

# TOWARDS A WEB SERVICE FOR GEOGRAPHIC AND MULTIDIMENSIONAL PROCESSING

Joel da Silva, Valéria C. Times, Robson Fidalgo, Roberto Barros  
*Information Technology Center – Federal University of Pernambuco, P. O. Box 7851  
Cidade Universitária, Recife – PE, Brazil, 50.732-970*

**Abstract:** A lot of research has been developed for integrating the analysis functionality that is available in both analytic and geographic processing systems. The main goal is to provide users with a system capable of processing both geographic and multidimensional data by abstracting the complexity of separately querying and analyzing these data in a decision making process. However, this integration may not be fully achieved yet or may be built by using proprietary technologies. This paper presents a service integration model for supporting analytic and/or geographic requests over the Web. This model has been implemented by a Web Service, named GMLA WS, which is strongly based on standardized technologies such as Web Services, Java and XML. The GMLA WS query results are displayed in a Web browser as maps and/or tables for helping users in their decision making.

**Key words:** GMLA Web Service, GIS and OLAP Integration, Services Integration Model, ISAG, GMLA Request Schema.

## 1. INTRODUCTION

Several researchers from the Information Technology community have thoroughly investigated the problem of integrating the analytic and geographic processing<sup>29-33</sup>. However, much of this work does no more than proposing an operator for the system interface. Moreover, this is an arduous task and deserves some special attention. The main idea is to develop an open and extensible system with the analysis capabilities available in these two technologies. Thus, a geographic processing system<sup>5-8</sup> could take the advantage of the facilities implemented by an analytic tool,<sup>1,16</sup> while the

latter would receive a considerable gain in aggregating some spatial treatment to the geographic dimension.

According to this, members of the project GOLAPA (*Geographic Online Analytic Processing Architecture*)<sup>17,18</sup>, have been studying a way of providing users with an abstraction of the complexity involved in querying analytic and geographic data for decision support<sup>34,35</sup>. GOLAPA is an software architecture that aims to be: 1) based on open and extensible technologies and 2) optimized for decision support in a geographic-multidimensional context. The first goal deals with the integration concerning the technological issue, that is, making sure that the system is based on technologies such as Web Services, Java and XML. The second considers the strategy that potentially is the best solution for the data processing integration.

The work presented in this paper is part of the GOLAPA project and aims to integrate the analytic and geographic services for decision support over the Web. This article presents the GMLA Web Service, which provides operations for performing analytic and/or geographic analysis over a geographic-multidimensional data source.

The remainder of this paper is organized as follows. The second section presents a summary of the main related researches. The third section outlines the XML and Web services technologies together with a view of some other related standards. The section four presents the GMLA Request Schema. In the fifth section, is presented the integration model namely ISAG. In the section six, details concerning the GMLA Web Service implementation are given. The section seven shows an application of the GMLA Web Service, with some experimental results. Finally, some conclusions regarding this investigation are given in the section eight.

## 2. RELATED WORK

A lot of research about the integration between analytic and geographical processing has been found in the literature,<sup>48-56</sup> but just the following studies have showed to be more relevant to the work given in this paper: MapCube,<sup>29</sup> GeoMiner,<sup>30</sup> GOAL<sup>31, 57</sup> and SIGOLAP<sup>32, 33</sup>.

MapCube is an operator used to perform aggregation and visualization of geographical data as a metaphor for an album of maps. MapCube is based on the Cube<sup>58</sup> operator and similar to this, it performs all combinations of aggregation for each data of each DW dimension. The main difference between these operators is the presentation of their results. The Cube operator just presents its results in a tabular view, whereas the MapCube operator shows the results as both tables and maps.

GeoMiner is a project aiming at the mining of geographical data, which is composed by three basic modules. However, just two of these modules can be considered as related work: the module for geo-cubes construction and the one for geographical OLAP. In your research, Han *et al.*<sup>59,60</sup> proposed two algorithms for the efficient construction of geographical data cubes: Pointer Intersection and Object Connection. These algorithms provide a means of building analytical and spatial cubes based on the selective materialization of a geographical dataset. The specified criteria were: 1) the geo-dataset access frequency, 2) its storage cost and 3) the support for building other derivatives geographical cubes.

Geographical Information On-Line Analysis (GOAL) is a project that aims to accomplish the integration between Data Warehouse (DW) / On-Line Analytical Processing (OLAP) and Geographical Information Systems (GIS). To achieve this, the authors have implemented an architecture where the main component used to manage this task is the Integration Module (IM)<sup>31, 57</sup>. For the case study presented by Kouba *et al.*,<sup>57</sup> the software GT Media98 and ArcView were used together with the MSOLAP server as the OLAP component. Because these tools have different interfaces for communication, the IM has to be adjusted to offer the appropriate support for each software component. The communication with ArcView was achieved by using Avenue scripts (the native language of ArcView) and Delphi libraries, while the communication with MSOLAP was done by implementing an OLE DB for OLAP provider<sup>61</sup> with Visual C++.

SIGOLAP<sup>32,33</sup> provides the integration between GIS and OLAP by a three tier architecture, which is based on a mediation approach. The case study implemented to demonstrate this architecture was developed using the following technologies: MSOLAP Server; MSAccess and AutoDesk Mapguide Server; SQL Server and Visual Basic, and, Visual Basic Script.

