INTRODUCTION

Modeling techniques play an important role in the development of database applications. One of the trends in current database management systems is that they become object-relational (Stonebraker & Brown, 1999). The most recent version of the SQL standard, SQL:1999, includes object-relational features, and a number of leading companies have already released packages that incorporate them.

Well-known modeling techniques for relational databases, such as entity-relationship diagrams, do not support important features of object-relational databases. In addition, the development of a database application involves a close working relationship between the software and database developers. Software developers deal with object-oriented software development and use object-oriented modeling techniques, such as a logical class model, to represent the main view of the application, whereas database developers model, design, build, and optimize the database. The most successful projects are marked by a shared vision and clear communication of project details (IBM, 2001). A common modeling language and supporting development tools can provide good conditions for it.

The Unified Modeling Language (UML) was adopted as an Object Management Group (OMG) standard for object modeling in 1997. Since that time, it has become popular and widely used and provides several types of diagrams that visualize a system from different perspectives. From database-design point of view, a class diagram is the most important diagram. It shows a set of structural elements and their static relationships. This model can be used not only as documentation, but also for data definition language (DDL) statements generation. If we want to employ the UML as a modeling language for development of a database application where persistent data is stored in an object-relational database, it is necessary to add the ability to model features of these kinds of databases in an effective and intelligible way, and the UML provides a proper extension mechanism for it. Modeling of an object-relational database schema will be called object-relational modeling in this article.

If we accept three perspectives for drawing class diagrams (Fowler, 2003)—conceptual, specification, and implementation—the need for object-relational modeling is only for the implementation, and possibly specification, levels. A conceptual model should be developed with little or no regard to implementation and a target database environment.

BACKGROUND

The UML provides three extensibility mechanisms that make it possible to extend the language in controlled ways (Booch, Rumbaugh, & Jacobson, 1998; Object Management Group [OMG], 2003):

- stereotypes,
- tagged values, and
- constraints.

A stereotype extends a vocabulary of the UML. It allows the introduction of a new model element derived from one existing in the UML metamodel. A tagged value extends the properties of the UML’s model elements. It is a keyword-value pair element that may be attached to any kind of a model element. The keyword is called a tag. A constraint extends the semantics of a model block by means of specifying conditions and propositions that must be maintained as true, otherwise the system described by the model is invalid. There are some standard stereotypes, tagged values, and constraints predefined in the UML. One of them is a stereotype <<Table>>, which is a stereotype of the UML class element.

The main purpose of the extendability mechanisms is to tailor the UML to the specific needs of a given application domain or target environment. It makes it possible to develop a predefined set of stereotypes, tagged values, and constraints, and notation icons that collectively specialize and tailor the UML for specific domain or process. Such a set is called a profile. Several profiles has already been accepted by OMG as standard profiles, but none of them is for data or object-relational modeling.

Several works that propose extensions of the UML for data and object-relational modeling has been presented. Most of the extensions have been proposed not for SQL:1999 but for Oracle8, because this database management system (DBMS) had provided object extensions
before SQL:1999 was published. Probably the most important proposal has been developed and implemented by Rational Software Corporation in their Rational Rose product, which is one of the best-known UML-oriented modeling tools. It provides support not only for object-oriented database modeling but also for relational database modeling (Rational Software Corp., 2001) and Oracle8 object-relational modeling. The Rose Oracle8 tool permits both forward and backward engineering of Oracle8 object-relational schemas.

Marcos, Vela, and Caverro (2001, 2003) proposed several stereotypes, tagged values, and constraints for the modeling of structured types, typed tables, ARRAY type, REF type, two types of methods in the SQL:1999, and for modeling of similar elements in Oracle8.

The approach presented in this article is based on extensions for Oracle8 by Rational Software, but it can be used for SQL:1999, too. Examples are drawn in Rational Rose, with the Rose Oracle8 tool.

OBJECT-RELATIONAL MODEL IN ORACLE8 AND SQL:1999

Both the SQL:1999 and the SQL dialect of Oracle8 (and more recent releases) extend the relational model in several important directions. Only those modeling features that are presented in this article are summarized. More on new features of the SQL:1999 can be found in Melton & Simon (2001) or in the standard specification (Database Language SQL, 1999). More information on the Oracle object-relational model is available in Oracle documentation (Oracle, 2003a, 2003b).

First, both Oracle8 and SQL:1999 relinquished the basic demand on the relation in the relational model—to be in the 1NF. The user can define user-defined data types. In Oracle, there are two types of user-defined data types: object types and collection types.

An object data type is an abstraction of a real-world entity, the representation of which will be stored in a database. An object type is a schema object with a name, set of attributes and methods. Each attribute is of either a built-in scalar data type or a user-defined data type. This allows for the defining object types with a complex data structure.

Methods of an object data type implement operations with the data type. Every object type has a system-defined constructor method.

An object data type is a template for objects. Objects can be instantiated by the constructor method of a given object type and stored in object tables. An object table can be viewed either as a single column table of row objects or as a multicoloum table. Each row object has assigned a unique object identifier (OID). It can be system-generated or primary-key based. Oracle provides a built-in data type called REF to encapsulate references to row objects. This type can be used to implement links between objects.

There are two collection types available: array types and table types.

Both collection types are sets of data elements of the same type, but there are important differences between them. An array type (called VARRAY) is an ordered and bounded set, whereas a table type (called a nested table) is unordered and unbounded. In addition, a VARRAY data value is stored and retrieved as one data unit, whereas a nested table value is stored in a storage table with every element of the collection mapped into a row of the storage table.

Another object extension concerns views. Just as a relational view is a virtual table, an object view is a virtual object table. Using object views, it is possible to create virtual object tables with columns of both built-in and user-defined data types mapped to columns of relational or object base tables. Object views provide the ability to offer specialized or restricted access to data stored in relational and object tables. In addition, they provide the ability to view relational data as objects. The object view definition contains information about the object type of the view objects, the way of constructing OID, and the mapping SELECT statement.

The Oracle8 object-relational model can be described as a metamodel in the UML (Zendulka, 2001). Although most of Oracle8 extensions are included in SQL:1999, there are some differences. First, the terminology of SQL:1999 differs from that of Oracle8 (e.g., in SQL:1999, object data types are called structured types and object tables/views are referred to as referenceable tables/views). In addition, only array as a collection type is available in SQL:1999. On the other hand, Oracle8 does not support inheritance (more recent versions do) whereas SQL:1999 does.

EXTENSION OF THE UML

The mapping used in Rational Rose Oracle8 can be perceived as a profile definition for object-relational modeling with Oracle8 as a target DBMS. The profile introduces several stereotypes, some constraints in a form of conventions, and tagged values. The tagged values have a form of schema-generation properties attached to a project, class, operation, and attribute. They contain such values as, for example, a WHERE clause of a view definition. Stereotypes of the profile are listed in Table 1.
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