

GEO-SPADE

A Generic Google Earth-based Framework for Analyzing and Exploring Spatio-temporal Data

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Abstract: Various frameworks are being developed to support geospatial data processing and exploration. However, these frameworks are insufficient due to their inability to support rapid development and reuse of existing geospatial operations. To cope with the difficulties that arise, more and more Web-based solutions are being implemented incorporating Web services and Open Geospatial Consortium (OGC)^a standards for data interchange and distributed geo-processing. Although these solutions often target specific problems, they rarely can be extended by a third party. As a result, analysts are frequently required to implement additional software in order to complete their exploration process. In this paper, we present a unified, extensible framework that can solve generic spatio-temporal analysis tasks. Specifically, we present the prototype of a new framework that allows quick hypothesis definition and testing. The proposed framework, which we term GEO-SPADE, uses Google Earth as a primary visualization platform and data interchange system. Pluggable components can easily be integrated into the framework. We demonstrate the feasibility of the GEO-SPADE framework by following the scenario of analysis of travel sequences near Funchal, Madeira Island.

^a<http://www.opengeospatial.org>

1 INTRODUCTION

Many GIS-related applications are available on the market. Some are commercial products, like ArcGIS¹; others are open source like OpenJump², MapWindow GIS³, UDig⁴, GeoDa⁵, GeoVista⁶, GRASS⁷. These applications, although written in different languages with various functionalities still share some commonalities: extensibility through exposed APIs; a range of geo-analytical functions; and support for commonly used data formats. Some applications

clearly define which tasks they can perform; others can be used as a general framework on which analytical capabilities can be built on top. The task of selecting the right tool for geo-analysis can be very time-consuming since it requires time to learn the tool's capabilities. Learning the exposed API for extensibility is another major issue, requiring a good knowledge of the application's specific programming language as well as an understanding of often complex sets of API functions. Dedicating development efforts into understanding complex APIs usually slows down progress in research, especially when rapid prototyping of ideas and concepts is needed. Usually, the analyst requires fast implementation of tasks and the decision to extend the GIS application is rarely favorable. Consequently, to achieve the desired results, the geo-processing task is split between multiple GIS applications. The issue of proprietary APIs and interop-

¹<http://www.esri.com/software/arcgis>

²<http://www.openjump.org>

³<http://www.mapwindowgis.co>

⁴<http://udig.refractions.net>

⁵<http://geodacenter.asu.edu>

⁶<http://www.geovistastudio.psu.edu/jsp/index.jsp>

⁷<http://grass.itc.it>

erability is addressed by OGC, which encourages developers to use standard interfaces and specifications when implementing geo-processing.

Most GIS applications process the data locally on the computer where the software is installed. This can present an issue when the analyst has to run several independent, resource-consuming tasks while keeping the system responsive. High demand for computer resources is still another issue that requires changes in the software architecture and the architecture of the GIS application in particular. A need for distributed geo-processing systems was addressed in recent publications (Friis-Christensen et al., 2007; Diaz et al., 2008; Schaeffer and Foerster, 2008; Foerster et al., 2009). Such systems split the workload between client and server, where clients are often Web applications, accessible by multiple users while the server performs all the required computations and delivers the results to the client using Web service technologies. Such architectures have several advantages over old, closed solutions: (1) there is no need to install a Web application; (2) many users can access the application using a Web browser; (3) the computation is performed on the server side, which relieves the user's computer from performing time consuming operations; and (4) there is no need to locally store the data (the data can be accessed directly by the service and hosted by the service provider).

Scalable, distributed architecture, that conforms to open standards, may solve the problem of interoperability and service reusability. However, the client side still has to be developed according to specific tasks defined in advance. Since any changes in the design or in extending the capabilities should be performed by the body responsible for maintaining the Web application, there is a need for a platform, that supports easy extensibility with minimum knowledge of the underlying API. Such a platform should support many of the general visual data exploration approaches like *brushing*, *focusing*, *multiple views*, *linking*. It should also be able to support (geo)visualization approaches such as direct depiction, visualization of abstract data summaries, and extraction and visualization of computationally extracted patterns. It should also be capable of integrating different geo-related tasks to allow the analyst to quickly generate and test her hypotheses (Andrienko et al., 2008). Google Earth has gained interest among researchers for visualizing and exploring (geo)processing results. The results are communicated using KML (Keyhole Markup Language), an XML-based language for geographic visualization. Providing satellite images of the Earth's surface, Google Earth implements basic visualization