With regard to the work discussed above, we shall now conclude that the MapCube approach just provides multidimensional analytical processing over geographical data, without considering the spatial queries (*e.g.* queries about distance and adjacency). However, despite using proprietary technologies and as a result, preventing them from being multi-platform based approaches and from providing extensibility and data interchange capabilities, the remaining work discussed above, namely GeoMiner, GOAL and SIGOLAP do integrate SIG and OLAP functionalities. This implementation with a lack of platform independence can be seen as a motivation for the work given in this paper.

### **3. XML AND WEB SERVICES**

This paper presents a XML (eXtensible Markup Language) based approach to provide users with analytic and geographical processing over the Web. The main goal is to provide an environment for decision making that abstracts the complexity involved in simultaneously querying multidimensional and/or geographical data. To overcome the limitations mentioned in the previous section, we have used the Web Services technology, because it is strongly based on XML, and thus, has allowed us to easily integrate systems with distinct functionalities. Using the Web Services and XML technologies, we have obtained an open and platform independent solution for the analytic and geographical processing integration.

The development of the XML<sup>20</sup> has been recognized as an important issue in the Information Technology research area. XML has become a standard for data publication and interchange over the Web. It is an extensible language that allows new standards to be specified from it, and thus, enables the development of new technologies to be operated in conformity with it.

Another technology that has been developed from XML is Web Services<sup>9</sup>. These compose a distributed computational architecture based on auto-descriptive services that can be published, located and executed through the Web, and which publish interfaces and connections that are both defined and described in XML. The syntax of a Web Service can be exposed through the Web Services Definition Language (WSDL),<sup>21</sup> which allows you to publish information related to the service location and its access mode. The publication of a Web Service is performed through Universal Description, Discovery and Integration (UDDI),<sup>10</sup> where the service provider makes available its information. The information interchange between a Web Service and a client application is performed through the Simple Object Application Protocol (SOAP),<sup>11</sup> which sends and receives information coded in XML, through the Hypertext Transfer Protocol (HTTP)<sup>12</sup>.

In this paper, both the XML and Web Service technologies are considered as essential for the processing, interchange and visualization of the analytic and geographic data over the Web. XML for Analysis (XMLA),<sup>13</sup> Web Feature Service (WFS)<sup>15</sup> and Geography Markup Language (GML)<sup>14</sup> are mainly standardized and key technologies, to provide the development of Web Services for geographic-multidimensional processing.

#### **3.1 Analytic Web Service**

XML For Analysis (XMLA) is one of the open technologies that is available to enable the OLAP<sup>1</sup> processing on the Web. It is a XML API

based on SOAP and created by an initiative of the Microsoft Corporation<sup>23</sup> and Hyperion Solutions Corporation<sup>24</sup> to provide an open access for multidimensional databases. This standardized access enables a non-proprietary communication between client applications and OLAP data servers through the Internet.

XMLA implementation is based on the Web Services architecture and the description of its service is defined in terms of a WSDL document. XMLA provides two methods for managing its functionality: *Execute* and *Discover*. These enable the access of both data and metadata stored in a multidimensional OLAP Server. As these methods are invoked through SOAP, the input and output are XML documents.

### 3.2 Geographic Web Service

The two most important XML based technologies that make the provision for the geographic data processing on the Web are GML<sup>14</sup> and WFS<sup>15</sup>.

GML is the OpenGIS<sup>27</sup> XML Schema for interchanging and storing the descriptive and geometric properties of geo-referenced data. GML is based on the abstract model<sup>26</sup> of the OpenGIS consortium and its last stabilized version (*i.e.* 2.1.2) supports vector geo-data only. Although the GML 3.0 has recently been launched already, this is still under industry evaluation, and for this reason, we have decided to use GML 2.1.2 which is an evaluated and stabilized version.

GML is a meta-schema with a set of elements and attributes for building geographic application schemas. Differently from the XMLA Web service, GML is just a vocabulary defined in XML Schema, and thus, the use of WFS (or another tool) is needed to manipulate geo-data in GML (e.g. FME<sup>i</sup>).

WFS<sup>15</sup> is the OpenGIS Specification for providing some interfaces for the description of operations used to manipulate geographic features (coded in GML) in a distributed environment through the HTTP protocol. The geographic features are spatial objects that must at least contain one geometric property and may have one or more descriptive properties. Operations for data manipulation include abilities to create, erase, change, obtain or search features based on spatial restrictions (e.g. adjacency and distance) and on non-spatial criteria (e.g. population  $\geq$  800.000 and gender = "M").

The recovery of both data and metadata stored in a geographic database is achieved by the use of the following WFS operations: *GetCapabilities*, *DescribeFeatureType* and *GetFeature*. The spatial, logic, arithmetic and comparison operators, which may be used in a WFS request are described in

<sup>i</sup> <http://www.safe.com/products/fme/>

the OpenGIS Filter Encoding Implementation Specification<sup>25</sup>. Some WFS services also implement the *Transaction* and *LockFeature* operations, which can be used to update, delete and include some data. However, for our case study, these operations have not been considered. This is because in decision support systems, after correctly loading the data, only reading operations should be performed.

