Interoperability of Conceptual Geographical Data Schemas using UML Infrastructure

Thiago Bicalho Ferreira[1,2], Sergio Murilo Stempliuc[3], Jugurta Lisboa-Filho[1]

[1]Departamento de Informática, Universidade Federal de Viçosa (UFV)
Viçosa - MG - Brazil

[2]Instituto Federal do Norte de Minas Gerais (IFNMG)
Almenara - MG - Brazil

[3]Faculdade Governador Ozanam Coelho (FAGOC)
Ubá - MG - Brazil

thiagao.ti@gmail.com, jugurta@ufv.br, smstempliuc@gmail.com

Abstract. *Issues in the area of geographic databases, caused by the lack of a standard geographic conceptual data model, can be classified as interoperability problems. This paper proposes a method to reach horizontal interoperability, i.e., a schema can be transformed in another schema designed using a different model. UML infrastructure and the Enterprise Architect CASE tool are used in the process. To reduce the number of transformations between all schemas, a UML Profile called GeoProfile is used as a base model. OCL expressions are used to enforce spatial constraints.*

1. Introduction

For over 20 years, researchers in the area of Geospatial Databases (GDB) have been proposing new conceptual models, which are extensions of the formalisms Entity Relationship (ER) and Object-Oriented models (OO) to represent the specificities of geographic data [Lisboa Filho and Iochpe 2008]. Several proposals have been presented to solve problems involving, for example, the lack of spatial/temporal constructs and the lack of CASE tools to aid in conceptual modeling of spatial/temporal data [Pinet 2012]. However, the large number of alternative extensions led to the lack of a standard model for the area of conceptual GDB modeling.

For Sampaio et al. (2010), the lack of a standard conceptual model causes problems to GDB designers and their teams, such as the difficulty in integrating different conceptual schemas and the difficulty in reusing projects already validated in previous systems. For Staub (2007) the problems caused by the lack of a standard conceptual model can be classified as horizontal interoperability problems.

The remaining of the paper is structured as follows. Section 2 describes the use of the UML infrastructure for conceptual GDB modeling and horizontal interoperability. Section 3 describes the steps taken in order to reach horizontal interoperability, specifying metamodels, UML profiles and transformation rules. Section 4 presents some conclusions.

2. UML Infrastructure and Horizontal Interoperability

Pinet (2012) presents a chronologic survey of the main conceptual data models in the literature and the main spatial and temporal requirements supported by these conceptual data models. Among the data models presented are the GeoOOA [Kösters et al. 1997] and UML-GeoFrame [Lisboa Filho and Iochpe 2008].

UML is a visual language to build, specify, visualize and document system artifacts while the Object Constraint Language (OCL) is an add-on to the UML standard used to express constraints and properties of the elements in the model.

UML needs to be extended for geographic data modeling. OMG defines two ways for the UML extension. The first uses MetaObject Facility (MOF), modifying the UML metamodel to create a new language in which the syntax and semantics of the new elements are adapted to the domain desired. The second is by defining a profile. The use of a profile allows the entire UML structure to be used, e.g., CASE tools and OCL.

2.1. GeoProfile

According to Sampaio et al. (2010), GeoProfile is a UML profile that combines the main characteristics of several specific conceptual models for GDB modeling, such as the models OMT-G, MADS, GeoOOA, UML-GeoFrame and the model of the Perceptory tool. The GeoProfile specification comprises six of the seven requirements studied by Pinet (2012): representation of the basic types of spatial objects; specifications of spatial relationships; representation of temporal aspects; multiple spatial representation; representation of continuous fields; and network representations.

Being a UML profile, GeoProfile allows for a higher level of abstraction guaranteed by the Model Driven Architecture (MDA) approach, which aids designers in the first steps of a project [Staub 2007]. Other advantages include being naturally supported by CASE tools already consolidated by the UML infrastructure and using OCL constraints in GDB schemas.

2.2. Horizontal interoperability

Interoperability is the seamless communication between different environments that takes place with no special effort by the users. According to Staub [2007], the interoperability of data schemas may occur in two axes, vertical and horizontal (Figure 1).