techniques like zooming and panning. With many layers of information provided by Google and user communities, Google Earth includes a built-in HTML browser and allows dynamic content to be streamed from a server in response to changes in a visible frame. Recent publications demonstrated that Google Earth can be effectively used for data exploration in various areas such as: weather monitoring (Smith and Lakshmanan, 2006), spatio-temporal data exploration (Wood et al., 2007), data mining (Compieta et al., 2007), insurance (Slingsby et al., 2008), crisis management (Pezanowski et al., 2007), and spatial OLAP (Martino et al., 2009). Despite these capabilities, Google Earth is still used as a "secondary" tool for data visualization because of its lack of geo-analytical functionality. Google Earth usually overcomes this geo-analytical deficiency by embedding Google Earth into a Web application using its JavaScript API. "Missing" features can then be implemented using *Network Link* element, which is part of KML, to point to the URL of the underlying server to request a specific operation. Although the *Network Link* feature is used for creating dynamic content, it allows data to flow in only one direction, from the server to Google Earth in response to the changes in the visual boundaries. Clearly, this feature does not allow more complex operations like passing parameters interactively, running the data mining algorithm on the server, and returning the results for a particular setup of objects being visualized by Google Earth. Other mechanisms for performing such operations are required.

Recently, embedding the Google Earth in desktop applications became possible⁸ using the Google Earth Web browser plugin⁹ COM interface. This makes it possible to write custom applications around Google Earth in high level languages like *c#* and to completely control the logic of the application thus bypassing the limitations of the stand-alone version of Google Earth. This possibility and the constraints of current GIS systems have encouraged us to develop a prototype desktop system called GEO-SPADE (**GEO SP**Atiotemporal **D**ata **E**xploration). In GEO-SPADE, Google Earth plays a primary role as geo-browser and the missing geo-processing features can be added on the server side using any available language. The results are delivered to the client in the form of KML files using Web service technology.

The goals of the paper can be summarized as follows: (1) to enhance the capabilities of Google Earth by making it a primary tool for geo-related analy-

⁸<http://code.google.com/p/winforms-geplugin-control-library/>

⁹<http://earth.google.com/plugin/>

sis; (2) to demonstrate that Google Earth is capable of assisting in geo-processing, visualization and data exploration methods by embedding it into a customizable desktop application; and (3) to present a SOA-based architecture that allows for quick hypothesis generation and testing by implementing extensible components.

We demonstrate the feasibility of our prototype by following an analysis scenario of travel sequences near Funchal, Madeira Island.

2 RELATED WORK

Issues in classical desktop GIS and the need to delegate GIS functionality using SOA (Service-oriented Architecture) are addressed in a series of recent publications and summarized by (Brauner et al., 2009). The main issues in geo-processing services are: reusability of services; the ability to solve complex geo-processing problems using orchestrated service chains; building service descriptions for easy service consumption; and the stateless nature of web services (Friis-Christensen et al., 2007; Brauner et al., 2009).

There have been various attempts in recent years to deal with these issues. For example, geo-processing functionality of GRASS, a desktop GIS application, was wrapped by Web Services using OGC WPS¹⁰ (Web Processing Service) specification (Cepický and Becchi, 2007; Brauner and Schaeffer, 2008). The WPS specification, which defines a standardized service interface to publish and perform geospatial processes over the network, consists of three operations: *GetCapabilities*, *DescribeProcess* and *Execute*. All have to be implemented by the service provider. Since the WPS defines only the standard interfaces, the responsibility of a service consumer is to acquire complete information about the specifications of a given Web service using *GetCapabilities* and *DescribeProcess* interface functions or via WSDL (Web Service Definition Language).

Integration, reusability and modularity of Web services accessing SDI (Spatial Data Infrastructures) were addressed by (Diaz et al., 2008). They wrapped several FOSS (Free Open Source Software) libraries as WPS-based services and implemented in a prototype system for creating hydrological models.

