Applying the Model Driven Architecture Approach for Geographic Database Design using a UML Profile and ISO Standards

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Abstract. In the last 20 years, several conceptual data models specific for Geographic Information Systems (GIS) have been proposed. However, so far there is no consensus on a model, causing several problems for the GIS area, such as the lack of interoperability among computer-aided software engineering (CASE) tools that give support to these models. A UML profile, called GeoProfile, was proposed to standardize the task of geographical data modeling. GeoProfile was designed based on the main models for geographic database in the literature, seeking to support some requirements for geographic applications modeling. This article describes the use of Model Driven Architecture approach (MDA) in the design of geographic databases, using the GeoProfile aligned with international standards of ISO 19100 series. The article also shows that with the automatic transformation of models it is possible to achieve the generation of scripts for spatial databases from a conceptual schema in a high level of abstraction.

Categories and Subject Descriptors: H. Information Systems [**H.2 Database Management**]: H.2.8 Database Applications - *Spatial databases and GIS*

Keywords: Geographic Information Systems, UML Profile, Database modeling, MDA, ISO/TC 211

1. INTRODUCTION

Software development is an activity that requires more and more the use of standardized methodologies and techniques that are widely known. Currently, the main concern of the designer is to understand well the problem domain in order to generate solutions that suit the real necessities of the users. To help in the task of understanding the problem and reducing the complexity of system to be developed, modeling is by far the most powerful abstraction mechanism available. A model is a reality simplification [Eriksson et al. 2003] and in database design, the use of more abstracts models helps in the design of data structures with no concern for implementation details. The Model Driven Architecture (MDA) approach [Miller and Mukerji 2003] enables the development of systems using models in different levels of abstraction.

In classic database design [Elmasri and Navathe 2010], the most abstract model level is called conceptual model. Conceptual data modeling is carried on by using languages with syntax and semantics that focus on the conceptual and physical representation of a system [Fuentes and Vallecillo 2001]. Currently, one of the most used and accepted languages is the Unified Modeling Language (UML), which is extensible through the use of profiles, a mechanism that allows its tailoring to specific domain semantics [OMG 2007].

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An application domain that has been calling attention at present is the geographic domain, due to the current availability of spatial data sets. In the last 20 years, much research has been done aiming to create or to adapt conceptual data models for geographic applications. However, the existence of several models has brought a problem for this area, which is the lack of a modeling standard. Specific CASE tools have been implemented based on some of the proposed models, making it hard to achieve interoperability among them, thus making it impossible the reuse of schemas created in different projects. Besides, there are certain modeling requirements of geographic applications that some models support while others do not.

As an effort towards the standardization of geographic information representation, some organizations, such as the International Organization for Standardization (ISO) and the Open Geospatial Consortium (OGC), have published international standards to help in the construction of standardized geographic applications. Under this context, a UML profile called GeoProfile was proposed in [Lisboa-Filho et al. 2010]. GeoProfile is a UML profile for conceptual modeling of geographic database (geoDB), which puts together the characteristics of the main existing conceptual models.

This article describes the usage of GeoProfile and some international standards of the ISO 19100 series on geographic database design, according to different abstraction levels of MDA models. Section 2 describes the MDA approach. Section 3 describes some requirements for geoDB design and how the GeoProfile is aligned with international standards from the ISO 19100 series. Section 4 describes the main characteristics of GeoProfile. Section 5 describes in details the application of the MDA approach for geographic data modeling. In Section 6 some conclusions, as well as future works, are presented.

2. MODEL DRIVEN ARCHITECTURE

With the promise of improving software development quality, the Object Management Group (OMG) has adopted the MDA approach, whose main characteristic is the emphasis given to models and modeling. In this approach, the software development process is directed by the system's modeling activity. A system model is a description using a specific notation. The artifacts produced in MDA are semi-formal models, they can be partially processed by computers [Eriksson et al. 2003].

