A STUDY OF THE SPATIAL REPRESENTATION IN MULTIDIMENSIONAL MODELS

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Abstract: In this work, we do an analysis on the different models proposed to model Multidimensional Databases *MDB*, and Spatial Databases SD. We analyze the basic and advanced rules that the conceptual multidimensional models should to support, according sort criterion exposed for some authors. As result of this study, we propose to add new rules to gather the spatial and temporal semantics. Are analyzed some of models more relevant, and a comparative table is presented, where the advantages of the model called FactEntity *FE*, with respect to the other examined modes, to collect multidimensional and spatial semantics, is obvious. We emphasizing on the novel contributions of *FE* model and shortcomings of the rest of seen models. We besides show a formalization of the *FE* model with a metamodel made up with the extended ER model, where the semantics of FE model is representing. Finally, an example of application clarifies our exposure.

1 INTRODUCTION

The Decision Support Systems and the Geographic Information Systems GIS, use the Data Warehouses or Multidimensional Databases *MDB*. The GIS locates spatial data on the Earth's surface and studies its evolution through time. The Multidimensional databases MDB, allow the storing of data in a special way to study these from different perspectives or dimensions and with different detail levels or granularities. The most proposals to model MDB reuse the models of operational databases *DB*, as the Entity Relation *ER*, or the Unified Modelling Language *UML*, although they are not appropriating to model these databases, since, they were conceived for other purposes. We believe as the authors in (Golfarelli, 1998), (Torlone, 2003), (Kimball, 1996) , that traditional conceptual models are not able to express all the semantics of the MDB, and we too are in agreement with (Piattini, 2006), which speak on the immaturity of multidimensional technologies.

In addition, the GIS, require models that support the process of reasoning about space, and that allow us to gather spatial data in different scales connected, as is commented in (William, 2006). For all above, we believe that specific models, that can to collect the multidimensional semantics and spatial semantics, are needs.

In this work, we are going to study on the one hand, the proposals that are to model MDB; and on the other hand, the proposals that are to include the space in the DB in general. In addition, we do a comparative study on several of more relevant models, to analyze how they to deal the spatio-temporal multigranularities. We stress the proposal in (Gascueña, 08), where the model called FactEntity *FE*, is presented, which permit us to collect multidimensional and spatial semantics. The *FE* model allows treating the different types of spatial granularity, *Semantic* and *Geometric*, which in the study of (Gascueña, 08), are distinguished. This model supports related spatial, temporal and thematic granularities interacting between them. None of the models studied collect previous characteristics.

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This paper is structuring, as follows: Section 2 includes a extend study on related works in multidimensional and spatial semantics and in addition, the rules provided by some authors, as necessary to the conceptual multidimensional *MD*, models, along other new rules, are exposed. Besides, a comparative table, between some more relevant model and the *FE* model, is showing. In Section 3, we present briefly the *FE* model, which include graphical representation and a Metamodel. The Section 4 includes an illustrative example. In section 5, some conclusions and future work are given.

2 RELATED WORK

Most of the models proposed to design MDB from a conceptual approach, are basing on concepts modelled from traditional DB and present extensions to the ER model such as in (Sapia, 1999). Other models, (Malinowski, 2004a) and (Golfarelli, 1998), adopt the starting point of an ER model providing guidelines for its transformation into a multidimensional MD model. In the StarER model (Tryfona, 1999) , there is a proposal to use the Star multidimensional model together with an extension of the ER model. Other authors such as (Lujan-Mora, 2006) and (Abello, 2006) present extensions to the UML model. Although researchers such as (Torlone, 2003) and (Kimball, 1996) consider, as we do, that the traditional data models are not adapted to represent the special semantics of MDB. Some classifications of the most important characteristics that must be gathered in a conceptual MD model, are shown in (Torlone, 2003), (Abello, 2000), (Malinowski, 2004a), and (Lujan-Mora, 2006). The authors in (Abello, 2000), propose to design the conceptual phase in three levels of detail increasing in complexity; with this design approach, a model called YAM2 presenting in (Abello, 2002), and (Abello, 2006), which uses an extension of UML model. The model in (Torlone, 2003) is presenting from a conceptual point of view and it specifies the basic and advanced characteristics that an ideal conceptual MD model would have. In (Lujan-Mora, 2006) the cardinalities in the hierarchies are considering and classified with concepts such as strictness and completeness; in addition, the additive of measures and the representation of some aggregation operators are exposed; they use the language Object Constraint Language (OCL) to specify constraints. A classification of the different hierarchies (*with regard to the cardinality between the different hierarchical levels*) that must support a model is presenting in (Malinowski, 2004a). This work is completing in (Malinowski, 2005), where it is defining as transforming these hierarchies into the logical model under the relational paradigm.

