EVALUATING AND EXTENDING SPATIO-TEMPORAL DATABASE FUNCTIONALITIES FOR MOVING OBJECTS

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ABSTRACT:
Miniaturization of computing devices, and advances in wireless communication and positioning systems will create a wide and increasing range of database applications such as location-based services, tracking and transportation systems that has to deal with Moving Objects. Various types of queries could be posted to moving objects, including past, present and future queries. The key problem is how to model the location of moving objects and enable Database Management System (DBMS) to predict the future location of a moving object. It is obvious that there is a need for an innovative, generic, conceptually clean and application-independent approach for spatio-temporal handling data.
This paper presents behavioral aspect of the spatio-temporal databases for managing and querying moving objects. Our objective is to impelement and extend the Spatial TAU (STAU) system developed by Dr.Pelekis that provides spatio-temporal functionality to an Object-Relational Database Management System to support modeling and querying moving objecs. The results of the impelementation are demonstrated in this paper.

KEY WORDS: GIS, Moving Object, MOD, DBMS, Spatio-temporal.

1. Introduction

Miniaturization of computing devices, and advances in wireless communication and positioning systems will create a wide and increasing range of database applications such as location-based services, emergency response, tracking and transportation systems and air traffic controlling systems. This new classes of applications has to deal with spatial objects whose position or extend changes continuously over time, for short, called Moving Objects.

Various types of queries could be posted to moving objects, including past, present and future queries. The key problem is how to model the location of moving objects and enable Database Management System (DBMS) to predict the future location of a moving object by using efficient index and query manners. DBMS's technology provides a potential foundation upon which to develop Moving Object Database (MOD) applications, however, Existing DBMS's are not well equipped to handle continuously changing data becouse there is a critical set of capabilities that have to be integrated, adapted, and built on top of existing DBMS's in order to support moving objects databases including location data model, query language, support for spatial and temporal information, support for rapidly changing real time data.

It is obvious that there is a need for an innovative, generic, conceptually clean and application-independent approach for spatio-temporal handling data. As such, the aim of this resarch is to propose and extend a spatio-temporal extention to an existing DBMS that will be capable for modeling, managing and querying a database with moving objects, and to build an application on top of this spatio-temporal database. Supporting spatio-temporal objects that change position or extent continuously as well as all pure spatial and temporal data types is the subject that is considered in this research. The aim is to support spatio-temporal queries for location information not only in the past and at present, but also in the future.

2. Moving Object Database (MOD)

A wide and increasing range of database applications such as tracking and transportation systems and air traffic controlling systems has to deal with spatio-temporal objects. Two types of spatio-temporal objects may be distinguished, namely discretely moving objects and continuously moving objects. Objects that change position or extent continuously, termed moving objects, for short, are pervasive but in contrast to the discretely changing objects, they are much more difficult to accommodate in the database.

Spatio-temporal database is a database that embodies spatial, temporal, and spatio-temporal database concepts, and captures spatial and temporal aspects of data. Spatio-temporal Database is a special temporal database and it has all the features of temporal databases. If we look at any timestamp only, it is almost the same as the conventional spatial database. An ideal spatio-temporal database, besides having the normal functions essential to every spatial database, also has the ability for keeping track of changed data. In such databases, the mechanism of renewing the most recent spatial and temporal topologies is implemented.

In Moving Object Database (MOD) applications, it is expected that a large number of updates are issued to a database and a large amount of trajectory data are stored and are manipulated. Querying and information or knowledge retrieval tools are needed. Indexing mechanisms and efficient query evaluation techniques are required so that useful information can be made available to a user in a timely fashion.

Moving object databases are becoming more popular due to the increasing number of application domains that deal with moving entities and need to pose queries. In the military, MOD applications arise in the context of the digital battlefield, and in the civilian industry they arise in transportation systems.

There is a critical set of capabilities that have to be integrated to existing DBMS's for moving objects databases. These capabilities are divided in four categories: Location Modeling, Linguistics Issues for query languages, indexing method and Uncertainty/Imprecision issues. [17]

Our objective is to build an envelope containing these capabilities specifically Modeling location and query language on top of Object-Relational Oracle 10g DBMS.