Integrating WPS-based services into Google Earth is addressed by (Foerster et al., 2009). Their approach has two parts to it. In the first part, the WPS client built on top of the uDig (desktop, Java-based GIS sys-

tem) exports configured processes into a KML file. In the second part, the KML file is loaded into Google Earth, which triggers WPS processes using *Network Link* element. The advantage of the WPS approach is that the exported processes can be consumed by the vast community of people using applications that handle KML formats such as Google Earth or Google Maps. This advantage was addressed in recent publications (Smith and Lakshmanan, 2006; Slingsby et al., 2008). However, the proposed approach has several disadvantages: although the approach has two parts, they are not autonomous and require manual implementation (configuration of the processes using WPS client, creation and export of KML and dissemination of the results). Another aspect is lack of interaction and control over the geo-process exported into KML. As soon as KML is loaded into the application with *Network Link*, the process will be triggered and the results returned.

The client side, which usually involves data visualization and manipulation, still remains more heterogeneous than the server side, since the way the data is presented cannot be enforced by standard specifications and interfaces. Here the choice of an appropriate software is driven by the needs of an expert. As was already mentioned, dozens of GIS applications are available, capable of solving specific spatial processing tasks and of supporting geo-visualization. When this is not the case, custom solutions and architectures are proposed (Wachowicz et al., 2002; Lundblad et al., 2009). However, the current trend in data visualization and exploration is to use mass-market applications such as Google Earth for visualization, combined with open source technologies for data processing and storage (Wood et al., 2007; Pezanowski et al., 2007; Martino et al., 2009).

Bringing geo-processing capabilities and Google Earth together is addressed by (Pezanowski et al., 2007) to support crisis management scenarios. For this task, "Google Earth Dashboard" was proposed. It combines several technologies: Adobe Flex, WMS (Web Map Service), WFS (Web Feature Service), WPS services and Google Earth as the cornerstone. The communication with services and the creation of dynamic data were carried out using the *Network Link* feature, whose disadvantages were discussed in Section 1.

(Wood et al., 2007) demonstrated how visually exploring mobile directory service log files with spatial, temporal and attribute components can be performed using Google Earth in combination with other open source technologies like MySQL, PHP and LandSerf. (Wood et al., 2007) discusses several aspects, like visual encodings, color and overplotting and shows how

¹⁰<http://www.opengeospatial.org/standards/wps>

Google Earth handles these features.

(Slingsby et al., 2008) presented the feasibility of exploring of catastrophic events and potential loss of information. The tasks that must be performed are outlined. The methods, with which Google Earth can handle such tasks, include: mapping, filtering by attribute, space, time, spatial aggregation, creation of new views.

The key differences between the existing architectures and prototypes and the concept presented in this paper can be summarized as follows: we demonstrate a generic solution from the client and server side perspective and our approach eliminates the above mentioned disadvantages by integrating Google Earth into a custom GIS client that invokes geo-processing Web services, returns results as KML streams and loads the results directly into Google Earth instance. The expert has a complete control over geo-processing and every visualized object. The generic framework we propose can be used for solving many geo-related problems without imposing a specific technology.

To our knowledge, the work described in this paper is the first that tries to implement an extensible geo-processing framework. This framework can be used for implementing a variety of geo-related tasks from visualization to complex geo-processing with Google Earth integrated into a desktop application, offering enhanced Google Earth capabilities, plug-gable components and SOA-based architecture.

3 GEO-SPADE APPLICATION AND ARCHITECTURE

In this section we present the main features of the system and discuss the proposed architecture.

3.1 Overview

The client is an MDI (Multiple Document Interface) desktop application that allows multiple windows to reside under a single parent window. The client is written in c# programming language. We tried to keep the application as generic as possible by implementing the core features shared by all tasks. However, further extensibility is possible. The main user interface is presented in Figure 1.

Views (labeled as 1 in Figure 1) are the main views that encapsulate instances of Google Earth. The user can open several windows and multiple instance of Google Earth will be instantiated. The basic functionality of these views is the same as in the stand-alone Google Earth application: navigation to a specific location, panning, zooming, and KML layer loading.

We also added support for custom shape creation by drawing on top of the map. This feature is described in further detail in the Section 3.2.

The session tree window (labeled as 2 in Figure 1) maintains a list of open Google Earth views (sessions) and KML objects that belong to every session. This window supports removing, renaming and hiding of any KML object. Moreover, the textual representation of a KML object (labeled as 3 in Figure 1) can be obtained by selecting it using a session tree node.

The toolbox window (labeled as 4 in Figure 1) is utilized for basic geo-coding and defining the width and color of a line used for manual region selection on top of the map of the current session.

The window labeled as 5 in Figure 1 records event logs and exception messages.