2.1 Space and Time in MDMs

Three types of space dimensions (depending on whether the space elements are included in all, some or none of the levels of the dimensional hierarchies) and two types of measures (space or numerical measures) are distinguishing in (Stefanovic, 2000). In (Malinowski, 2004a) the inclusion of the spatial data at a level of a hierarchy or as measures is proposing, though they do not include the spatial granularity. In (Malinowski, 2005), the same authors present a classification of the space hierarchies following the criteria set in (Malinowski, 2004a), (with regard to the cardinality). A study is presenting on the temporality of the data at column and row level in (Malinowski, 2006). None of the previous works contemplates spatio-temporal multigranularity. In (Gascueña, 2006) is studied the multigranularity of the spatial data from a logical approach. In (Gascueña, 2005) is detailed a comparative view of how to deal the spatio-temporal multigranularity with two different logical models: Object Oriented (OO) and Multidimensional. In (Gascueña, 2008) is presented the specific FactEntity multidimensional model, from a conceptual approach, which gather the spatio-temporal multigranularities. In addition, these authors make up a study on how to represent the spatial granularity in a MDB, and distinguish between *Semantic* and *Geometric* granularities.

2.2 Space and Time in OO Models

The treatment of the multigranularity in OO models exists, as in the work of (Camossi, 2003) that extends Object Data Management Group (ODMG), for the inclusion of this concept in its model called Spatio Temporal ODMG (T_ODMG). The ST_ODMG model supports the handling of entities with a spatial extension that changes their position on temporary maps. It provides a frame for mapping the movement of a moving spatial entity through a geographic area, where the spatial objects can be expressing at different levels of detail. In (Khatri, 2006) a study on the spatio-temporal granularities by means of ontology is carrying out. They propose to model it in two phases: first, by using a conventional conceptual ER model, without considering spatial or temporal aspects, it would model "what". In the second phase, it completes with notations or labels that gather the associated semantics of time and space, “when and where”, as well as the movement of the spatial objects, although they only handle one granularity for each spatial data. In (Parent, 1999) it shows the MADS model as an extension of the ER model, although it uses elements OO and some authors present it as a hybrid between OO and ER. It uses complex structures and abstract types of data to support the definition of domains associated with space and time over object and relations. But none of the proposed models above distinguish, between *Semantic* and *Geometric spatial granularities*, as we do.

2.3 Multi-representation

In reference (Parent, 2006) an extension to the MAD model is added to handle multiple resolutions in the geographic databases. It presents four orthogonal dimensions in order to model: data structures, space, time and representation. It distinguishes two approaches to support multiple spatial resolutions. The *multi-resolution* approach only stores the data of the upper level of resolution, delegating the simplification and space generalization to the databases system. The *multi-representational* approach stores the data at different levels of resolution and allows the objects to have multiple geometries. In (Bedard, 1999) and (Borges, 2001) objects with different interpretations and scales are defined. In (Timpf, 1999) series of maps, are used and handle with hierarchies. In (Jones, 1996) objects with different representations (multi-scale) are associated. In (Sell, 1998) the objects at different levels of detail are organized, such as stratified maps. In (Bedard, 2002) the concept of “VUEL” (View Element) and new definitions of multi-representation are introduced with four dimensions: semantics, graphic, geometry and associated scale. It proposes to model the space using the expressivity of the MD models, where the spatial data is dealt with in the *table of facts* and the dimensions are marking the different semantics of multi-representation, although it is not a MD multidimensional. The Geo_Frame-T model (Vargas, 2001) uses the OO paradigm and an extension of UML model, and introduces a set of temporal and space stereotypes to describe the elements and the class diagram. The Temporal Spatial ER *STER*, model is presented in (Tryfona, 2003) as an extension of the ER model maintaining the concepts used in ER and including sets of spatial entities. In (Le, 2005) space and temporal data models for Temporal GIS is proposed. The integration of multiple representations is basing on common spatial and temporal reference systems. It uses layers to keep the spatial data, one layer for each space representation in a determined time. For the evolution through time, it uses a layer for each spatial element and every moment of time. It distinguishes between temporal representations based on characteristics and data models based on layers. It uses the map itself with different thematic data in the time interval itself.

