
Modeling for application data with 3D spatiale feature in MADS

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ABSTRACT. A conceptual spatiotemporal data model must be able to offer users a semantic richness of expression to meet their diverse needs concerning the modeling of spatio-temporal data. The conceptual spatiotemporal data model must be able to represent the objects, relationships and events that can occur in a field of study, track data history, support the multi-representation of these data, and represent temporal and spatial data with two and three dimensions features. The model must also allow the assignment of different types of constraints to relations and provide a complete orthogonality between dimensions and concepts. The MADS model meets several requirements for the design of spatio-temporal data. Nevertheless, we present in this article an improvement of the spatial concepts of MADS in order to ensure the design of data in 3D.

RÉSUMÉ. Le modèle conceptuel spatio-temporel doit être capable d'offrir aux utilisateurs une richesse d'expression pour répondre à la diversité des besoins concernant la modélisation des données spatio-temporelles. Le modèle conceptuel spatio-temporel doit être capable de représenter les objets, les relations et les événements qui peuvent se produire dans un terrain d'étude. Il doit aussi être capable de suivre l'historique des données, de supporter la multi-représentation de ces données et de représenter les objets spatiaux en deux et trois dimensions. Le modèle doit également permettre l'attribution des différents types de contraintes aux relations et doit fournir une orthogonalité totale entre les dimensions et les concepts. De plus, le modèle conceptuel doit être interopérable et susceptible d'être extensible au niveau de ses schémas. Le modèle MADS répond à plusieurs exigences relatives à la conception des données spatio-temporelles. Néanmoins, nous présentons dans cet article des améliorations des concepts spatiaux de MADS et ceci pour assurer la conception des données en 3D.

KEYWORDS: conceptual model, spatiotemporal data, MADS, 3D data.

MOTS-CLÉS : modèle conceptuel, données spatiotemporelles, MADS, données en 3D.

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1. Introduction

GIS are tools for management and development of territories. They allow the users to formulate queries on the geographic data with different levels of complexity and to visualize the response to these queries through graphical interfaces. Applied to the urban space, they are tools for diagnosis, management, consultation and decision support that can involve both experts and non-experts users. However, the information on geographic data has a particularity that considerably complicates their management by GIS: they refer to attributes that are structural, spatial and/or temporal.

Our main line of research focus on the proposal of a methodology to describe the overall modeling process of urban geographic data beginning from the design phase until the implementation in an information system (Zaki *et al.*, 2009, 2010). To be able to effectively model urban geographic data we believe that a GIS must be based on a powerful conceptual model specific to spatiotemporal data. This conceptual model should mainly allow:

- Modeling of spatial and temporal dimensions as well as the temporal evolution of objects (history tracking).
- Modeling objects and events that occur in a field of study, along with their interactions.
- Multiple data representations that include multiple resolutions (scales of different maps) and numerous points of view (based on the user's profile).
- Orthogonality between the structural, spatial and temporal dimensions; which means that a choice of representation in one dimension does not limit the choice possibilities in another dimension.

Several spatiotemporal modeling approaches that take into account these exigencies have already been proposed. Most of them are based on modeling techniques used for traditional data modeling like Entity-Association (EA) and Object-Oriented (OO) approaches. Among the models of the OO approach we can mention Perceptory (Bédard and Larrivé, 2008). Perceptory provides support (as icons) for spatiotemporal features. The spatial and temporal properties can be used simultaneously, and can be assigned to classes and attributes. The drawback is that it does not assign spatial nor temporal properties to associations between the objects.

Among the models of the EA approach we can cite STER (Spatio-Temporal Entity-Relationship) (Tryfona and Jensen, 1999) and MADS (Parent *et al.*, 1997). STER allows treating complex geographic features and gives the possibility to create spatial and temporal relationships between these entities. However, it does not permit to describe multi representation of data. As for MADS, it allows the representation of real world entities as objects and associations. It supports orthogonality between dimensions. MADS also manages, effectively, multiple data representations. It has intuitive and very readable visual notations to represent spatial and temporal concepts, as well as a specific language to query the data model (Parent *et al.*, 2006). Comparing

with other models, MADS is favored in several studies (Parent *et al.*, 2006; Laplanche, 2002; Pelekis *et al.*, 2004).

