SPATIAL DEDUCTIVE DATABASE

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ABSTRACT

This paper presents a new architecture of database to deal with the complex structure and large volume of the spatial data. The object-oriented technology, which has the powerful modeling ability to describe the complex objects, is used to model the spatial objects. The massive storage that is base on the tertiary storage device is preferred to the large volume of spatial data. The deductive rules help to form more powerful query, optimize the query process and accelerate the data retrieval. Here we integrate the technologies of object-oriented, massive storage and deductive database into the traditional spatial database and build a new framework in which each part is described in detail.

1 INTRODUCTION

The number of computer applications in which database systems called spatial databases are used to store and manage spatial information has grown rapidly during the last decades. CAD/CAM, VLSI-design, robotics, Geographical Information Systems (GIS), and medical imaging are only a few examples of applications that use two-dimensional or three-dimensional spatial information (Kuipers, 1995, Grumbach, 1998, Kim, 1993). The main characters of spatial data are the complex structure and large volume.

The goals of the spatial database systems (Paredaens, 1995) are to extend existing database management systems by introducing rather trivial spatial data types and extending SQL in an ad hoc way. They mainly consider about the data type and operations, but neglect the spatial relations between the spatial objects. The object-oriented approach (Fernandes, 1997) provides comprehensive mechanisms for structuring both programs and the data to which they relate. So it is used to enhance the modeling capability of spatial database, and the technology of deductive databases is used to describe the rich relationships between the spatial objects.

The deductive database uses the deductive rules to make the database more practical. A deductive database system (Lu, 1995) integrates logic programming with relational database technology and constructs a high-level, deductive query interface supported by rules. The deductive approach (Fernandes, 1997) supports the declarative expression of queries and rules in the context of data models that are essentially relational and a formal frame that builds upon first order logic.

The spatial data handling needs the deductive and object-oriented technologies and their integration with spatial database systems, based on the following observation:

(1) Many spatial relationships can be expressed concisely and conveniently as logical rules and/or integrity constraint, on which powerful spatial reasoning mechanisms can be developed.
(2) The complexity of spatial data modeling and complex spatial object management can be coped with object-oriented technology.

The tradition second storage cannot hold on the large volume of the spatial data. And the tertiary storage devices such as magnetic tapes and compact disks are hard to manage. The massive storage technology must be used to deal with the spatial data and provide convenient and efficient retrieval of the data.

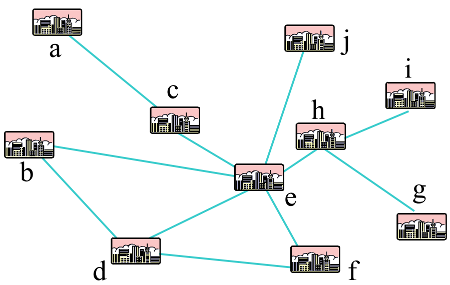

Figure 1 A road map

Let's look at the example (Figure 1). Travel information is often provided to the train traveler by means of a spatial database such as the railway map shown in Figure 1. In the above map, points labeled with the city name represent the stations and train tracks between the stations are represented by curves connecting these points. Such spatial databases don't have exact geographic information. There is no information in this map concerning the exact position of stations. And there is not such question as "What is the distance between Peiking and Shanghai?" Since the traveler's main concern is not the longitude or the latitude of cities. Using the technologies of object-oriented and deductive make it is very easy to deal with such queries.

The remainder of the paper is organized as follows: In section 2, some preliminary concepts are presented. Section 3 gives out the architecture of the spatial deductive database and describes each part in detail. Section 4 concludes the paper.

2 PRELIMINARY CONCEPTS

In this section, the concepts of GIS, the Spatial Databse, Spatial Queries, the Deductive Database, the Object-Oriented Technology and Massive Storage are presented.

2.1 GIS and Spatial Database

GIS is the main application of spatial database. Geography Information Systems (Shekhar, 1997) are used to collect, analyze and present information describing the physical and logical properties of the geographic world. Geographically referenced data is the spatial data that pertain to a location on the earth's surface. The four major functional units in a typical GIS are: Data Input Unit, Data Model, Data Manipulation Capabilities and Result Presentation Facilities.

