

GlobeOLAP

Improving the Geospatial Realism in Multidimensional Analysis Environment

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Abstract: The combination of Geographic Data Warehouses (GDW) and Spatial OLAP (SOLAP) provide efficient browsing and storing of very large spatio-temporal databases. However, some advanced techniques of geovisualization are not well supported in many of these tools. Three-dimensional Thematic Mapping through Virtual Globes is one of them, and it can provide a friendly but powerful mechanism for summarize visually huge amounts of geospatial-analytical data and their changes over time. This paper shows the GlobeOLAP, a prototype of a Web-based SOLAP tool that allows the customized generation of many types of Thematic Maps to be visualized three-dimensionally in a Virtual Globe (Google Earth), together with the traditional tabular view. This tool can improve management decisions by allowing managers to identify patterns and build knowledge in a spatial realistic environment.

1 INTRODUCTION

Storing and browsing efficiently very large geospatial databases for multidimensional analysis and decision making can be a challenging task. Many authors point Geographic Data Warehouses (GDW) and Spatial On-Line Analytical Processing (SOLAP) as a good approach (Bédard, 1997; Rivest et al., 2003; McHugh, Roche, Bédard, 2008; Tao and Papadias, 2009) to such task. By combining this mature technology of Business Intelligence with very useful functionalities from Geographic Information Systems (GIS), it is possible to provide a complete and homogeneous platform for decision support.

The inherent complexity of geospatial data (Wieczorek and Delmerico, 2009) and its related decision problems (Andrienko et al., 2007), makes evident the need of interactive visualization mechanisms that not only displays data and allows its browsing but also do it intuitively, making substantially easier for human beings the pattern recognition and to build knowledge that will help to solve real problems (Dykes, MacEachren, Kraak, 2005).

Within a typical GDW-SOLAP approach, geospatial data have several levels of aggregation and can be retrieved under many perspectives through multidimensional analysis. In this case, it is

necessary some particular techniques for summarizing and presenting, in an organized way, the results of complex, multidimensional and geospatial queries.

This work shows the GlobeOLAP, a prototype of a Web-based SOLAP tool, which is capable of generating several types of KML-based Thematic Maps with a high level of customization to be visualized within a three-dimensional environment provided by a Virtual Globe. Consequently, decision makers can experience the advantages of a plausible, flexible and friendly geospatial analysis environment.

The remainder of this paper consists of three main sections. First, in section 2, we discuss some key concepts together with related works. Next, in section 3, we present the prototype architecture and its functionalities through a study case in the domain of a national education system planning analysis. Finally, we make some conclusions and discuss future works.

2 RELATED CONCEPTS AND WORKS

Essentially, in this section, we try to present some answers to the following question: “Once geospatial data are inherently complex and its related problems

are sometimes difficult to solve through an automated approach, how can we build computational tools capable of retrieve and interactively explore very large geospatial databases, providing an intuitive, realistic and analytical environment for efficient decision making?"

2.1 Geographic Data Warehouses and Spatial On-line Analytical Processing

The combination of Data Warehouses (DW) and On-Line Analytical Processing (OLAP) technologies (Chaudhuri, Dayal, 1997; Inmon, 2002; Kimball and Ross, 2002; Song, 2009; Abelló and Romero, 2009) is widely used to establish environments for decision support that prioritizes efficient querying of huge amounts of historical, clean and consolidated data.

Frequently, a geospatial perspective is needed for strategic analysis. A DW that contains geospatial data is called Geographic Data Warehouse (GDW). A GDW is generally modeled using one of the flavors of star schema. This kind of multidimensional modeling is comprised by a fact table with one or more measures that can be numeric or geospatial. The calculation of these measures is made regarding a set of dimensions of interest.

A GDW can be spatially queried and processed by a Spatial OLAP (SOLAP) tool that allows easy and fast exploration of very large geospatial data repositories and offers a set of visualization techniques such as maps, tables and diagrams (Bédard, 1997; Bédard, 2005; Rivest et al., 2005)

Additionally to OLAP operators (e.g. drill-down, roll-up, slice and dice, pivot and drill across), different authors have proposed a number of SOLAP operators. Ruiz and Times (2009) reviewed these proposals and organized them into a taxonomy.

Siqueira et al. (2009) propose to add one or more geospatial dimensions to avoid redundancy. Further reading on GDW modeling strategies can be seen in Damiani and Spaccapietra (2006), as well as index structures can be found in Tao and Papadias (2009).