None of these models support multidimensional concepts, for this reason they are not adapted to model the multidimensional semantic; in addition neither do they distinguish between *Semantic* and *Geometric* spatial granularities. The study done in (Gascueña, 2008) separate the way of divide a space of interest for semantic qualities; and the way to store this space by geometries in a DB; and in addition, the way of represent this space in a computer, when it is recovered from a DB.

This section has carried out the study of data models from the focus of MDB and from the focus of DB in general. It has verified that a great effort have been made, to gather the space and temporal characteristics of the data in traditional models. But, there are not specific approaches for the MD models that gather the spatio-temporal multigranularities considered in (Gascueña, 2008), only the *FE* model define their own constructors to gather the specific multidimensional and spatio-temporal semantics, which justifies our proposal to use the *FE* model.

2.4 Rules to the MD models

The authors in (Blaschaka, 98), (Pedersen, 00), (Torlone, 01), (Abello, 00), (Abello, 02), (Malinowski, 04a), propose the basic and advanced rules that the conceptual MD models must comply. We look these in Tables 1, 2, 3 and 4.

Table 1: Basic rules according to (Pedersen, 2000), (Blaschaka, 1998), (Torlone, 2001).

Explicit separation of structure and content
Explicit notions of dimension and data cube
Explicit hierarchies in dimensions
Multiple hierarchies in each dimension
Level attributes
Measures sets
Symmetric treatment of dimensions and measures

Table 2: Advanced characteristics proposal for (Torlone, 2001).

Support for semantic aggregations	The *FE* model include explicit specification over as to make up the aggregation
Support for non standard aggregations of facts	
Non-strict hierarchies	Relationship (N:M) between parent/child levels of dimensions
Non-onto hierarchies	Parent level without representation in child level. We control this whit the cardinalities (1,1)→ (0,n)
Non covering hierarchies	Child level without representation in inmediate superior parent level. We control this whit the cardinalities (0,1)→ (1,n)
Many relationships between facts and dimensions	We think that it is not semantically correct, though our model allows its representation
Handling change and time	The *FE* model incorporates: *Temporal factEntity, Temporal level and Temporal attribute*
Handling vagueness	The *FE* model allow us to include all the semantic necessary for what this problem to be known and controlled.

Table 3: Characteristics proposed for (Abello, 2000), (Abello, 2002).

It allows us to see several fact in a scheme
Identification of facts
Mathematical constructs used for operations
Elements over which operations are defined
User defined aggregation functions

Table 4: Characteristics proposed for (Malinowski, 2004b).

Symmetrical hierarchy	For each member *m* of a level there at least a member *m'* of the inferior level and for each member *m'* of a level there only a member *m* of the superior level. Cardinality (1,1) → (1,n) parent/child
Multiple alternative hierarchies	Several non-exclusive simple hierarchies sharing some levels but with the same analysis criterion.
Parallel hierarchies: A dimension has several hierarchies but with different analysis criterion	
Dependent	Different hierarchies sharing some levels
Independent	Different hierarchies do not sharing levels.

We also added the following rules, to gather the spatial component:

Spatial Multigranularity (it is support for the multi-representation): *Semantic* and *Geometric* granularities.

Temporal Multigranularity into different structures: *factEntity*, *hierarchical level*, *attribute*.

Spatio-Temporal Multigranularity is the possibility to represent on the scheme different granularities related and interacting. The *FE* model in (Gascuenña, 2008) supports all the previous characteristic.

