SUPPORTING GEOGRAPHICAL MEASURES THROUGH A NEW VISUALIZATION METAPHOR IN SPATIAL OLAP

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Abstract: Pivot tables are the de-facto standard paradigm for the visualization of data in the context of multidimensional OLAP analysis. However it is recognized that they are not suited, in their original definition, to support spatio-temporal data analysis (and in particular geographical measures). In this paper, we propose the GeOlaPivot Table, a visual metaphor intended as an extension of the pivot tables specifically conceived to assist decision makers in analyzing geographical measures in spatial data warehouses. In order to show the analysis capabilities of our metaphor we describe it using an example concerning the supervision of infectious diseases in Italy. This approach represents a first effort in adapting advanced geovisualization techniques to SOLAP ones, in order to create a specific visual paradigm for Spatial OLAP able to effectively support and fully exploit spatial multidimensional analysis process. Moreover, we present an architecture for a web-based environment able to support geographical measures in SOLAP analyses exploiting the GeOlaPivot Table visual metaphor.

1 INTRODUCTION

Nowadays organizations are collecting in Data Warehouses even more and more heterogeneous information, often containing precious but hidden information. OLAP (OnLine Analytical Processing) systems support the Decision Makers in discovering this concealed information, by allowing him/her to interactively explore the multidimensional database through a visual interactive user interface.

Indeed, the main strength of these solutions is the possibility to gain an insight into the data, allowing the user to discover unknown phenomena, patterns and data relationships without requiring him/her to master neither the underlying multidimensional structure of the database, nor complex multidimensional query languages (Stolte et al. 2002). For these reasons, OLAP solutions are widely and successfully adopted in many business contexts.

(Franklin, 1992) has shown that about 80% of the data stored in databases integrates some kind of spatial information. It is clear that a fully exploitation of spatial data into decisional process could add a lot of significance to the analytical process. On the other hand, it is also clear that if the spatial dimension is treated as any other descriptive dimension, without consideration for the cartographical component of the data, the resulting analysis capabilities will be highly compromised. However, current OLAP tools present serious limitations when dealing with spatio-temporal analysis: they lack of visual interactive maps, that, revealing spatial trends or relationships and stimulating user’s thinking process, represent the main instruments to support a real and effective spatio-temporal analysis process (MacEachren, 2001).

To overcome these limitations, previous researches on integration of spatial information into multidimensional models leaded to the definition of the Spatial OLAP (or SOLAP) concept (Bedard,

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1997). SOLAP solutions usually lie on coupling OLAP functionalities, used to provide multidimensionality, and Geographic Information Systems (GIS) functionalities, used to store and visualize the spatial information (Rivest et al, 2005). These solutions, thanks to a cartographic representation of the multidimensional data, permit to visualize measures on map and to discover geographical correlations between facts and members. It is worth pointing out that common GIS techniques, such as *Overlay* or *MultiMaps*, are not appropriate. This because the Overlay, even if reveals spatial relations, hides the precious information that a measure could belong to different layers (a spatial measure could be associated to different combination of level members), while MultiMaps are conceived to emphasize thematic relations rather than spatial ones.

Even if the numerous ongoing works (Malinowski, E., and Zimányi 2005), (Bimonte et al 2006), (Kouba et al 2000) confirm the importance and the innovating character of SOLAP, a detailed analysis of capabilities of current SOLAP tools reveals that many further enhancements are required in their user interfaces. In particular, at best of our knowledge, currently there are no SOLAP tools offering the possibility to visually compare geographical measures (for instance to compare areas of two regions affected by some kind of phenomenon). This is a crucial task in the analytical process, since it can take advantage of human abilities to perceive visual patterns and to interpret them.

To address this issue, in this paper we propose a new visualization metaphor, named *GeOlaPivot Table*, especially suited to deal with spatial measures in SOLAP environments. It exploits the concept of Pivot Table, adding to it a 3rd dimension by using the *Space-Time Cube* (Hägerstrand, 1970) 3D representation. In this way, it is possible to overlap, into a single and coherent visual representation, different layers of information, thus permitting to evaluate the relationships among the geographical measures. To better explain the usefulness of the proposal, we provide an example of application to a real Spatial Data Warehouse concerning the supervision of infectious diseases in Italy.

Moreover, we also propose a user interface and an architecture for a web based SOLAP solution, supporting the *GeOlaPivot Table* metaphor, starting from existing (S)OLAP frameworks.

