AN MULTIDIMENSIONAL APPROACH TO THE REPRESENTATION OF THE SPATIO-TEMPORAL MULTI-GRANULARITY

Concepción M. Gascueña  
*Computer Science Department Universidad Carlos III Madrid, Avenida de la Universidad 30 Leganés 28911 Spain*  
cmgascue@inf.uc3m.es

Dolores Cuadra  
*Computer Science Department Universidad Carlos III Madrid, Avenida de la Universidad 30 Leganés 28911 Spain*  
dcuadra@inf.uc3m.es

Paloma Martínez  
*Computer Science Department Universidad Carlos III Madrid, Avenida de la Universidad 30 Leganés 28911 Spain*  
pmf@inf.uc3m.es

Keywords: Multidimensional model, Spatio-temporal Database, Spatio-temporal multi-granularity representation.

Abstract: Many efforts have been devoted to the treatment of spatial data in databases both in traditional database systems and decision support systems or On-Line Analytical Processing (OLAP) technologies in datawarehouses (DW). Nevertheless, many open questions concerning this kind of data still remain. The work presented in this paper is focused on dealing with the spatial and temporal granularity within a logical multidimensional model. The spatial data representation through a multidimensional model clarifies the understanding of the data analysis subject and it allows discovering special behavior hardly detected without it. We propose an extension of the Snowflake model to gather the spatial data and to show our proposal to represent the spatial evolution through the time in an easy and intuitive way. We represented the temporal and spatial multi-granularity with different levels in the hierarchies of the dimensions, and we present a typology of hierarchies to include more semantics in the Snowflake schema.

1 INTRODUCTION

Many works are addressed to the study of the treatment of the spatial data and their management in Database to avoid the inconsistencies caused by Geographic Information Systems (GISs), which make a heterogeneous treatment of data separating the spatial data and storing them in files systems and the non-spatial data, in general, stored in databases systems. Nevertheless, there are still unresolved many questions and that arise when managing this singular data. One of these questions is derived from the use of spatial-temporal data and is related to the granularity definition. The spatial granularity is defined as the unit of measure chosen to represent the spatial element within of a given reference system, and the temporal granularity is defined to represent the variations of an element, above the time. In relation to the time, we distinguish two kind of temporal granularity: those inherent to each element and those that decide the behavior of a set of elements, denoted in the Relational model as granularities at column or row level, respectively [Snodgrass et al., 1999]. Also, we distinguish between foreseeable and indefinite temporary. First, it is introduced by well-known and
pre-established points of time. Second, it is produced by events and the points of time, in chosen granularity, are unknown. We understand by event something that happens at a point of time and which we want to store. Many studies use measures of time with intervals, but in our proposal will use points of time due to their simplicity and to avoid the coalescence problem. For our research, we defined a spatial object as a data abstract type with a identity, a granularity or unit of measure which is associated to a reference system, a geometric representation which is associated to a dimension, and a temporal granularity or time in which the object characteristics are valid. Our proposal is based on the Multidimensional Model. The spatio-temporal multi-granularity is dealt in two different ways. One of them when the points of time are pre-established. The other taking into account that the changes of values in the time are produced by events. We propose an extension of the Snowflake scheme for gather both the spatial granularity one and the temporary granularity other. Beside to represent the topological relations between different spatial data with different granularities in the table of facts. Without loss of generality, our work could extend to the Constellation scheme.

The main objective of this proposal is to enrich the Multidimensional Models using the schemes previously mentioned, from a logical representation point of view to include semantics and information about spatio-temporal data. This work is organized as follows: the section 2 contains some references to works related to the treatment of the spatial and temporal data in databases. Section 3 contains logical multidimensional concepts to gather the spatial data and their models of representation. Section 4 defines the concepts of spatio-temporal multi-granularity, leading to section 5 where a proposal for the multi-granular treatment is made in the Snowflake sheme. In section 6 several examples are presented in order to clarify the proposal and finally some conclusions are given in section 7.

