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

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Abstract: Many efforts have been made to the treatment of spatial data in databases both in traditional database systems and decision of 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. We propose an extension of the Snowflake model to gather the spatial data and to show our proposal to represent the spatial evolution through time in a simple and intuitive way. We represent the temporal and spatial multi-granularity with different levels in the hierarchies of dimensions, and we present a typology of hierarchies to include more semantics in the Snowflake scheme.

1 INTRODUCTION

Many works have addressed the study of the treatment of spatial data and its management in Database to avoid inconsistencies caused by Geographic Information Systems (GISs), which make a heterogeneous treatment of data separating spatial data and storing them in file systems and non-spatial data, in general, stored in database systems. Nevertheless, these are still many questions unresolved 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 a given reference system. The temporal granularity is defined to represent the variations of an element, through time. The spatial-temporal multi-granularity represents the units of measurement chosen to store a geometric object in different moments of time. Many studies measure time in intervals, but in our proposal we will use points in time which, due to their simplicity, avoid the problem of coalescence. The main objective of this proposal is to enrich the Multidimensional models from a logical point of view to include semantics and information about spatio-temporal data. We propose an extension of the Snowflake scheme to gather both the spatial granularity and the temporal granularity. This paper is organized as follows: Section 2 contains references to works related to the treatment of the spatial and temporal data in databases. Section 3 contains logical multidimensional concepts. Section 4 is made a proposal for the multi-granular treatment using the Snowflake scheme. Section 5 presents several examples to clarify our proposal and some conclusions are given in section 6.

2 RELATED WORKS

There is a great amount of research about the special characteristics of the spatial data and its representation in Multidimensional schemes. (Sefanovic *et al*., 2000) distinguish between three types of spatial dimensions, according to whether the spatial elements are include in every hierarchy, in some hierarchy or in no hierarchy. Also they consider two types of measures, spatial and numerical. (Miquel *et al*.,2004) establish that if a spatial measure is required in the fact table, then the model must include a spatial dimension, as opposed

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to (Malinowski and Zimanyi , 2004) who propose the inclusion of the spatial data in the different levels of a hierarchy and also in measures. (Rives *et al*., 2001), study the spatial data in the dimensions and in the fact table. (Kouba *et al.* 2002) treat 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 that gather the concepts of OLAP and apply them to spatial data. The proposal of (Pourabbas *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. According to (Camossi, *et al*.,2003) the spatio-temporal multi-granularity concept is very important in representing the semantic of domain.

3 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 represented at a logical level by multidimensional models and these use Star, Snowflake or the Constellation scheme. 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, that reflect a characteristic whose evolution we wish obtain. In the previous example, the sales are measures and the stores, the city, and the days are dimensions. The Dimensions provide a view of the data from different perspectives and the hierarchies provide a more generalized view of them. The dimensions can form hierarchies like Day-Month-Year and moreover, they can contain attributes that complete information, such as holidays in a month. The Star scheme consists of dimensions, without hierarchies, and a fact table with measures. The Snowflake scheme permits that the attributes of dimensions are structured into different groups. These groups form levels and these levels form a hierarchy. The Constellation scheme can contain several fact tables in the scheme, each one with its corresponding measures and these fact tables can share it's hierarchies. Within a hierarchy, the lower level is called leaf level. The OLAP Systems allow dynamic manipulation of the DW for the process of decision making. The SDWs combine DW and Spatial System Databases and allow storage of huge volumes of spatial data, spatial statistical analysis and spatial data mining. We use an extension of the Snowflake scheme to include spatial data and make our proposal.

4 INCLUDING MULTI-GRANULARITY IN A SNOWFLAKE SCHEMA

We propose a extension of the Snowflake scheme due to its intuitive manner of representing the evolution of an object through time. The aim is to add semantic information to the scheme. We propose to treat the spatial and temporal granularity as dimensions in the Snowflake schema.

Table 1: Temporal conversion functions.

Proj (index)	It returns, for each granule in the coarser granularity, the value corresponding to the granule of position index at the finer granularity
First,, Last	First and last index in the Proj (index) function
Main	It returns, for each granule in the coarser granularity, the value which appears most frequently in the included granules at the finer granularity
All	It returns, for each granule in the coarser granularity, the value which always appears in the included granules at the finer granularity if this value exists, the null value otherwise

In order to operate and compare objects with different granularity, we must use conversion functions. Some conversion functions are shown in Table 1 and Table 2. The application of these functions guarantees the topology consistency (Camossi et al., 2003).

Table 2: Patial conversion functions.

