Chapter XVII
Towards a Fuzzy Object–Relational Database Model

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ABSTRACT
This chapter introduces a fuzzy object-relational database model including fuzzy extensions of the basic object-relational databases constructs, the user-defined data types, and the collection types. The fuzzy extensions of these constructs focus on two main flexible aspects, a way to flexibly compare complex data types and an extension of collection types allowing partial membership of its elements. Collection operators are also adapted to consider flexibly comparable domains for its elements. Such a fuzzy object-relational database model, and its implementation in a fuzzy object-relational database management system, provides an easy and effective way to manage a great amount of complex fuzzy data in object-relational databases for emerging fuzzy applications. As a sample of the proposal advantages, an application for dominant color based image retrieval, which is built on an object-relational database management system implementing the proposed fuzzy database model, is introduced.

INTRODUCTION
The introduction of the fuzzy set theory by Prof. Zadeh (1965) has provided the database community with a very useful tool for representing imprecise, uncertain, and inapplicable data. This approach eases and makes flexible the way in which real world data can be represented and managed in databases. Fuzzy databases are databases able to represent and retrieve fuzzy data and, some of them, also able to process flexible queries including weakly defined conditions. Fuzzy databases are a very convenient data storage and retrieval system for dealing with classical and nonclassical
problems in which real world data, user perception, and/or natural language concepts and descriptions are involved.

Research in the field of fuzzy databases has led to a significant number of fuzzy database models. The aim of these models was always to extend current, widespread, and accepted database models in order to make them suitable for fuzzy data storage and retrieval. Fuzzy models have evolved along with the conventional, or crisp, database models to answer data processing needs. During the apogee of the relational model for databases, several fuzzy relational database models appeared. When the object database model appeared for solving some of the lacks in the relational one, the fuzzy database research focused on fuzzy object databases.

In recent years, a new kind of database, the object-relational database, is progressively breaking through in the database mainstream. This kind of database was born in order to solve the relational model lacks by enriching it with some features of object databases. Object-relational databases aim to merge the good qualities of both, the well-known relational model, and the object oriented database paradigm, while neutralizing their drawbacks. Currently, object-relational databases are well accepted by database professionals and manufacturers, and their most important concepts are gradually being incorporated in recent SQL standards. As object-relational databases are gradually conquering the database market, it seems natural to work on their extension to allow fuzzy data storage and retrieval. In fact, this kind of database is very suitable for such an extension, as one of its most important features is its extensibility.

This chapter proposes a model that extends object-relational databases for fuzzy data representation and querying. This model makes the database able to represent a number of new types of fuzzy data that are derived from the extension of the basic object-relational databases constructs, the user defined complex data types, and the multi-valued attribute. Additionally, the model also supports all fuzzy data types that were considered in earlier models.

The chapter is organized as follows. First, the chapter includes an introduction on object-relational databases. Second, a brief background on fuzzy databases is also presented. Afterwards, the proposed fuzzy object-relational database model is depicted. Next, the basis of an implementation of a fuzzy object relational database management system (FORDBMS), which is based on the proposed model, is described. Then, an application of the introduced FORDBMS and some examples of its queries are given. Finally, some concluding remarks and future research directions are proposed.

**OBJECT-RELATIONAL DATABASES**

Even though nowadays the relational model is the most commonly used model in database theory and practice, as computer applications started to manage large amounts of complex data, it was noticed that this database model was not very suitable for managing complex data. The relational model faces special difficulties to manage complex data resulting from the composition of other data elements, which is very common in computer aided design, geographical information systems, and multimedia applications. A relational database stores the data elements of an entity in a relation and relates a complex data element with its components by foreign keys. When the application requires retrieving a complex data element, a number of join predicates has to be performed to gather all its atomic components, which lead to severe performance reductions.

The aim to seamlessly represent and manage complex data in databases led the database community to propose the concept of object oriented DBMS (OODBMS). An OODBMS represents data elements as objects. The objects are uniquely identified by an object identifier, or oid, that substitutes the primary key concept of the relational model. Data are modeled using classes of objects and following the object oriented principles: encapsulation, inheritance, and polymorphism. Moreover, the procedures related to the manipulation of the data,
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