2 RELATED WORKS

There are a great amount of research about the special characteristics of the spatial data and their representation in multidimensional schemata. (Sefanovic et al., 2000) distinguish three types of spatial dimensions according to whether they include spatial elements in every hierarchy levels, in some of them or in none of them; in addition, two types of measures, spatial and numeric are considered. (Miquel et al., 2004) establish that if an spatial measure is required in the fact table, then the model must include a spatial dimension, as opposed to (Zimanyi et al. 2004) who propose the inclusion of the spatial data in the different levels of a hierarchy and too in measures, specifying examples in which they do not consider necessary spatial data in any dimension, in order to represent a measure as an spatial data. Also, they expose a conceptual model for to model a Spatial Data Warehouse (SDW), proposing extensions to E/R model and to the Star and snowflake multidimensional models. (Kouba et al. 2002) are related to the navigation consistency among the levels of the hierarchies for spatial data and OLAP systems. (Han et al., 1997), establish Spatial On-Line Analytical Processing (SOLAP) prototypes where they gather the concepts of OLAP to apply them to the spatial data. Moreover a spatial data mining system is presented called Geo Miner. The proposal of (Porabbas et al.) and (Ferri et al, 2000) integrates GIS systems and DW/OLAP environments. None of these approaches define the spatio-temporal multi-granularity concept, although in an implicit way, the temporary is reflected by the representation of a time dimension. According to (Camossi, et al.,2003) the spatio-temporal multi-granularity concept is very important to represent domain semantics and it provides an integration and inter-operability environment to spatio-temporal elements.

3 LOGICAL MULTIDIMENSIONAL CONCEPTS

A Data Warehouse (DW) is defined as a collection of subject-oriented, integrated, non-volatile data that vary in time, which support decision making processes (Sefanovic et al., 2000). DW are usually represent at a logical level by multidimensional models and these use Star, Snowflake or Constellation schemes (Toby J., et al, 1999). A
logical multidimensional model consists of different elements: dimensions, hierarchies and fact tables. A fact table contains the focus of analysis and subject-orientation, e.g. analysis of daily sales of stores in a city. Also a fact table contains measures based on the dimensions, reflecting a characteristic whose evolution wish to be obtained. In the previous example the sales are measures and the stores, the city and the days are dimensions. The dimensions provide a vision of the data from different perspectives and the hierarchies provide a more generalized vision of them. The dimensions can to form hierarchies like Dia-Mes-Año, and moreover can contain attributes for to complete information, such as number of inhabitant in a city. The Star scheme consists of dimensions and a fact table with its corresponding measures. When the attributes of a dimension is structured into different groups, this can to form levels within hierarchies and we have the Snowflake scheme. When there are several fact tables in the scheme, each one with its corresponding measures, which can share hierarchies we have the Constellation scheme. In a hierarchy the less level is called leaf level. The OLAP Systems allow manipulation of the DW data dynamically for the process of decision making. The systems are classified as M-OLAP, R-OLAP and H-OLAP according to whether data is stored in a multidimensional array, a relational system or mixture both respectively. The SDWs combine DW and Spatial System Databases. Thus OLAP systems extend to SOLAP systems allowing great volumes of spatial data to be stored, spatial statistical analysis and spatial data mining. There are several proposals to include the spatial data within multidimensional models, (Malinowski et al, 2004), both in the dimensions and in the fact table (Rives et al., 2001). We use a extension of the Snowflake scheme to include the spatial data for make our proposal.

4 SPATIO-TEMPORAL MULTI-GRANULARITY CONCEPT

This section explains the spatial-temporal multi-granularity concept and the conversion operations for the spatio-temporal objects. The multi-granularity concept consists of two orthogonal notions, the temporal granularity and the spatial granularity, both of them considered as a discrete partition of the time or the space. The temporal granularity has been defined as a partition in groups of elements ordered according to an index set in a temporal domain. Each group of elements is an indivisible unit called a granule (Bettini et al., 2000). The granularities set is denoted by $G_T$, and its elements are related by the relationship $\text{fine than}$. A granularity $S$ is $\text{finer than} R$ if for each index $i$ an index $j \in R$ exists such that $S(i) \subseteq R(j)$, where $S(i)$ denotes the granule belonging to the $i$