3.2 Main Features

In this section we outline the main features of the proposed framework:

Multiple Instances of the Google Earth. Every view encapsulates a new Google Earth instance (labeled as 1 in Figure 1). This feature allows the analyst to work independently on different regions or to separate the visualization of different objects applied to the same area.

Synchronization between Views. When the exact positioning of several views is required for comparison, the view's boundaries can be synchronized to match the boundary of another view.

Session-based Views. We introduced a notion of session when working with views. As was already mentioned, the analyst may work simultaneously with multiple views. If several time-consuming algorithms are activated, the application should know in which view the results of computation are directed. Since Web services are usually stateless, that is to say each individual request sent from the client should contain all the information because the server does not store the session state data (MicrosoftTeam, 2009), the session id of the view is sent along with other service specific information. When the service produces the KML result, the original session id is attached in the response. Therefore, when the client receives the server response, the framework tries to match the session id extracted from the KML to all existing sessions. If one is found, the result is visualized in that view, otherwise, the result is discarded. The discarding of a result can occur, for example, when the analyst closes the view that was active when the service

request was performed. Sessions and objects that belong to the session are displayed in a session tree (labeled as 2 in Figure 1).

Shape Drawing on top of Google Earth. We anticipated that some tasks may require manual region selection on top of the Google Earth map. This selection can be used in different scenarios such as finding objects that are located within the boundaries of the selection. The region creation is described by coordinates, line color and width, and stored as a regular KML object that can later be saved and reused.

Pluggable Components. To keep the core system as simple as possible, it includes only the components necessary for storing and visualizing KML files, maintaining views, logging and exception management. The complexity of geo-related tasks is delegated to the custom implementation using pluggable components. The components follow specific requirements and conceptually do not differ from the plugins used in other frameworks like MapWindow GIS or OpenJUMP.

View Separability. This is not strictly the feature of the framework, but the outcome of the MDI architecture. If two or more displays are available, the views and pluggable components can be positioned on different displays in order to isolate different tasks and to free more visual space. For example, the analyst may want to position two maps on separate displays or separate between session views and the main UI.

Chaining of Analysis Steps. Results obtained from the server are visualized using KML. However, the elements of the KML are objects that hold some state and relevant information (for example, cluster boundaries or area). The analyst can further refine the results by focusing on the subset of the obtained objects. Consequently, a new invocation of an algorithm can be accomplished using the selected objects to pass information.

Service Oriented Architecture. Allows service reuse and interoperability across programming languages and platforms. Changes in the service implementation remain transparent to the client as long as the number and naming of parameters in a service contract do not change.

3.3 Architecture

The proposed architecture is based on a thin-client paradigm whose main purpose is to pass off geoprocessing to a remote server using Web services. The core system visualizes the results, drawing upon any of the Google Earth wrapped views as described in Section 3.2. However, the provider of the plugin component is responsible for the basic UI view and complex interaction if needed (see Section 4 for illustration).

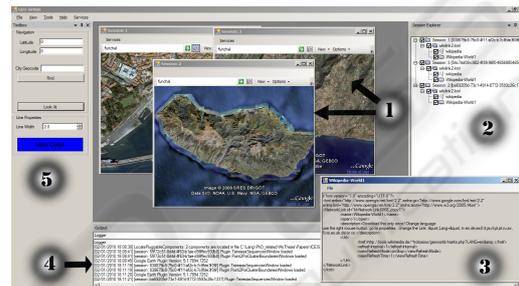


Figure 1: Basic GEO-SPADE components.

The selection of a communication protocol depends on the service provider and different protocols can be integrated as extension points. However, the application proposes asynchronous REST (representational state transfer) services (Fielding, 2000). REST is an architectural style of networked systems and relies on HTTP protocol and data exchange based on XML. Since REST does not deal with implementation details, the Web services based on REST can be created and consumed by different programming languages. The advantages of using REST-like architecture in GIS are described in WPS standard specifications. The extension mechanism is performed by creating pluggable UI components whose basic purpose is to obtain from the user the parameters for invoking the Web service. The overall architecture of the application can be seen in Figure 2. The geoprocessing task can be provided as one pluggable component and/or can be split into a chain of steps. The server side is presented as a collection of geo-processing services.