Most of the existing Geographic Information Systems (Grumbach, 1998) rely on a strict distinction between alphanumerical data and geometric data. For instance, Arc/Info extends an efficient module (ARC) for manipulating geometric and topological information with a relational module (INFO) for manipulating alphanumeric information associated with geometric objects. Initially, spatial database management systems for such applications were built by extending traditional database management systems by introducing rather trivial spatial data types and by extending SQL in an application-dependent way. Current efforts in spatial database systems, however, aim at developing systems that are specifically suited to deal with spatial information, but which are nevertheless application-independent (Gunther, 1990).

Spatial database systems (Shekhar, 1999) aim at the effective and efficient management of spatial data. Commercial examples of spatial database management include Informix's spatial data-blades, Oracle's Universal server with either Spatial Data Options or Spatial Data Cartridge and ESRI's Spatial Data Engine. However, their model capabilities are also very weak.

2.2 The Spatial Queries

Queries in GIS use spatial relationships within the query predicates. Spatial relationships can be organized into three categories (Guting, 1994, Papadimitriou, 1996):

- Topological relationships: These include connected, adjacent, inside and disjoint. These are invariable under topological transformations like translation, scaling and rotation.
- Direction relationships: These include above, below, or north_of, southwest_of.
- Metric relationships. These include relationships such as the distance between two entities.

Queries in spatial databases involve set operations on the geometric and topological properties of spatial entities. These set-operations could be classified into the following groups (Shashi, 1997, Guting, 1994, Papadias, 1998):

- *Spatial selection* of a subset from an entity set that fulfills a spatial predicate. Some examples are: *Find all cities in Henan, Find all cities no more than 500 miles from Peiking.*
- *Spatial join* produces a set of pairs of spatial objects from two layers or entities that satisfies a spatial predicate. For example: *For each river, find all cities within 50 miles.*
- *Transformation* synthesizes a set of layers (a set of spatial objects) into a new layer using spatial predicates. Some examples are: *Map generalization, transformation of vector layer to raster representation.*
- *Network analysis* represents a set of queries on spatial networks, such as route evaluation, network overlay and path optimization. Route evaluation is concerned with aggregating attribute data over route-units. A route-unit represents a collection of arcs with common characteristics (e.g., name). A network overlay enables the integration of disparate network-attribute databases, which join two or more sets of attributes. Path Optimization models several problems, including shortest path analysis and optimum tour routing.
- Some other various set operations including fusion, nearest neighbor, etc.

2.3 The Deductive Database

The term *deductive database* (DD) (Tsur, 1991, Sagonas, 1994) has been applied to a class of database systems that extend the power of relational systems (Figure.2), as e.g. embodied by SQL, in several ways:

1. The capability to express, by means of logical rules, recursive queries and the efficient algorithms for their evaluation against the stored data.
2. Support for the use of nonmonotonic features such as negation. This entails selecting a minimal fixpoint that reflects the intended meaning in situations where the minimal fixpoint may not be unique.
3. The expansion of the underlying data domain to include structured objects such as trees, lists and sets.
4. Extensions beyond first-order logic for the declarative specification of such database operations as updates.
5. The development of optimization methods that guarantee the translation of the declarative specifications into efficient access plans and their termination when executed.

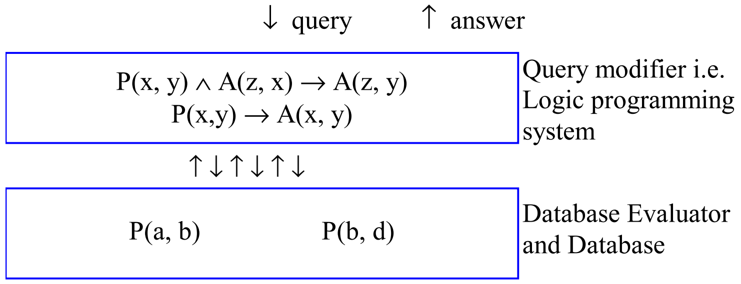

Figure 2 The components of deductive databases

The technology deployment and its use for application development by practitioners is of a vital interest to the database research community for two reasons:

1. Wide accept will ensure continued funding and support for further theoretical and technical development in the area.
2. Applications are a rich source of problems that would benefit from a theoretical treatment.

