensing technologies provide frequently updated GI, at relatively reduced costs, coming from environmental sensors, satellite etc. This forces the GI community to reconsider current data models, taking into account time as one of the main variables.

BRISEIDE - BRIdging SErvices, Information and Data for Europe is a Pilot B, funded by the ICT Policy Support Programme (or ICT PSP), tries to bridge the aforementioned gap, by building on top of existing SDIs in order to provide users with more complete and adequate data and processing tools capable to handle the time dimension. BRISEIDE develops spatial analysis WPSs and integrates them within existing open source frameworks. Spatio-temporal processing services are exposed via the web and are made available through compatible WebGIS applications.

Open Geospatial Consortium Web Services, already made available by relevant INSPIRE-related EU projects, exposing standard services such as WMS, WCS and WFS, can be used to provide access to relevant geodatabases, enriched, when needed, with information, extracted from heterogeneous, distributed user operational databases. In addition to this, in order to achieve optimality geo-processing functionalities distribution, standardized services capable to extract data of interest can be provided to ensure spatio-temporal information ingestion, querying, processing, visualization and value added processing. Spatial analysis and Spatio-temporal web processing services (WPS) are exposed via the web and are made available integrating them within existing open source frameworks through compatible WebGIS applications

1. INTRODUCTION

1.1 General Overview

Civil Protection operators and Public Administrations, engaged in urban planning, resource and environmental management, clearly need spatio-temporal processing of GI to support decision-making. Natural disaster monitoring and mitigation is characterized by frequently updated repositories as well as by provision of dynamic data. For these stakeholders being able to access to the most up-to-date information is crucial.

Today, many of the elements of Digital Earth, meaning as a multi-resolution, three-dimensional representation of the planet, are not only available but also used daily by hundreds of millions of people worldwide thanks to innovative ways to organize and present the data and rapid technological advancements. 3D Geobrowsers can provide higher usability and interactivity that can facilitate exchange and dissemination of spatial information among stakeholders and government agencies. However providing access to harmonized data is only a first step towards providing adequate support to environmental management, which requires development of analysis and spatio-temporal data models functionalities.

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1.2 Motivation

Many environmental analyses cannot be performed without considering the evolution, over time, of geographic features. Examples of these are monitoring the evolution of a sequence of earthquake epicenters, forecasting the path of a storm, monitoring the advancement of a forest fire, predicting the spread of pollutant across a given area.

In the perspective of the hugely populated European SDI envisioned by INSPIRE, it's necessary to filter out geographic resources that not only refer to a given spatial location, but also match both the temporal coverage of interest and the temporal resolution suitable to the application purposes.

This should lead the GI community to reconsider current data models, taking into account time as one of the main variables.

Analysis of spatio-temporal data is especially challenging. It requires tools for representation and manipulation of all three aspects of the data: thematic (values of attributes), temporal and spatial. Due to increased speed, space, and graphical displays modern computers offer new opportunities to properly visualize the temporal variation of spatially referenced data.

However within most GIS systems and, more recently, within most SDIs, time as variable is only partially considered or not taken into account. Furthermore current OGC standards do not provide consistent support for time with only few standards considering time as a variable (e.g. GML).

For this reason BRISEIDE proposes to extend current data/metadata models to be able to benefit from information available at high refresh rate (e.g. from sensors) as well as to be able to analyse evolution of phenomena over time.

The first aim is to extend the current metadata models developed in the context of previous INSPIRE-related initiatives (e.g. eContentPlus projects), to improve description of geodata with the possibility of expressing articulated temporal information related to observations as well as on the observed phenomena, together with information related to temporal resolution. The second is to build on top of such extended model, and in line with recommendations from the aforementioned study by JRC, developing values added spatio-temporal online services. These include both service capable to provide both basic reasoning over time (e.g. capable to understand how a period within a search can be associated to time information within a feature) as well as more advanced services, required for instance for offline/online harmonization of temporal information.