4 USE CASE

The purpose of this section is to demonstrate the capabilities of the presented prototype system. We selected a scenario that analyzes travel sequences using geo-tagged photos. The analysis of people's movement has become a major topic in different domains

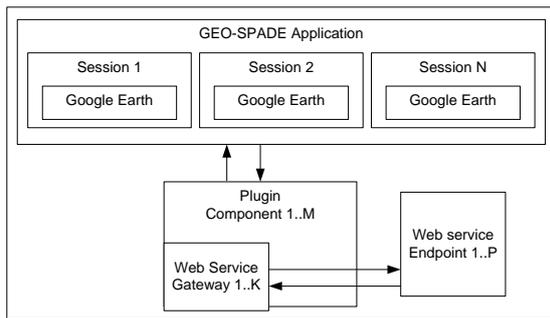


Figure 2: GEO-SPADE architecture.

such as transportation management and tourism (Girardin et al., 2008; Andrienko et al., 2009). Recently, the analysis of travel sequences and people's movement using geo-tagged photos has become possible due to the availability of photo sharing sites like Flickr or Panoramio that provide public APIs to collect information from millions of shared photos. In our recent work (Kisilevich et al., 2010a; Kisilevich et al., 2010b), we defined a number of tasks for analyzing attractive areas, people's behavior and movement. GEO-SPADE performed the analysis.

Without going into much detail regarding algorithms involved in a task processing, we show how GEO-SPADE can facilitate the task of finding frequent travel sequence patterns in an arbitrary region of the World (Kisilevich et al., 2010a). We outlined six possible steps for completing the task. These steps actively involve the analyst in the process of finding sequence patterns by reviewing the results of every step in the process, changing the parameters and activating the new steps using results (a subset of) of the previous step.

In the first step, presented in Figure 3, the analyst selects the desired area. The visible frame constitutes the boundaries of the region.

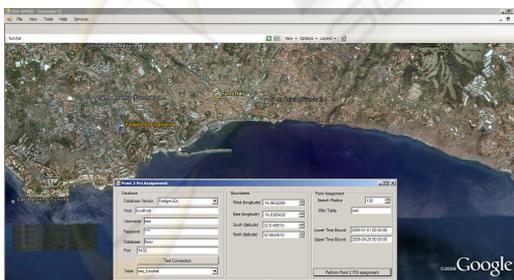


Figure 3: Step 1. Selection of the area of interest.

The process of finding travel sequences is divided into two parts. In the first part, every photo location is matched against a database of points of interest (in our

case we used the Wikipedia database) and the closest POI is assigned to the photo. This creates clusters in which every photo is assigned to existing POIs. In the second part, the remaining unassigned photos are clustered using a density-based clustering algorithm. The results of the second step are presented in Figure 4. The left part of the figure shows clusters in which photos were assigned to known POIs, while the right part of the figure presents clusters of photos that were not assigned to a POI.

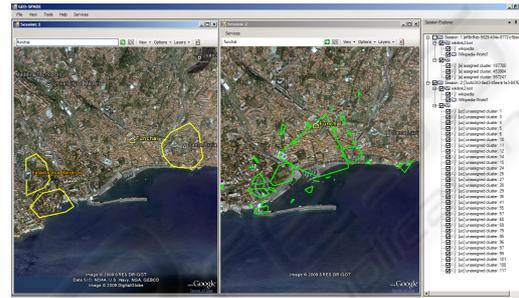


Figure 4: Step 2. Multiple view of regions assigned to some existing POI (left) and regions where no POI was found (right).

In step 3, the analyst should inspect the created clusters and perform the clustering again if needed. If steps 1 and 2 are satisfactory, the analyst can inspect the clusters of unassigned photos. She may remove some clusters that are irrelevant or unimportant using either the statistical information of the cluster (number of photos and owners in a cluster) or her background knowledge of the area. The session window on the right lists all the unassigned clusters. Figure 5 summarizes this step by presenting a view in which the analyst can select unassigned clusters and artificially create a new POI identification for every selected cluster.

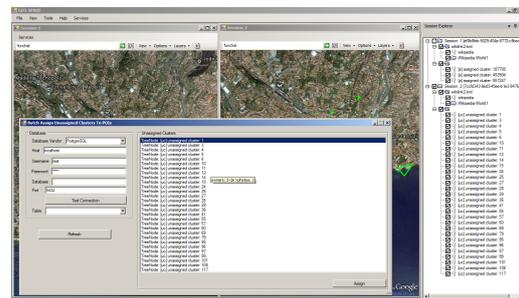


Figure 5: Step 3. Selection of unassigned regions and creation of artificial POIs.