This paper focus on the horizontal interoperability, where different schemas can be mapped each other at any level of the MDA approach. For example, at the Platform Independent Model (PIM) level, a conceptual schema developed with the constructs of metamodel X, can be replicated by the constructors of metamodel Y and vice versa. That can happen among the different MDA levels, as illustrated in Figure 1. Both the horizontal and vertical mappings are made up of transformation rules. These transformation rules can be carried out manually or automatically (by transformation tools).

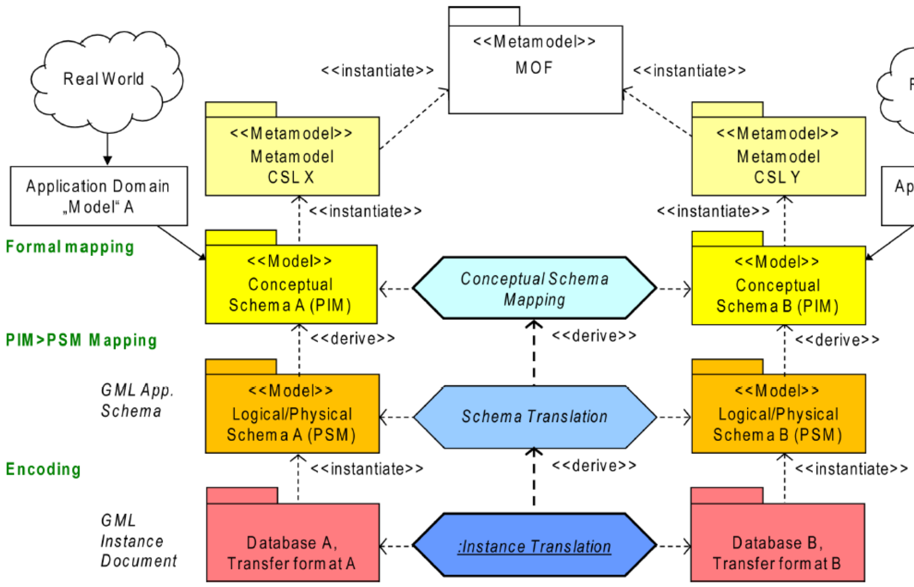

Figure 1. Schema interoperability [Staub 2007]

3. Method for the Interoperability of Geographical Data Schemas

This section describes the method proposed to reach horizontal and vertical interoperability of geographical data schemas using the GeoProfile as an intermediate conceptual data model. The method was tested using the Enterprise Architect (EA) CASE tool [EA, 2016].

3.1. Step 1: Choosing the Interoperability Base Model

An initial proposal about the horizontal interoperability is the direct transformation between the used models. The problem of this trivial solution is the number of possible combinations, where the interoperability of 9 known geographical conceptual models, results in 72 transformations rules, ie, each model would have to be transformed into the other 8 models. Another solution is to use a base model so each conceptual model can be transformed into 8 other models using only 8 transformation rules. To act as base, a conceptual model must have a broad set of spatial and temporal constructors, offer resources and facilities for extension, not be bound to a specific CASE tool, and offer infrastructure so other models can be adapted without losing their main features.

According to Pinet [2012], it can be seen that no conceptual model described in the study can be used as an interoperability base. First, these models do not comprise all requirements needed. Second, many of these models are bound to a specific CASE tool. Therefore, GeoProfile is proposed as an interoperability base for the following reasons: it can use the whole UML infrastructure; it is not bound to a specific tool; since it is an UML profile, it can be extended; and it can be used at a high MDA abstraction level.

When GeoProfile is used as base model, the number of transformation rule sets is reduced and only transformation rules between each model and GeoProfile are needed. This paper presents the transformation among schemas prepared in the conceptual models GeoOOA and UML-GeoFrame focusing on the network domain.

3.2. Step 2: Specifying Metamodels for the Models Selected in Step 1

According to Pinet (2012), there are proposals to formalize network structures into diagrams. The proposal used by the conceptual models GeoOOA and UML-GeoFrame is to use classes with graphical icons to represent nodes and arcs in a network.

The GeoOOA model uses the pictogram to represent the network, the nodes and the arcs. The metaclass Network is used to organize the metamodel and is associated to Node and Link. This association must be maintained when a network application is modeled using GeoOOA.