Because of the beneficial features MADS offers, we decided to use it as the basic conceptual model for our approach. However, MADS does not natively allow a clear distinction between objects and events and does not allow to represent the 3D data during the design. We have proposed in (Zaki *et al.*, 2010) an approach that clearly distinguishes the modeling of objects and events. We propose in this article a way to allow MADS to represent spatial data in 3D.

The rest of this article is organized as follows: in sections 2 and 3 we present respectively the state of the art of spatial data design in MADS and the design of 3D spatial types. In section 4, we present an improvement of MADS allowing taking into account the spatial data in 3D. The last section is about the conclusion and perspectives.

2. Spatial data design in MADS

Spatiality describes the shape and location (position in space) of objects, attributes or associations.

MADS proposes pictograms to model generic spatial types that are used to describe the shape of the objects to be modeled. These types are organized in a hierarchy (Figure 1) that starts from abstract types to specific types. Specific types designate simple objects like “Point, Line, Oriented Line, Area” or uniform complex like “PointBag, LineBag, OrientedLineBag, ComplexArea (AreaBag)”. “Geo”, “Simple Geo” and “Complex Geo” abstract types are used to model simple or complex multiform objects whose instances may have different types.

Spatial types can be assigned to classes, attributes, and associations. For classes and associations, spatiality is affected by adding one of the spatial types to the class / association, Figure 2 gives an example of the transformation of the “Building” class into a spatial class characterized by a single surface (area).

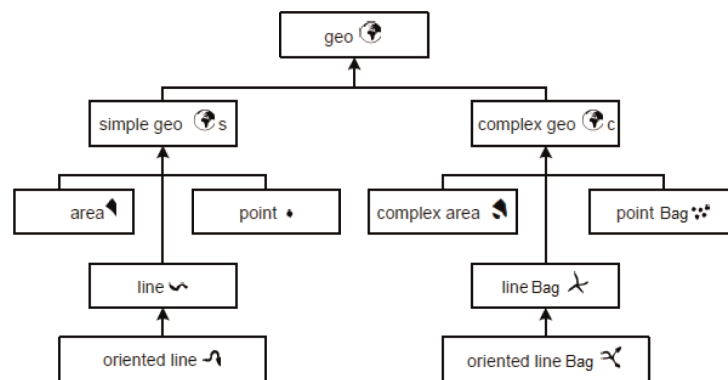


Figure 1. Hierarchy of spatial types in MADS (Parent *et al.*, 1997)

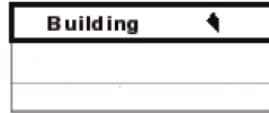


Figure 2. Building class with spatial feature

For attributes, spatiality is assigned when the attribute domain is a spatial type. For associations, MADS makes it possible to assign spatial constraints in the form of pictograms that describe topological relationship between spatial classes (Parent *et al.*, 2006). However, MADS cannot design the 3D spatial features of data.





3. Design of the 3D spatial feature of data



Larrivée *et al.* (2005) proposed an extension of the existing pictograms (point, line, surface) in Perceptory to generate conceptual models of 3D spatial databases. The improvement consists in defining the notion of 3D data.

When designing spatial data, it is necessary to differentiate between a universe (environment) having a number n of dimensions (number of spatial axes necessary to position the real objects), and the objects represented in this universe, which also have a dimension that may be less than or equal to n . This distinction gives the opportunity to establish a typology of cases and leads to a set of new pictograms to design the 3D data (Larrivée *et al.*, 2005).

For each object modeled in a 3D universe, it is necessary to choose the adapted geometry (and subsequently the adapted pictogram). It is also important to distinguish between 2.5D objects (for such objects, there is a single altitude for the same position on the horizontal plane) and 3D objects (for such objects, it exists for a given position, several altitude). Indeed, in a 3D universe, deciding whether an object is 3D or 2.5D must be done by a designer, and the conceptual model must support and distinguish these different possibilities.