Contract functions	
l_contr	It contracts an open line, endpoints included, to a point
r_contr	It contracts a simple connect region and its bounding to a point
r_thinning	It reduces a region and its bounding lines to a line
Merge functions	
l_merge	It merges two lines sharing an endpoint into to single line
r_merge	It merges two regions sharing a boundary line into a single region
Absorption operations	
P_abs	It eliminates (abstracts) an isolated point inside a region
l_abs	It eliminates a line inside a region

Table 2.1: Some conversion functions for multidimensional model.

Ml_contr	It contracts an open line, endpoints included, to a point
Mr_contr	It contracts a simple connect region and its bounding to a point
Mr_thinning	It reduces a region and its bounding lines to a line
M_Last	It chooses the last element within a rank

We propose a notation based on multidimensional concepts (see Figure1).

In order to represent the different spatial granularities, we propose to include a new type of hierarchy called Static hierarchy. This hierarchy type is different from the ones used previously by the multidimensional scheme. Each spatial granularity will be treated as a level within this hierarchy.

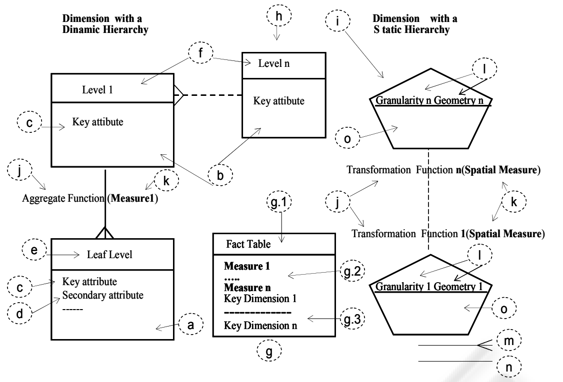
The Dynamic hierarchy, (figure 1,h), where the route (navigate) from one level to another implies changes in measures of the fact table. The Static hierarchy, (figure 1,i), where the route (navigate) from one level to another does not imply changes in measures of the fact tables. Nevertheless, Static hierarchies contribute semantically to the model and provide clarity in the study of facts in the decision making processes.

Each Static hierarchy level, different to leaf level, is graphically represented by a pentagon (figure 1,o*)*. We define the granularity within hierarchy as 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 $N_1 < N_2$ and $N_1, N_2 \in J_i$ and $J_i \in D_k$ where N_1 and N_2 are levels of the hierarchy J_i. Where J_i is a hierarchy of the D_k dimension and also $g1 \subseteq g2$.

Sapatial Data Type	Topological Relationshipa
Surface	Cross Surface and Line
Line	Cross Line and Line
Point	Cros Point and Line

Figure 2a: Some spatial data types and topological relationships.

The leaf level marks the finer granularity in each dimension. In order to navegate between different levels of hierarchies, we use multidimensional operators, some of these are shown in (Figure 2,b). To represent the geometry of the spatial data, we use SQL3 with its extension to spatial data type and the topological relationships among them, according to OpenGis Specification (Figura 2,a). In order to show the conversion function that we wished for when applying Roll-up in the hierarchy, we introduced a new label in the scheme. (Figure 1,j) (Figure 1,k*)*. We think that it is important to express the aggregation functions used when we navigate through different levels of hierarchies. Some funtions are shown in Table3 and Table4.



a) Dimension table of leaf level
b) Dimension table of a dynamic hierarchy
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, g.3 Key from dimensions.
h) Dynamic Hierarchy
i) Static Hierarchy
j) Label expressing the associate function from each measure in roll-up of dimensions
k) Measure in which function is applied
l) Representation of geometry and units expressed in a spatial reference
m) The cardinality 1:N, between levels
n) The cardinality 1:1, between levels
o) Represents a level in a static hierarchy

Figure 1: Notation for a Logical Model.

Navigating through the levels of hierarchy	
Roll-up	Navigating from lower level to higher level
Drill-Dow	Navigating from higher level to lower level
Selecting elements	
Slice, Dice	Selection and projection of elements

Figure 2b: Multidimensional Operators.

We distinguish between *thematic dimension* which do not contain spatial data and *spatial dimension* 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
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 studing the spatial data within the fact table according to if it is treated as a measure or as a dimension with some examples: In the example 1, we study when spatial data is only one spatial dimension present in the fact table, (Figure 3).

In the example 2 we study when there is more than one spatial dimension and in addition, spatial data acts as measures within the fact table, these spatial elements must be related among them to some of spatial topological relations *(spatial join)* described in Figure (2 a), (Figure 4).

Table 4: Spatial data Functions.

Distributive	Convex hull, geometric union, geometric intersection
Algebraic	Center of n geometric points, center of gravity
Holistic	Equi-partition, nearest-neighbor index
User Defined	

In the example 3, the spatial data is a measure within the fact table and we want to study its evolution in time from different granulaties, (Figure5).

