REVISITING THE OLAP INTERACTION TO COPE WITH SPATIAL DATA AND SPATIAL DATA ANALYSIS

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Abstract: In this paper we propose a new interface for spatial OLAP systems. Spatial data deals with data related to space and have a complex and specific nature bringing challenges to OLAP environments. Humans only understand spatial data through maps. We propose a new spatial OLAP environment compounded with the following elements: a map, a support table and a detail table. Those areas have synchronized granularity. We also extend OLAP operation to performed spatial analysis, for instance, spatial drill-down, spatial drill-up and spatial slice. We take special care in the spatial slice where we identify two main groups of operations: spatial-semantic slice and spatial-geometric slice.

1 INTRODUCTION

Nowadays OLAP (On-Line Analytical Processing) is a very important component of Decision Support Systems in any medium or large organization since they provide rapid and interactive ways of exploring large amounts of information stored, in most of the cases, according to the multidimensional data model (Kimball and Ross, 2002). However OLAP systems are optimized to handle alphanumeric data and are not well prepared to handle spatial data represented by data types like vectors or images. Spatial data can be digitally represented through image, vector or alphanumeric data types. Vectors are represented by points, lines and polygons and are in agreement to some coordinate system (latitude, longitude). They also have a different and complex nature compared with alphanumeric data types. In deed, to store the geometry of a lake is necessary to collect hundreds of points (depending of the precision). Visualization is another concern that is only possible through maps.

A Geographic Information System (GIS) is a computer system capable of assembling, storing, manipulating and displaying geographically referenced information i.e. data identified according to their location (Workboys and Duckham, 2004). A GIS is a system dedicated to the manipulation of spatial data providing powerful cartographic functionalities. It is possible to couple OLAP operations in a GIS environment. GIS systems are manipulated by experts and have a poor interaction for on-the-fly OLAP operations. To build a spatial query, in a GIS, is necessary some SQL background and perform fewer configurations. GIS software manufactures provide components for map display used in the development of desktop and web applications. Those components have capabilities to establish connections with spatial databases and to render geometric columns. Some commercial OLAP systems start to include spatial data but only with display concerns. In those systems spatial data is stored outside the database and later linked to spatial data stored in dedicated files. The evolution of database management systems turns feasible to store, manipulate and retrieve spatial data from databases, meaning that is also possible to integrate spatial data in ROLAP (Relational OLAP) systems.

In this paper we propose a new approach for the OLAP interaction, by redefining and extending the typical OLAP operations and visualization methods to cope with spatial data. A prototype was developed

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whose demonstration can be visualize in http://www.estg.ipleiria.pt/~rmatias/iceis07/.

In the next section, OLAP concepts are introduced namely: (*i*) the multidimensional model; (*ii*) OLAP operations; and (*iii*) typical OLAP interaction. Section 3 presents and analyzes related work. Our proposals are introduced and discussed in section 4. In the last section, some conclusions are presented as well as future research directions are pointed out.

2 OLAP CONCEPTS

In 1993 E. F. Codd proposed, the term OLAP (On line Analytical Processing), to define a category of database processing, addressing the emerging need of data analytical activities over large amount of data collected by OLTP (On-Line Transaction Processing) systems (Codd et al., 1993).

The entity-relationship model is a success as a conceptual model for databases supporting OLTP systems, but is not appropriate for designing decision support applications like OLAP. The strong normalization applied to information spread data over a large number of tables. Therefore to answer analytical queries, database engines have to execute join operations with too many tables. To overcome this problem it has been proposed the multidimensional data model (Kimball and Ross, 2002).

In the development of a multidimensional data model there are the following elements: (i) a central table (fact table) that contains the bulk of the data and whose main objective is measure the business performance (price of a sold product, quantity sold, etc.); and (ii) a set of smaller tables (dimension tables) that represent the aspect in business organization (time, stores, products, clients, etc). Figure 1 presents a multidimensional model for sales in a chain of stores for traditional commerce, measuring the number of units and the sales amount (in dollars) of a product sold to a customer in one store at a given time.