(Larrivée *et al.*, 2005) proposed a “cube” pictogram to specify the spatial feature of objects in 3D universe. The x and y axis of the cube are in the foreground and the z axis is the depth. The geometry symbol represents the ground trace of the object or the projection of its geometry on the ground. (Larrivée *et al.*, 2005) introduce different pictograms to represent objects in 2.5D and 3D within the 3D universe as following:

- Point object : a point representing a manhole covers for example,
- Linear object : a curved line representing a road for example,
- Surface object : a polygon representing a football field for example,
- Extruded point : Object having an altitude but whose projection on the digital terrain models (DTM) is summarized at a point: a right tree trunk for example

- Extruded curved line : Object having an altitude but whose projection on the DTM is summarized with a linear object: a wall for example,
- Extruded polygon : Object having an altitude but whose projection on the DTM is summarized on a surface object: a building for example.

4. Defining new types for designing 3D spatial feature in MADS

We were inspired by (Larrivée *et al.*, 2005) to propose a representation of 2.5D and 3D objects within a 3D universe in MADS. We present in Figure 3 an hierarchy of spatial types in 3D universe starting from the abstract types (geo, geo 2.5D, geo 3D) to the specific types that designate simple and complex objects in 2.5D (point, oriented line, area, point bag, oriented line gag and complex area) and in 3D (extruded point, extruded oriented line, extruded area, extruded point bag, extruded oriented line gag and extruded complex area).

We use the abstract types “simple geo, complex geo, extruded simple geo and extruded complex geo” to model simple or complex multiform objects (in 2.5D or 3D). These terms are useful for describing spatial phenomena whose instances may have different or unknown types when creating conceptual schemas.

We present in this section some real examples of the use of spatial types (we used the examples of (Larrivée *et al.*, 2005)):

- Category 1: The following objects have an altitude relative to the ground. In a 3D environment these objects are considered objects of dimension 2.5D (geo 2.5D):
 - A transmitter at the end of an antenna (generally considered as a point),

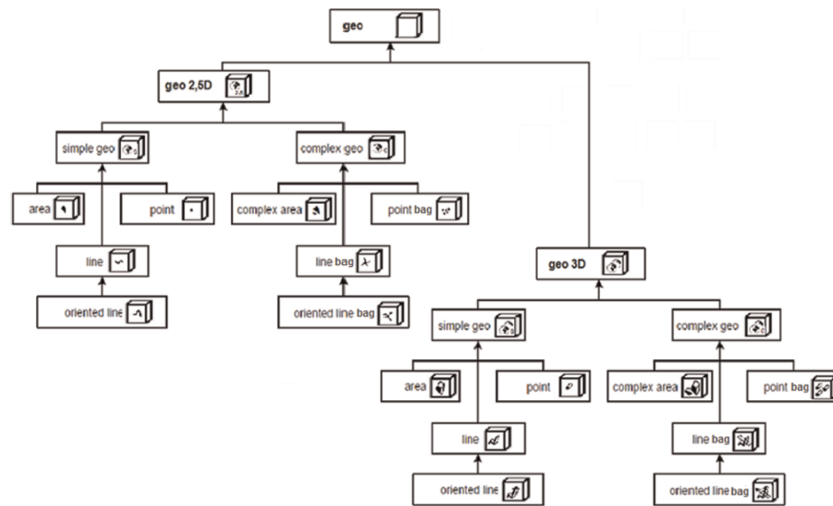


Figure 3. Hierarchy of spatial types in 2.5D and 3D

- A bridge (generally considered a linear object),
 - A heliport built on a building (generally considered as a surface object).
- Category 2: The following objects have several altitudes and change dimensions depending on whether the universe is 2D or 3D. In a 3D environment these objects are considered objects of dimension 3D (geo 3D):
- An antenna built on the roof of a building is modeled as a point in a 2D universe and as an extruded point in a 3D universe,
 - A raised billboard is modeled as a linear object in a 2D universe and as an extruded line in a 3D universe,
 - An underground car park is modeled as a surface object in a 2D universe and as an extruded surface in a 3D universe.