### 3.3 Geography Markup Language for Analysis - GMLA

We have specified the GMLA<sup>17</sup> according to the XML Schema<sup>22</sup> syntax which is based on both XMLA and GML standards. Thus, GMLA imports, extends, and integrates the original XML Schemas. With GMLA, data that had been previously described by two distinct schemas, can now be described and semantically integrated by just one schema. This resulting schema is then used by the GMLA Web Service to describe and validate the geographic-multidimensional data.

GMLA can either be used as a schema or a meta-schema. In the first case, data are exactly described as defined by the GMLA Schema. In the second one, GMLA plays the role of a basic vocabulary that may be used to outline other geographic-multidimensional data schemas. The advantage of the second approach is the possibility of building schemas that are semantically customized. This is not allowed in the first case, because it is a generic schema. For example, in the first instance, all geographic features are member elements, which are organized in the *featureType* element. However, in the second case, we can define some geographic features as special types (e.g. *residenceMember*), which may be disposed in a special theme (e.g. *residenceTheme*). The elements of a GMLA document are defined in its *geoMDResult.xsd* XML Schema, which can be downloaded from [www.cin.ufpe.br/~golapa/schemas/gmla](http://www.cin.ufpe.br/~golapa/schemas/gmla).

The technologies discussed in this section have fundamentally contributed for the integration of the analytic and geographic processing. Using them helped in the development of the *GMLA Request Schema*, the integration model and the *GMLA Web Service*. These are described in the following sections.

## 4. GMLA REQUEST SCHEMA

Before developing the integration model and the GMLA Web Service for the analytic and geographic services integration, the GMLA Request Schema<sup>37</sup> was defined. This XML schema is responsible for the validation of requests that are processed by the GMLA Web Service and, consequently,

for the prevention of syntactic errors. The GMLA Request Schema integrates the request syntax of the XMLA and WFS services and was defined to support the following three query types: MD (*Multidimensional*), GEO (*Geographic*) and GEOMD (*Geographic-Multidimensional*).

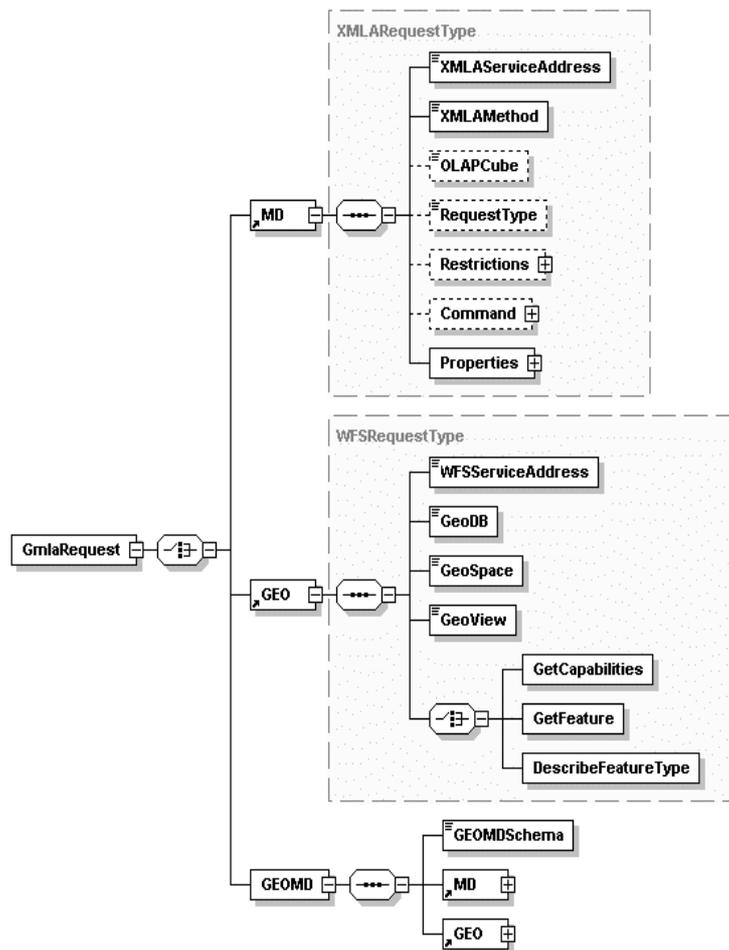


Figure 1. GMLA Request Schema diagram.

A query of type MD just contains analytic parameters that allow the execution of a multidimensional expression<sup>28</sup> or a metadata request. When this query type is submitted to the GMLA WS, it delegates this request to the XMLA analytic service that will process the corresponding result. On the other hand, a request of type GEO just contains geographic parameters, where the GMLA WS activates the WFS service to produce the needed result. Finally, a GEOMD request contains both analytic and geographic

parameters, and in this case, both services (*i.e.* XMLA and WFS) are processed to obtain a solution satisfying the query. In addition, a GEOMD request can be further classified as follows: 1) *Mapping GEOMD*, where an analytic request is sent to the GMLA WS and data with geographic correspondence<sup>ii</sup> are displayed on a map, and 2) *Integration GEOMD*, where analytic and spatial restrictions are specified and used in the request processing. The GMLA Request Schema can be downloaded from <http://www.cin.ufpe.br/~golapa/schemas>, while some query examples can be downloaded from <http://www.cin.ufpe.br/~golapa/gmlaws/requests>.