<table>
<thead>
<tr>
<th>Proj (index)</th>
<th>Contract functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>First, Last</td>
<td>$l_{contr}$: It contracts an open line, endpoints included, to a point</td>
</tr>
<tr>
<td>Main</td>
<td>$r_{contr}$: It contracts a simple connect region and its bounding to a point</td>
</tr>
<tr>
<td>All</td>
<td>$r_{thinning}$: It reduces a region and its bounding lines to a line</td>
</tr>
<tr>
<td></td>
<td>$l_{merge}$: It merges two lines sharing an endpoint into to single line</td>
</tr>
<tr>
<td></td>
<td>$r_{merge}$: It merges two regions sharing a boundary line into a single region</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Absorption operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{abs}$: It eliminates (abstracts) an isolated point inside a region</td>
</tr>
<tr>
<td>$l_{abs}$: It eliminates a line inside a region</td>
</tr>
</tbody>
</table>

Table 1. Temporal conversion functions Table 2. Spatial conversion functions

index position. This relation is denoted by $S \leq_T R$. Semantically, when we define a granularity for an object we specify the time instants at which the object’s values are relevant to the specific application domain. Days, months and years are several kinds of temporal granularity where the days
are finer than months (Bertino et al., 2005). The spatial granularity is defined as the unit of measure in a spatial reference system. It thus represents the unit according to which spatial properties are measured. The set of the spatial granularity is denoted by $G_s$. The elements of $G_s$ would be meters, kilometers, grades and others. Each one of those elements must be defined with respect to a spatial reference system. In $G_s$, the relation finer_than is similar to the temporal granularity given before and it is denoted by $M \leq N$, representing that $M$ is finer than $N$ (Bertino et al., 2005).

Operations and comparisons between objects at different temporal granularity need the conversion functions. These functions change the temporal properties of an object from a finer granularity to a coarser granularity and we can compose a macro function with the function composition. Conversion functions can be like the ones shown in the Table 1. Possible conversion functions between objects at different spatial granularity are shown in Table 2; we refer the reader to (Camossi et al., 2003), for additional details. The application of these conversion functions guarantees the topology consistency (Camossi et al., 2003). The spatial-temporal multi-granularity represents the units of measurement chosen to store a geometrical object in different moments in time.

5 INCLUDING MULTI-GRANULARITY IN A SNOWFLAKE SCHEMA

We propose to use an extended Snowflake scheme to include the treatment of the spatio-temporal multi-granularity. The Snowflake scheme is usually used to model DW. This work is based on different works to contemplate to the inclusion of the space in these systems, (Malinowski et al., 2004), (Sefanovic et al., 2000), (Rives et al., 2001). We adopted the extended Snowflake scheme due to its intuitive manner of representing the evolution of an object through time. We will use some examples where the characteristics of our approach will be applied to different situations. The aim is to introduce some extensions to add semantic information of the granularity and moreover the conversion functions to apply in order to achieve a coarser level of granularity. We propose to treat the spatial and temporal granularity like dimensions within the Snowflake scheme. We propose one notation based on multidimensional concepts as is shown in Figure 1.
c) Key attributes as primary key of each level

d) Secondary Attributes that complete information of each level

e) Name of the leaf level

f) Name of level

g) Fact table:
   g.1 Fact table name
   g.2 Measure, focus of analysis (represented in bold)
   g.3 Key from dimensions in leaf level, (primary key on fact table)

We propose to treat the changes of spatial granularity of the data in relation to the system of reference used, including a kind new of hierarchies. This hierarchy type is different from the ones used previously by the multidimensional schemes. Therefore, each spatial granularity will be treated like a level within this hierarchy

Our proposal distinguishes two classes of hierarchies within dimensions: Dynamic hierarchy, (figure 1.h), where the route (navigate) from one level to another implies changes in measures of the fact table. Static hierarchies, (figure 1.i), where the route (navigate) from one level to another does not imply changes in measures of the fact tables; nevertheless, static hierarchies semantically contribute to the model and provide clarity in the study of the facts for decision making processes. Each level, different from the level leaf, of a static hierarchy is graphically represented by a pentagon (figure 1.o). We define the granularity within hierarchies as it follows: a granularity $g_1$ is finer than another one $g_2$, if $g_1 \in N_1$ and $g_2 \in N_2$ where $N_1 \times N_2$ and $N_1, N_2 \in J_1$ and $J_1 \in D_k$ where $N_1$ and $N_2$ are levels of the hierarchy $J_1$ and $J_1$ is a hierarchy of the $D_k$ dimension and also $g_1 \subseteq g_2$. The leaf level being the one that marks the finest granularity of each dimension treated in the model. In order to sail between different levels of the hierarchies we use multidimensional operators, some of these are show in (Figure 2.b). For representing the geometry of spatial data, we use SQL3 and its extension to spatial data type according to OpenGis Specification and with the topological relationship among theirs, (Figura 2.a). A spatial data is represented like set of vertex interpreted through of a linear interpolation among them. We introduce a new label in the schema in order to represent the conversion function to apply when Roll-up in the hierarchy is produced (Figure 1.j) (Figure 1.k), because we believe that in schemata, the aggregation functions used when navigating through the different levels of hierarchies must be expressed. A classification of the functions is show in Table 3 and Table 4.