2.2 Virtual Globes as Geobrowsers

The entry point of a SOLAP tool is its graphical interface. Many authors have been integrating Geobrowsers to their SOLAP solutions in order to bring suitable visualization techniques for geospatial data.

Geobrowser is defined by Craglia et al. (2008) as a software that offers interactive navigation in a set of information organized over a geographic space. It

can be seen as the visualization module of a GIS.

Between the free 2D Geobrowser that provide API for mashup on web applications, stand out Google Maps (Google, 2010a), Bing Maps (Microsoft, 2010), Yahoo! Local Maps (Yahoo, 2010) and OpenLayers (OpenLayers, 2010). These API offer pan, zoom, layer control and exhibition of detailed information about geospatial objects, plus a set of services such as geocoding, route calculation and local search. Most of these API also provide access to some base layers whose set of tiles has two main types: street/boundaries maps or remote sensing images.

However, it is quite known that 2D Geobrowsers are deficient in portraying dynamic and three-dimensional phenomena, causing a gap of realism between the bi-dimensional model and the real world. Some works have pointed that Virtual Reality (VR) techniques can help to mitigate this issue, especially regarding to knowledge construction for decision making (MacEachren et al., 1999; MacEachren et al., 2004; Hodza, 2009). VR provides 3D environments capable of giving to the users a feeling of "being there", enhancing their cognitive experience.

Fortunately, there are 3D Geobrowsers such as Google Earth (Google, 2009b) and NASA World Wind (NASA, 2010) that uses a three-dimensional model of the Earth surface, known as Virtual Globe (Butler, 2006). To overlay this model, the same base layers of maps and remote sensing images are used, but now with a new projection which includes an orientation angle for each tile. Additionally to the same other functionalities present in 2D Geobrowsers, we got the camera control to travel through the space in any desired inclination and to rotate the virtual globe with ease.

The most popular 3D Geobrowser between general users is Google Earth because of its ease to use (Goodchild, 2008). Moreover, there are desirable functionalities in Google Earth such as access to user-generated content, high rendering performance, the resolution of the satellite images and orthophotos reaching to 1m/pixel in hundreds of places, visualization of 3D models and orthorectified volumetrically images.

For *developers* in particular who want to use maps in their decision support tools, *mashing up* Google Earth API (Google, 2009c) with a web-based application makes possible to generate datasets and add them in a georeferenced virtual reality environment as "custom overlays" of vector and raster geospatial elements. However, for *users* in particular who want to use this realistic environment for analyzing summarized thematic data and make

decisions, all mentioned technologies could bring better results if we add among them a set of geovisualization techniques.

2.3 Thematic Mapping

The main type of map for analysis of summarized and contextualized (both geographically and thematically) data are Thematic Maps (TM). MacEachren (1979) sees Thematic Cartography as a representation of the spatial distribution of phenomena at specific points in time. Therefore, he states Thematic Cartography as a primary mechanism of visual communication suggesting that TM have played substantial influence in knowledge construction and dissemination.

Slocum et al. (2005) brings an overview of all aspects of TM, including the set of existing techniques, its corresponding symbolization principles and when to use them. All techniques and symbols supported in this work are discussed in section 3.

TM are widely used in today's GIS, but we point some arguments that suggest TM as powerful visualization artifacts for GDW/SOLAP environment. First, any GDW is intrinsically thematic, since every dimension can be seen as a theme (e.g. one can say that the transformation of a query from "sales quantity by product" to "sales quantity by client" is a theme change). Following, data can be aggregated in many ways by a number of (S)OLAP operators which go toward a theme refining. Finally, the resultsets from these queries can contain geospatial data (e.g. client's "region" attribute), thus some TM could be efficiently drawn in order to allow geospatial-enabled analysis and decision making.

2.4 Advantages and Issues of the Third Dimension

The use of Virtual Globes for thematic mapping brings some technical advantages. Most of 2D Geobrowsers uses Mercator projection which is a good choice for mosaics of remote sensing imagery, but causes area distortions which is bad for thematic mapping. This issue is partly overcome in Virtual Globes because of its Perspective Orthographic projection (Sandvik, 2008). A second point is the whole new thematic mapping techniques using volume symbols (Slocum et al., 2005) that a three-dimensional environment allows, such as Prism maps.