The remainder of the paper is structured as follows. Section 2 describes the main OLAP and SOLAP concepts and provides a panorama of existing SOLAP tools. In Section 3 we describe our GeOlaPivot *Table* visualization metaphor and the case study. In Section 4 we introduce the architecture and the user interface of a solap tool supporting the *GeOlaPivot Table* methaphor together with the main technical issues we deal with. Some final remarks and future work conclude the paper.

2 OLAP AND SOLAP

In Data Warehouse systems, data is usually modelled conforming to the *multidimensional model* (Immon, 1992): analysis axes are *dimensions*, that can be organized into hierarchies, and the subject of the analysis is a *fact*, described by several numerical measures. This approach permits the Decision Maker to explore the Data Warehouse at different levels of details, from aggregated to detailed measures. Typical OLAP operators are *Slice* (selection of a part of the dataset), *Dice* (eliminate a dimension), *RollUp* (moves up into a dimension hierarchy) and *DrillDown* (reverse of RollUp).

An example of OLAP multidimensional analysis carrying on a fact "*sales*" of a stores chain can be realized defining as measures "*quantity*" and "*amount*" of sold products, and as dimensions "*Time" (Month<Year)*, "*location*", and "*product*" *(Item<Type)*. Figure 1 represents the multidimensional model for this application and its measure values (the cells of the cube). Thus, an OLAP query in our example can be: "What are the volume and the amount for all the sold products *Alc 54* in *1999* in the store *Carebim*?

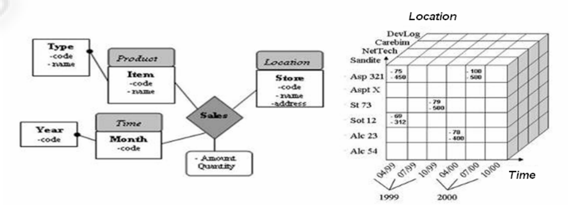


Figure 1: "Sales" OLAP application: multidimensional model and cube values.

OLAP decision making process is interactive and iterative, so OLAP tools have to support the user into this kind of particular decisional process by a simple interaction with the user interface, translating his/her actions into OLAP operators.

Integration of spatial data in OLAP systems brings to two new concepts: *spatial dimension* (Bedard et al, 2001) and *geographical measure* (Bimonte et al 2005). The former is a hierarchy of members with alphanumeric and spatial attributes, while the latter extends the classical concept of measure, being not only a numeric value but also a set of alphanumeric and spatial inter-dependent attributes having a meaning as whole, or in other terms a geographical object.

2.1 (S)OLAP Visualization Issues

In order to effectively support OLAP analysis of multidimensional databases, some specific interaction metaphors are required to present and browse data.

The *Pivot Table* is the most used visualization paradigm for OLAP tools, due to its intrinsic characteristics of incorporating the multidimensional structure of the Data Warehouse and the visual support for an easily measures' comparison. Basically, a Pivot Table is a 2D spreadsheet with associated subtotals and totals that supports viewing more complex data by nesting several dimensions on the *x*- or *y*-axis and displaying data on multiple pages. Pivot tables generally permit to interactively select a subset of the data warehouse and change the displayed level of detail.

As a result, Pivot Tables are a very powerful interaction metaphor, to support the browsing of alphanumerical Data Warehouses, and it is implemented in almost all OLAP tools (Pende, 2005), (Thomsen and Pedersen, 2005). However the Pivot Table, in its original formulation has the inherent constraint to be limited to deal with alphanumeric information, thus turning out to be inadequate with spatial data.

It is worth pointing out that some OLAP solutions (e.g. (Stolte et al., 2002)) have extended the pivot table concept with graphic representations and visual variables (shape, size, etc…). Following this approach, cells of the pivot table are graphic canvas which collapse using visual variables members of a same hierarchy levels into a unique visual description. The main advantage of this approach is to effectively support the user in data comparison.

2.2 SOLAP Tools

The introduction of cartographic data in the (S)OLAP process implies a reformulation of classical visualization paradigms, to support a multidimensional analysis based on maps, tabular and graphical data representation, that have a different expressive power. Indeed a SOLAP user interface has to support multidimensional analysis using maps, tabular and graphical data representation in a concerted, interactive and synchronized way. Synchronization means that an action (i.e. drill-down or roll-up) on one interface widget (i.e. map) has to be replied on the other ones (i.e. pivot table and graphic displays). Finally ad-hoc semiology rules, or particular geovisualization techniques as for example the choremes (Laurini et al., 2006) for visualization of alphanumeric measures on maps could improve the expressiveness power of SOLAP tools.