1.3 Related Works

The world of Geographic Information (GI) Science has changed Maps are increasingly conceived as useful tools for "visual thinking", i.e. for the analysis of spatially related data in the context of problem solving and decision making. To fulfil this role, the maps should not only be properly designed according to cartographic principles. What the users really need are highly interactive, dynamic map displays that are linked to various additional instruments supporting these creative activities (MacEachren 1994, MacEachren and Kraak 1997).

Evolving research on space-time representation has focused on a number of specifc areas, including; (i) the ontology of space and time, (ii) development of efficient and robust space-time database models and languages, (iii) inexactness and scaling issues, (iv) graphical user interfaces and query optimization, and (v) indexing techniques for space-time databases (Abraham and Roddick 1999, Sellis 1999).

In the INSPIRE Metadata Implementation Rules (Version 3, dated 26 October 2007), four elements of temporal information are defined:

- The time period covered by the content of the resource (also called the temporal extent of the resource)
- The date of publication of the resource
- The date of last revision of the resource if the resource has been revised
- The date of creation of the resource if it has not been revised.

A geo-object or feature in general consists of aspects related to a given theme, geometry, topology and time. However today

GIS systems do not deal with all these aspects equally well. The temporal dimension in fact is certainly an important aspect of almost all phenomena of the real world. However databases as well as GIS systems, traditionally deliver only a snapshot of the real world condition. As result several authors have clearly stated the need data models that allow handling of temporal data (Snodgrass and Ahn, 1985, Tansel et al. 1993)

Time is a dimension analogous to any of the spatial dimensions. Like space, time has geometry and topology. A point in time occupies a position that can be identified in relation to a temporal reference system. Distance can be measured. Unlike space, however, time has a single dimension – temporal reference systems are analogous to the linear referencing systems that are used to describe spatial position for some kinds of applications.

With Virtual Globes, the analyst is able to interact with the encounter and examine the event at a spatial and temporal scale, not possible with previous tools. The ability to add other geophysical data to the model simulations, such as earthquake locations and webcams views is greatly increased and a much easier process with the Virtual Globes tool (Webley, 2010). Displaying of geophysical data in Virtual Globes is now becoming more common place and the next transition is to display near-real-time data from multiple data sources (Webley, 2008). The visualization of geophysical data in four-dimensions (x, y, z and t) was a time-consuming process with no common interface for different data sets.

Within this context, temporal aspects play a major role at multiple levels, especially when considering some key applications that involve dynamic phenomena. In order to improve the definition of time-related metadata, some authors have proposed a set of six recommendations (Dekkers, 2008). Several other studies have proposed to manage temporal series of data sets, and have discussed the need for metadata extensions in the temporal domain (Bordogna et al., 2009).

2. PROJECT'S DESCRIPTION

2.1 Objectives of BRIESEIDE

BRISEIDE (BRIdging SErvices, Information and Data for Europe) aims at delivering:

- An extension to current data models, developed in the context of previous/ongoing EU INSPIRE related projects (e.g. in the context of GMES, eContentPlus), to include time as one of the main variables time-aware;

- Application (e.g. Civil Protection) based on the integration of existing, user operational information;

- Value added services for spatio-temporal data management, authoring, processing, analysis and interactive visualization.

In particular the services delivered by the project will be tested in several operational pilots whereby operators in the environmental risk management and civil protection area will be able access to services available. The pilots will involve data providers, technology partners and, most importantly, final users.

Considering the spatio-temporal dimension the complexity of the services and representation of results increase. BRISEIDE services deliver Geo-Visual Analytics (GVA) functionalities through OGC-compliant services (e.g. WPS or WCPS), capable of identifying relevant data or information pattern within a vast information flow made of multidimensional time-varying geographical data coming from databases, as well as from sensors.

2.2 Framework for advanced interactive visualization and Analysis.

The availability of GI has significantly increased over the last few years. Typically operators have to refer to an extremely wide range of heterogeneous multi-source, multi-dimensional, time-varying information sources, today digital GI include, among others, high-resolution satellite images, digital maps, LiDAR data sets, real-time data being captured by environmental sensor monitoring systems. The main goal was therefore to develop a platform for GVA capable to ensure the convergence of several tools for visualization, analysis and synthesis of GeoData.