Combining three-dimensional thematic mapping

and Virtual Globes for analytical purposes are an emergent approach, and some authors raise potential issues to be addressed. Goodchild (2008) warns that overlaying Virtual Globes with survey and census statistics may produce confusing hybrids of the visual and symbolic, which is also pointed by Monmonier (1996) when he claims that any map must omit all non-essential features. Shepherd (2008) remembers that this is an old discussion among researchers and cites the varying of scale caused by perspective visualization, which prejudices the volume estimation by humans and, consequently, the comparison among volume symbols.

On the other hand, Shepherd raises advantages of the three-dimensional mapping, such as: (1) a richer environment where symbols are more detailed and there is more space for information on the same display; (2) possibility of extruding areas to emphasize and to detail a traditional visual variable (see the second example in section 3.2) or to introduce a new one; (3) possibility of resolving the problem of symbol occlusion more efficiently than in 2D maps (e.g. by adding transparency and spinning the globe); and finally, (4) providing a familiar environment for complex analysis, by taking advantage of the user's intimacy with the Earth shape, then providing a convenient and intuitive cognitive experience. Tiede and Lang (2010) also point such familiarity and conducted case studies with three-dimensional symbols for analytical-geospatial data, concluding that unfamiliar scientific content can be grasped more directly by simple embedding it in a seamless geospatial context.

This work was conducted considering such discussion and partial solutions to these problems, as well as its advantages can be seen at sections 3.2 and section 4. Furthermore, three-dimensional thematic mapping through Virtual Globes is not a natural evolution or the state-of-art of digital mapping, but actually one additional and useful functionality in mapping tools, including SOLAP solutions, which existing implementations we discuss briefly in the next section.

2.5 Related Works on Geovisualization in SOLAP Tools

There are several proposals, prototypes and full SOLAP tools, including both free and commercial final products that are already established in Business Intelligence market. Each one of these tools has its own innovations, strengths and weakness. We will discuss briefly these tools.

Table 1: Comparison of existing SOLAP tools.

Authors	Tool name	Platform	Geobrowser	Geovisualization techniques
Han et al. (1997)	GeoMiner	Desktop	2D	Simple
Shekhar et al. (2000)	Map Cube	Desktop	2D	Simple, choropleth and multimap
Stolte et al. (2002)	Rivet	Desktop	2D	Simple and choropleth
Fidalgo et al. (2004)	GMLA WS Client	Web	2D	Simple
Scotch and Parmanto (2005)	SOVAT	Desktop	2D	Simple and choropleth
Rivest et al. (2005)	JMap® Spatial OLAP Extension	Desktop	2D	Simple, choropleth, proportional symbol, multimap
Colonese et al. (2005)	PostGeoOlap	Desktop	2D	Simple
Bimonte et al. (2007)	GeWOlap	Web	2D	Simple, choropleth, bar, pie
Compieta et al. (2007)	-	Desktop	3D	Simple, remote sensing and complex vectors
Silva et al. (2008)	WebGeoOlap	Web	2D	Simple and remote sensing
Di Martino et al. (2009)	GooLAP	Web	3D	Simple, remote sensing, 3D-bar, pie
Pentaho	Pentaho Google Maps Dashboard	Web	2D	Simple, colored point
ESRI	OLAP for ArcGIS	Desktop	2D	Simple, bars
JRubik	JRubik	Web	2D	Simple, bars
SpatialAnalytics	SOLAPLayers	Web	2D	Simple, choropleth
	GlobeOLAP	Web	3D	Simple, remote sensing, choropleth, prism, bar and custom proportional symbols

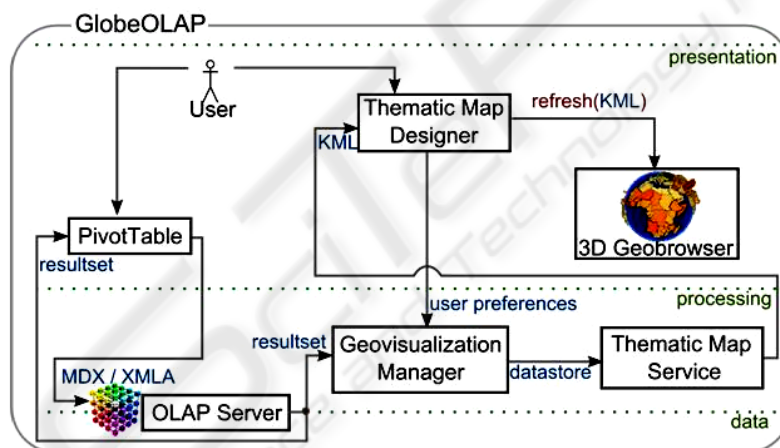


Figure 2: An overview of GlobeOLAP architecture.