2.5 A View Comparative between some Models

Table 5 shows a comparison between some of the most outstanding models. We observe that in (Trifona, 2003), (Golfarelli, 1998), (Sapia, 1999), (Abello, 2006), and (Torlone, 2001), they do not support all the multidimensional hierarchies proposed in for (Ma&Zi, 2004b), this work does the classification of hierarchies with regard to the cardinalities. Only the *FE* model in (Gascueña, 2008) supports the temporal multigranularities in all the structures as *factEntity*, *hierarchical level*, and *attribute*.

The *Semantic* and *Geometric* spatial granularities are not defined and therefore do not supports, for any models excepting the *FE* model, although some authors as (Parent, 2005), (Khatri, 2006), (Trifona, 2003), (Malinowski, 2004a) consider the spatial granularity of different way as we do. The models (Trifona, 1999a), (Sapia, 1999a), (Torlone, 2001) not representing multiple facts in the scheme. The explicit aggregation of measures, that is, the explicit representation of the functions that are applied to each *measure fact*, when the granularities change, is partially gathered in (Tryfona, 2003), (Lujan-Mora, 2006), (Golfarelli, 1998), (Sapia, 1999a), (Abello, 2006), and is not gathered in (Torlone, 2001), and (Malinowski, 2004a), the *FE* model in (Gascueña, 2008) gathers totally this characteristic. In addition, any of the models studied, except (Gascueña, 2008), represent the spatial conversion functions that are to apply when a spatial element changes to a coarser granularity. In conclusion, only the FE model supports completely all the characteristics shown in Table 5, from a conceptual multidimensional approach.

3 FACTENTITY MODEL

A multidimensional model allows us to study certain *facts* under the perspective of certain dimensions and with different levels of detail or granularities. We show briefly The *FE* model, for more details see (Gascueña, 2008).

3.1 Spatial Characteristics

We define a *Spatial data* type as an abstract data type that contains an identifier, a unit of measurement within a given reference system, a geometry of representation associated with this unit, and a dimension associated with this geometry. Points associated to kilometers are examples of geometrics associated to units in a reference system. See table 6.

Table 5: Comparing models.

	Enfoque	Extension	Paradigm	Multidimensional	Hierarchies *(cardinality)*	Temporal Multigranularity	Spatial Multigranularity: Geometric/Seman.	Multi Facts	Explicity Agregation of Measures	Function to change the Granularity
[Parent,05] *MADS*	C	E/R&UML	OO	N	-	NT	NT	-	-	-
[Khatri,06] *DISTILL*	C	E/R	R	N	-	NT	NT	-	-	-
[Tryfona,03] *STER*	C	E/R	R	N	-	NT	NT	-	-	-
[Tryfona,99] *StarER*	C	E/R	R	Y	NT	NT	N	N	NT	N
[Luján-Mora,06] *MDLujan-Mora*	C	UML	OO	Y	Y	NT	N	Y	NT	N
[Golfarelli,98b] *DF*	C	E/R	R	Y	NT	NT	N	Y	NT	N
[Sapia,99a] *M/ER*	C	E/R	R	Y	NT	NT	N	N	NT	N
[Abelló,06] *YAM2*	C	UML	OO	Y	NT	NT	N	Y	NT	N
[Torlone,01] *MDTorlone*	C	-	R	Y	NT	NT	N	N	N	N
[Malinowski,04a] *SpatialMultiDiER*	C	E/R	R	Y	Y	NT	N	Y	N	N
[Gascueña, 08] FactEntity	**C**	**--**	**R/& OR**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

Y = yes	NT = no otallly	N = no	L = logical	C = conceptual	OO = object oriented	R = relational
- = the script means that the model does not contemplate that characteristic						

Table 6: Spatial data and topological relations.

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

Spatial granularity is the chosen detail level to analyse the spatial data. We distinguish two types *Semantic* and *Geometric* granularities. The *Semantic spatial granularity* considers space divided by means of a semantic characteristic; for example political limits countries, etc. In Table 7, we can see some spatial functions used when the *Semantic granularity* changes. A set of *Semantic*

granularities enables us to consider the space divided as bigger or smaller units that are "*part-of*" a total, where, each part is considered a unique spatial element.