3. Spatio- temporal Queries

A query in a spatio-temporal database is a predicate over the database history. Queries can be classified as spatial, temporal or spatio-temporal queries based on the type of relation ships between objects. Spatial queries can return spatial attributes or attributes calculated from them, and are formulated in terms of spatial operators. Temporal queries are those containing at least one temporal operator and no spatial operator. Spatio-temporal queries involve spatial and temporal predicates, using spatio-temporal operators. [5]

Three types of spatio-temporal queries can be considered based on the history on which the query is evaluated and on the evaluation time; instantaneous, continuous and persistent. The same query may be entered as instantaneous, continuous and persistent, producing different results in each case. In contrast, in traditional databases the situation is simpler. An instantaneous query is a predicate on the current database state, and a continuous query is a predicate on each one of the future states. continuous and persistent queries can be used to define temporal triggers. [22]

Based on the temporal state of database, queris can be divided into past, at present and future queries. When querying moving objects, the users may be interested in the past or current position information. However, in many circumstances, location information in the future, especially in the far future, may be more attractive to querying users.

In MOD, most queries Based on the Spatio-temporal geometry, fall into the three categories as point query, range query and k-nearest neighbor (KNN) query. Point queries search for the location of a certain moving object at a given time instant. Range queries search moving objects that cross a given geographic region in a given time period. An example of k-nearest neighbor query is "find k moving objects which are closest to (xq , yq) around time tq". Different from range queries, KNN queries are evaluated by incremental searching. [26]

4. Comparison of different DBMS

With concider to spatio-temporal database specifications, and based on the capabilities that are needed by moving objects database applications, some existance DBMS's are evaluated to find best DBMS to extend it for design and development a moving object database. DBMS such as Oracle, DB2 universal database that is short form of database 2 universal database an IBM production, Microsoft SQL server 2000 and also MySQL and PostgreSQL as Open source databases. In summery, different DBMS package has different features and capabilities. [3]

As conclusion, with consider to specifications of different commercial database management systems and based on the capabilities that are needed by moving objects database applications, we recommend Oracle as the first choice for managing spatio-temporal data. DB2 universal database and SQL server are the next alternatives. [2]

Oracle database include different languages and interfaces that allow programmers to access and manipulate the data in the database. Oracle PL/SQL, a procedural language extension to SQL, is commonly used to implement program logic modules for applications.PL/SQL is a completely portable, high-performance transaction processing language, which bridges the gap between database technology and procedural programming languages and offers several advantages. Additionally, applications written in PL/SQL are portable to any operating system and platform on which Oracle runs. One of the strongest features of the Oracle database is its ability to scale up to handle extremely large volumes of data and users. Oracle scales not only by running on more and more powerful platforms, but also by running in a distributed configuration. Oracle database on separate platforms can be combined to act as a single logical distributed database. [23]

A major feature of Oracle is Oracle Spatial. This is a spatial extender that provides storage, indexing and proximity queries for location-based information, which may include road networks, wireless service boundaries and geo-coded customer addresses. Oracle Spatial, an option to Oracle Database Enterprise Edition, provides a robust foundation for complex GIS applications which require more spatial analysis and processing in Oracle Database.[23]

In addition to the efficient and secure management of data ordered under the relational model, Oracle provides support for data organized under the object model. Object types and other features such as large objects (LOBs), external procedures, extensible indexing, and query optimization can be used to build powerful, reusable server-based components called data cartridges. Data cartridges extend the capabilities of the Oracle server. By data cartridges, the database user is able to define own complex data type and manipulate and store this object in a single column, in a single row in a database table by means of nested tables. The most important technical characteristic of Oracle10g utilized in the implementation of all of the moving types is the nested table feature that enables us to model the moving types as collections of their corresponding unit moving types.[2]