In the following we will describe how these problems have been tacked in the literature. Several SOLAP tools have been developed until now. In the following we focus on their visualization features. (Rivest et al, 2005) describe a SOLAP tool which supports pivot table and several different types of diagrams and maps, composed by visual variables and maps superimposed with graphical diagrams, for supporting spatial dimensions, numeric measures and spatial measure (result of topological and metric operators on spatial dimension members. In (Scotch and Parmanto, 2005) authors describe SOVAT, a multidimensional spatial-numerical decision support system. This tool permits to navigate into multidimensional databases, and to analyze spatio-temporal data using graphical displays, maps, and tabular representation. SOVAT provides some multidimensional and spatial data mining operators, but allows user to analyse only numerical measures. In (Voss et al, 2005) is presented CommonGIS, a powerful tool for interactive visual geo-analytics, extended to process hierarchical multidimensional data from OLAP warehouses. This approach is very different from the previous ones, since no tabular representation of data is provided for the multidimensional navigation, which is permitted by means of some parametric geovisualization techniques. Finally a commercial SOLAP tool (ESRI 2006) has been developed by ESRI and SAS, providing a solution for spatial multidimensional application using spatial dimensions

All these works try to introduce a link between the cartographic representation of a dimension and the corresponding tabular representation of the multidimensional database, to achieve a synchronized multidimensional navigation. Visual representation of numeric measures on maps (spatial dimensions) is sometime supported by geovisualization techniques (i.e. multimaps). But how geovisualization tools and visualization-based techniques for exploratory analysis of spatio-temporal data (Andrienko and Andrienko, 2005) can be coupled for a more coherent analysis of geographical measures and spatial dimensions rest an open issue.

3 THE GEOLAPIVOT TABLE

As for numeric data, to answer the strong needing for a visual technique suited to compare geographical measures, according to different members of the same hierarchy level, and to effectively understand spatial/thematic relations between measures, we propose the metaphor of *GeOlaPivot Table*, intended as a 3-Dimensional extension of the OLAP Pivot Table.

Our main idea is to exploit the 3rd dimension to provide insight on how a spatial phenomenon evolved in function of another factor (such as time, or incidence), by overlapping data onto a map. To this aim, we have combined the concept of *Space-Time Cube* (Hägerstrand, 1970) (Gatalsky et al., 2004) and *Pivot Table* giving rise to the notion of *GeOlaPivot Table.* Indeed, cells of the *Pivot Table* related to spatial data are cubes, representing into a single, visual description measures associated to different members of a same hierarchy level, like previously described OLAP tools. A cube can be rotated to obtain the best point of view, avoiding screen and information cluttering. So, user can freely rotate the cube on 3 axes, to analyze the dataset. The base of the cube is associated to a spatial dimension (if it exists) and its 3rd dimension to another alphanumeric dimension. Spatial measures associated to the same fact are depicted by the same color. All the data that do not match the query parameters, set by the user, are removed from the visualization cube. An example of GeOlaPivot Table is reported in Figure 2, showing the district of the Northern Italy affected by some infectious diseases during the period 2001-2003.

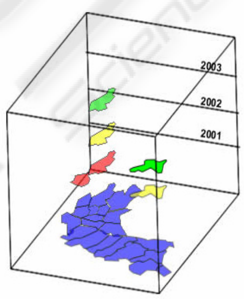
Incidence	*Location*	*Time.All Time -Dept*
>6.0	+ Northern Italy	

Figure 2: Example of a GeOlaPivot Table.

In GeOlaPivot Table, geographical measures can be associated to a spatial context that permits to localize them in the space. In other terms a spatial dimension can be present in a SOLAP application with geographical measures. The cartographic members of the spatial dimension will be the base of the cube. Moreover, thematic attributes of geographical data are necessary for an effective decision-making process. For example, what characterize a particular area can help decision-maker to understand the causes of a particular localization of a phenomenon.

As a result, the main characteristics a SOLAP client tool based on *GeOlaPivot Table* are:

1. Visualization of spatial geometric dimension and spatial measure at same time.
2. Adoption of a visualisation technique to compare spatial and thematic relations between measures associated to different members of a same hierarchy level.
3. Explicit visualization of spatial relations between measures and dimensions members.
4. Visual encapsulation of the structure of multidimensional application.
5. Visual representation of OLAP operators
6. Display of thematic attributes of measures.