In a conceptual view, this structure can be seen as a cube where, each edge is a dimension and each cell express values of measures for values of dimensions. This model, that crosses the fact table with the dimensions tables, is considered to be near user's intuition and enables the development of software that supply easy navigation through data (Kimball and Ross, 2002). Dimensions are organized in conceptual hierarchies that specify how attributes are organized and relate each other. A hierarchy defines a sequence of mappings from a set of low-level concepts to a set of more general and higher-level ones (Kimball and Ross, 2002). For example, in Date dimension, a Day can be mapped in Month, which can be mapped in a Quarter and a Quarter can be mapped in a Year. This mappings form a conceptual hierarchy in the Date dimension that enables the navigation from Day level to Year level. It can happen that more that one hierarchy is defined on a dimension. For instance, from Day to Week and from Week to Year.

Hierarchies play an important role in OLAP operations because they enable the navigation by levels of abstraction, bringing flexibility to observe data from different perspectives.

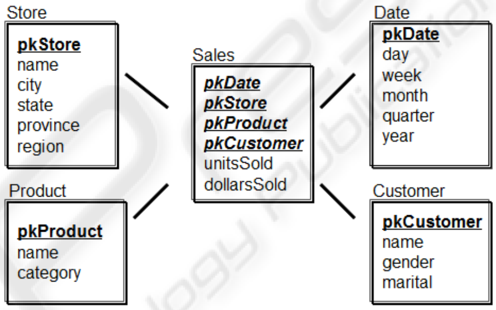
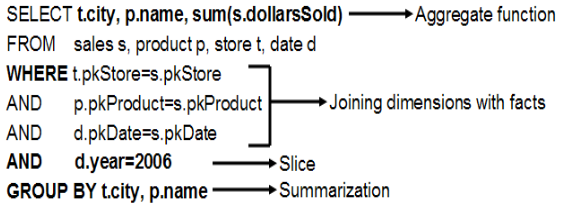


Figure 1: Multidimensional model.

The asymmetry present in a multidimensional model (one fact table connected to many dimensional tables) is exploited by OLAP engines by specific query patterns. Figure 2 presents a typical OLAP query and the following elements can be pointed out: (i) the where clause specifies the join between the dimensions and the fact table; (ii) the where clause specifies constraints over some dimensions attributes, which correspond to a user selection of parts of the data cube (slide operation); (iii) the group by clause, in conjunction with selected columns and aggregation functions (sum) (to be applied on selected measures), corresponds to user's specifications in intended summarization, i.e., the level of detail of the result.



```
SELECT t.city, p.name, sum(s.dollarsSold)
FROM    sales s, product p, store t, date d
WHERE t.pkStore=s.pkStore
AND     p.pkProduct=s.pkProduct
AND     d.pkDate=s.pkDate
AND     d.year=2006
GROUP BY t.city, p.name
```

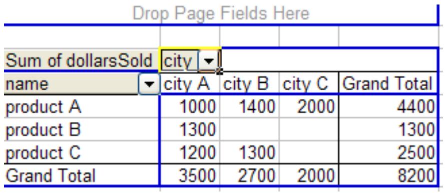
Figure 2: Typical query in OLAP.

The Drill-up (roll-up) operation reduces the level of detail. The drill-down operation increases the level of detail.

Drill-up operations performs aggregation on a data cube either by using a hierarchy (going from a lower level concept to a higher one) or by dimension reduction (removing a dimension's attribute).

Drill-down operations can be done using a hierarchy (going form a higher level concept to a lower one) or by dimension addition (adding a dimension's attribute).

Figure 3 shows a two-way table for presenting answers of OLAP queries.



Drop Page Fields Here

Sum of dollarsSold	city			
name	city A	city B	city C	Grand Total
product A	1000	1400	2000	4400
product B	1300			1300
product C	1200	1300		2500
Grand Total	3500	2700	2000	8200

Figure 3: Pivot table layout.

Users, in most of OLAP systems specify OLAP queries in interactive ways from a GUI. Pivot tables that are frequently used to perform OLAP operations. They supply a flexible way to dispose attributes and measures by means of drag-and-drop operations in four main areas: page, row, column and data. In row's and column's areas users put attributes that they want to cross. In the data area users put measures whose values they want to obtain and that result from the cross of attributes. In the page area users put attributes they want to use for controlling the data used on the query.

Roll-up and drill-down operations are performed by dragging-and-dropping attributes into (or removing from) row and column areas.