5. Spatio-Temporal Data Models

Development and research in Spatio-temporal databases area started decades ago. Since the beginning of research into spatio-temporal databases, an abundance of spatio-temporal data models have been presented. They define object data types, relationships, operations and rules to maintain database integrity. The most recent approaches are Moving Object Data Models. Researchers have tried to model spatio-temporal databases using the concept of moving object. This approach models the time as integral part of the spatial entities. The time dimension is based on the linear, discrete/continuous, absolute time model and initially only valid time is considered. The model captures both change and movement and it is well suited for all types of spatio-temporal queries. [11]

In comparison of different Spatio-temporal data model it is concluded that in terms of temporal semantics all of the models support multiple granularities except moving objects that is directly associated with the finest granularity. The tactic that is followed by the moving objects approach where time is incorporated as integral part of the spatial entities in terms of simple continuous functions is the best method that should be followed by a new, generic spatio-temporal model. In terms of spatial semantics the majority of the models assume vector structure of space. Object-oriented approaches and moving objects model are the only models that support all types of spatial data handling, in terms of measurement, topological relationships. In terms of spatio-temporal semantics, almost all models are capable to handle discrete changes, while movement and continuous change is considered in moving objects models. Only object-oriented and moving object approaches maintain methods and functions for defining the topology and measuring the evolution of spatio-temporal objects in space and time. In terms of query capability, all models have adequate support for attribute and simple queries in all spatial, temporal and spatio-temporal queries and only Moving objects models can resolve any type of spatio-temporal query. [11]

An interesting approach following the paradigm of moving objects was presented in STAU project proposed by Dr.Nikos Pelekis in 2002. [12]This research was focused on the representation and querying of continuously as well as discretely moving objects. From a theoretical point of view Pelekis proposed a datatype-oriented model that supports the representation of objects both under object-oriented and object relational platforms. From a technical point of view, two data cartridges under the Object-Relational DBMS of ORACLE were developed. The first cartridge provides pure temporal functionality implementing TAU Temporal Types. The second cartridge supports the previously mentioned spatio-temporal data types and has been implemented by merging the temporal cartridge with Oracle's Spatial cartridge that offers an integrated set of operations on pure spatial data. The resulted system supports a wide set of object methods that extend Oracle's query language PL/SQL with spatio-temporal semantics. [11]

6. Spatial TAU System (STAU)

One of the models that follow moving objects model was proposed by Dr. Nikolas Pelekis in 2002 for querying of continuously and discretely moving objects under object-oriented and object relational platforms. STAU system models the time as integral part of the spatial entities. Spatial TAU system provides spatio-temporal object-relational database functionality in the form of extensible Oracle 10g data cartridges.

The main components of the STAU system are: [12]

- TAU TLL Data Cartridge
- Spatial Data Cartridge
- Moving Data cartridge

TAU TLL Data Cartridge is the object-relational solution for temporal issues. TAU TLL cartridge is the mapping of the TAU time model into object relational database technology. The model supports multiple granularities, and absolute times. User defined times are supported through the temporal literal types, which augment the four Standard temporal data types namely, Date, Time, Timestamp and Interval, with three new temporal object data types: Timepoint, Period and Temporal Element. TAU Temporal Literal Library has been implemented in C++ and is the base for the development of the TAU TLL data cartridge.

The STAU system is provided with pure spatial object-relational functionality by this data cartridge. Spatial Data Cartridge is implemented by Oracle and is an integrated set of functions and procedures that enable spatial data to be stored, accessed, and analyzed quickly and efficiently in an Oracle10g database. The geometric operations, which form the behaviour of the object types supported by this data cartridge, handle queries statically, meaning that there does not exist intrinsically the notion of time associated with the spatial objects. [12]

Moving Data Cartridge (STAU-MDC) is the most important components of the STAU system architecture and supports spatio-temporal object data types. Types in STAU System are divided into Base Types, pure Temporal Types, pure Spatial Types and Moving Types. Base types contain primitive types such as Boolean, short, long, double (real), char and string. Pure temporal types consist of the object types introduced in TAU-TLL, such as date, time, timestamp, interval, timepoint, period, and temporal element. Pure spatial types represented by the SDO_GEOMETRY object type.