<table>
<thead>
<tr>
<th>Spatial Data Type</th>
<th>Topological Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Cross Surface and Line</td>
</tr>
<tr>
<td>Line</td>
<td>Cross Line and Line</td>
</tr>
<tr>
<td>Point</td>
<td>Cross Point and Line</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Navigating through the levels of hierarchy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll-up</td>
<td>Navigating from lower level to higher level</td>
</tr>
<tr>
<td>Drill-Dow</td>
<td>Navigating from higher level to lower level</td>
</tr>
<tr>
<td>Selecting elements</td>
<td></td>
</tr>
<tr>
<td>Slice, Dice</td>
<td>Selection and projection of elements</td>
</tr>
</tbody>
</table>

Figure 2 a. Some spatial data types and topological relationships, Figure 2 b. Multidimensional Operator
We distinguish between pre-established or foreseeable temporary and indefinite temporary:

- Usually in a DW the data are inserted periodically from different sources, and it can be considered as pre-established temporary. So the different temporal granularities desired are modeled with the different levels from the hierarchy of the time dimension.
- The points of indefinite time are produced by events. We considered the indefinite time marked by events in a DW like points of outstanding time for the application domain, which implies change in some of the dimensions or measurement that is desired to register.

In the multidimensional model, when the points of pre-established time are used, these marks the temporary granularity of all the dimensions i.e., all of them are updated simultaneously, also it is the granularity of row level. The points of the time dimension inserted by events, could be considered as simultaneously granular at row and column levels, i.e., a event can implies both changes, one in a dimension (column level) and other in fact table to insert new row (row level).

We distinguished between thematic dimensions which do not contain spatial data and spatial dimensions that contain spatial data.

| Table 3. Non Spatial data Functions | Distributive | Sum, Min, Max... | Reuse aggregates of a lower level of a hierarchy in order to calculate the aggregates for higher level |
| Table 4. Spatial data Functions | Distributive | Convex hull, geometric union, geometric intersection |
| Algebraic | Average, Variance, Standard deviation,... Need an additional treatment for reusing the values |
| Holistic | Median, most frequent, rank... Required new calculations using the data of the leaf level |
| User Defined | | |

We present our proposal with some examples. And we study the spatial data within fact table, according to if it is treated like a measurement or like a dimension:

There is only one spatial dimension present in the fact table, and must be related in some form to the rest of the thematic dimensions, this is studied in example 1, and is shown in Figure 3. There is more than one spatial dimension and in addition the spatial data acts like measures within fact table, these spatial elements must be related among them with some of the spatial topological relations (spatial join) described in Figure (2 a), this is studied in example 2, and it is shown in Figure 4.

<table>
<thead>
<tr>
<th>Table 2.1 Some conversion functions for multidimensional model</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI_contr, It contracts an open line, endpoints included, to a point</td>
</tr>
<tr>
<td>Mr_contr, It contracts a simple connect region and its bounding to a point</td>
</tr>
<tr>
<td>Mr_thinning, It reduces a region and its bounding lines to a line</td>
</tr>
<tr>
<td>Last, It chooses the last element within a rank</td>
</tr>
</tbody>
</table>

The spatial data is a measure within fact table and it is wanted to study its evolution in time; the fact table can have, or not, other related measures, we see this in the example 3, and it is shown in Figure 5. We used the following functions (Table 2.1) like an extension of the presented ones in Table 1 and Table 2 for model multidimensional. Although there are many more possibilities, the size of this paper prevents us to treat all, so we have chosen some of the outstanding ones.