In MDA, system requirements are modeled using a Computation Independent Model (CIM). This model is called domain model or business model and it uses a vocabulary that is familiar to the domain experts. A CIM does not show details of the systems structure, but the environment in which the system will operate, being useful to understand the problem [Miller and Mukerji 2003].

In the second level of abstraction we find the Platform Independent Model (PIM), which is a model with a relatively high abstraction level, which is independent from any implementation technology [Miller and Mukerji 2003]. It carries more detail than the CIM, approaching implementation in a step-by-step fashion.

In another step, a PIM should be transformed into a Platform Specific Model (PSM). A PSM is customized in order to specify the system in terms of implementation constructors which are available in a specific implementation technology. For instance, a relational database PSM should include terms such as "table", "column", "foreign key", among others. A PIM can be transformed into one or more PSMs. For each specific technology platform a specific PSM is generated. Next step is the transformation of each PSM to source code. This transformation is relatively direct, since the PSM is adjusted to a specific technology.

A key element for MDA is that part of the transformations should be automatically executed. Traditionally, the transformations from model to model or from model to code are made manually. In the MDA approach, transformations are executed preferably by tools [Kleppe et al. 2003].

The OMG also provides some ways of transforming models into MDA. One of them is the transformation using UML profiles. A CIM and a PIM can be prepared using a UML profile that is considered a PIM. This model can then be transformed into a PSM using another profile driven to a specific platform [Miller and Mukerji 2003].

3. GEOGRAPHIC DATABASE DESIGN

Geographic database (geoDB) is a special kind of spatial database, which has the capability to handle geometric data (e.g. point, line) [Shekhar and Chawla 2003]. Geographic information has, besides the descriptive attributes, a geometric representation in the geographic space; these data are known as georeferenced data.

The geoDB design holds some particularities that cause the development of specific solutions for this domain. Friis-Christensen et al. [Friis-Christensen et al. 2001] describe a survey of geographic data modeling requirements, which were classified into five groups: space-temporal properties, roles, associations, constraints and data quality.

Another requirement list is exhibited in [Lisboa-Filho and Iochpe 1999]. In that study, eight kinds of requirements are mentioned, five of them equivalent to the ones presented by Friis-Christensen et al. [Friis-Christensen et al. 2001]: modeling phenomena in the field and object views, spatial aspects, spatial relationships, temporal aspects and quality aspects. The other three requirements, which are not explicitly mentioned in the article [Friis-Christensen et al. 2001], are: possibility of differentiation between geographic phenomena and objects without spatial reference, necessity of organizing the phenomena by theme and possibility of modeling of phenomena with more than one spatial representation (multiple representations).

Currently there are several proposals for modeling geographic data, among the most known are: GeoOOA [Kösters et al. 1997], OMT-G [Borges et al. 2001], MADS [Parent et al. 2008], UML-GeoFrame [Lisboa-Filho and Iochpe 2008] and Perceptory [Bédard and Larrivée 2008]. Each of these models presents particular characteristics and tries to implement the requirements of geographic applications modeling. Pinet et al. [Pinet et al. 2007] describe the use of UML and the OCL (Object Constraint Language) to modeling constraints in spatial databases.

3.1 International standards for geographic information

The efforts for international standardization in the area of geographic information have been taking place since the last decade through organizations such as ISO and OGC. The Technical Committee ISO/TC 211 is the one responsible for the preparation of the ISO 19100 series, which define the international standards regarding geographic information. These standards aim to promote the usage of geographic information in an efficient, effective and economical way, thus contributing to the solution of global problems, such as humanitarian and ecological problems.

These standards can contribute in several levels of abstraction, from abstract modeling through implementation aspects. In this article some standards related to data models for geographic information, more specifically the standards ISO 19107 Spatial Schema [TC211 2003], ISO 19108 Temporal Schema [TC211 2002] and ISO 19123 Schema for Coverage Geometry and Functions [TC211 2005] are discussed and analyzed.