In the Figure 1, the GMLA Request Schema diagram is presented, which was generated by the XML Spy tool<sup>iii</sup>. In this diagram, the main elements of this schema are displayed. The GMLARequest is the main element and its child element may be *MD*, *GEO* or *GEOMD*. The *XMLAServiceAddress* element represents the location of the analytical service. *XMLAMethod* identifies the method of the analytical service that will be invoked. The *OLAPCube* element represents the name of the analytical data cube that will be used in the query. The last four subelements of *MD* (*i.e.* *RequestType*, *Restrictions*, *Command* and *Properties*) are inherited from the XMLA service request syntax<sup>13</sup>. In the *GEO* element, the subelement *WFSServiceAddress* represents the location of the geographic service. The name of the geographical database used in the query is given by the *GeoDB* element. *GeoSpace* identifies the name of the geographical space used in the request. The *GeoView* element represents the name of the geographical view used in the query. Finally, the last *GEO* subelement may be represented by one of the following elements inherited from the WFS request syntax: *GetCapabilities*, *GetFeature* or *DescribeFeatureType*. The element *GEOMD* is composed by the *GEOMDSchema* subelement, which represents the name of the integration schema<sup>42,62</sup> used in the request and two references for the previous defined elements (*i.e.* *MD* and *GEO*).

## 5. A SERVICE INTEGRATION MODEL FOR ANALYTIC AND GEOGRAPHIC PROCESSING

In software engineering methodologies, models<sup>36</sup> are used to simplify and graphically indicate the main concepts, activities, processes and/or data involved in the development of a system. In using models, some aspects regarding to the implementation can be abstracted, enabling a better understanding of the main processes that compose a system.

<sup>ii</sup> A geographic correspondence is the information representing the spatial object geometry.

<sup>iii</sup> <http://www.xmlspy.com>.

After specifying the GMLA Request Schema, which defines the operations types that would be supported, the services integration model named ISAG<sup>37</sup> was specified. This model was specified in UML<sup>36</sup> and defines a group of activities to enable the integration of the analytic and geographic processing.

In Figure 2, the highest abstraction level of the ISAG model is given. The activities of this model are sequentially performed and each execution result is used by the following activity in the sequence, until the processing is completed and the final state is reached. Each model activity has some sub activities, which need to be performed so that the main activity is concluded.

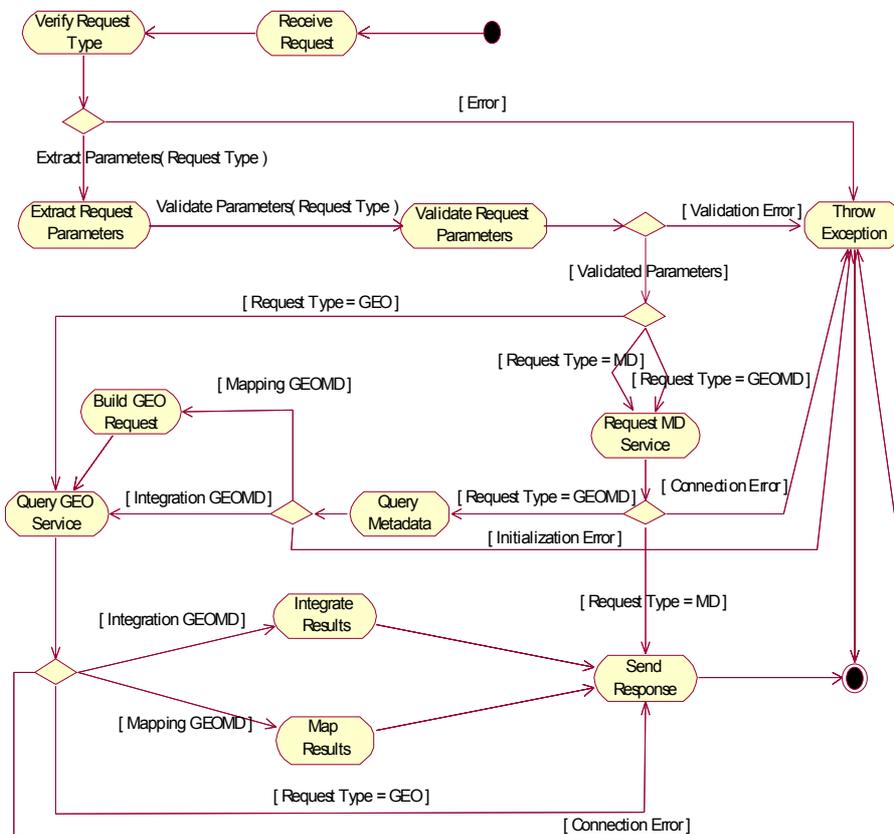


Figure 2. Integration Model diagram.

The ISAG model takes into account the existence of a metadata source, which contains information about which analytic data have a geographic correspondence, and about how to recover these correspondences. These are very useful for requests needing to either integrate or map the final query

results. Data with geographic correspondences are considered here as those analytic data which are associated with some information that represents their geometry.