The GeoMiner tool, introduced by Han et al. (1997), allows OLAP operations over GDW and includes an efficient method for materialization of geospatial datacubes. Map Cube, a data operator proposed by Shekhar et al. (2000), generates galleries of maps as visualization method for a given set of aggregated geospatial data. Stolte et al. (2002) developed the Rivet tool which focuses in multiscale visualization for generating abstract overviews of data in a GDW. Scotch and Parmanto (2005) presented SOVAT, an effort to implement new SOLAP operators so that both geospatial and numeric aggregations can be performed. Compieta et al. (2007) investigates VR and SOLAP integration for building simulation

environments of climate phenomena with complex vectors.

Recently some works focused in Web-based and distributed SOLAP tools. Fidalgo et al. (2004) proposed OLAP and GIS bridges through GMLA Web Services. Bimonte et al. (2006) developed GeWOlap which are also based on open source tools. Silva et al. (2008) made a Web mashup with Google Maps in their WebGeoOlap tool which kernel are based on PosGeoOlap tool from Colonese et al. (2005). Di Martino et al. (2009) presented a Web-based prototype of SOLAP tool that makes use of existing well-established modules such as Mondrian OLAP Server, JPivot and Google Earth as geobrowser.

There are also final products which aim to bring some SOLAP functionalities to users of DW/OLAP software packages. Among commercial solutions, Rivest et al. (2005) presented JMap® Spatial OLAP Extension, one of the most complete existing SOLAP tools with regard to the set of SOLAP operators and geovisualization techniques provided. Pentaho Google Maps Dashboard (Pentaho, 2010a) is part of an open-source and commercial package for Business Intelligence which allows to plot colored point symbols reflecting localizations of objects of interest and a numerical measure regarding them. Yet another commercial tool is OLAP for ArcGIS (ESRI, 2010). Among free and open-source solutions, SOLAPLayers (Spatialanalytics, 2010) is a web mapping client for exploring geospatial data cubes and create choropleth maps. Finally, JRubik (JRubik, 2010) has a SOLAP module that allows creating bar chart maps.

An overview of geovisualization capabilities of all cited works are summarized in Table 1. Besides the obvious transition for Web-based SOLAP tools, it is possible to see that the use of Virtual Globes in SOLAP tools is quite rare. Furthermore, the use of three-dimensional thematic maps for multidimensional exploration was practically unexplored in literature. This motivated us to investigate the potential of combining such technologies. The main result is a SOLAP tool prototype called GlobeOLAP.

3 THE GlobeOLAP PROTOTYPE

This section is dedicated to the GlobeOLAP system prototype. We will discuss its architecture; enumerate its functionalities of analytic geovisualization and how they can improve decision support solutions. Some issues are also discussed along this section.

3.1 Architecture

The chosen architecture preserves the possibility of changing the Geobrowser or even the OLAP server, with low additional refactoring cost. A three-tier approach was applied. Each tier comprises a set of modules based on open standards. Figure 2 shows an overview of the architecture, where all modules are presented following SADT notation for better comprehension of the information flow.

3.1.1 Presentation Tier

The main role of this tier is to provide some of the interactive visualization techniques considered in this work. In order to achieve this goal, we designed the following modules:

a. *Pivot Table*: Shows resultsets in a tabular view and allow dynamic modification of the query through interactive OLAP operations and an ad hoc Multi-Dimensional eXpressions (MDX) query editor. In our prototype we used JPivot (JPivot, 2010).

b. *3D Geobrowser*: A Virtual Globe capable of rendering three-dimensional and animated thematic maps. We choose Google Earth API (Google, 2010c) which consists of a Web browser plug-in and a set of JavaScript libraries for custom overlaying of the globe with thematic data.

c. *Thematic Map Designer*: Allows user to set their thematic mapping preferences (e.g. color scale, classification method, TM type, among other Thematic Cartography project decisions).