6 \textbf{JUSTIFYING THE APPROACH THROUGH EXAMPLES}

Example 1. Different information must be managed regarding the recollected agricultural production of a set of plots through the time. We wished to store the production, as kilograms of product gathered in a plot. This production varies in the time and these annotations are made in the database per semester. The plots have certain geography, the area in meters and its changes for semester must be stored. Each parcel has assigned a unique owner identified by the SSN, also it is required to store information of owners by plot. In order to facilitate the understanding of the example it is considered that the production of each plot is of only one product that does not vary in time, though
the same product can be simultaneously cultivated in several plots.

We modeled this example with an extension of Snowflake scheme (Figure 3). We have three dimensions, Time Dimension, Owner Dimension and Plot Space Dimension and Production fact table. The Time dimension is established with three granularities (semester, year and decade), i.e. a hierarchy with three levels, one for each granularity. Here, the temporal dimension marks the times of changes of all the dimensions. In the Plot dimension three granularities are defined, i.e. three units have been chosen within Metric reference system, the m, the Hm and the Km. We have chosen two-dimension geometries for represented the spatial data, the smaller granularity, leaf level, represents the spatial data with a geometry of surface associated to the m; the second level of the hierarchy represents the spatial data by a lineal geometry associated to the Hm; and the third level this data is represented with a point associated to the Km. (Figure 2.a). The Owner dimension does not have spatial data and it does not have any hierarchy. The Production fact table have one measure, KProd, which gathers the sum of the production of each plot in each semester; besides contains the keys of the leaf levels of each one of the dimensions; the set of these keys form the key of this fact table. We observe that the key of the Plot dimension is composing by a spatial data, which contains a identity, a geometry of surface and the unit m. Also this key is completely propagated inside fact table. Since we want to represent the spatial data along with the measure Kprod

![Dynamic Hierarchy](image)

**Time Dimension**

Dynamic Hierarchy

- Decade
  - Sum (KPro)
- Year
  - Sum (KPro)
- Semester
  - Sem_x

**Owner Dimension**

- Owner
  - SSN
- Production
  - KProd
  - IDP
  - m
- Sem_x

**Plot Space Dimension**

Static Hierarchy

- Km
- Hm
- Mr_thinning (IDP)

![Plot Spatial Element](image)

Figure 3. Example with one spatial dimension present in the fact table

The hierarchy of the Temporal dimension is dynamic hierarchy because it implies changes in the measure of the fact table when navigating through its levels. The aggregation function which we needed to change the temporal granularity of the Kprod measure when doing Roll-up in the Time dimension, i.e. when we want a coarser granularity, is the function Sum, the same as for all levels. The hierarchy of the Plot spatial dimension is an example of static hierarchy, because the KProd measure not change when navigating through its levels, nevertheless changing spatial granularity of plot spatial element and the Mr_thinning and Ml_contr functions are used (Table 2.1), a different function one for each level of the hierarchy, which will be applied on the plot spatial element. Thus when making the Roll-up from the leaf level to the second level of this static hierarchy, is applied the Mr_thinning function on the plot spatial element, it is reduced from a region (m) to a line (Hm), and when making the Roll-up from the on the plot spatial element, it is reduced from a region (m) to a line (Hm), and when making the Roll-up from the second level to the level third, is applied Ml_contr
function on the plot spatial element, it is reduced a line (Hm) to a point (km). This model can gather the surface of the plot with maximum production in Hm units in the last five years. The time interval [2000, 2005] is fixed at the level, choosing the maximum of all the units of production in these years, The Mr_thinning function is applied to the plot to change its granularity. The solution is displayed like a linear geometry associated to the Hms. We also allow to compare the surface of the plot with maximum production with its current surface. In this query we found the application of our contribution; we can choose the desired unit within the given reference system, i.e. between different granularities, and therefore its associated geometric representation for the visualization of the contained spatial elements in the fact tables.

**Example 2.** We want to represent the evolution of the riverbeds and the plots through which they pass in a certain geographic zone over time. The updates are made each month and besides we want to study geographic zone from the perspective of city, state and country. We modeled this example using our proposal and scheme Snowflake (Figure 4). We have four dimensions, River Space Dimension, Plot Space Dimension, Location Dimension, Time Dimension, and a Cross fact table. In this shema it is applied the topology functions with two spatial data, gathering the intersection or cross of two different geometries, one for the rivers and another for the surfaces of the plots. We choose two-dimension geometry for both of them. The River Space Dimension have two granularities, the less granularity (leaf level) is represented with a lineal geometry associated to the meters, unit chosen within its reference system and the second level is represented for Hm units associated to a point geometric this dimension have. For the Plot Space Dimension, there are three granularities, the less granularity chosen is meter unit within the same reference system associated to a polynomial representation, the second level have Hm unit associated to a linear geometric and third level is represented with Km unit associated to a point geometric. The Location dimension has three levels City-State-Country.