The ISO 19107 Spatial Schema standard specifies a schema to describe and manipulate the spatial characteristics of geographic features. A feature is an abstraction of a real world phenomenon. This abstraction is a geographic feature if it is associated to a relative location on Earth [TC211 2003]. The standard consists of class diagrams that can be used in an application schema, profiles and implementation specifications. It also defines spatial operations, standards for use in the access, query, management, processing, and data exchange of geographic objects. The ISO 19107 standard defines in detail the geometric and topological characteristics that are necessary to describe geographic features.

The ISO 19108 Temporal Schema standard defines concepts regarding the temporal characteristics of geographic information, showing how these characteristics are abstracted from the real world. Jensen [Jensen 1994] considers two kinds of time attribute: the valid time and the transaction time. The first one is the time when a fact is true in the observed reality and it is generated by the user. The second one is the time when a fact is stored in a database from which it can be recovered. This international standard emphasizes valid time over transaction time. The standard consists of a class hierarchy that considers the geometric and topological aspects of temporal characteristics [TC211 2002].

The ISO 19123 Schema for Coverage Geometry and Function standard, on the other hand, defines a schema for the spatial characteristics of coverage. Coverage is a feature that has multiple values for each type of attribute and can represent a simple feature or a set of features. They integrate discrete and continuous geographic phenomena [TC211 2005]. Examples of coverage include raster, TIN, point coverage and polygon coverage. They are used in several specific areas such as remote sensing, meteorology, soils and vegetation.

Some works have analyzed conceptual data models and their integration with geographical standards. Belussi et al. [Belussi et al. 2004] describe the GEOUML conceptual model, in which a geographic database schema can be designed from the specialization of ISO TC211 standards. However, this model does not use graphic symbols to indicate the spatial representation of the phenomena, which is a feature present in various models proposed in the literature [Bédard and Larrivée 2008]. A study where the model elements of the Perceptory tool are related to the ISO standards is presented in [Brodeur et al. 2000].

4. GEOPROFILE - A UML PROFILE FOR GEODB CONCEPTUAL MODELING

UML is a modeling language which can be used in several application domains [OMG 2007]. However, there are situations in which UML is not able to express all the concepts of certain domains. Thus, as it is mentioned by Eriksson et al. [Eriksson et al. 2003], in order to avoid making UML too complex, its creators made it extensible, that is, it is possible to adapt it to a domain or specific platform, through its extension mechanisms, which are *stereotypes*, *tagged values* and *constraints*.

The set of extension mechanisms can be grouped into a UML profile. The intent of the UML profile mechanism is to supply a direct path to adapt an existing metamodel with the constructors that are specific to a particular domain, platform or method. The profile mechanism is consistent with the Meta Object Facility (MOF) specification.

A well-specified UML profile would be directly supported by existing CASE tools. In other words, once the profile is defined there is no need to implement new CASE tools to support it. Enterprise Architect (EA)[1] and Rational Software Modeler (RSM)[2] are examples of CASE tools that support UML profiles. Hence, the development of a UML profile has proven an excellent method to standardize modeling of specific domains, as it uses the language's popularity and tools compatible with UML2, favoring standard acceptance and reducing time for training in new languages.

The UML profile proposed for geoDB conceptual modeling, called GeoProfile [Lisboa-Filho et al. 2010], puts together the characteristics of the previously existing main conceptual data models, thus seeking to achieve the requirements of geographic applications modeling. GeoProfile was specified following the guidelines for specification of UML profiles discussed in [Fuentes and Vallecillo 2001] and [Selic 2007]. The first step was the construction of the domain metamodel [Lisboa-Filho et al. 2010], in which concepts from geoDB modeling and the basic requirements were approached.