3 RELATED WORK

Bédard introduced in 1997 the term SOLAP (Spatial On-Line Analytical Processing) as a type of software that allows rapid and easy navigation within spatial databases, offers many levels of information granularity, many themes, many epochs and many display modes (maps, tables, graphics) synchronized or not. (Bédard, 1997). Since then many works have been done, especially in the Centre of Research in Geometric at the University of Laval in Quebec, Canada.

OLAP systems are divided in three main layers: (i) data layer; (ii) server layer; (iii) client layer. That's why the integration of spatial data in OLAP systems brings questions in all those layers.

Han et al. (Han et al., 1998) addresses problems related to the integration of spatial data in the data layer. Namely, identifies new types of dimensions, attributes, hierarchies and measures. Later Malinowski and Zimányi (Malinowski and Zimányi, 2004) addresses the representation of those new types of dimensions, attributes, hierarchies and measures in the multidimensional data models.

A spatial dimension can have (Han et al., 1998): (i) semantic attributes, i.e., alphanumeric data; (ii) spatial-semantic attributes, i.e., alphanumeric data related to space, for instance, the name of cities; (iii) spatial-geometric attributes, i.e., geometry data (point, line, polygon), for instance, the political boundary of cities.

Because, there are three types of attributes there are different types spatial hierarchies, classified according to the generalization been made (Han et al., 1998): (i) semantic-to-semantic hierarchy (total semantic) is a hierarchy where in all concept levels there are semantic attributes; (ii) geometric-to-semantic hierarchy (hybrid) is a hierarchy where the lower level concept is a spatial-geometric attribute but after some level of degree there are only spatial-semantic attributes; (iii) geometric-to-geometric (total geometric) is a hierarchy where in all concept levels there are spatial-geometric attributes.

The spatial hierarchies' attributes have a total or a partial order. Attributes of hybrid and total hierarchies have including relationships.

A fact table has two types of spatial measures: (i) spatial-semantic measure, for instance, the area of a polygon; (ii) spatial-geometric measure, for instance, a point specifying where an accident has happened.

Compared with alphanumeric data, spatial data (vector data) tends to occupy more disk space and performing geometric operations takes more CPU. So a balance between space storage and CPU response time has to be carried. Han et al. (Han et al., 1998) presents the following approaches to deal with materialized and spatial views (Han et al., 1998): (i) without spatial materialized views (spatial data is used only for visualization proposes); (ii) spatial materialized views with approximations. For instance, store geometry approximations like the Minimum Bounding Rectangle (MBR); and (iii) selective pre-aggregation (identify the most required spatial aggregations and materialize them). This will have a performance enhancement for the most common usage of the system.

Rivets et al. (Rivest et al., 2005) proposes interfaces for SOLAP interaction. Their work compares OLAP and GIS systems, and presents the advantages of integrating concepts from those two different worlds. They develop a new solution where GIS components are integrated OLAP environments. The results of common OLAP operations, namely aggregated data, are displayed in maps. Other ways of display are tabular and graphic formats. The map enables users to configure the layout (as in GIS software).

4 SOLAP INTERACTION

As we have already mentioned, in previous sections, OLAP systems should provide an easy and flexible way to explore datasets and so the introduction of this new component – the map, can't obstruct those capacities. In this section we first present the proposed graphical user interface (GUI), namely the layout of visual elements. Then we present new OLAP operations – spatial OLAP operations. For simplicity concerns, we concentrate our efforts in a scenario with only one spatial dimension.

4.1 OLAP Interaction Coped with Maps

Let us consider the scenario related to a chain of commerce stores geographically disperse in a country as described in section 2.1 and represented in Figure 1. The store dimension has the following spatial-geometric attributes: Point-of-Store that represents the location of stores and four other spatial-geometric attributes (polygons representing administrative divisions (Table 1)).

A spatial-geometric attribute has a spatial-semantic attribute that describes it. We call that spatial-semantic attribute the **spatial-semantic attribute of reference**. See in Table 1 the list of spatial-geometric attributes and the related spatial-semantic attributes.

Table 1: Spatial-semantic attributes of reference and spatial-geometric attributes.

Spatial-Geometric	Spatial-Semantic
Point-of-Store	Name
Polygon-of-City	City
Polygon-of-State	State
Polygon-of-Province	Province
Polygon-of-Region	Region

The GUI of a SOLAP client should provide map visualization features including the ability of controlling the way the spatial-geometric attributes are represented on the map, based on the values of some of the observed metrics. For instance, the size the points are represented on a map could be controlled by the values of a metric (for example the total amount of sales associated to a store). The way the metrics affect the display of spatial-geometric attributes can be user-defined and is called the visualization-theme. We consider fundamental that a SOLAP client provides the user with both table and map visualisations, and that they are kept synchronized.