Table 7: Spatial 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	

A *Geometric spatial granularity* is defining as the unit of measurement, in a space reference system, associated with geometry of representation. A set of *Geometric spatial granularities* allow representing the same spatial data in different forms and size in a moment of time. In table 8, we can see some functions used when the *Geometric spatial* granularity changes the other greater one.

Table 8: Spatial conversion functions (Berloto, 1998).

Contract functions	
l_contr	It contracts an open line, endpoints included, to a point
r_contr	It contracts a simple connect region and its boundary to a point
r_thinning	It reduces a region and its boundary lines to a line
Merge, functions …….	
Absorption operations ….	

3.2 Temporal Characteristics

The *FE* model, allows representing temporal characteristics on different structures as *factEntity*, *hierarchical level*, and *attribute*; which we called *Temporal FactEntity; Temporal Level* and *Temporal Attribute* respectively. We consider the temporal characteristics called: *Type of Time, Evolution* and *Granularity*. The *Type of time*: (*TT*) represents the Transaction Time, (*VT*) represents the Valid Time and (*TVT*) represents the combination of both. The *Evolution* considers *Specific evolution and Historical evolution,* the former only gathers the new values*,* and the moment in which a change has happened; the latter keeps all the values and moments in which the changes have happened. *A*

Granularity is one partition of a time domain chosen to represent an event, and is the maximum update frequency of an object or element.

3.3 Multigranularity Characteristics

We define the *spatial multi-granularity* as a spatial characteristic that allows us to represent a space of interest with different *Semantic granularities*, where each *Semantic granularity* can have one or several *Geometric granularities* different. The *temporal multi-granularity* is a characteristic that allows us to represent the changes of an element or group in different temporal granularities. The *spatio-temporal multi-granularity* allows us to represent a spatial data with both: *spatial multi-granularity* and *temporal multi-granularity*.

3.4 Elements

The *FE* model has two main concepts: *dimension* and *factEntities.*

A *factEntity* contains only a *fact, which* is the object of study and focus of analysis. A *fact* makes up one or various *measures*. The *dimensions* are the different perspectives under which we wish to observe this *fact*. The *FE* model, allows an explicit representation on the schema, of the functions that are apply on *hierarchical levels* and *measures* when is executed the *Rollup*, i.e, (the granularities change). We see the graphical representation in Figure1.

The *FE* model introduces the concept of *factEntity.* A *factEntity* allows representing a *fact (*by means of its measures) and its *dimensions* associated. We distinguish two types of factEntities: B*asic* and V*irtual.*

A B*asic factEntity*, is made up of *basic data* (the identifiers of each *leaf level* of all dimensions and *basic* measures); The *Virtual factEntities* are made up of the "evolution" of *basic data*, when is done the Rollup on one or various dimensions. Thus, a V*irtual factEntity* contains the unfolded data of some dimensions and *derived measures*. The *derived measures* are the result of applying aggregation functions on the measures of the *basic factEntity*. See, Table 7 and Table 9.

Table 9: Spatial 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	

The spatial data are relevant to this work when they are included in a *factEntity* and they are representative of dimensions or measures. The *FE* model considers three types of *hierarchies*, according to the implication that has the "navigation" between its levels, on the *basic measures*; these are *Dynamic, Static* and *Hybrid.* In *Dynamic hierarchy,* the navigation between its different levels implies changes in *basic measures*, are suitable to represent the granularities of the *thematic dimensions*, and the *semantic granularities* of spatial data. In *Static hierarchy,* the navigation between its different levels does not imply changes in *basic measures*, and are appropriate to represent the different *geometric* granularities of spatial data. The *Hybrid hierarchy* is composed of a mixture of the two previous types and allows us to represent a spatial data with different and interrelated *Semantic* and *Geometric spatial granularities*.

3.5 Graphical Presentation

The *FE model* proposes constructors to gather the semantics of the multidimensional data models and the spatio-temporal multigranularity. See Table 10, and Figure 1.