The way each conceptual model in this proposal (GeoOOA, MADS, UML-GeoFrame, OMT-G and Perceptory) meets the requirements was examined. The inclusion of the main mechanisms present

[1] http://www.sparxsystems.com/products/ea/
[2] http://www-01.ibm.com/software/awdtools/modeler/

Table I. Comparison between requirements and models, and major contributions to the GeoProfile

Models vs. Requirements	**GeoOOA**	**MADS**	**OMT-G**	**Perceptory**	**UML-GeoFrame**	**Contribuition for GeoProfile**
Geographical phenomena and conventional objects	Yes	Yes	Yes	Yes	Yes	Perceptory
Field visions and objects	Partial	Partial	Yes	No	Yes	OMT-G
Spatial aspects	Partial	Yes	Yes	Yes	Yes	OMT-G, UML-GeoFrame
Thematic aspects	No	No	Yes	Yes	Yes	UML-GeoFrame
Multiple representations	Partial	Yes	Yes	Yes	Yes	UML-GeoFrame
Spatial relationships	Partial	Yes	Yes	Partial	Partial	MADS, OMT-G
Temporal aspects	Partial	Yes	No	Yes	Partial	MADS, Perceptory

in each of these models into GeoProfile allows it to meet most requirements of a geoDB. Table I summarizes the results obtained in the comparative analysis between requirements and conceptual models, but also displays in its last column the models that had the largest influence over GeoProfile construction in each requirement.

The second step was to extend the UML metaclasses to create the profile itself. In this step the stereotypes, tagged values and constraints were defined. GeoProfile stereotypes are shown in Figure 1. Most GeoProfile stereotypes extend the metaclass *Class*. Both the *GeoObject* and *GeoField* stereotypes represent the geographic phenomena perceived in the objects and fields views, respectively. Since these stereotypes were defined as abstracts, as well as the *NetworkObj* and *Arc* stereotypes, they will not be included in the schema classes during the usage of the GeoProfile, but their corresponding subclasses will.

To deal with temporal aspects, the *TemporalObject* stereotype, which also extends the metaclass *Class*, was included. The two enumerations that were included (*TemporalPrimitive* and *TemporalType*) are used to list the possible values that the meta-attributes (*tagged values*) *temporalPrimitive* and *temporalType* may assume, which are: *instant* and *interval*.

Besides the extensions to the metaclass *Class*, extensions to the metaclass *Association* were included. These extensions are aimed to creating stereotypes to serve the topological relationships, which are: *Touch*, *In*, *Cross*, *Overlap* and *Disjoint*. In addition to the extensions, designers are allowed to indicate that an association between two objects is only valid for one period of time and this history should be kept in the database. This is done by simply assigning the stereotype *Temporal*.

Besides the stereotypes, some *constraints* were also added, which are useful for conceptual schema validation. The constraints were defined using OCL and have the created stereotypes as context. Details about the specification of constraints can be obtained in [Lisboa-Filho et al. 2010].

5. APPLYING MDA APPROACH FOR GEOGRAPHIC DATA MODELING

GeoProfile was designed having in mind higher abstraction levels, helping the designers in the first steps of a geoDB design. This abstraction level, in the classical approach of database design, is called conceptual level, in which only the aspects related to the problem domain are taken into account, without dealing with implementation details. In the MDA approach, this more abstract level is the CIM. According to OMG [Miller and Mukerji 2003], such model uses a vocabulary that is familiar to the domain experts. GeoProfile also acts as a CIM, since it represents the geoDB in a more abstract way.

These models of higher abstraction levels should be transformed into lower level models, enriched with elements of a more technical order until they achieve implementation details. In the classical approach, this transformation is called conceptual-logical modeling. It is what happens, for example, in the transformation of a Entity-Relationship schema into the Relational schema. In the MDA approach, it is said that a CIM is transformed into a PIM.

Since the international standards of the ISO 19100 series present some technical details, they are in the level of abstraction of a PIM. Table II shows the correspondence between elements of GeoProfile and elements of the ISO 19100 series standards.

The realization of these correspondences can be obtained as a transformation between a CIM, that is a schema using the GeoProfile, and a PIM, that is a schema enriched with elements from the ISO 19100 series standards. For instance, the phenomena perceived in the object views modeled with the GeoProfile will be mapped to a PIM enriched with the ISO standards in the following way: the classes that were stereotyped as *Point* will be mapped into a class that will have an attribute called *geometry* of *GM_ Point* type. In the ISO 19107 standard, *GM_ Point* is a kind of basic data for objects with 0-dimension. The same will be done with the other three classes, *Line*, *Polygon* and *ComplexSpatialObj*, which will be mapped into a class with geometry attribute of *GM_ Curve*, *GM_ Surface* and *GM_ Complex* types, respectively.

