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Object-Relational Approach to the Representation of Multi-granular Spatio-Temporal Data

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stract. The notion of spatio-temporal multi-granularity is fundamental when deling objects in GIS applications in that it supports the representation of the nporal evolutions of these objects. Concepts and issues in multi-granular tio-temporal representations have been widely investigated by the research nmunity. However, despite the large number of theoretical investigations, no nprehensive approaches, have been proposed dealing with the representation multi-granular spatio-temporal objects in commercially available DBMSs. e goal of the work that we report in this paper is to address this gap. To ieve it, the paper first introduces an object-relational model based on enGis specifications described in SQL3. Several extensions are developed in er to improve the semantics and behavior for spatio-temporal data types roducing an approach to represent the temporal dimension in this model and multi-representation of spatio-temporal granularities.

oduction

0 when Codd [5] proposed the relational model, database system technology uced several important changes in the way data are stored and managed. The data model has had a great impact on commercial products, mainly because of pment of the SQL language, which included several additional features with those specified by the theoretical definition of the relational model. Since its inition, SQL has been widely extended [9]. A relevant set of extensions has the introduction of object modeling capabilities [21], resulting in the notion of tional data model. Such a model combines the simplicity and the power of bility of describing new data types with their associated operations, typical of -oriented approach. The object-relational data model is thus a powerful model g the best aspects of two different approaches.

QL3 standard [10] is the reference language for the object-relational model. en defined by extending the previous SQL92 standard with the ability to portant class of applications is represented by spatial and GIS applications. plications are relevant in a number of different domains, such as tion, urban planning, homeland security, and environmental protection. ta management is often combined with temporal data management, because ases one needs to record the temporal evolution of spatially-related entities. ting data models are thus termed spatio-temporal data models. One of the ial issues when dealing with spatio-temporal databases is the management formation concerning moving objects in a spatial context. Such an issue an important requirement in several application domains, like air traffic d habitat control of endangered species and so on. So far, the GIS systems dled the spatial and the non-spatial data separately, which increases the y of maintaining data integrity. The use of an object-relational database manage this kind of data represents a good alternative, in particular because ystem is able to homogeneously and efficiently manage user-defined on, and to improve integrity for data of different nature.

f the spatial-temporal data approaches proposed so far do not exploit the modeling and management features that are provided by recent versions of ally available DBMSs. Another main limitation of current approaches is that ot support multiple granularities in the representation of spatio-temporal tiple granularities, defined as a set of measure units for space and time, are facilitating the management of information for applications such as air ntrol, meteorological forecast and so forth [3], [17]. The goal of the work n this paper is to address such limitations by developing an object-relational to the management of spatio-temporal data supporting multiple granularities pace and time.

cular, in the paper we propose a temporal extension expressed in the SQL3 specifically tailored to the OpenGis specifications [29]. Our start point is the ational model and meta-model that verifies the OpenGis specifications from develop an extension of the spatial and non-spatial data types defining a type composed the two parts; the first part is the object value and the second time for this value. This extension provides the support required to model patio-temporal granularities and tools to operate on objects with different ies in order to address their integration and inter-operability.

mainder of this paper is organized as follows. Next section gives an of related work dealing with the spatial and temporal representation in the ational model. Section 3 introduces the notions of spatial and temporal y and their basic properties. Section 4 describes the OpenGis specifications [29] and presents our extension to supporting multiple spatial granularities. then extends the model and meta-model developed in Section 4 by g time as an extension of the SQL3 data types. The last section concludes and outlines future work.

ted Works

are both crucial. However, those early approaches have dealt with space representations separately. Most recent proposals have proposed integrated s able to model both spatial and temporal aspects of data objects.

relevant approach has been developed by Guting et al. [16]. The approach he change of the position or extension for geometry through the use of ata type definition capabilities. It develops a set of constructors and query in an abstract model thus giving a compact and uniform vision for every In the proposed approach [16], some data types, namely Integer, Boolean, an be transformed in a temporal data type. Such an abstract model has been formed in a discrete model [14], closer to the implementation but more with respect to the abstract model. The discrete model represents the object t have a temporal dimension through the use of snapshots. This method is red to as *sliced representation*. As part of their work, Guting et al. [14] have w the sliced representation can be mapped onto relational data structures cords and arrays. However, they do not have specifically addressed how to abstract model onto the SQL3 standard.