We used the functions in (Table 2,1) as an extension of Table 1 and Table 2. For the example, we define a spatial object as a data type abstract with an identity, a granularity, a geometry of representation and a temporal granularity. The granularity or unit of measure is associated to a reference system. The geometry of representation is associated to a dimension. We will utilize geometries of two dimensions and the metric system as reference. Although there are many more cases, the size of this study prevents us from locking at all of them.

5 JUSTIFYNG WE APPROACH

Example 1. *We want to manage the collected agricultural production of a set of plots through the time. We wish to store the production as kilograms of product gathered per semester in each plot. The Plots have certain geography and we want to store its area in meters and its changes for semester, as well as the plot owner identified by the SSN. We consider that the production of each plot is only one product that does not vary in time, though the same product can be simultaneously cultivated in several plots.*

We model this example with the extension of the Snowflake scheme proposal (Figure 3). We have three dimensions: Time Dimension, Owner Dimension, and Plot Space Dimension; and a Production fact table. The Time dimension is established with three granularities: semester, year and decade, and are represented in a hierarchy with three levels, one for each granularity. Here, the temporal dimension marks the time of changes of all the dimensions. In the Plot dimension three granularities are defined, Meter, Hectometer, and Kilometer with three levels. The smaller granularity, leaf level, represents spatial data with a geometry of surface measured in meters; the second level represents the spatial data with a lineal geometry measured in hectometers; and the third level, the data is represented with a point measured in kilometers (Figure 2,a). The Owner dimension does not have spatial data and it does not have any hierarchy. The Production fact table has one measure, *KProd*, which gathers the production of each plot every semester; it also contains the keys of leaf level of each dimension; the set of these keys form the key of this fact table.

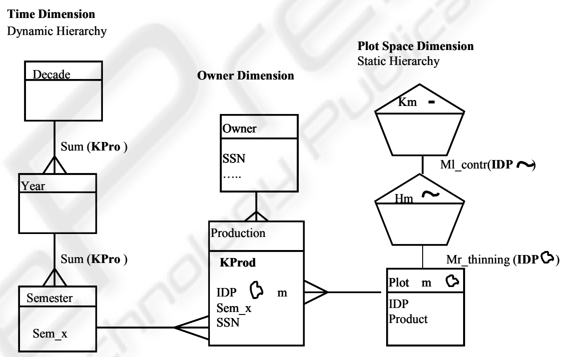


Figure 3: Example with one spatial dimension present in the fact table.

We can see that the key of the Plot dimension is spatial data, which contains an identity and a geometry of surface associated with the unit metre. Also, this key is propagated inside the fact table. As we want to represent spatial data along with the measure *KProd*.

The hierarchy of the Temporal dimension is a dynamic hierarchy because it implies changes in the measure of the fact table when navigating through its levels. When doing Roll-up in the Time dimension, i.e. we change the temporal granularity from a smaller granularity to another more coarser granularity, the aggregation function which we need apply to *Kprod* measure the function Sum, the same as for all levels. The hierarchy of the Plot spatial dimension is an example of static hierarchy, because *KProd* measure does not change when navigating through its levels, however the spatial granularity of plot spatial element changes. Thus, when making the Roll-up from the leaf level to the second level of this static hierarchy, the Mr_thinning function is applied

(Table 2,1) 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 third level, Ml_contr function is applied on the plot spatial element, it is reduced from a line (Hm) to a point (km).

Example 2. *We want to represent the evolution of the riverbeds and of the plots that cross a certain geographic zone, through time. The updates are made each month and we also want to study geographic zones from the perspective of city, state and country.*

We show this example as Figure 4. We have four dimensions: River Space, Plot Space, Location and Time; and a fact table: Cross. In this scheme, the topology functions are applied with two spatial data, gathering the intersection or cross of two different geometries, one for rivers and another for surfaces of plots. The River Space Dimension has two granularities, the less granularity *(leaf level)* is represented with a lineal geometry show in metre and the greatest granularity *(second level)* is show in Hm unit associated to a point geometric. Plot Space Dimension has three granularities, the less granularity chosen is metre associated to a polynomial representation, the second level has hectometre unit associated to a geometric linear and third level is represented as kilometre unit associated to a geometric point. The Location dimension has three levels: City, State and Country. The Time dimension show by two granularities, month and year, and has pre-established points in time. The changes in the DW are made every month, and the variations experienced by the different elements present in the scheme, are only reflected at that time. The Cross fact table has a measure that is the intersection or crossing of the two spatial data, 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.