It is important to highlight the fact that these standards offer several ways to model the same geographic information. The correspondences presented here were the closest possible to GeoProfile concepts. The ISO 19100 series standards used above are the ones that come closer to the requirements for geoDB conceptual modeling. For example, the ISO 19107 standard was used to build the correspondence with the GeoProfile stereotypes which represent geographic objects perceived in the objects view and also with network elements. The standard is divided into two parts. In the first one, which deals with the geometric aspects of geographic information, the correspondence with objects perceived in the objects view is established. In the second one, which deals with topological

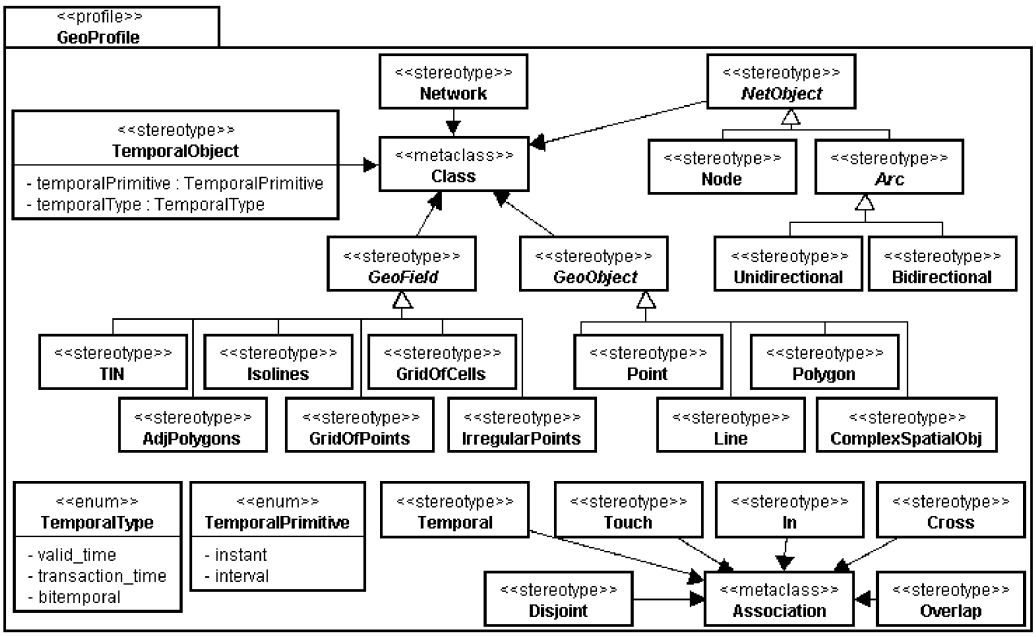

Fig. 1. GeoProfile's Stereotypes

Table II. Correspondence between GeoProfile and the ISO 19100 series standards

Requirements of BDGeo modeling	GeoProfile	Classes in the international standards	Standard
Geographical objects in the object view	Point	GM_Point	ISO 19107
	Line	GM_Curve	ISO 19107
	Polygon	GM_Surface	ISO 19107
	ComplexSpatialObj	GM_Complex	ISO 19107
Geographical objects in the field view	TIN	CV_TINCoverage	ISO 19123
	Isolines	CV_SegmentedCurveCoverage	ISO 19123
	AdjPolygons	CV_DiscreteSurfaceCoverage	ISO 19123
	GridOfPoints	CV_DiscreteGridPointCoverage	ISO 19123
	GridOfCells	CV_GridCell	ISO 19123
	IrregularPoint	CV_DiscretePointCoverage	ISO 19123
Network elements	Node	TP_Node	ISO 19107
	Arc	TP_Edge	ISO 19107
	UnidirectionalArc	TP_DirectedEdge	ISO 19107
	BidirectionalArc	TP_DirectedEdge	ISO 19107
Temporal objects	Temporal Object	TM_Object	ISO 19108
	Instant	TM_Instant	ISO 19108
	Interval	TM_Period	ISO 19108

aspects, the correspondence was done by using the GeoProfile network elements. The ISO 19108 standard was used to build the correspondence with elements that represent the temporal aspects of geographic objects and the ISO 19123 standard was used to make the correspondence with the GeoProfile stereotypes which represent the geographic objects perceived in the fields view.