We also point out that we can set apart objects for which there are exactly two z's (altitudes) for one (x, y). The dimension of this type of object is actually called $2^{3/4}$ D. These objects are common in urban environments (all the examples of the second category are in reality type of $2^{3/4}$ D). To differentiate them from objects in 3D we create new types to conceptualize them. The hierarchy of spatial types in $2^{3/4}$ D is presented in Figure 4.

The pictograms used in Figure 4 are consistent with those that designate the 2.5 D types, but we associate the pictograms with a black color thickness to represent the values of the “z” axis. This new hierarchy can be merged with the hierarchy of Figure 2 to build a general hierarchy of a 3D universe with objects in 2.5D, $2^{3/4}$ D and 3D.

With these new types, we have the following new distribution of (previous) examples of the use of spatial types in a 3D universe:

- Category 1: objects of dimension 2,5D:

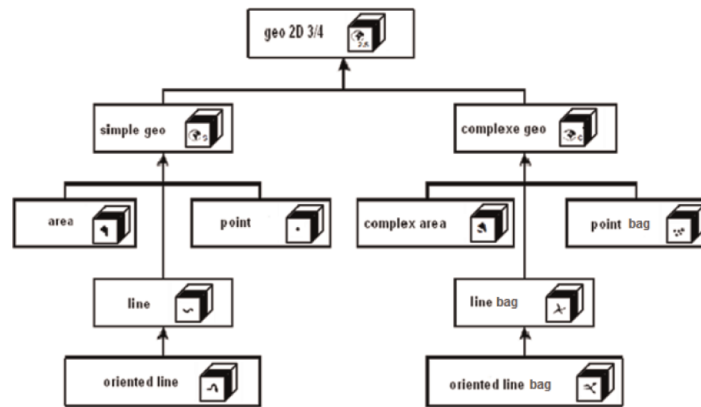


Figure 4. Hierarchy of spatial types in $2^{3/4}$ D

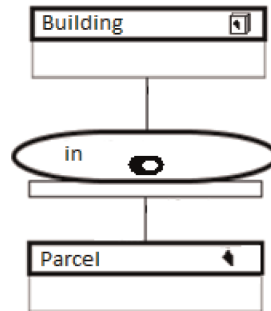










Figure 5. Example of using of 2D and $2^{1/2}$ D spatial concepts in MADS

- A transmitter at the end of an antenna ,
- A bridge ,
- A heliport built on a building .
- Category 2: objects of dimension $2^{3/4}$ D:
 - An antenna built on the roof of a building ,
 - A raised billboard ,
 - Underground parking .
- Categories 3, objects of dimension 3D:
 - Multi-level underground parking ,
 - The compound composed of several buildings .

We present in Figure 5 a case study where we use MADS to design two spatial entities (building and parcel) and the spatial association between them. Spatiality is insured by adding spatial types to classes. The “Building” class is modeled in $2^{3/4}$ D using area type and the “parcel” class in a 2D area spatial type. The topological constraint in the association “contains” represents the fact that a building is contained in the parcel. The orthogonality of types in MADS gives the designer the ability to use the 2D and 2.5D environments in the same case study.

5. Conclusion

In this article, we present a way to improve MADS by adding new pictograms to design spatial types in a 3D universe.

The conceptual improvements on one side increase the semantics and expressiveness of the MADS model, on the other hand, it adds new requirements regarding their implementation. Unlike the basic types and primitive spatial types of MADS, the implementation of our new types (2.5D, $2^{3/4}$ D and 3D) is not standardized.

In our previous work (Zaki *et al.*, 2011) we proposed a transformation of MADS model into an object oriented model and we used the db4o object database to store data. With db4o the recording of 3D data is done in a transparent way (DB4O, 2019). However, the implementation of applications that use spatial data in 3D does not have a single solution. We are working on coupling MADS with an adapted business model BPMN (Business Process Model and Notation) (OMG BPMN v.2.0.1, 2013) to preserve the semantic richness of the conceptual model when implemented into an object model and accordingly enhance the already done MADS-to-Object Java transformation.

According to our perspectives, we aim to define transformation rules to implement the 3D concepts of MADS into an object and/or relational model automatically.

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