6.1 Moving Types

The *sliced representation* concept is adopted by the spatio-temporal data model that utilized in the implementation of STAU-MDC. The basic idea of the concept of sliced representation is to decompose the temporal development of a moving value into "slices" such that within the slice this development can be described by some kind of "simple" function. In order to use the sliced representation to define a moving type, each moving type decomposes into several *unit* moving type that corresponds to a simple function. (See Figure 1)

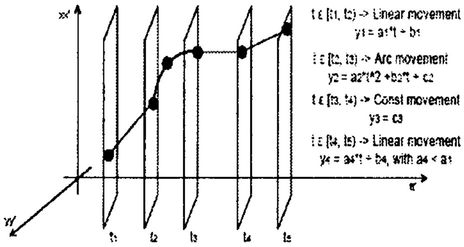

Figure 1, Sliced representation [12]

Based on this approach, there are two real world notions that are directly mapped to the STAU model as object types, namely time period and simple function. There exists a composition relationship between the unit moving type and the moving type, which means, each moving type is a collection of each corresponding unit moving type. As such, the Moving_Point, was introduced as a collection of Unit_Moving_Point, object types. Similarly, multi-moving types were defined as collections of the corresponding moving types. Moving_Collection object type, which aggregates the interfaces, the object methods and the spatio-temporal semantics of all the multi moving types. Moving_Object object type is the conjunction of all the other moving object types and also models any moving type that can be the result of an operation between moving objects. Summarizing, Figure 5.4 illustrates a UML class diagram for STAU-MDC.

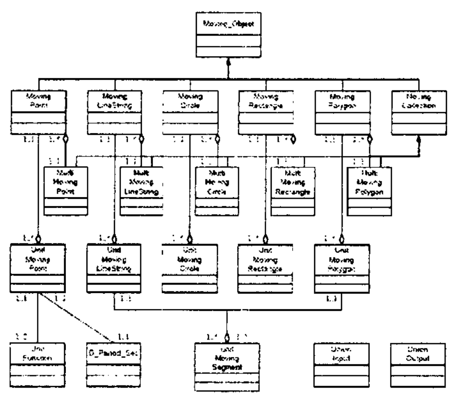

Figure 2, UML Class diagram for STAU-MDC [12]

6.2 Operations on Moving Object Data Types

The operations of the moving types introduced by STAU-MDC are classified into appropriate categories that enable us to describe and analyze the new query capabilities. [13]

- Checking operations are responsible for keeping the database in a consistent state.
- Predicates are operations that return Boolean values concerning topological and other relationships between moving types.
- Projection and interaction to temporal and spatial domain are Operations that restrict and project moving types to temporal and spatial domain.
- Numeric operations are functions that compute some numeric value such as the perimeter of a moving polygon.
- Distance and direction operations facilitate the computation of for example the minimum distance between moving types or the angle formed between moving points, at user defined instants.
- Set relationships include basic set operations, such as the set union and set intersection.
- Rate of change operations describing the rate of change of motion properties of the time-dependent object types.

7 Developing an Object-Relational Database for Truck Companies

A number of big truck-transportation companies need a flexible and easy way to supervise the motion of their lorries that transfer commercial products. For such companies it is crucial not only to know where is the exact current location of all of their trucks, but they also need to plan future routes so they can improve the effectiveness of their transportation network to keep their clients satisfied. In general, the ability to model and query the spatio-temporal configuration and activities of such companies would be an important aid to the decision makers of the companies. In this section, an application example that considers the evolution of trucks in space and time will be presented in a very simplified manner and the expressive power and the applicability of STAU data cartridges in such a commercial domain will be demonstrated. In order to present the capabilities of the data cartridges introduced by STAU system and all the interesting spatio-temporal phenomena applying in the previously discussed domain of truck motion analysis, a series of object relational database tables are constructed and are separated in two categories. The first set consisting of the following six relations describes topologically the environment inside which the trucks are moving. These object tables include PROVINCE, ROAD, CITIES FUELST, POLICE, and TERMINALS. [2]