Regarding topological relationships, in which GeoProfile are represented by the *Touch*, *In*, *Cross*, *Overlap* and *Disjoint* stereotypes and extend the *Association* metaclass, in the standard they are dealt with as operations. The ISO 19107 standard specifies these operations, which are inherited by all the geometric classes defined in the standard. Therefore, the correspondence with GeoProfile will not be made, since these operations may be accessed by all the geometric classes, from which the correspondences were made.

5.1 An application example

Figure 2 shows an example of conceptual schema modeled with the GeoProfile. The schema uses a visual notation for the GeoProfile stereotypes. This is a possibility that is suggested by the OMG for UML profiles. In geoDB modeling, several models use a visual notation to represent the geographic objects and their characteristics. Some models use other denominations, such as the "pictograms" developed by Bédard and Larrivée [Bédard and Larrivée 2008]. In these schemas a visual notation for the stereotypes «Polygon» and «Point» is used.

The schema shows four classes, three of them with spatial characteristics, which were represented using GeoProfile stereotypes. This level of abstraction only considers *which* geographic representations are modeled along with some basic attributes, and not *how* they should be implemented. Therefore, the schema is a CIM, which uses concepts that are the closest to the business model.

After the construction of the CIM using the GeoProfile, it should be transformed into a PIM, which will take into account some technical details. Figure 3 shows a PIM resulting from this transformation.

The spatial characteristics were transformed into attributes with types according to the correspondence with the ISO 19100 series standards. For example, the class *City*, which was modeled using the stereotype «Polygon», in this level of abstraction, has a *geometry* attribute of the *GM_ Polygon* type. The same thing was done with the other classes that possess spatial characteristics.

The next step is to transform the PIM into a PSM, it can be, for example, an object-relational

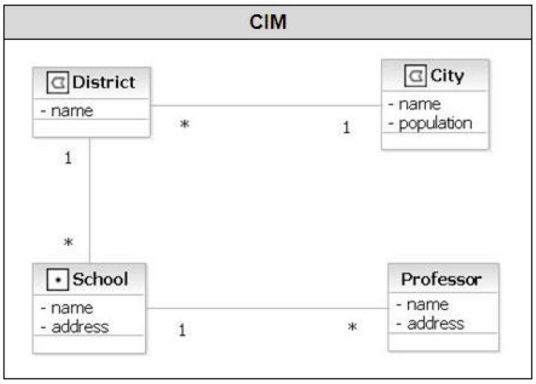

Fig. 2. A GeoProfile data conceptual schema (CIM level)

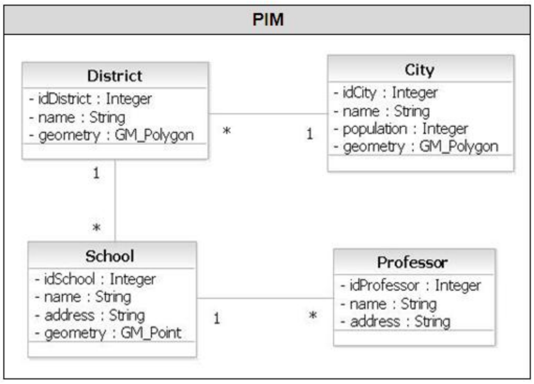

Fig. 3. A conceptual data schema enriched with the ISO 19100 series standards (PIM level)