3.1.2 Processing Tier

The Processing Tier is responsible for processing requests from Presentation Tier and generation of resultsets and thematic maps. The modules are following:

a. *OLAP Server*: This module has both Processing Tier and Data Tier components since existing OLAP Servers such as Mondrian (Pentaho, 2009b) perform internally the MDX query parsing and also handle with database connection drivers. Subsequently, the OLAP Server receives a response from DBMS which include analytical and geospatial data, so that a resultset can be formatted. Finally, this module sends it simultaneously to the *Pivot Table* and to *Geovisualization Manager*.

b. *Geovisualization Manager*: Behaves as an interface between *3D Geobrowser*, *Thematic Map Designer* and *OLAP Server*. As soon as it receives a new resultset from *OLAP Server*, this module merges user preferences with the resultset into a data store which is then encapsulated within a REST (Fielding and Taylor, 2002) request for the *Thematic Map Service*. Once TM is generated, it is sent to *Thematic Map Designer*.

c. *Thematic Map Service (TMS)*: This module is a standardized geospatial Web service, more precisely a Web Processing Service (WPS) (OGC, 2007). *TMS* has a mandatory Execute() operation which receives as parameter the request containing the encapsulated data store. After extracting this data store, *TMS* has all data needed (user preferences,

summarized data and geospatial data) for generating a Thematic Map.

The kernel of the modules TMS and Thematic Map Designer is a generation engine of KML-based Thematic Maps, adapted from Sandvik (2008).

3.1.3 Data Tier

Data Tier is comprised of some of the modules from the OLAP Server that derivate SQL queries from MDX and XML mappings between dimensional model and physical model of the GDW. The other module in this tier is the GDW itself and its DBMS hosting.

3.2 Study Case

In order to set an evaluation for our proposal, we implemented an instance of GlobeOLAP architecture for the domain of a national education system planning. This study case was conducted under the context of a larger project called WebPIDE, which main goal is integrating several heterogeneous databases containing real data from a set of national evaluations applied by the Brazil's Ministry of Education.

We choose a test called SAEB (Evaluation System for Basic Education) which is applied every two years for 4th and 8th grades for basic education and 3rd grade for high school students. We built a GDW which included cleanup analytical data extracted from the original dataset. Figure 3 shows its schema. GDW was modelled using a star schema and a geospatial dimension (geometry attributes were omitted).

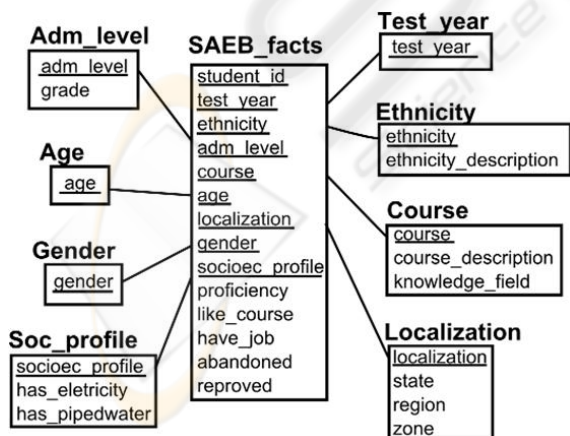


Figure 3: The GDW proposed for the SAEB tests.

Writing an XML schema and loading it on Mondrian, it is allowed the tabular view of the data

through JPivot and the execution of OLAP operators for multidimensional exploration.

By slicing ‘Test Year=2003’, choosing *Localization* as column and *Avg Proficiency* as a measure, we can answer the following question: “Which are proficiency average the students have in each state in 2003?” By the end of these OLAP operations, a choropleth Thematic Map is rendered in the geobrowser, as can be seen in Figure 4. The map shows evidence of the better proficiency of students from the southern and south states of the country.

The user is allowed to choose, at any time, different colour scales, classifications methods, thematic mapping techniques, types of labels, among other settings. For instance, let us choose *Prism* map, setting a *max height* of ‘600000’. In this case, the polygons of are proportionally raised up according to the chosen measure, as we can see in Figure 5.

Height and colour are used as visual variables for the same measure to emphasize it and to allow the appearance of some detail such as height difference between polygons classified with the same colour. When such difference becomes too high, despite the "emphasizing factor" works even better, a potential issue with prism maps shows up: there is possibility of visual occlusion of lower areas by taller prisms. Setting suitable *max height* is important to avoid it.

It is also important to choose a suitable *transparency* for the map, so that it can be more opaque when no other prism or volume symbol is hidden, less opaque in the contrary, or substantially transparent when other features or lower layers are useful in the analysis.

Moreover, the presence of labels, legend and descriptions in the map help users with some difficulty with estimation of volumes and with the lack of a “zero point” while spinning the globe (and consequently, rotating polygons and prisms).