The framework developed provides seamless integration of computational and visual techniques. For instance, a visual overview may be based on some preliminary data transformations appropriate to the given data and task. Interactive focusing, selecting, and filtering could be used to isolate data associated to certain hypothesis, which could then be passed to an analysis engine with informed parameter settings. In this way the software platform can be used to provide support to understanding of complex spatial relationships among information spaces and different datasets, for instance to define the most appropriate evacuation routes or to plot an emergency plan.

The system proposed is based on an articulated enterprise level Service-Oriented Architecture designed to provide all the functionalities required to access, manage and process large sets of multi-dimensional GIS and satellite data through OGC -OpenGIS Consortium compliant web services. The system goal is to deliver a web-based 3D and OGC compliant solution capable to provide interoperable access to geographical information through the support of several web services such as WMS, WFS, WCS, and WPS, and provide a strong support to operators looking for decision support through an ideal environment for analysis that integrates computational and visual techniques. The entire application has been developed on Java with the client application extending the World Wind APIs. The client is based on World Wind software library is used to ensure 3D Geo-Visualization and it makes use of Java Web Start technology to facilitate the deployment of client applications.



Figure 1. The image of the system where the user concurrently accesses satellite imaging, real-time sensor information, GIS vector layer within a single environment

The web services developed can provide access to multiple types of content such as imagery, vector information and processing functionalities through multiples services. Furthermore, servers can also provide access to a web catalogue where the user can perform searches and find the list of all available services.

2.3 Spatio-temporal data management.

Considering time extension in the geographical data set increases the dimension of the space domain of the analysis. It is possible to consider three issues related to the management of temporal information in spatial domain. The first is the possibility to retrieve information based on temporal information of the dataset, the second involve the capability to manage temporal information in order to generate analysis and process and, the last involve the capability to simply represent the temporal dimension in a useful manner.

The possibility to retrieve or query data set based on time properties is a fundamental requirement of the BRISEIDE framework. This involves an extension on the metadata implementation rules which define the four above mentioned categories. However these categories don't allow to completely considering the whole spectrum of temporal information.

For instance if we consider the derived data set such as a change detection layer generated using two land use classification we should be able to retrieve the information considering the time interval of the analysis. Another example is the meteorological or fire propagation foreseen, we should be able to collect the data based on data and foreseen time (12, 36, 48 h).

In case of Sensor Observation Services (SOS) it is possible to connect the system with the data sensor and filter data based on time. The system allows accessing real-time information within the very same 3D environment. The information on every sensor, corresponding to the same sensing station, is presented in a compound 3D pie and displayed after the user selects the corresponding 3D sector of interest.



Figure 2. Sensor measurements data visualization

In terms of data analysis the Time is an important variable to consider: time is related to the availability of resources such as emergency vehicles or evacuation plan. Furthermore to the time dimension are related the foreseen analysis and propagation model used by civil protection agency.

An important aim of BRISEIDE project is to deploy processing services in order to relate the time and spatial dimension in order to perform analysis useful for civil protection agencies.

These analysis here taken in account are focused to use spatiotemporal data in order to monitoring the state of the environment and to foresee some potential dangerous situations. The last issue related to Spatio-temporal analysis is the useful visualization of the results. The most common visualization is done by a series of dynamic maps which represent the evolution of some phenomena during the time; this way is useful and very intuitive but in some most articulated cases is not possible to use it. Furthermore considering the first issue mentioned above it should be possible to identify and groups all the single maps that compose the dynamic one with specific information about the time properties.

In some other cases it should be possible to represents the time information such a layer properties (i. e. different colour for two different routing path with estimated time of path covered). Some foresee layer can be visualized such as isochrones.



Figure 3. Isochrones lines for path covered time for 5 interesting point.

However, in many other cases this simple visualization are not enough and it is to use more complex diagrams in order to visualize the analysis results and this can make the understanding more difficult.