The main advantage of this approach is to effectively support the user in data comparison. Our proposal is an improvement of SOLAP solutions, because it permits to coherently merge, in a single visual environment, the key concepts of pivot tables and Space-Time Cube. This allows us to represent and effectively analyze geographical measures according to spatial and alphanumeric dimensions.

3.1 A Case Study

In order to illustrate the fundamental characteristics of the designed visualization tool, we describe a scenario of use, exploiting data on infectious diseases (as for example AIDS, tetanus, etc…) in Italy. The complete dataset is freely available on the web site of the Italian Health Institution "*Istituto Superiore di Sanità*" (www.iss.it).

The multidimensional application presents as dimension:

– *Location*: (Region, Nation) Spatial geometric dimension, i.e. Lombardia, Italy.
– *Time*: (Year, 3 Years), i.e. 1991, 1990-1992
– *Infectious Disease*: (Disease, Class) A classification of diseases according to the International Classification of Disease, i.e. AIDS
– *Incidence*: (Rate) Rate of incidence of deaths by population per 100000 inhabitants, i.e. 2,5-3,0

Districts are measures. A district is characterized by some attributes, as the *Name*, the *Geometry*, the *Number of Hospitals* and the *Areaclass*. The latter one is a social-economic classification of the district, such as "cities and services". Aggregation functions are spatial union for geometry, sum for the number of hospitals and a ratio function for the areaclass. An example of the fact table is presented in Table 1.

Table 1: Fact table of the Infectious Diseases Spatial Data Warehouse.

Disease	Time	Incidence	Location	District
AIDS	2001	>6.0	Lombardia	Piacenza
AIDS	2002	>6.0	Lombardia	Brescia, Piacenza
AIDS	2003	>6.0	Lombardia	Lecco, Piacenza
AIDS	2002	>6.0	Emilia-Romagna	Ravenna
…	…	…	…	…

In our case study we considered the years 2001, 2002 and 2003. If user wants to know what zone of Italy has an incidence rate superior to 6.0 for AIDS in the time period 2001-2003, the UI configuration shown in figure 4 permits to answer to this question. We notice the *AIDS* value in the Filter component of the Cube Navigator and *3 Year* in the Cube Axis component. So, now the *GeOlaPivot Table* will contain only one cell showing a cube which has as base the cartographic representation of Italy, as vertical axis the 2001-2003 time period, and a geographical zone as internal value. It shows that the highest incidence rate for AIDS from 2001 to 2003 regards at most north Italy districts. What characterize this area? Answers could be found in thematic attributes. Showing thematic attributes for the new aggregated measure it can be noticed that the areaclass for this area is classified as "cities and services".

Let us suppose that the user wishes to have a more detailed insight of the application, and in particular she/he wants to know what districts have an incidence rate superior to 6.0 for AIDS for each year.

He/she can apply the Drill-Down on the *Location* dimension, by clicking on the '+' operator at the left of Italy in the *GeOlaPivot Table*.

Then using the Cube Navigator he/she choices to no more visualize measures for Italy, and through the Cube Axis component he/she applies a drill down operator in the Time dimension too. This action changes the axis of the cube in the *GeOlaPivot Table,* which now shows the districts for each year. The UI configuration shown in figure 5 permits to answer to this question.

The *GeOlaPivot Table* permits to see that for the region "Lombardia", three districts are present and in particular the district Piacenza is always present from 2001 to 2003. Moreover these districts are all neighboring. Changing year does not imply changing of geographical area.

4 VIS³OLAP: A WEB BASED SOLAP TOOL

We are currently developing a web-based system, named VIS³OLAP, meant to provide SOLAP features and to support geographical measures by exploiting the *GeOlaPivot Table*. In this section we present the software architecture of the system and then we detail the mock-up of its user interface.

4.1 System Architecture

VIS³OLAP is based on a three tier architecture, as shown in Figure 3. It consists of a DBMS able to support spatial data, an OLAP Server, and a web client providing the GeOlaPivot Table metaphor.

More in detail, Oracle 10g will be used to implement the Data Warehouse tier, due both to its native support of spatial data and to its Object-Relational capabilities. Indeed, user-defined aggregation functions and user defined types, which are necessary when dealing with spatial data, can be easily implemented over an Object-Relational DBMS. Moreover Oracle's native support for spatial data ensures scalability and security to spatial multidimensional applications.