The proposed SOLAP GUI has the following three areas (see figure 4): (i) a map where he spatial-geometric attributes are displayed according to the values of some metric and using a visualisation-theme (ii) a support table, kept synchronised with the map, that contains the spatial-semantic attribute of reference related to the spatial-geometric attributes used on the map and some metrics (including that ones used on the visualisation-theme); (iii) a detail table, related to the support table, that could present some additional detail data and metrics.

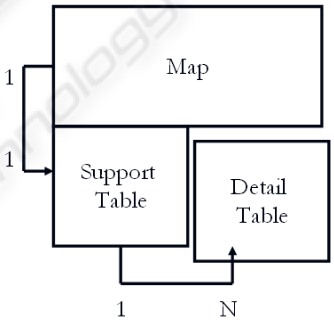
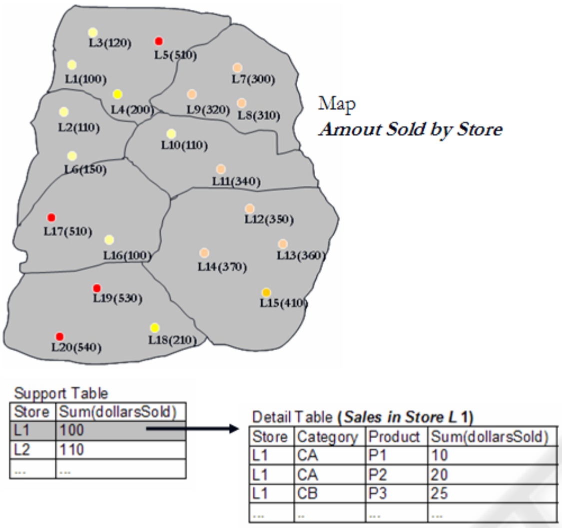


Figure 4: The three main areas.

Those three areas are filled with data from three different, but related, queries. The map has a one-to-one relation with the support table, in order to guarantee the required synchronisation between the data displayed on the map with the data displayed in the support table. Each value of spatial-geometric attribute is represented by a point or by a polygon which visualisation is controlled by some metric values present in the corresponding row on the support table. The support table has a one-to-many relation with the detail table and the required synchronization is guarantee by applying restrictions, to the detail table, using attributes and values currently selected in the support table.

Figure 5 shows a typical OLAP analysis displaying the sum of sales amount per store (for a given period and for all products). Each row of support table contains data for one store. The data corresponding to one row is represented in the map area, according to a visualization theme: each point (the store location) is labelled with the store name and its sum of sales amount; the point colour depends on the sum of sales amount of the store. The map also shows administrative divisions of the country helping users contextualize the stores. The detail table shows (for the user selected row in the support table) the sum of sales amount distributed by products.



Support Table

Store	Sum(dollarsSold)
L1	100
L2	110
...	...

Detail Table (*Sales in Store L 1*)

Store	Category	Product	Sum(dollarsSold)
L1	CA	P1	10
L1	CA	P2	20
L1	CB	P3	25
..	..	...	...

Figure 5: Map, support table and detail table.

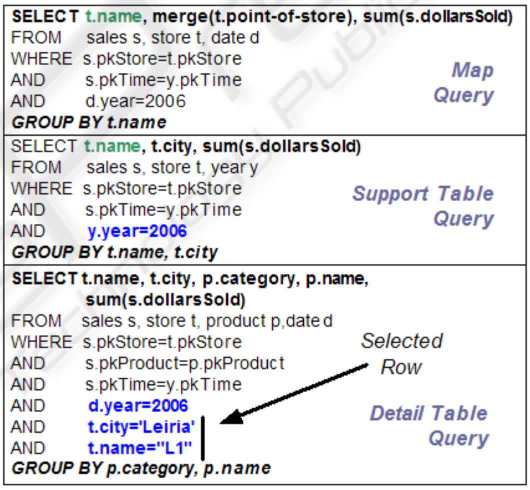
To guarantee the relation between the map and the support table: (i) they are related by the **spatial-semantic attribute of reference**. For instance, points in the map have a corresponding attribute in the table (name of the store); and (ii) **granularity must not be modified**. Therefore is possible to add (to the map or support table): (a) attributes of a higher level then the spatial-semantic attribute of reference; (b) attributes of others dimensions; and (c) spatial-geometric attributes (intersections are performed).