The problems that appear to benefit from the DD technology fall into the following categories:

1. Extensions to traditional database applications.
2. Exploratory data analysis.
3. Enterprise modeling and information systems design.
4. Scientific databases.

As an important extension to relational approach (as Fig.3), research into deductive database systems represents a direction towards declarative query processing, high-level database programming, and integration of logic programming and relational database technology (Han, 1994, Remarkrishnan, 1993).

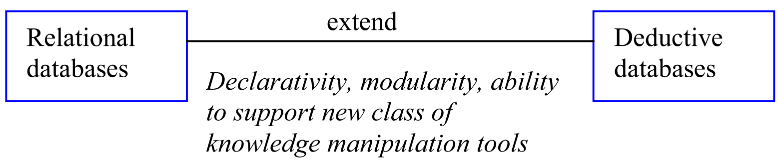

Figure 3 Relational database to deductive database

2.4 The Object Oriented Technology

The basic concept is presented in Figure 4. The objects are organized as classes that have attributes and methods that are defined by deduction rules, computational routines, property inheritance rules, class composition (aggregation) hierarchies, class associations, concrete values and so on. An object-oriented database design integrates object-oriented programming with database technology and provides us with powerful tools for semantic data modeling, construction of class hierarchy and property inheritance, methods manipulation, etc.

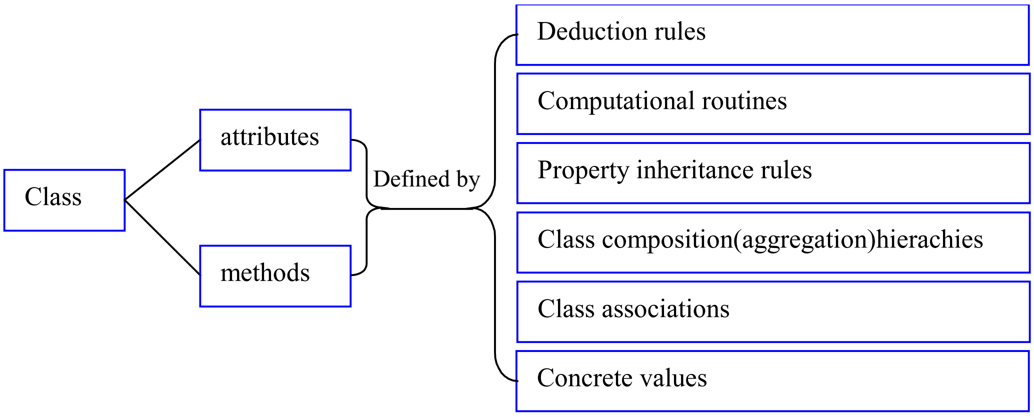

Figure 4 The structure of class

2.5 The Massive Storage

The massive storage systems are usually based on the next management methods:

- Hierarchy storage management: It is hierarchically manage the storage structure that is “second storage memory---on line tertiary storage memory---off line tertiary storage memory”, i.e. the management of the buffer---on line storage---off line storage. The main feature is that the access unit is file, such as Unitree Central File Management (UCFM) and High Performance Storage System (HPSS).
- Multi-level storage management: It manages the storage structure that is consisted of the main memory, second memory storage, online tertiary memory storage and offline tertiary memory storage. The most important feature is that the data is distributed on every storage devices according to the requirement and the characters of the devices, and the retrieval to every kind of storage is according to the necessary (one or several parts of the one file and multi-files), such as the storage systems of Postgres--database and Paradise–object-relation database.

The characters of the storage space:

- The storage space is large and extends fast: It is considering the extensibility of the system;
- Heterogeneity of the storage medias: These medias are main memory, the magnetic disk, compact disk and magnetic tape;
- Physical online space can shift: It is because of the existence of the warehouses of the magnetic types and the compact disks that have the movable device.
- Good for parallel operation: It is because of the lots of independent medias.