The first activity of the ISAG model shown in Figure 2 is *Receive Request*. Then, the activity *Verify Request Type* is performed which classifies the request according to the query types defined by the GMLA Request Schema (*i.e.* MD, GEO or GEOMD). The next activity is *Extract Request Parameters*, which extracts some information from the analytic and/or geographic parameters found in the user request. Following this, these parameters are validated by the activity *Validate Request Parameters*. Next, the analytic and/or geographic services are asked to produce the query results. Following this, for a request of type MD, the activity *Request MD Service*, solves the query and returns its final response. For a GEO request, the next activity to be executed is *Query GEO Service* which recovers the geographic information satisfying the query.

If the request type is GEOMD, the next activity executed is the *Request MD Service*. After this, the activity *Query Metadata* is performed. For a mapping GEOMD, the metadata source is used to identify which analytic data have geographic correspondences and how to recover these correspondences. After doing this, in the activity *Build GEO Request*, the GEO query that enables to recover all geographic correspondences of the analytic members involved in the request is formulated. In the activity *Map Results*, the resulting document is built, which contains the analytic data together with their corresponding geographic correspondences. If the request is of type integration GEOMD, after querying the metadata source, the next activity is the *Query GEO Service*, which recovers all geographic features satisfying the request. Then, in the activity *Integrate Results*, the response document is built, which just contains the geographic and analytic data that satisfy the spatial operators found in the user request.

The integration model given in this section has been implemented by the GMLA Web Service that will be presented in the next sections.

## 6. GMLA WEB SERVICE - GMLA WS

The main components of the GMLA Web Service (*i.e.* GMLA WS) architecture proposed here are displayed in Figure 3. The GMLA WS enables the integration of the analytic (*i.e.* XMLA) and geographic services (*i.e.* WFS), discussed in the third section of this paper. This integration provides users with the capability of executing their geographic-multidimensional requests.

This enables users to query and analyze geographic and/or multidimensional data stored in a Geographic Data Warehouse (GDW)<sup>19,40-42</sup>. A GDW schema is similar to the traditional Data Warehouse schemas (e.g. star schema)<sup>1-4</sup>. However, the geometries of the geographic data are stored in the GDW as well.

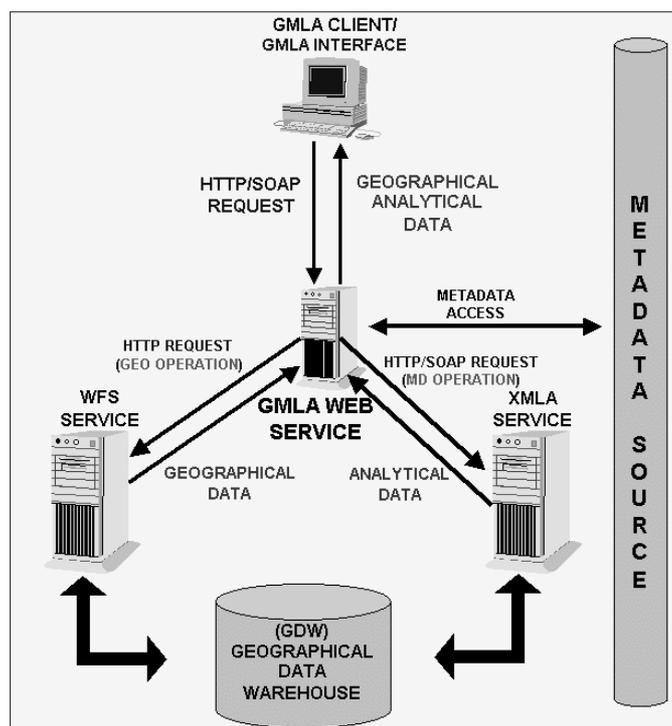


Figure 3. GMLA WS architecture components.

The metadata source (METADATA) plays an important role in the integration of the XMLA and WFS services. The integration metadata are accessed by the GMLA WS whenever a GEOMD request is received. Thus, the GMLA WS can find out if the analytic data have or not have some geographic correspondences. The metadata source implementation has been based on the MOF (*MetaObject Facility*)<sup>38</sup> specification, by the OMG (*Object Management Group*)<sup>39</sup> and on the metamodels GAM (*Geographical and Analytical Metamodel*) and GeoMDM (*Geographical Multidimensional Metamodel*)<sup>62</sup>.

The GMLA WS implementation has been based on the Web Services architecture<sup>9</sup>. Thus, the GMLA WS provides a WSDL<sup>21</sup> document with the service description and available operations, allowing a client application to

be implemented regardless of the chosen operating system or programming language.

The GMLA WS is both client and server. It can be seen as a client because it may access two other services (*i.e.* XMLA and WFS), and as a server, because a WSDL interface is provided to allow other applications to be developed.

The communication between the GMLA WS and the XMLA is based on the Web Services standard, and made by sending and receiving information coded in a SOAP envelope. On the other hand, the communication between the GMLA WS and the WFS service is achieved by sending and receiving HTTP<sup>12</sup> requests, instead of using the SOAP protocol due to the WFS does not operate according to the Web Services standard.

The GMLA CLIENT component is responsible for formulating the requests according to the GMLA Request Schema, sending these requests to the GMLA WS and then, after obtaining the response document, for graphically displaying the results.

When a client application sends a request to the GMLA WS, this is executed and a XML document is returned as the final result. The structure of this document is defined and validated by the GMLA Schema<sup>17</sup> outlined in section 3.3.