Table 10: Explanations of *FE* mode*l* constructors.

a) Dimension name	b) Hierarchy name	c) Leaf level
d) Level of Dynamic Hierarchy	e.1) Level of Static Hierarchy different from leaf level	e.2) Geometric spatial granularity
f) Parent-child relation	g) Primary attribute	h) Secondary attribute
i) Temporal attribute	j) Attribute with historical evolution	k) Basic FactEntity
l.1) Basic Measures	l.2) Primary attribute	m) Cardinalities: minimum and maximum number of members related between two consecutive levels
n) Exclusivity	o) Functions applied on the measures when Rollup is done	p) Functions to reach a coarser granularity between levels

3.6 A Metamodel of *FE* Model

We present the formalization of FE model with a Metamodel made up with the extended ER model, which represent the semantic of constructor of *FE* model. See Figure 2.

4 EXAMPLE OF APPLICATION

We want to study "*the evolution of riverbeds and plots within a geographic area and in addition the percentage of pollution that have these zones. These data are analyzing each year. The rivers each five years and the plot each two years, are checked. Besides we desire have a history on the number of inhabitants for Village, these data are gathering once month*. See Figure 3.

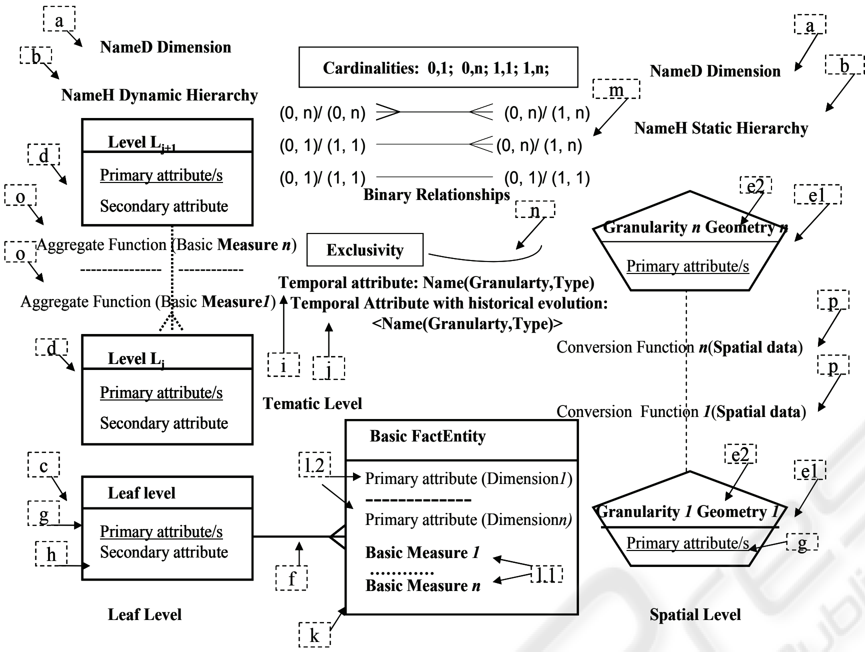

Figure 1: Notations to *FE* Conceptual Multidimensional Model.