2.6 The Deductive Object-Oriented Database (DOOD)

The DOOD (Vieille, 1993) (Figure 5) system combine the novel functionalities (relying on the associated technology) developed in deductive database projects, the ability to manipulate the complex objects appearing in many applications and the architectural advances achieved by Object-Oriented DBMS’s. DOOD is based on the modeling of the complex objects and data abstract ability that are the kernel, and takes the OODB query language based on rule as the interface language.

A deductive and object-oriented spatial (DOOS) (Lu, 1995) database system enhances a spatial database system with deductive and object-oriented features.

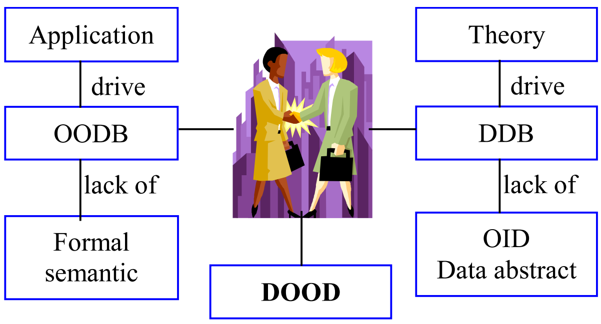

Figure 5 The combination of OODB and DDB

3 THE ARCHITECTURE OF THE SPATIAL DATABASE BASED ON THE TECHNOLOGIES OF OBJECT-ORIENTED, DEDUCTIVE DATABASE AND MASSIVE STORAGE

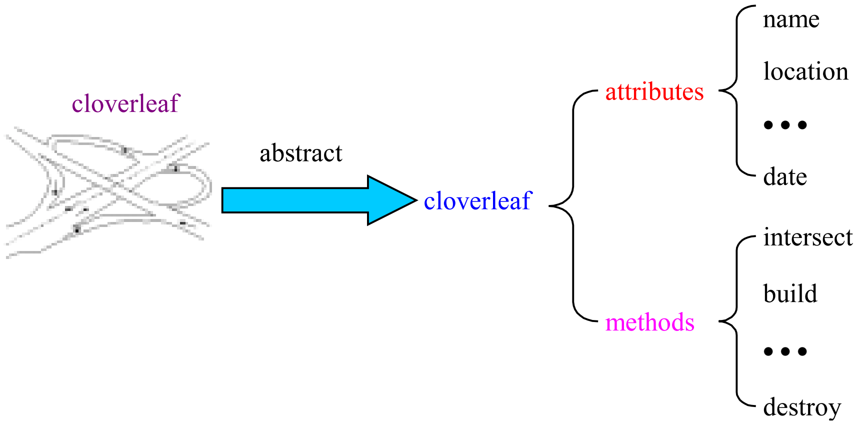

Figure 6 Using the OO technology to extract the attributes and methods of cloverleaf

3.1 The Modeling of the Spatial Objects

The spatial representation considers the following aspects: what kinds of spatial entity (i.e. ontology), and what kinds of relationship between these kinds of spatial entity (for example, their topology, size and distance between them, or their shape). The spatial objects are very complex, so the object-oriented technology should be used to extract the attributes and operations of them, as Figure 6.