## 7. A GMLA WS APPLICATION

To illustrate an application for the GMLA WS, the processing of a GEOMD query having both analytic and geographic requests is demonstrated. In this example, the idea is to visualize the total of the product sales, classifying by the product category and grouping the results by country, states and cities. The key issue in this request is that users wish to graphically visualize the result on a map. Then, a query of type mapping GEOMD will be sent to the GMLA WS containing the proper request parameters.

After having received the request parameters sent by the client application, the GMLA WS performs the multidimensional request, which will result in a collection of product categories, together with their total of sales organized by country, states and cities. This processing is performed by the multidimensional service XMLA.

Following this, the GMLA WS identifies the resulting elements of the multidimensional request that have geographic correspondences, so that the needed information is displayed on a map. This is done by using the GMLA WS metadata source. Accessing this metadata allows the system to elaborate a request that will be sent to the WFS geographic service to

recover all the geographic features that are involved in the corresponding query.

After having received the response from the WFS geographic service, the GMLA WS builds a XML document containing the integration of the multidimensional and geographic data, creates a SOAP envelope and then, returns it to the client application that had previously sent the request. Next, the client application receives the SOAP envelope and graphically shows the result.

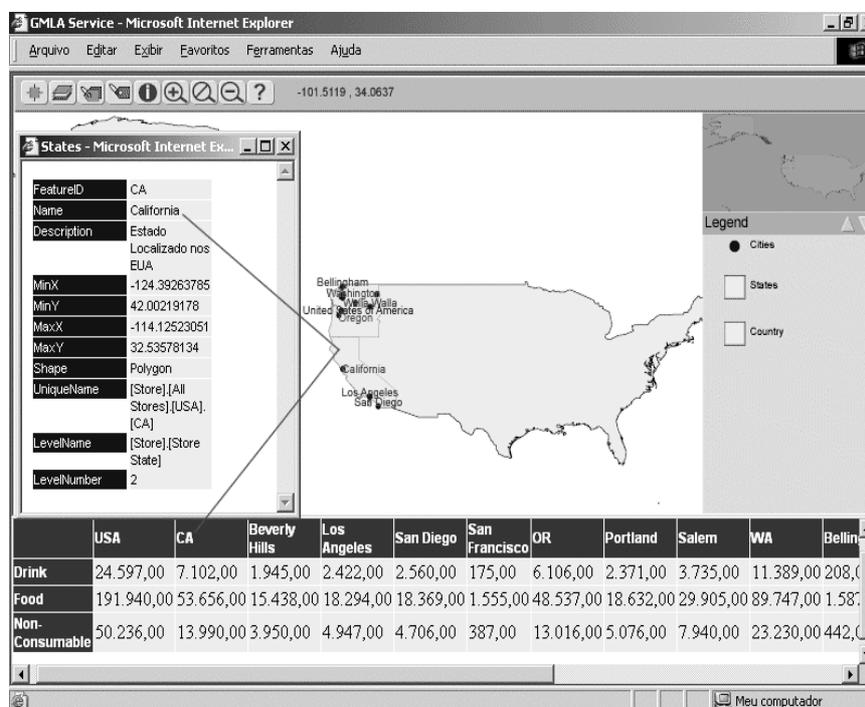


Figure 4. Graphic visualization of a GEOMD request result.

Then, the geographic data of the resulting document are transformed by the GMLA CLIENT to the Scalable Vector Graphics format (SVG),<sup>43</sup> showing them as a map. The multidimensional data are also submitted to a XSLT processing<sup>47</sup> and visualized in the HTML format. The Figure 4 demonstrates this query processing result, where a table with the multidimensional data is given at the bottom, and a map showing the elements involved in the request that have geographic correspondences is given at the top. The final graphic result can be visualized in a Web browser with a SVG Plugin<sup>44</sup>. For this case study, the Internet Explorer<sup>45</sup> was used.

As it can be seen in the legend, given in the right side of the browser screen (Figure 4), the geographic data are organized in three themes: 1) Country, 2) States and 3) Cities. In these themes, all members showed in the multidimensional data table given at the bottom of the browser screen are displayed. To manipulate the data found in these themes, the operations available in the toolbar, located at the top of the web browser screen and above the map, may be used. These available operations include zoom in, zoom out, pan operator, label insertion and exclusion, and presentation of detailed information about each geographic feature of the map. The interface component that is responsible for graphically showing the geographic data coded in the SVG format is an adaptation of the GeoClient Component of the GeoServer Project<sup>46</sup>.

Any other request type that satisfies the GMLA Request Schema (see section 4) can be sent to the GMLA WS to be processed. However, the processing of these has not been shown here for the sake of simplicity and limitation of space.

## 8. CONCLUSIONS

The integration between analytic and geographic processing as a single tool provides a wider context for decision support. This is so because it aggregates: the capability of quickly analyzing a large volume of data and the power of visualizing data on maps and running spatial queries.

The work presented in this paper is part of the GOLAPA project, which is concerned with the development of a service layer, making a set of operations available for the geographic-multidimensional processing. Due to the use of open and extensible technologies, the solutions discussed in this paper are independent from the GOLAPA, and as a result, it may be applied to any other projects aiming at integrating analytic and geographic processing.