To guarantee the relation between the support table and the detail table: (i) **selected rows**, in the support table, **controls** data been display in the detail table. Attributes present in the support table are also present in the detail table which also shows additional attributes. It is possible to add any attribute (in contrast with what it happens in the support table).

Figure 6 shows three related queries – one for each main area. The first query has the spatial attribute of reference 'name of store' (t.name) and loads the location of stores (points); the second query also has the attribute 'name of store' (t.name) and the attribute 'city' (t.city) (both belong to the same hierarchy); finally, the third query has restrictions that reflects selected values in the support table (t.name='L1', t.city='Leira') – observe that year=2006 is inherited by omission from the second query.

4.2 Spatial Drill

Spatial Drills are executed in the following ways: (i) using a total spatial-hierarchy (a spatial-geometric attribute is replaced by another); (ii) adding or removing some spatial-geometric attribute (interception of spatial-geometric attributes). In a spatial roll-up, through hierarchies, users navigate from lower level spatial-geometric attributes to higher level ones. The opposite happens in drill-down (navigate to more detail areas of space).



```
SELECT t.name, merge(t.point-of-store), sum(s.dollarsSold)
FROM    sales s, store t, date d
WHERE  s.pkStore=t.pkStore
AND     s.pkTime=y.pkTime
AND     d.year=2006
GROUP BY t.name
```

Map Query

```
SELECT t.name, t.city, sum(s.dollarsSold)
FROM    sales s, store t, year y
WHERE  s.pkStore=t.pkStore
AND     s.pkTime=y.pkTime
AND     y.year=2006
GROUP BY t.name, t.city
```

Support Table Query

```
SELECT t.name, t.city, p.category, p.name,
        sum(s.dollarsSold)
FROM   sales s, store t, product p,date d
WHERE  s.pkStore=t.pkStore
AND     s.pkProduct=p.pkProduct
AND     s.pkTime=y.pkTime
AND     d.year=2006
AND     t.city='Leiria'
AND     t.name="L1"
GROUP BY p.category, p.name
```

Detail Table Query

Figure 6: Three queries for three areas.

In a spatial drill-down through the addition of some spatial-geometric attribute interceptions are made. The support table will have a spatial-semantic attribute of reference by each spatial-geometric attribute in the map. For instance, having the attribute Polygon-of-City and adding the attribute Polygon-of-Metropolitan-Area. Cities will be divided in areas, corresponding to overlap relations between cities and metropolitan areas. Each area will have a different measure. It is not always possible to perform this operation. For instance, when dealing with geometric objects not spatially comparable (points and polygons), or polygons that does not overlap. In those cases, we propose that a spatial-semantic attribute of reference goes to slice.

4.3 Spatial Slice

As explained in the section 2.1 on spatial slice operations restrictions are applied to dimensions' attributes. We identify two mode of operand for spatial slice: (i) using semantic attributes; (ii) using geometric-attributes.

4.3.1 Spatial Slice with Semantic Attributes

In a spatial slice through a semantic-attribute the spatial cube is restricted by values of that semantic attribute.. To perform this operation we propose a graphic control, called navigation bar (slider). Once in a slice bar the attribute influence a subject in the spatial cube. With a slider we can navigate through values of attributes (go to: first, next, prior, last; move to) (figure 7).

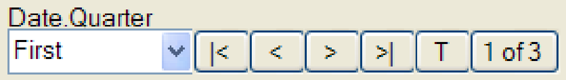


Figure 7: The slider, a map navigation bar.

This enables easy generation of maps, by simply clicking in the buttons of the slider. For example, users can look at the total sales of a product by location of stores in the first quarter of a year and then change to the next quarter enabling the graphic identification of differences. On the fly, maps are automatically generated. Usually, maps are created by specialized human recourses, needs specific software and take some time.

Another feature of the navigation bar is the movie; using a time interval the current value of an attribute changes automatically. That utility enables the analysis in time and space. For example, using the spatial-geometric attribute location of store, fixing the year, and using a slider for month users can look at the evolution of the total sales in the months of the year. We consider this feature interesting for others situations. For a data warehouse that stores the thawing of glaciers it will possible to see that evolution in space and time, and detect what was the interval of time where there was a bigger thawing.