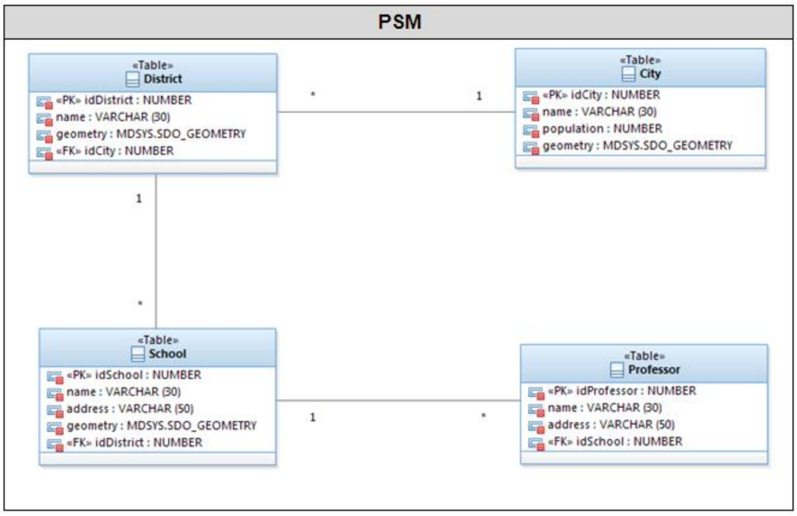

Fig. 4. A logical data schema (PSM level) for *Oracle Spatial*

data model extended to manage spatial objects (e. g., Oracle Spatial or PostGIS). To illustrate this transformation, Figure 4 shows an example of the PSM corresponding to Oracle Spatial, which was generated from the PIM shown in Figure 3. This model already takes into account details of the platform in question, for example, its data types. Some attributes were also marked with the stereotype «PK» and «FK», which represent the primary and foreign keys, respectively. The purpose of this step is to make the model as close as possible to the chosen platform to automate the generation of the database script.

One of the main benefits of the MDA approach is the productivity gain in the development of software systems through the emphasis given to modeling and to the transformation of models from higher abstraction levels into models of lower abstraction levels in an automated way [Kleppe et al. 2003]. The geoDB project can follow these steps. For example, using tools that support model transformation languages, it will enable the generation of models of lower abstraction levels and, later on, models for specific platforms. An example of model transformation language is *Atlas Transformation Language* (ATL) [Jouault and Kurtev 2006]. The schemas shown in this example (Figures 2, 3 and 4) were produced using the GeoProfile in the RSM CASE tool.

6. CONCLUSIONS

GeoProfile development had as its main motivation the fact that it can use UML, together with all its available resources, for example CASE tools, to conceptually model a geographic database. GeoProfile gathers in its definition the main requirements for geographic applications and it uses characteristics of the main existing conceptual data models.

By applying the MDA approach, it was possible to show that GeoProfile could be used in the first step, i. e., to create the Computation Independent Model (CIM). Elements of the ISO 19100 series appear in the second step, i. e., the Platform Independent Model (PIM). Finally, the Platform Specific Model (PSM) corresponds to the implementation model of a specific data model or DBMS. It was shown through an example the use of Oracle Spatial as a PSM, but any other DBMS with spatial support or the Geographic Markup Language (GML) can be used. This process can be automated by developing a transformation model, using ATL, for example. This automation of the transformations constitutes one of the main benefits of the MDA approach.

As future work, we are developing some experiments of the GeoProfile in real geoDB design. The first experience was the use of GeoProfile into the Enterprise Architect CASE tool, in a project of the municipality of Belo Horizonte. Since the designers of this project were used to modeling using OMT-G [Borges et al. 2001], the customization of the graphical stereotypes followed the OMT-G's symbols, but the GeoProfile's metamodel did not change. It solved one of the biggest problems of the OMT-G model, which was exactly the lack of support by a CASE tool.

Finally, the most important result of the use of MDA and GeoProfile aligned with international standards is to reach schema interoperability. More information about GeoProfile, as for example how to customize different CASE tools, can be obtained at http://www.dpi.ufv.br/projetos/geoprofile.

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