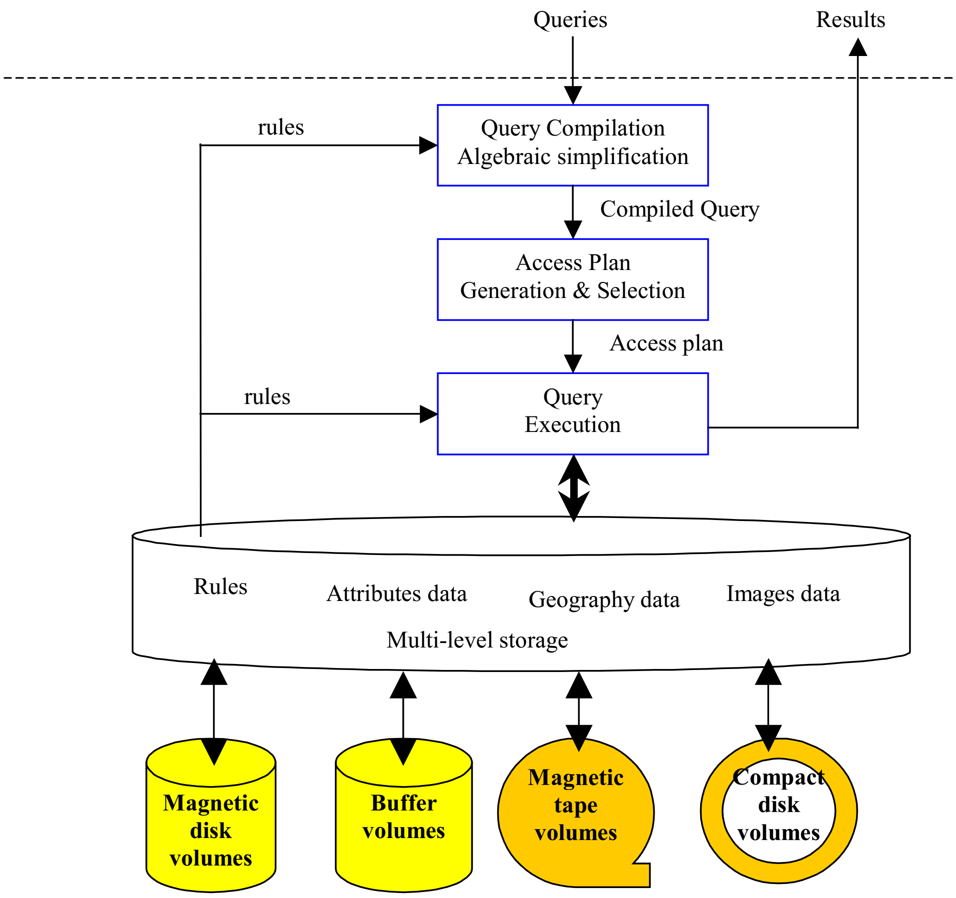

Figure 7 The architecture of the spatial deductive database

3.2 The Architecture of the Spatial Deductive Database

As Figure 7, the architecture of spatial deductive database can be divided into the following parts: (1) Query compilation and algebraic simplification; (2) Access plan generation & selection; (3) Query execution; (4) Multi-level storage. These four parts are presented below.

3.3 The Query Compilation and Algebraic Simplification

A deductive spatial query can be done in these steps: (1) Compilation of a high-level deductive query into a set of primitive level predicates or method calls; (2) Optimizing an algebraic simplification of the compiled query expressions. The deductive rules can be converted to (1) primitive relational operations; (2) spatial operations; (3) method calls.

3.4 Access Plan: Generation & Selection

To the compiled query, this step generates a set of candidate query access plans by a dynamic candidate graph transformation technique and selects a sub-optimal query processing plan based on relational and spatial indexing information and database statistics. In the selection, it is should minimizes the impedance mismatch by promoting set-oriented processing of relational, geo-relational operations together with computationally intensive spatial methods. A set of optimizing techniques are studied, including performing first less expensive operations on highly selective operands, preprocessing techniques, grouped and pipelined processing to minimize the size of intermediate data, etc.

3.5 Query Execution

During this process, the query manager executes the query under the rules that can be used as heuristic principles to accelerate the query, such as prune the unnecessary candidate in the search tree.

3.6 Multi-level Storage

The multi-level storage consists of four parts: magnetic disk volumes, buffer volumes, magnetic tape volumes and compact disk volumes. The placement of the various data is according to the database manager or some rules, the goal is to provide the users with the most efficient search, i.e. costs the minimum search time. Such as, the most used data can be placed in the faster storage devices using LRU algorithm, or put the buffer in the faster storage devices.

4 CONCLUSION

In this paper, the existing technologies including spatial database, deductive database, object-oriented and massive storage are discussed. The architecture of the spatial deductive system is presented. This architecture is appropriate to the complex and massive spatial data. In the future, we will fulfill the functions of each part, and do more deep research.

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