The UML-GeoFrame model received network constructors where a Network is formed by several network objects that can be of specific type of representation, which can be a Node or an Arc. The arcs can be uni or bidirectional.

3.3. Step 3: Defining UML Profile and OCL Constraints

In this step, the UML profiles for the GeoOOA and UML-GeoFrame metamodels are specified. The UML profile illustrated in Figure 2 was specified according to the GeoOOA metamodel described in Step 2. All stereotypes presented in Figure 2 are extended from the metaclass `Class`. The attribute `_Image` placed in non-abstract stereotypes is used to associate graphical icons with the stereotypes.

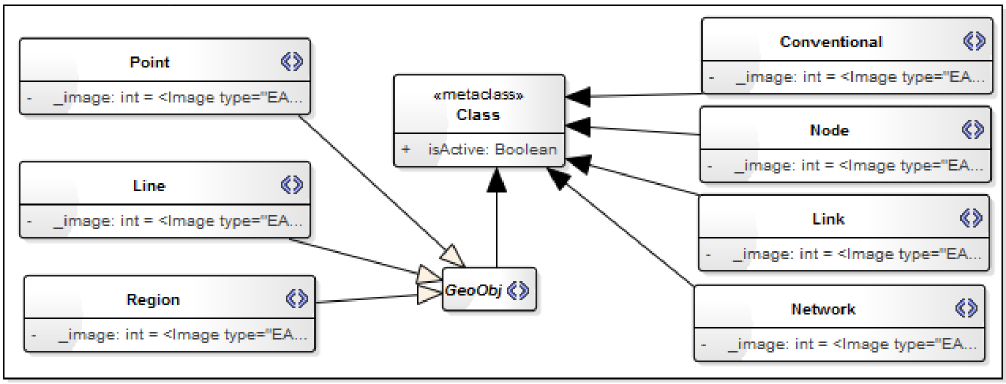

Figure 2. UML GeoOOA profile

As specified in the GeoOOA metamodel, some attention must be taken for conceptual network modeling. To prevent inconsistencies, OCL constraints are specified in GeoOOA profile based on the following rules: the whole Network must have at least one Node and one Link; every Node must be associated with a Network; every Link must be associated with a network; and Nodes and Links cannot be associated directly.

Specification of the UML-GeoFrame Profile

The UML profile illustrated in Figure 3 was specified in the same way did for GeoOOA, but now according to the UML-GeoProfile metamodel described in Step 2. Also, OCL constraints are specified in the UML-GeoFrame profile in order to prevent to following inconsistencies in network modeling: Every class stereotyped by <<Network>> must be associated with at least one node <<Node>> and one arc <<BidirecionalArc>> or <<UnidirectionalArc>>.

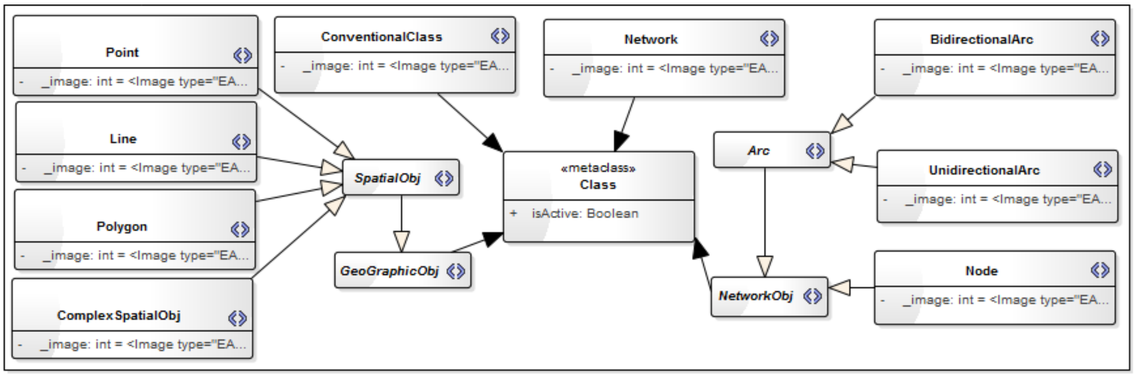

Figure 3. UML-GeoFrame profile

3.4. Step 4: Application and Configuration of the MDG for UML Profiles

The Model-Driven Generation (MDG) technology supported by the EA CASE tool provides resources to extend its modeling capability without changes on its source code. The environment can meet the needs of a specific domain, adding support to merging the UML profiles, MDA Transformations, profile toolboxes, scripts and images.