![Diagram](image_url)

**Figure 4.** Example with more than one spatial dimension present in the fact tables

The Time dimension is modeled with two granularities Month-Year and has pre-established points of time in months, which implies that the changes in the DW are made every month, and that the variations experienced by the different elements present in the schema are only reflected at that time.

The Cross fact table has a measure that is the intersection or crossing of the two geometries, the river spatial data and plot spatial data, the key of this table is formed by the plot and river identities, and also with the keys of the leaf levels of the Location dimension and Time dimension.
We study next that it is happens when the Roll_up is made on the different hierarchies for our model. In the Location dimension when Roll-up is performed to reach a coarse granularity, the aggregation function applied for the "intersection (river, plot)" measure is the Union the same one for all levels.

When it is done Roll-up on the Time dimension, in order to reach the coarse granularity years, the $M_{last}$ function, (table 2,1) is applied on “intersection (river, plot)" measure, and this obtains among all the values of the spatial data of the granularity months, the last one of every year. When Roll-up on the static hierarchies of the two spatial dimensions are done, a change occurs in the spatial granularities and in its geometric associates; in this case, $Mr_{thinning}$ and $ML_{contr}$ functions are used, (table 2,1). In the River dimension for to reach a coarse granularity from the leaf level is applied the Roll-up and the $ML_{contr}$ function is used on the river spatial attribute, which reduces a line (m) to a point (H). In the Plot dimension, when making the Roll-up from the leaf level to the second level of this static hierarchy, is applied the $Mr_{thinning}$ function on the plot spatial attribute, which reduces a region (m) to a line (Hm), and when making the Roll-up from the second level of the static hierarchy to the level third of the same one, is applied $ML_{contr}$ function on the plot spatial attribute, which reduces a line (Hm) to a point (km).

Each spatial element can change its granularity independently to one of another one, and the intersection or crossing between river spatial measure and plot spatial measure can will be performed through polygons and lines, lines and points or across lines and lines, as is shown in Figure 4.

With this schema it is possible to answer queries such as visualizing the rivers that crossed the plots of a certain city, with an Hm granularity for both, in the year 2000. When changing the temporal granularity to a coarser one (for instance, year) the $M_{last}$ function is used which gathers the last value for year 2000, corresponding to December, visualizing the intersection or cross of the rivers and plots as points on lines. Notice the intuitiveness of the schema when using the labels between the levels of the hierarchies to express the functions required when changing the granularities.

**Example 3.** We want study the evolution of the plots whose variation is conditioned by the city to which it belongs and by its owner, through the time. We want to store the plots as a spatial data and beside its area as a numerical data. Also the timestamps included in the DW will be motivated by the changes in ownership and location of the plot, or in other words, by events.

---

**Figure 5.** Example with a spatial data like a measure in the fact table and one related measure
In this example, Figure 5, the spatial data is included in the fact tables as a measure. A two-dimensional geometry is used to represent the spatial data. Thus, we have the following dimensions: Location, Owner, Time and Plot, and one fact table Evolution.

The Location dimension and Owner dimensions are thematic dimensions and the Time dimension is a temporal dimension with indefinite temporary which is produced by events. Although we considered that it is not necessary to have a spatial dimension in order to a spatial measure exists in the fact table, we propose that it be included in the schema when it is desired to treat different granularities from a space object. Thus, we included the Plot dimension like a static hierarchy with three granularities where the smaller granularity, leaf level, means that the spatial data is represented with a polynomial geometry associated to the unit of reference within chosen reference system, in this case meter. The Hm and the Km are associated with linear geometric and point geometric respectively to represent the corresponding granularities. In the fact tables we have the measures focus of study; we took two measures, one that marks the evolution of the plot through time and another to gather the area of the plot in each evolution. Both of them are spatial data although the characteristics and the treatment of them differ; Plot measure (represented by an identifier, a geometry and a system of reference) and the measure Area expressed in numerical form. The Location dimension is represented with a dynamic hierarchy of three levels: city, state and country. The Owner dimension does not have spatial data and it does not have hierarchy.