In the Location dimension when Roll-up is performed to reach a coarser granularity, the aggregation function applied to the "intersection (river, plot)" measure is the Union the same for all levels. When Roll-up is done on the Time dimension, in order to reach the coarser granularity *year*, the *M_last* function, (Table 2,1) is applied to “intersection (river, plot)” measure, and among all the values of the spatial data of the granularity months, we obtain at the end of every year. In the River dimension to reach a coarse granularity from the leaf level the Roll-up is applied and the *Ml_contr* function is used on the river spatial attribute, which reduces a line (m) to a point (Hm). In the Plot dimension, the Roll-up applies the *Mr_thinning* or *Ml_contr* function to the plot spatial attribute, which reduces a region (m) to a line (Hm) or reduces a line (Hm) to a point (km), respectively.

Each spatial element can change its granularity independently of one another, and the intersection or crossing between river spatial measure and plot spatial measure can be performed through polygons and lines, lines and points or across lines and lines, (see Figure 4).

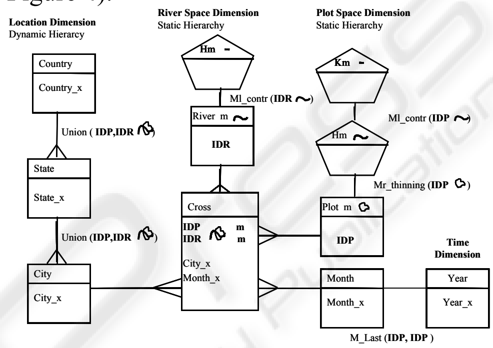


Figure 4: Example with more than one spatial dimension present in the fact tables.

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 time. We want to store the plots as spatial data and its area as 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.*

This example is modelled in Figure 5. In the fact table we have two spatial measure focuses of study. The Plot measure that gathers the evolution of the plot through time and another Area measure, that gathers the area of the plot in each evolution. Although both of them are spatial data, the characteristics and the treatment of them are differ; Plot measure (represented by an identifier, a geometry and a system of reference) and the Area measure expressed in numerical form.

We believe that it is not necessary to have a spatial dimension in order for a spatial measure to exist in the fact table, nevertheless we propose that it be included in the schema, when it is needed to treat different granularities from a space object. Thus, we introduce the Plot Space dimension associated to Plot measure. Notice the intuitiveness of schema when using the labels between the levels of hierarchies to express the functions, applied to the measures, when changing the granularities, i.e. when the Roll-up is made, (Figure 5).

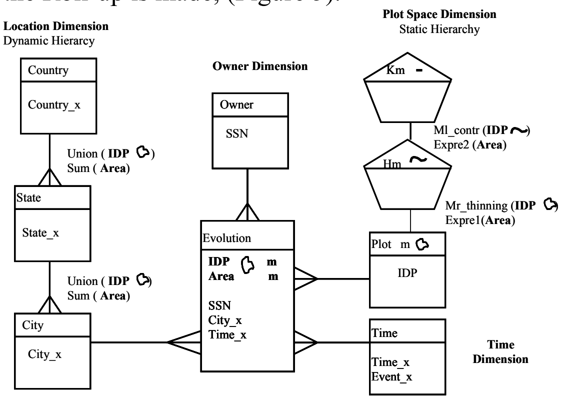


Figure 5: Example with a spatial data like a measure in the fact table and one related measure.

6 CONCLUSIONS

In this paper we have described a novel approach to extend multidimensional logical model using an extension of the Snowflake scheme. Our objective is the treatment of spatio-temporal granularity in the multidimensional model. We have studied the behaviour of spatial data when is included in a dimension or in fact tables. Moreover, we have shown the changes of spatio-temporal granularity in spatial data, within a scheme which is clear and intuitive. The Temporal dimension is presented with a point of time pre-established and like time points produced by events. We propose a new class of hierarchy, called Static hierarchy, within the spatial dimensions to gather the different granularities in a chosen spatial reference system. The treatment of the Static hierarchy is different from the treatment of the hierarchies used until now by traditional multidimensional models. The navigation through the different levels of this Static 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 table. Nonetheless the navigation through Static hierarchy implies changes in the spatial representation of spatial element that appear in the fact table, allowing its study from different persperctives. We also propose to place a label between the consecutive levels of the hierarchies, with information of name of function and with the measure which uses the function when Roll-up is made on the hierarchies. This clarifies and increases the semantic representation of the scheme. Our future work focus on including spatial objects in the multidimensional model from a conceptual perspective, taking advantage of the expressiveness that this offers to derive a conceptual sheme independent from the platform, the study of spatial data in movement and the study of new static hierarchies searching for more applications.

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