GeoVisual Analytics (GVA) is a discipline that combines the benefits of data mining and information visualization within a geospatial context. GVA is capable to provide integrated visualization, filtering and reasoning solutions to better support operators looking for design decision support [De Amicis et al. 2009]. Through GVA tools, users can typical acquire visual cues that can help them formulate a set of viable models. The possibility to provide the potentiality of GVA within web-based 3D geo-browsers is a central issue in the usability of Geographic Information (GI) and in better understanding of Geographic-dependent phenomena.

2.4 The Provincia Autonoma of Trento (PAT) pilot

BRISEIDE project Deploys operational pilots, in the environmental risk management and civil protection area, whereby operators can access the services available through an interactive web-based 3D client capable to allow management, authoring, interaction, filtering with existing data through the orchestration of the available services. Involves a value-chain of stakeholders to validate the pilots technical, organizational and legal feasibility.

One of these Pilot is located in Autonomous Province of Trento (Italy) and specifically through the Civil Protection Department. The services deployed in the context of BRISEIDE will be used to better plan and coordinate response to emergencies caused by hydrogeological disturbances. In fact To prevent disturbances it is essential to know their position, their movement mechanisms, causing factors and possible land reclamation works.

The process includes monitoring, forecast and assessment of disturbances and it is performed by the Geological Unit through IT tools based on GI. During this phase the unit identify the risk level and the evolution of the disturbance to assess if the deformation patterns are within a normal trend or if they represent a risk for local population.

More specifically the pilot envisaged for the project focuses on a concept of interoperable management of multiple sensors within a landslide monitoring scenario. In fact currently the geological unit has installed a number of monitoring systems, using different technologies, both in terms of physical hardware (sensors) and in terms of data acquisition software.



Figure4. Example of monitoring system in an area subject to hydrogeological disturbance

In this case the temporal dimension is very important because based on time analysis of the displacement the alarm threshold will be setting.

The pilot is related to all the three central issue in the spatiotemporal management analysed in this paper.

In first the information have to be retrieved and queried both starting from geometric position of the measurement system and both on time information contained in the time series. For these reasons all the measurement systems have to expose their data through a standard interface in order to make easily to connect them to the system and visualize the information.

The second issue is related to the time based analysis on the data, the most important is to correlate the rainfall with the displacement, for this reasons it should be possible to access to simple statistical operator, such as correlation and process the cumulative rainfall with the displacement.

Another important process should be to create the displacement maps starting from the time series of the measurements. To do this an operator access to data and request the data set need also searching by time. Then by a simple process transform the SOS data into geographic features such as GML. Then import the features to the system and by another process interpolating the data using an appropriate algorithm. The last step will be the publication of the final map into the system and the creation of the metadata.

The system allows to combine different elementary processing functionalities to create complex simulations in a very user friendly way. The different processing functionalities are made available through the network by a federation of processing services. Each processing unit is represented by a black box that receives data and provides an output as a result of its computing



Figure 5. Process workflow to generate a displacement map



Figure6. Graph generated starting from SOS.

The information visualization comprises the possibility to visualize both the data exposed such as Open Geospatial web services both the measurements recorded by the monitoring system. These involve the capability to create graphs and diagrams based on the historical series.

3. CONCLUSION

In this paper we presented the first phase of the EU project BRISEIDE. Aim of the project will be to develop some services specially focused on Spatio-Temporal dimension The result of the project will be deployed in 9 different Pilot dealing with different scenarios related to the civil protection themes (flooding, hydrogeological disturbance, landslide etc.). The work has identified three principal issue related to temporal dimension in the GEO-spatial domain.

The first concerns the meta information describing the temporal properties of the data; some extension to the current model are needed in order to consider some lacks which don't allow a complete explanation of the different typologies of time properties.

The second is related to the process functionalities involving the time dimension. In particular we have to consider all that functions that put in relation the time dimension with the spatial one. This mean to consider both the time as a magnitude, for instance the time to cover a path, both the time as a temporal series considering the change in some other observation during the time.

The last issue is the visualization of the results which involve considering, in case of 3D spatial representation, the 4th dimension. The work should to develop some useful representations of the temporal analysis through GVA tools.

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