For the OLAP tiers, two widely-adopted, free tools for OLAP applications will be employed: *Mondrian* (Mondrian 2006) and *JPivot* (JPivot, 2006).

The former is a software package designed to provide OLAP functionalities in an open and extensible framework, on the top of a relational database. This is achieved by means of a set of JAVA APIs, that can be used for writing applications, such as a graphical interface, for browsing the multidimensional database. These APIs can also be invoked by JSP/Servlets, within a web environment. Mondrian includes a Calculation layer, that validates and executes MDX (Multidimensional Expressions) queries, and an Aggregation layer that controls data in memory and request data that is not cached. MDX is a standard language to query multidimensional databases, just like SQL for the relational ones. In order to guarantee the greatest flexibility, to interface the relational data, an XML description of the multidimensional application has to be written.

JPivot is a software package designed for providing a web-based, graphical presentation layer on top of Mondrian. It provides specific JSP tags for easily building powerful graphical interfaces, suited to explore the data warehouse.

In order to implement the visual metaphor of the GeOlaPivot Table in this system, *JPivot*'s APIs should be deeply modified, to generate on-demand, within the cells, the 3D cube. Details about data presentation are provided in the next section.

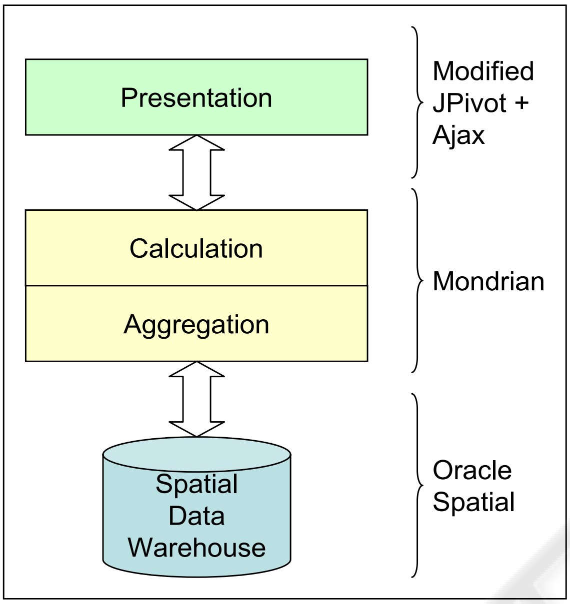


Figure 3: The System Architecture.

4.2 The User Interface

In an environment like the one described in the previous section, a Knowledge Engineer can query the Spatial Data Warehouse by defining the analysis dimensions and the level of detail to use, to get insight on spatial relationships occurring among data. In particular, a direct manipulation of both attributes and depicted values is allowed. To this aim, the interface should propose some widgets to carefully select the information to deal with, which will be rendered in 3D using the *GeOlaPivot Table*.

To clarify the main aspects of the *GeOlaPivot Table*, we have developed a mock-up of the User Interface (UI) of the visualization tool meant to support the proposed metaphor (see figure 4 and 5).

This UI is aimed at providing an interactive environment which graphically encapsulates the structure of the multidimensional application and translates interactions with the visual interface into operators.

The UI is an extension of the standard one provided by *JPivot*, and is composed by two main blocks: the OLAP tool bar, and the *GeOlaPivot* Table. The former set of controls provides functionalities to navigate in the cube, affecting the pivot table in several way: *drill-down replace, drill-down position, expand-all, drill-through*.

The *drill-down replace* enables drilling from one pointed member to its child members in the dimension hierarchy, hiding the parents. *drill-down position* enables drilling from one pointed member to its child members, still showing the members of the initial higher level in the table. The *expand-all* operator enables drilling from all visible members in the table to child members. Moreover the OLAP tool bar permits through the Cube Navigator tool to select dimensions, levels and members to display. This browser is used by the user in order to map the hierarchies on table axes and to express selection of members to slice or dice the cube. Finally the Cube Navigator permits to select the level's members to be used as vertical axes of our cube metaphor by the icon:

The *GeOlaPivot* Table is used to show in 3D, at an arbitrary detail level, the geographical data. It allows for 6 Degree of Freedom, achieved through some specific buttons placed at the bottom of the cube.