More specifically, the PROVINCE relation is a set of polygon geometries describing the territories of several provinces in the south-west and centeral parts of Iran and the ROAD relation is a set of linestring geometries along which the lorries are supposed to be moving. Other relation contains positions of certain well-known sites such as petrol stations, citiy centers, police stations, etc. The second category is composed of the subsequent three object relational database tables. [2]

Truck (company: Varchar2, id: Varchar2, type: Varchar2, route: Moving_Point)

Weather (name: Varchar2, kind: Varchar2, extent: Moving_Polygon)

Truck_Companies (company: Varchar2, trucks: Moving_Collection)

Attributes company and id of the relation Truck identify the route of a lorry that is modeled as a moving point. The type attribute stamps each lorry with a characteristic description of each kind (e.g. refrigerator, container, etc.). For all other relations the first attribute plays the role of the primary key of the relation. The relation Weather records weather events that could influence the route or the schedule of a truck such as hurricanes, storms, or temperature maps. Some of these events are given names to identify them. The attribute kind gives the type of the weather event, such as "snowstorm" or "tornado", and the extent attribute provides the time-varying area of each weather phenomenon.

8 Querying the Object Relational Database for trucks

In this section some example of common spatio-temporal queries that would require answer in the domain of the application example are introduced.

- *What distance does truck "100" of company "A" traverse over "Khozestan"?*

This first query shows that pure spatial objects as well as moving types can be stored and retrieved by traditional database tables following the same syntax, as they were standard data types. Having in hand two variables, one of type Moving_Point describing the truck and another of type SDO_GEOMETRY describing the territory of Khozestan, the query can be resolved by finding the intersection of Khozestan with the trajectory followed by the truck. This query can be answered just with pure spatial operations (offered by Oracle) upon the trajectory of the moving truck, which is basically the projection of the time-varying point on the spatial domain.

- *What are the departure & arrival times of truck "100" of company "A"?*

In this query, in order to calculate the departure and arrival timepoints of the moving point, the latter is projected on the continuous time line and as such finding the temporal element that consists of the time periods for which are defined the unit moving objects of the moving truck. The departure of the truck can be estimated as the starting second of the first period of the temporal element and its arrival as the ending second of the last period of the temporal element.

- *Give a list of options to driver of truck "100" of company "A" to refuel his truck in the next 50km?*

In this simple example the capability of STAU system to answer queries that need an immediate response, meaning that they refer to current needs and situations, is exhibited.

- *For which periods of time was truck "100" within storm "B"?*

This query is an example of that a moving type can be restricted inside another moving type. This operation returns a time-varying string that at each timepoint verifies if the mask parameter stands for the two involved moving types.

9 Conclusions

From the above presented research, the following conclusions can be made:

- We recommend Oracle as the first choice for managing spatio-temporal data. DB2 universal database and SQL server are the next alternatives.
- The STAU system, can be considered as a system that is able to satisfy any demand in manipulating spatio-temporal data.
- Modelling and querying of moving objects is the main functionality of the STAU system
- The temporal functionality of the STAU is provided through the Temporal Literal Library (TLL) as a data cartridge
- The spatial functionality of the STAU is provided by Oracle as a separate data cartridge
- A uniform representation of all kinds of geometries (SDO_GEOMETRY), increases the flexibility and the interoperability between moving types and pure spatial objects.
- In addition to Spatio-temporal queries, the STAU system can answer to pure spatial and pure temporal queries
- STAU system supports all of Past,at present and future queries.
- STAU system offer a solution to some problems in dealing with large amount of moving objects such as TIS

10 Recommendations for future works

Due to the fact that this research concerns only 2-Dimensional spatial objects as well as the change and motion of such geometries in the 2D Cartesian plane, there is need to investigate the way that could model surfaces and 3-Dimensional spatial objects and the time-changing variants of them.

Moreover, with consider to the fact that the STAU system eventuate a series of textual spatio-temporal queries and the result of queries are also offered in text format, there is a need to develop the system with a appropriate Graphical User Interface (GUI) in order to add visual functionalities to the system.

The indexing method and uncertainty and imprecision issues and the updating process of the data are some other aspects of a spatio-temporal database that should be considered as future works and there is a need for more investigation on these areas.

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