4 CONCLUSIONS AND FUTURE WORK

It is possible to use three-dimensional Thematic Maps and Virtual Globes for geospatial-enable visualization of multidimensional queries. It can make easier for managers to summarize and analyze huge amounts of data and make faster decisions. Some issues still need to be addressed such as the world mapping become prejudiced in a Virtual Globe, since only half of the world is visible at once.

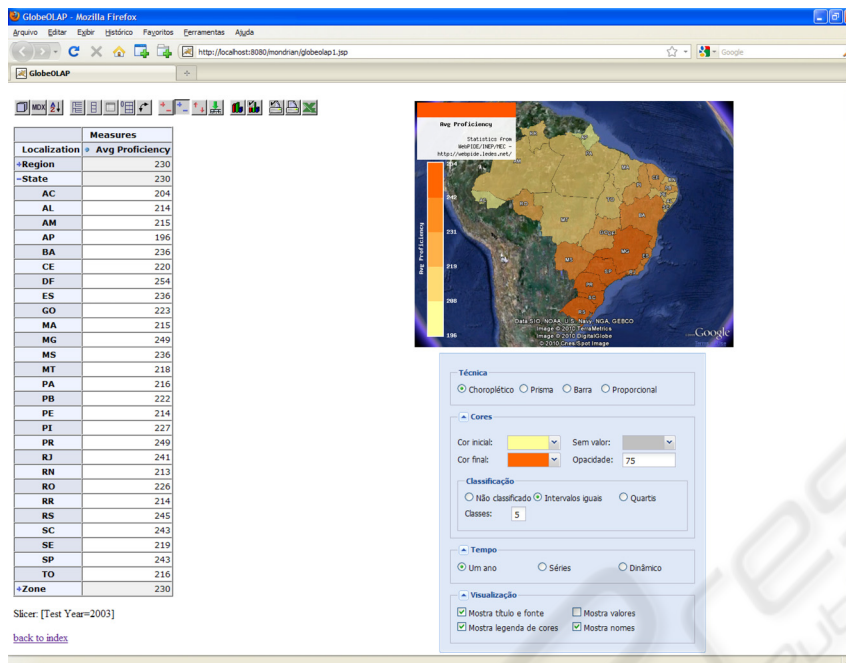


Figure 4: GlobeOLAP showing results in a choropleth thematic map.

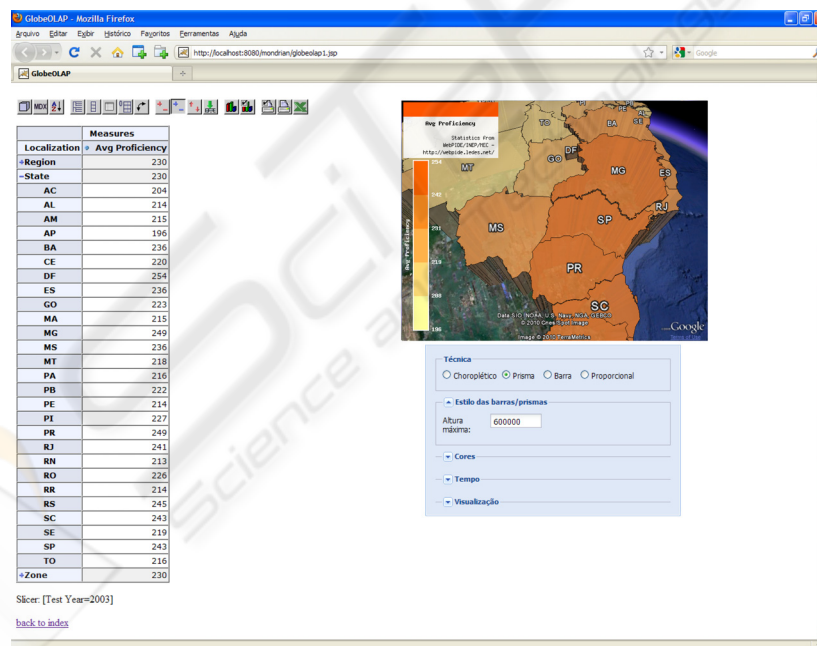


Figure 5: GlobeOLAP showing results in a prism thematic map.

In future work we will to use two side-by-side Virtual Globes to overcome this situation. Pie chart thematic maps will also take place on GlobeOLAP. The GlobeOLAP prototype demonstrated to be very customizable, bringing a high level of personalization for most of the common Thematic Cartographic Project decision.

The main idea of this work was tested against real data and users reports will help to define further future improvements.

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