4.3.2 Spatial Slice with Spatial-geometric Attributes

A spatial slice with spatial-geometric attribute is performed using a spatial-geometric attribute. It consists in inquire a relation between a geometric attribute and others geometric objects. For instance, restrict data to sales persecuted in stores located at 1 km of main roads in some year. In this context we identify three types of operations: (i) spatial-topology slice; (ii) spatial-distance slice; (iii) spatial-direction slice.

As the name states in a spatial-topology slice a topology relation is inquired. There are nine possible topology relations between two objects as identified by Egenhofer (Egenhofer and Herring, 1994): disjoint, meet, overlap, touch, inside, contains, covered-by, equal, covers). For instance, display a map with the total sales, in some year, for stores in the border of metropolitan areas.

Spatial-distance slice uses distance operators to detect if two objects are at some distance from each other. For example, obtain the total sales of stores located 5 km of concurrent shopping centers in February of 2007 (figure 8).

Spatial-direction slice uses direction operators to establish some direction relationship. For instance, obtain the total sales, in some year, only in stores located at north of some road.

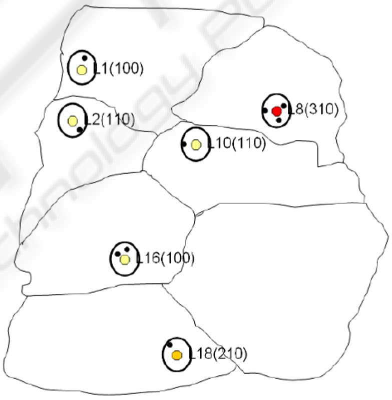


Figure 8: Sales in stores located 5km of shopping centers in 2006. A buffer of 5km is drawn around stores.

This kind of spatial slice is not available in common OLAP system neither in OLAP system that only uses spatial data for display concerns and it requires a spatial database system (spatial data types, spatial operators, spatial indexes).

4.4 Overlapping Spatial Cubes

When dealing with spatial cubes it becomes possible to overlap spatial cubes. For example, overlap the map with the amount of sales by district, in some year, with the map with the amount of sales by store in the same year. That enables to discover, in a single view, the contribution of each store to the overall value of sales (in a district). This feature is not available in common OLAP systems - tables in contracts with maps can not be overlapped.

4.5 System Elements

In figure 9 one system architecture is proposed. It has three layers as is usual in OLAP systems. The elements are the following: (i) data layer - is a spatial data warehouse; (ii) server layer - has a framework of objects that represent the multidimensional structure (this structure is generated from metadata), a SQL engine that generates on-the-fly spatial SQL statements and a data access component for data retrieval; (iii) client layer supplies a GUI for performing spatial OLAP operations.

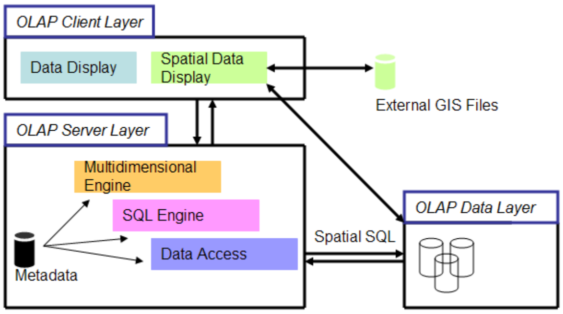


Figure 9: A system architecture.

From the GUI spatial operations are translated in spatial SQL statements submitted to the spatial data warehouse.

5 CONCLUSIONS

In this paper we propose an interface for easy and rapid exploration of spatial data in OLAP systems. The interface has three main areas (map, support table and detail table) relate to each other through one-to-one-to-many relation. Our spatial data model consider the existence of one spatial dimension compounded with spatial attributes, spatial hierarchies and spatial measures (spatial-numeric and spatial-geometric). The storage of geometric data in the data warehouse brings some performance issues, since geometric data needs more space and more CPU than non-spatial data. Materialization and algorithms for forwarding requests are important steps for the viability of such a solution. Spatial OLAP operations incorporate geometric operations for answering questions not possible to answer in common OLAP systems and can be applied in a wide range of case of studies.

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