nd Zaniolo [6], based on the spatial-temporal representation model proposed oys [26], propose a number of SQL3 extensions aiming at supporting queries. Unlike the previous proposals, they adopt a point-based approach the time dimension and queries are expressed through user-defined functions. Such an approach to handle time for spatio-temporal databases d in a relational framework, it is very simple and minimizes SQL3 s in comparison with the complex functions one has to apply when using rvals approaches [13], [19]. Such an approach has then been architected by supporting efficient storage [7]. Finally, a more recent paper [8] by the same escribes how to implement these functions in ATLAS [28] in order to model pplication domains. This approach keeps the SQL philosophy; therefore it is e for developers and users. A major drawback of this approach is that it is o support multiple temporal attributes with different granularities in the ion.

r approach very close to implementation has been proposed by Lee [18]. l object history is modeled through the creation of relations. The developed k is based on the creation of some special purpose relations, called *s*, storing the current values of the object geometry. Besides those relations, the approach requires the introduction of two additional relations istorical information. The approach by Lee also includes a set of macro that are used to execute queries. The macro operators are applied to spatial oral data, and spatio-temporal data. Also, an aggregate operator is defined e the history of a spatio-temporal data. The main drawback of this approach requires executing join operations among the dimension tables in order to omplete spatial information. The use and maintenance of data under such an is thus quite complicated.

tensive analysis of the most important approaches to represent spatio- n the object-relational model has been carried out by Erwig et al. [12]. This sents an extensive comparison between two approaches to represent the ng temporal information. The column essentially records the temporal f row values. The second approach exploits the expressive power of the ational model. It is based on the definition of an abstract data type (ADT) ace and time on the same column. The second approach better represents tics of the original data and allows one to create relations containing time on at column level.

red to previous work, the main contributions of our work are summarized as irst, the spatial representation we adopt is based in the proposal of OpenGis ions described through SQL3 [29]. The above approaches, by contrast, ch simpler spatial data models not supporting OpenGis. Second, we provide r multiple spatial granularities. Third, we use an abstract data type approach nt and manage the temporal dimension; thus our approach is more flexible approaches and supports a finer degree of control over temporal behavior. oach facilitates the formulation of queries in SQL and provides a tion which is more intuitive and easy to use. Finally, we propose solutions in multiple granularities, in both space and time, and provide conversion to map data representations among different granularities. None of the cribed approaches provides such functions.

minaries: Multi-granular Spatio-Temporal Representation

tion, we introduce the relevant notions underlying our approach to multiple ies in both time and space aspects. From an informal view point, we can a temporal or spatial granularity as a discrete partition of time or space. partitions may be defined, thus resulting in multiple granularities.

nporal granularity has been defined as the partitioning of a temporal domain of elements ordered through an index set, where each group is perceived as sible unit (a *granule*) [2]. The granularities set is denoted by G_T and its are related by the relationship *finer_than.* A granularity *S* is *finer_than R* if ndex i a index j∈R exists such that S(i) ⊆ R(j), where S(i) denotes the granule to the i index position. This relation is denoted by $S \leq_T R$. *S*emantically, when a granularity for an object we specify the time instants at which the object's relevant to the specific application domain. Days, months and years are nds of temporal granularity; days are finer than months and months are finer s. Operations and comparisons between objects at different temporal require the use of *conversion functions*. These functions change the temporal of an object from a finer granularity to a coarser granularity and we can a macro function with the function composition. Conversion functions can be nes shown in the Table 1, or aggregation functions available in SQL [4] or cording to the application's semantics.

atial granularity is defined as the unit of measure in a spatial reference thus represents the unit according to which spatial properties, like the area, red. The set of the spatial granularity is denoted by G_S. The elements of G_S meters, kilometers, grades and others. Each one of those elements must be

Table 1. Temporal and spatial conversion functions

It returns, for each granule in the coarser granularity, the value corresponding to the granule of position index at the finer granularity
First and last index in the Proj (index) function
It returns, for each granule in the coarser granularity, the value which appears most frequently in the included granules at the finer granularity
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

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

e conversion functions are shown in Table 1; we refer the reader to [1] for details. The application of these conversion functions guarantees the consistency.

e we were interested in studying the evolution of a river's course. g to this specification, we can define a time unit as century thus obtaining sentation shown in the Fig. 1. Semantically speaking, the temporal and anularity integration provides, on the one hand, the timestamp at which a ject is observed and, on the other hand, establishes the spatial measure eference system.

pproach represents spatial-temporal multiple granularities considering the presentation of an object with respect to one temporal granule. Therefore, we eify the observation unit for both space and time. These objects are called *bjects* [16]. The Fig. 1 shows the time variation in the river course with as temporal granularity.

mporal and spatial multi-representation is built when executing user queries the conversion functions defined for each application depending on the In the next section, we show how to specify the conversion functions