In the dimension Time we considered that units of time in the leaf level of the temporal dimension are marked by events, understanding by events something that causes some change, which are considered outstanding in the Locality or Owner dimensions, and that directly influence the evolution of the plots, (changes in the measure). We can choose the temporal unit of representation with the desired granularity: days, months, etc. When Roll-up is done over the Location dimension, the aggregation function which we need applied to the measure Area is the function Sum, the same as for all levels; the aggregation function needed to apply in the measure Plot is Union.

In Area and Plot measures, browsing through the Plot static hierarchy, are changes its numerical or geometric representation respectively, but not its value. Thus when the Roll-up is made from the leaf level to the second level, \text{Mr.thinning} function is applied on Plot medidaure, which reduces a region (m) to a line (Hm). When making Roll-up from the second level to the third level is applied \text{ML_contr} function on Plot medidaure, which reduces a line (Hm) to a point (Km). The functions used to change the granularity of the measure Area with respect to the Plot spatial dimension is an arithmetical expression, to move from an area expressed in meters to an area expressed in hectometers or kilometers. We place the label on each level \text{Expref1(Area)} and \text{Expref2(Area)}, to see Figure 5. This schema could answer queries such as representation of all the changes produced in the plots of the city of Madrid during 2000 July and can compare them with the plots from the same city at the present time, and to verify how they have changed. Beside we would take all plots from all the cities, (union of plots) of a state determined, etc..

7 CONCLUSIONS

In this work we have described a novel approach to extend multidimensional logical model using an extension of the Snowflake scheme. We object is the treatment of spatio-temporal granularity in the multidimensional model. We study the behaviour of the spatial data when these are including in a dimension or they are including in fact tables. Moreover we represent, the changes of spatio-temporal granularity in the spatial data, within schema of a clear and intuitive way. The Temporal dimension is presented with point of time pre-established, also like time points produced by events. We treat the spatial and temporal granularity like hierarchies within the dimensions, giving each granularity a leve within them. A new class of hierarchies is proposed within the spatial dimensions to gather the different granularities in a spatial reference system chosen, whose treatment is different of the treatment of the hierarchies used until now by the traditional multidimensional models. The route through the different levels of this hierarchy does not imply changes in the measures of
the fact tables, nor in the spatial attributes inherited from a spatial dimension present in the key of the fact tables. But this does nonetheless imply changes in the spatial representation of spatial element that appears in this table, allowing its study since different perspectives.

We also propose to place a level between the consecutive levels of the hierarchies, with the name of the function and with the measure which uses the function when Roll-up is made on these hierarchies. This clarifies and increases the semantic representation of the schema.

We have seen how to handle spatial granularity in three different examples; in the first example, spatial data is part of a dimension and participates solely in the fact tables by its geometric representation: in the second example has two spatial data represented in two spatial dimensions. When both spatial dimensions propagate its keys within fact table, these are combined in a “spatial join” and is applied a topology relation among them. Beside the spatial multi-granularity is represented by static hierarchies for both, and several possibilities of crossing between the different granularities of the spatial data are seen. In the last example, is studied how to treat the spatial data when these are measures of fact table, distinguishing between spatial data with numerical representation and spatial data with geometric representation. Also we include a static hierarchy for to treat the changes of spatial granularity of these spatial data. Our future lines of work focus, on including spatial objects in the multidimensional model from a conceptual perspective. For take advantage of the expressiveness that this offers to derive a conceptual scheme independent from the platform. The study of spatial data in movement, the study of new static hierarchies searching for more applications.

8 REFERENCES


Camossi, E. Bertolotto, M. Bertino, E. Guerrini, G. A Multigranular Spatiotemporal Data Model, GIS ‘03.


Miquel, M. Brisebois, A. Bédard, Y. and Edwards, G., Implementation and evaluation of hypercube-based method for spatio-temporal exploration and analysis. SCG661 2004


Rives, S. Bédard, Y. and Marchand, P. Toward better support for spatial decision making: Defining the characteristics of spatial on-line analytical processing (SOLAP). Geomatica, 55 (4), 2001


Stefanovic, N. Han, J. and Koperski, K. Object-based selective materialization for efficient implementation of spatial data cubes. IEEE Trans.


OpenGis Specification [www.opengis.org](http://www.opengis.org)