After performing step 3, the analyst may want to see the results of cluster to a POI assignment. This

can be done in the same session window or by opening another session such as presented in Figure 6.

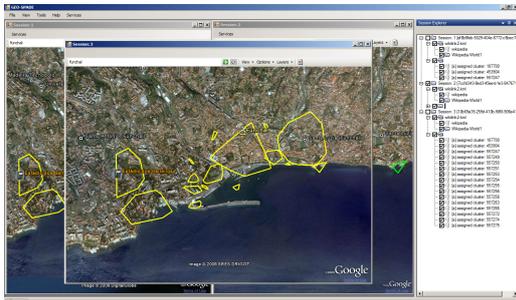


Figure 6: Step 4. Combined view of all regions visited by people.

In this step, the analyst generates sequence patterns from the clusters that were assigned to existing and artificial POIs. Figure 7 shows a form in which the analyst can select such parameters as: database properties and the length of generated patterns. When sequence patterns are generated, they are presented by POI names in the main view along with additional information (frequency and cluster id's).

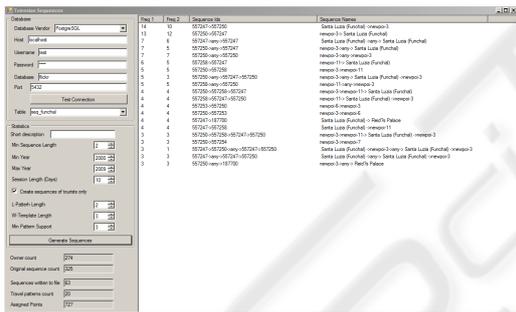


Figure 7: Step 5. Sequence pattern generation.

The most frequent pattern generated is *Santa Lucia* ⇒ *newpoi-3*. While Santa Lucia is a parish in the district of Funchal and may be known to the domain expert, *newpoi-3* is a name assigned by the system to an area in which the Wikipedia database does not contain a known POI. Clearly, this area should be visualized to give the analyst a hint about the sequence. Sequences can be highlighted by clicking on the sequence pattern. Placemarks will be added to the centers of the areas that are part of the selected sequence and the number assigned to them will highlight the relative order of the area in the sequence. In the case of *Santa Lucia* ⇒ *newpoi-3*, Santa Lucia will be highlighted with a number one, while *newpoi-3* will get number two, Figure 8.

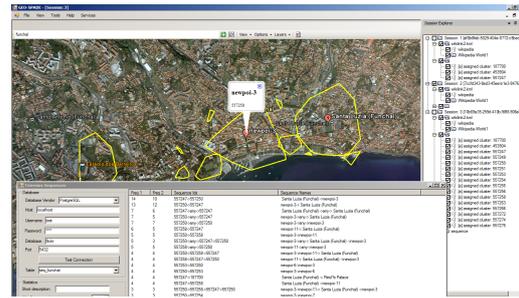


Figure 8: Step 6. Combined view of obtained sequence patterns and map. Highlighting of regions by clicking on the sequences.

5 CONCLUSIONS AND FUTURE WORK

In this paper we presented a framework called GEO-SPADE based on service-oriented architecture. On the client side, we demonstrated that Google Earth is capable of performing data exploration and visualization tasks by embedding it into a customizable application using high level language. We enhanced those capabilities of Google Earth that are not available in a stand-alone version such as manual region selection, multiple and synchronized views. We also built the framework around pluggable components.

On the server side, the SOA-based architecture allows for distributed processing of time and resource-consuming tasks as well as reduced coupling between the client and service implementation details. This feature facilitates rapid development. The analyst may generate a hypothesis and formulate the tasks needed to test it. The developer's task is to create service implementation and pluggable UI components that interface with the services. These services perform computations and return results in the form of KML streams.

Since the KML holds the description of visualization, it can be easily stored and reused in any system that supports KML file format. Moreover, the service oriented nature of the framework allows other experts to reuse services.

We demonstrated the feasibility of our prototype by following a scenario of finding frequent travel sequences.

In future research we will concentrate on enhancing the capabilities of the framework and extending the use of the framework by working on various GEO-related problems.