The proposed integration model defines a set of activities that are performed for integrating the tools provided by the analytic and geographic services used in the query and analysis of geographical-multidimensional data. The model is based on three request types defined by the GMLA Request Schema, which integrates the syntax of both the XMLA and WFS services. Also, this model takes into account the use of a metadata source to provide information about the relationships existing between the analytic and geographic data.

The implementation of the integration model was achieved by the specification and development of a Web Service namely GMLA WS. This integrates both the XMLA and WFS services to make operations available

for the processing of analytic and/or geographic requests. This system prototype provides an environment that abstracts the complexity found in the joint use of analytic and spatial operators in decision support queries. Moreover, the GMLA WS provides the visualization of both the analytic and/or geographic information on maps and/or tables, through the use of a simple Web browser. Finally, for implementing the system prototype, technologies such as Web Services, GML, SVG, MOF, Java and XML were used to provide an extensible and platform independent solution.

## REFERENCES

1. S. Chaudhuri, U. Dayal. Decision support, Data Warehouse, and OLAP, Tutorials of the Twenty-Second international Conf. On Very Large Data Base, 1996.
2. W. H. Inmon. Building the Data Warehouse. 2nd edition. John Wiley & Sons, 1997.
3. R. Kimball. The Data Warehouse Toolkit., John Wiley&Sons, Inc, 1996.
4. R. Kimball, L. Reeves, M. Ross, and W. Thornthwaite. The Data Warehouse Lifecycle Toolkit. Wiley, 1998.
5. G. Câmara, et al. Anatomia de Sistemas de Informação Geográfica. 10ª Escola de computação, <http://www.dpi.inpe.br/geopro/livros/anatomia.pdf>, 1996.
6. N. Chrisman. Exploring Geographic Information Systems. John Wiley and Sons, 1996.
7. P. A. Longley, et al. Geographical Information Systems: Principles, Techniques, Applications and Management. 2nd Edition, John Wiley and Sons, 1999.
8. M. F. Goodchild. Geographical Data Modeling. Computers & Geosciences. 1992.
9. W3C, Web Service Official Home Page, (<http://www.w3.org/TR/2002/WD-ws-arch-20021114/>).
10. UDDI, UDDI official home page, last visit on 2003, (<http://www.uddi.org/>).
11. W3C, SOAP official home page, last visit on 2003 (<http://www.w3.org/TR/2002/CR-soap12-part0-20021219/>).
12. W3C, HTTP official home page, last visit on 2003 (<http://www.w3.org/Protocols/>).
13. XMLA.org, XML For Analysis Specification, Version 1.1, Microsoft Corporation & Hyperion Solutions Corporation. 2002.
14. OpenGIS® Geography Markup Language (GML) Implementation Specification, version 2.1.2, 2002.
15. OpenGIS® Web Feature Service Implementation Specification, Version: 1.0.0., 2002.
16. E. Thomsen. OLAP Solutions - Building Multidimensional Information Systems. John Wiley, 1997.
17. R. N. Fidalgo, J. Silva, V. C. Times, F. F. Souza, R. S. M. Barros. GMLA: A XML Schema for Integration and Exchange of Multidimensional-Geographical Data. GEOINFO 2003, (<http://www.geoinfo.info/Anais/geoinfo2003-48.pdf>).
18. R. N. Fidalgo, V. C. Times, F.F. Souza - GOLAPA: Uma Arquitetura Aberta e Extensível para Integração entre SIG e OLAP. In Proc. GeoInfo 2001, 2001.
19. Fidalgo R. N., Times, V. C., Silva, J., Souza, F.F.:GeoDWFrame: A Framework for Guiding the Design of Geographical Dimensional Schemas. Proc. Int. Conf. on Data Warehousing and Knowledge Discovery (DaWaK), 2004.
20. W3C, XML official home page, 2003, (<http://www.w3.org/XML>).
21. W3C, WSDL official home page, last visit on 2003 (<http://www.w3.org/TR/2001/NOTE-wsdl-20010315>).
22. W3C, XML Schema official home page, last visit on 2003 (<http://www.w3.org/>).