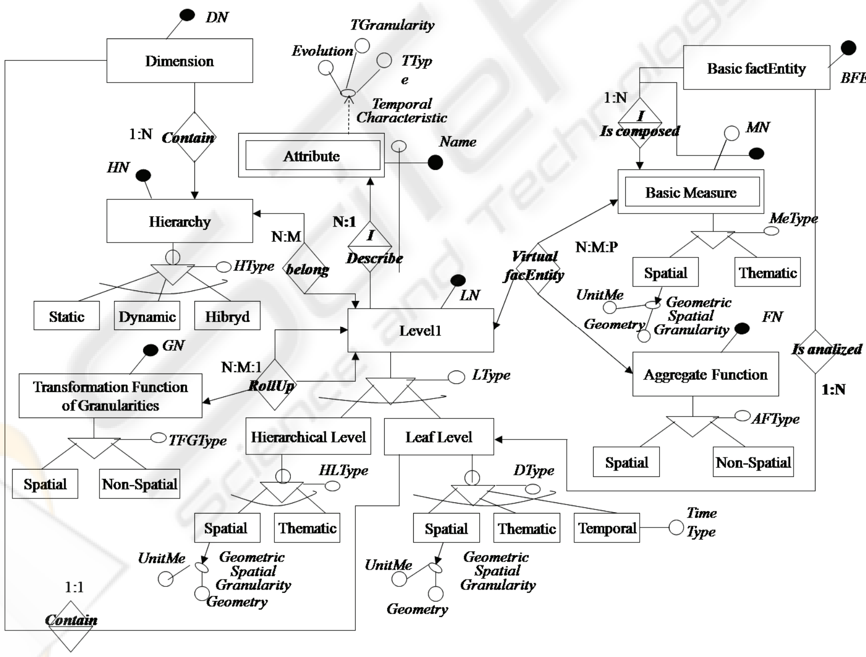

Figure 2: Metamodel of FE model, made up with the ER model.

This is an example with temporal characteristic in *factEntity*, *hierarchical level*, and *attribute* and multiple spatial and temporal granularities interacting.

5 CONCLUSIONS

This work has presented a study on the one of some models proposed to model multidimensional databases, and on the other one, of models that includes spatial data. We have also seen that most

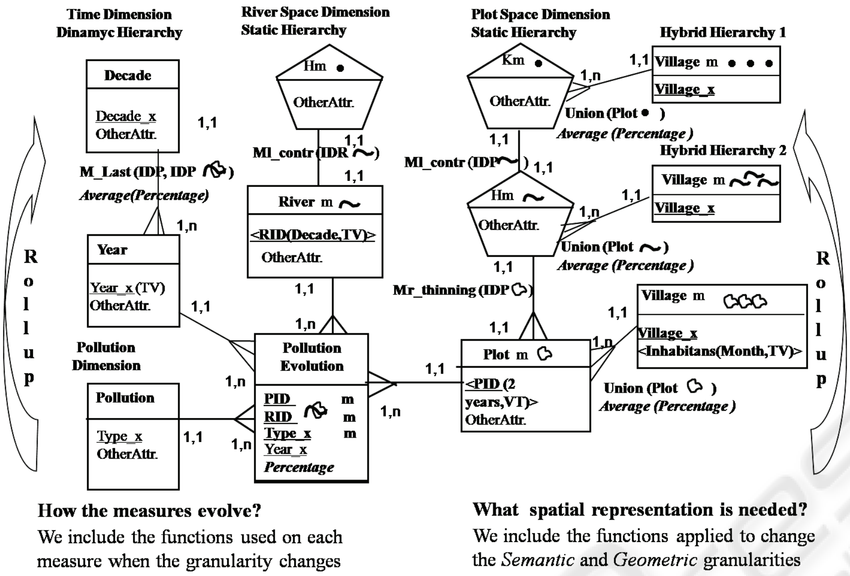

Figure 3: Example with different and related Spatial and Temporal granularities.

models reuse the conventional models of database design, to deal these two semantics. However, we have shown that they are fully adequate to pick up spatial and multidimensional semantics. In addition, we have proved that the analyzed models not reflect these two semantics together. We have made up a comparison between some more relevant models and the *FE* model proposed in our previous works, and we are shown that the models studied are not gather the multidimensional and spatial characteristics as the *FE* model does, highlighting the *Semantic* and *Geometric* spatial granularities, these, are not distinguished by neither of analyzed models. We emphasize on the novel contributions of our *FE* model to handle the spatial component and shortcomings of the rest of model compared. We have propose to add into the characteristics that a conceptual multidimensional model should to gather, some rules as need to handle spatial characteristic as are the spatial and temporal multigranularities. We analyze how to divide a space of interest for semantic characteristics and as to represent this in a database, with different form and size. In addition, we have presented a Metamodel that gather the semantic of the *FE* model, made up with the ER model. Finally, we analyze an example of application where we expose explicitly how to represent the *Semantic* and *Geometric* spatial granularities interrelated, using as framework the *FE* model. We emphasize on the utility of that the models support the spatio-temporal multigranularities semantics, as the *FE* model does.

In the near future, we make up the formal definition of *FE* model with logical formulas and BNF grammars. We intend to study specific constraints for space and time in order to maintain the consistency between all objects of the database. We are considering making up a case tool that support the *FE* model and enable us to transform our conceptual model into models that are closer to the implementation of databases.

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