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REFERENCES

- Andrienko, G., Andrienko, N., Bak, P., Kisilevich, S., and Keim, D. (2009). Analysis of community-contributed space-and time-referenced data (example of panoramio photos). In *GIS '09: Proceedings of the 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, pages 540–541.
- Andrienko, G., Andrienko, N., Dykes, J., Fabrikant, S., and Wachowicz, M. (2008). Geovisualization of dynamics, movement and change: key issues and developing approaches in visualization research. *Information Visualization*, 7(3):173–180.
- Brauner, J., Foerster, T., Schaeffer, B., and Baranski, B. (2009). Towards a research agenda for geoprocessing services. In *The 12th AGILE International Conference on Geographic Information Science*.
- Brauner, J. and Schaeffer, B. (2008). Integration of grass functionality in web based sdi service chains. In *Academic paper on the FOSS4G Conference, Cape Town*.
- Cepický, J. and Becchi, L. (2007). Geospatial processing via internet on remote servers—pywps. *OSGeo Journal*, 1(1).
- Compieta, P., Di Martino, S., Bertolotto, M., Ferrucci, F., and Kechadi, T. (2007). Exploratory spatio-temporal data mining and visualization. *Journal of Visual Languages and Computing*, 18(3):255–279.
- Diaz, L., Granel, C., Gould, M., and Olaya, V. (2008). An open service network for geospatial data processing. In *An Open Service Network for Geospatial Data Processing: Free and Open Source Software for Geospatial (FOSS4G) Conference*.
- Fielding, R. T. (2000). *Architectural styles and the design of network-based software architectures*. PhD thesis, University of California, Irvine. Chair-Taylor, Richard N.
- Foerster, T., Schaeffer, B., Brauner, J., Jirka, S., and Muenster, G. (2009). Integrating ogc web processing services into geospatial mass-market applications. *IEEE GeoWS*.
- Friis-Christensen, A., Ostlander, N., Lutz, M., and Bernard, L. (2007). Designing service architectures for distributed geoprocessing: Challenges and future directions. *Transactions in GIS*, 11(6):799.
- Girardin, F., Fiore, F. D., Ratti, C., and Blat, J. (2008). Leveraging explicitly disclosed location information to understand tourist dynamics: a case study. *Journal of Location Based Services*, 2(1):41–56.
- Kisilevich, S., Keim, D., and Rokach, L. (2010a). A novel approach to mining travel sequences using collections of geo-tagged photos. In *The 13th AGILE International Conference on Geographic Information Science*.
- Kisilevich, S., Krstajic, M., Keim, D., Andrienko, N., and Andrienko, G. (2010b). Event-based analysis of peoples activities and behavior using flickr and panoramio geo-tagged photo collections. (submitted).
- Lundblad, P., Eurenus, O., and Heldring, T. (2009). Interactive visualization of weather and ship data. In *Proceedings of the 13th International Conference Information Visualisation*, pages 379–386, Washington, DC, USA. IEEE Computer Society.
- Martino, S. D., Bimonte, S., Bertolotto, M., and Ferrucci, F. (2009). Integrating google earth within olap tools for multidimensional exploration and analysis of spatial data. In *Proceedings of the 11th International Conference on Enterprise Information Systems*, pages 940–951.
- MicrosoftTeam (2009). *Microsoft Application Architecture Guide*. Microsoft Press.
- Pezanowski, S., Tomaszewski, B., and MacEachren, A. (2007). An open geospatial standards-enabled google earth application to support crisis management. *Geomatics Solutions for Disaster Management*, pages 225–238.
- Schaeffer, B. and Foerster, T. (2008). A client for distributed geo-processing and workflow design. *Location Based Services Journal*, 2(3):194–210.
- Slingsby, A., Dykes, J., Wood, J., Foote, M., and Blom, M. (2008). The visual exploration of insurance data in google earth. *Proceedings of Geographical Information Systems Research UK (GISRUK)(Manchester, UK, 2007)*, pages 24–32.
- Smith, T. and Lakshmanan, V. (2006). Utilizing google earth as a gis platform for weather applications. In *22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology, Atlanta, GA, 29 January-2 February 2006*.
- Wachowicz, M., Ying, X., Ligtenberg, A., and Ur, W. (2002). Land use change explorer: A tool for geographic knowledge discovery. In *In Anseling, L., Rey S.J. (eds), New Tools for Spatial Data Analysis, Proceedings of the CSISS specialist meeting*.
- Wood, J., Dykes, J., Slingsby, A., and Clarke, K. (2007). Interactive visual exploration of a large spatio-temporal dataset: Reflections on a geovisualization mashup. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1176.