23. Microsoft Corporation Official Home Page ([www.microsoft.com](http://www.microsoft.com)).
24. Hyperion Solutions Corporation Official Home Page ([www.hyperion.com](http://www.hyperion.com)).
25. OpenGIS® Filter Encoding Implementation Specification, <http://www.opengis.org/techno/specs/02-059.pdf>.
26. OpenGis. The Abstract OpenGIS Specification. OpenGIS Document Number 99-100. Jun., 1999.
27. OpenGis Official Home Page ([www.opengis.org](http://www.opengis.org)).
28. Introduction to Multidimensional Expressions - MDX (<http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnolap/html/intromdx.asp>).
29. S. Shekhar, et al. Map Cube: A Visualization Tool for Spatial Data Warehouse. 2000 (<http://www.cs.umn.edu/Research/shashi-group/Mapcube/mapcube.html>).
30. J. Han, K. et al. GeoMiner: a system prototype for spatial data mining. Proc. ACM SIGMOD, 1997.
31. GOAL Project official home page. Last visit on 2003 (<http://krizik.felk.cvut.cz/goal/>).
32. A.C. Ferreira, et al. An Architecture for Spatial and Dimensional Analysis Integration. In Proc. of World Multiconference on Systemics, Cybernetics and Informatics (SCI 2001), 2001.
33. A.C. Ferreira. Um Modelo para Suporte à Integração de Análises Multidimensionais e Espaciais. Dissertação de Mestrado - UFRJ, 2002.
34. Daniel J. Power, Decision Support Systems Web Tour, <http://dssresources.com/tour/index.html>, 2002.
35. Daniel J. Power, What is a Decision Support Systems?, <http://dssresources.com/papers/whatisadss/index.html>, 1998.
36. G. Booch, J. Rumbaugh, and I. Jacobson. The Unified Modeling Language User Guide. Addison-Wesley, 1999.
37. J. Silva, V.C. Times, R. S. M. Barros, Integrando Serviços Analíticos e Geográficos para Suporte à Decisão na Web. MSc. Thesis – Universidade Federal de Pernambuco (UFPE), 2004.
38. OMG - Object Management Group. MetaObject Facility (MOF) Specification 1.4. Especificação, 2002.
39. Object Management Group Home Page, ([www.omg.org](http://www.omg.org)).
40. H. B. Zghal, S. Faiz, H. B. Ghézala, Exploration Techniques of the Spatial Data Warehouses: Overview and Application to Incendiary Domain, IEEE International Conference on Computer Systems and Applications (AICCSA'01), 2001.
41. T. Barclay, R. D. Slutz, J. Gray, TerraServer: A Spatial Data Warehouse. Proceedings of the 2000 ACM-SIGMOD Conference, 2000.
42. R. N. Fidalgo, Integração de Processamento Analítico com Sistemas de Informações Geográficas para Suporte à Decisão em Ambientes de Data Warehouse Geográfico, Phd Proposal, Universidade Federal de Pernambuco (UFPE), 2003
43. W3C Scalable Vector Graphics (SVG). <http://www.w3.org/Graphics/SVG/>.
44. Adobe SVGviewer, (<http://www.adobe.com/svg>).
45. Microsoft Internet Explorer Official Home Page, (<http://www.microsoft.com/windows/ie/default.asp>).
46. The GeoServer Project, (<http://geoserver.sourceforge.net/html/index.php>).
47. World Wide Web Consortium, XSL Transformations (XSLT), <http://www.w3.org/TR/xslt>.
48. F. Ferri, E. Pourabbas, M. Rafanelli, F.L. Ricci, Extending Geographic Databases for a Query Language to Support Queries Involving Statistical Data, International Conference on Scientific and Statistical Database Management (SSDBM'00), 2000.
49. E. Pourabbas, M. Rafanelli, A Pictorial Query Language for Querying Geographic Databases Using Positional and OLAP Operators, SIGMOD Record, Vol. 31, N° 2, June 2002.
50. D. Papadias, Y. Tao, P. Kalnis, J. Zhang, Indexing Spatio-Temporal Data Warehouses, IEEE International Conference on Data Engineering (ICDE), 2002.

51. L. Zhang, Y. Li, F. Rao, X. Yu, Y. Chen, D. Liu, An Approach to Enabling Spatial OLAP by Aggregating on Spatial Hierarchy, International Conference on Data Warehousing and Knowledge Discovery (DaWaK), 2003.
52. J. Han, K. Koperski, N. Stefanovic, Object-Based Selective Materialization for Efficient Implementation of Spatial Data Cubes, IEEE Transactions on Knowledge and Data Engineering, 2000.
53. T. B. Pedersen, N. Tryfona, Pre-aggregation in Spatial Data Warehouses, International Symposium on Spatial and Temporal Databases, 2001.
54. S. Prasher, X. Zhou, Multiresolution Amalgamation: Dynamic Spatial Data Cube Generation, Australian Database Conference (ADC2004), 2004.
55. L. Zhang, Y. Li, F. Rao, X. Yu, Y. Chen, Spatial Hierarchy and OLAP-Favored Search in Spatial Data Warehouse, ACM Sixth International Workshop on Data Warehousing and OLAP, 2003.
56. D. Papadias, P. Kalnis, J. Zhang, Y. Tao, Efficient OLAP Operations in Spatial Data Warehouses, International Symposium on Spatial and Temporal Databases, (SSTD), 2001.
57. Z. Kouba, K. Matousek, P. Miksovsky. On Data Warehouse and GIS integration. International Conference on Database and Expert Systems Applications (DEXA), 2000.
58. J. Gray, et al. Data cube: A relational aggregation operator generalizing group-by, crosstab, and sub-totals. In Proc. 12th ICDE, 1996.
59. J. Han, et al. Selective materialization: An efficient method for spatial data cube construction. In PAKDD, 1998.
60. N. Stefanovic. Design and implementation of on-line analytical processing (OLAP) of spatial data. M.Sc. Thesis, Simon Fraser University, Canada, 1997.
61. Microsoft OLE DB 2.0. Program Reference and Data Access SDK, Microsoft Press, 1998.
62. Fidalgo R. N., Times, V. C., Silva, J., Souza, F.F., Salgado, A.C.: Providing Multidimensional and Geographical Integration Based on a GDW and Metamodels. Proc. Brazilian Symposium on Databases (SBBD). 2004.