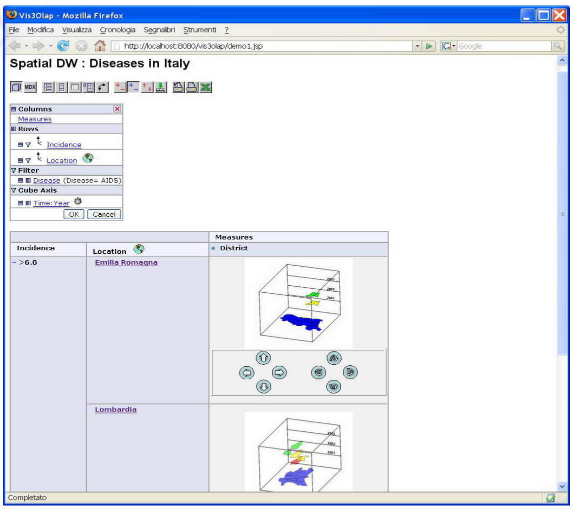


Figure 4: Districts in GeOlaPivot Table.

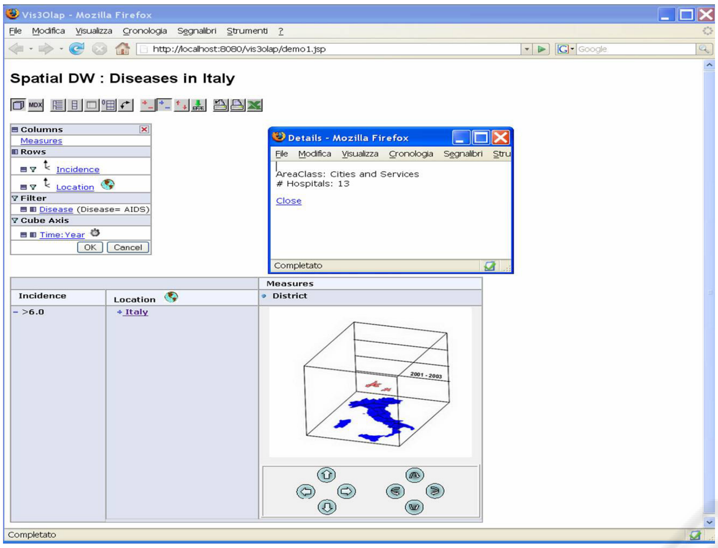


Figure 5: An example of User Interface with Aggregation of Districts in GeOlaPivot Table.

In our opinion, one of the most critical implementation aspects could be the generation of the 3D cubes with the underlying map, since it requires (I) to rasterize the vectorial geographical information provided by Oracle Spatial (this could be achieved by many APIs), and (II) to project this bitmap on the base of the cube, with the corresponding perspective adjustments

5 CONCLUSIONS AND FUTURE WORK

The growing amount of spatial information in Data Warehouses leads to the formulation of the SOLAP concept. Indeed, it is a key technology to take full advantage of the knowledge concealed within enterprise datasets, and many efforts are being devoted in this field to provide Decision Makers with powerful analysis tools. However, when introducing geographical measures in the SOLAP domain, many problems arise, mainly because there isn't a widely accepted interaction metaphor to support comparisons of spatial measures.

In this paper, starting from an analysis of existing SOLAP tools, revealing a lack in the support of geographical measures, we have firstly proposed the metaphor of *GeOlaPivot Table*, which coherently merges, in a single visual environment, the key concepts of Pivot Tables and Space-Time Cube. This approach represents a first effort in adapting advanced geovisualization techniques to SOLAP ones, in order to create a specific visual paradigm for Spatial OLAP able to effectively support and fully exploit spatial multidimensional analysis process.

A preliminary case study has been described, presenting a possible application of our metaphor to a spatial Data Warehouse concerning the supervision of infectious diseases in Italy.

Then, we have illustrated the main issues about the development of a web-based environment exploiting the GeOlaPivot Table visual metaphor to support geographical measures in SOLAP analyses and a three tier architecture has been described. Currently we are working on the implementation of the proposed architecture. In particular, for the development of the Graphical User Interface able to present the 3D cube of the GeOlaPivot Table, we are currently experimenting the use of AJAX technology, in order to significantly reduce the amount of network traffic, and consequently the latency of the user interface. It is worth to remark that the projection of raster maps within the cubes could require significant programming efforts. Thus, we plan to develop an API supporting this kind of task.

About future work, we would like to extend the *GeOlaPivot Table* with adequate graphic semiology rules to visualize thematic attributes of spatial dimensions and measures and by introducing *chorems* in order to visualize spatial trends.

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