Showing all the details of the MDG used is beyond the scope of this article. A tutorial with specific scripts to modify the appearance of the stereotypes and the scripts to add images to the stereotypes can be found at the web site of the Geoprofile project (http://www.dpi.ufv.br/projetos/geoprofile/).

After undergoing the process of the MDG technology of the EA tool, the profiles UML GeoOOA, UML-GeoFrame, and GeoProfile were named MDG_GeoOOA, MDG_UML-GeoFrame and MDG_GeoProfile, respectively.

3.5. Step 5: List of Horizontal Transformation Rules

The set of horizontal mappings in this section is described by small conceptual data schemas with the MDG_GeoProfile used as an interoperability base between the MDG_GeoOOA and MDG_UML-GeoFrame technologies.

Mapping between MDG_GeoOOA and MDG_GeoProfile.

Figure 4 shows the mapping between these two profiles containing elements of an electric energy grid. In Figure 4-a, the mapping from MDG_GeoOOA to MDG_GeoProfile generates a stereotyped class Node. Figure 4-b illustrates the constructor Link, which can be mapped to a class with <<UnidirectionalArc>> or <<BidirectionalArc>> stereotypes. Figure 4-c illustrates the mapping of Network to a class with <<Network>> stereotype.

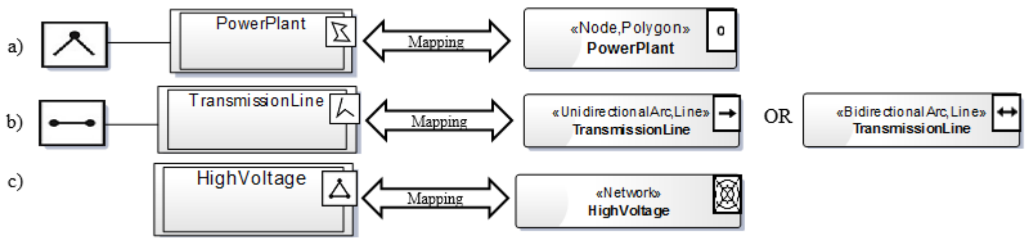

Figure 4. Mapping between MDG_GeoOOA and MDG_GeoProfile

Mapping between MDG_UML-GeoFrame and MDG_GeoProfile.

In MDG_GeoProfile, the network node and the bidirectional or unidirectional arcs are associated with a class with the stereotype Network. This class may contain alphanumeric data about the network. Figure 5 presents the mapping of the network requirement between MDG_UML-GeoFrame and MDG_GeoProfile.

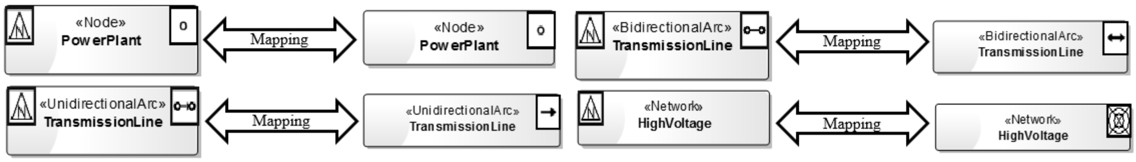

Figure 5. Mapping between MDG_UML-GeoFrame and MDG_GeoProfile

5. Conclusions

This paper showed that horizontal interoperability can be achieved among different conceptual geographic database schemas using GeoProfile as base. The Enterprise Architect CASE tool was used to implement the method proposed with the horizontal interoperability exemplified at the PIM level of the MDA approach.

Besides this paper focus on Network elements, the whole proposal has already done the horizontal transformations for GeoObjects, represented by the primitives Point, Line and Polygon. The proposal has also done the vertical transformations, with the objective of perform the full MDA transformations, until the source code (SQL). A complete description of this method can be found in [Ferreira 2016].

Acknowledgment

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