Building Spatio-Temporal Database Model Based on Ontological Approach using Relational Database Environment

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ABSTRACT

Everything in this world is encapsulated by space and time fence. Our daily life activities are utterly linked and related with other objects in vicinity. Therefore, a strong relationship exist with our current location, time (including past, present and future) and event through with we are moving as an object also affect our activities in life. Ontology development and its integration with database are vital for the true understanding of the complex systems involving both spatial and temporal dimensions. In this paper we propose a conceptual framework for building spatio-temporal database model based on ontological approach. We have used relational data model for modelling spatio-temporal data content and present our methodology with spatio-temporal ontological accepts and its transformation into spatio-temporal database model. We illustrate the implementation of our conceptual model through a case study related to cultivated land parcel used for agriculture to exhibit the spatio-temporal behaviour of agricultural land and related entities. Moreover, it provides a generic approach for designing spatio-temporal databases based on ontology. The proposed model is capable to understand the ontological and somehow epistemological commitments and to build spatio-temporal ontology and transform it into a spatio-temporal data model. Finally, we highlight the existing and future research challenges.

Key Words **Ontology, Spatio-Temporal Data, Spatio-Temporal Database Ontology, Spatio Temporal Database Ontology, Spatio-Temporal Database Modelling, Spatio-Temporal Database Application.**

1. INTRODUCTION

The word Ontology [1] is derived from philosophy and it is used in various disciplines of management, basic and applied sciences, medicine, humanities and social sciences. Ontology means conceptualization of data semantics in terms of type, properties and relationships among objects in a particular domain. Ontological definition helps us to understand actual semantics of the objects and their behavior in any given system. Ontology depicts the data and relationships in accordance with the domain from given mini-world and translates (maps) into a given model for a more realistic view [2].

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There are many applications of ontology in the field of computer science and information technology areas such as databases, medical informatics, data mining, information retrieval through WEB, and natural language processing [3]. Integration of formal ontology for different domain applications is necessary for building software applications. These different ontologies are developed in order to better understand the underlined concepts and to depict important notions and relationships among objects. Classical database systems have the clear understanding of concepts due to its basic structure but in modern database systems the data has no restriction (size), no boundaries (limit) and also not limited to structural data types. There are many real life database applications involving multimedia content, statistical data, spatial data, temporal data and fuzzy data [4].

Spatial data has its own semantics and difficult to comprehend. It may be 2D (Two Dimensional), 3D or 4D, it may represent point, line or region and how it can be represented in the database model and mapped into an actual relation (or table). Spatial objects are represented with the help of spatial coordinates which may change their position over a span of time, this behavior is called spatio-temporal [5]. For example, storm is represented as region because it covers a certain space and it weakens or strengthens over a span of time. The movement of storm from one place to another can be observed. Similarly a vehicle is a moving point and can be observed on a road network and its movement from one place to another is recorded over a particular time point or interval.

Ontology helps to clearly understand the concepts, objects, there properties and the relationships among different objects in a certain domain. For example web ontology [6] describes the concepts related to WWW (World Wide Web) and the hierarchy of interrelationships between different web objects web site, web page, web link, hyperlink and hypertext. Similarly for medical databases we need medical ontology for understanding the underline concepts and interpretations.

Spatio-temporal data [4,7] is complex in nature and sometimes it is very difficult to comprehend the actual semantics for a certain application. This information may lead to incorrect model which is unable to represent the real scenario. There are different phases of development data gathering is one issue, its analysis and representation is a different issue and to build database system is another task and lastly the interface for the end user. Spatio-temporal database ontology [8] fills this gap of misinterpretation of data semantics by providing a formal mechanism of defining such objects and the relationships among objects with clear assumptions. However, different applications have different mechanisms because domain ontology is different in each case. Once the ontology is defined it can be mapped into a database model.

In this paper we present a conceptual framework for the design of spatio-temporal database system by integrating the ontology with the conceptual data model and the design of physical infrastructure for spatio-temporal data using relational database environment. The paper also presents important concepts related to temporal and spatial data.

The rest of the paper is organized as follows. We present brief background and related work in section 2. Section 3 presents the core of conceptual framework of our methodology. In section 4, we present our proposed methodology of building spatio-temporal data base modelling using ontological approach and its integration in detail. We present an example of spatio-temporal database modelling example through a case study in secton5. Section 6 encompasses research challenges followed by conclusion.

2. BACKGROUND& RELATED WORK

Spatial systems can be classified into four main categories based on application. First category is GIS (Geographical Information Systems) [8,9] which deals with digitized maps and contain geographic information. Second, AMS (Automated Mapping Management), which automates the management and maintenance of mobile, telephone or power grid networks. Third, LIS (Land Information Systems) or CS (Cadastral Systems), which tracks the change in land parcels with time and related information, such as individual ownership, which manage land parcel information. Forth, IPS (Image Processing Systems) which process remote sensing images acquired by aircrafts and satellites.

2.1 Background

In the domain of IT (Information Technology), CS (Computer Science) and IS (Information Systems), the term ontology refers to what is included in the IS. For instance land parcel system includes details of land and the related concepts, similarly GIS [8] include details of maps, distance, location and other important concepts. In database systems, database schema provides the complete definition of database, very much similar to ontological definition.

There are different conceptual models used for database modeling [10]. Conceptual model represents data/ information with respect to the application and development environment. It represents the data semantics, which can be easily mapped to physical design model. However it is independent of implementation details and issues. In relational database entity relationship model is the conceptual data model which can map the data semantics into actual database. In contrast, the ontologies are application independent and provide a high level semantics of given concepts for better understanding of the system and reduces the ambiguity in interpretation. Ontologies give the global perspective of objects, terminologies and relationships in a certain domain. It is interlinked with other higher level (hierarchal) ontologies to capture complete semantics. Ontologies can also be converted into a formal language and automated systems can infer knowledge from them and also mapped into a desired model. Database ontologies [11,12] are not restricted for database schema generation, in fact it has more knowledge about the data semantics as compare to schema definitions. However, database schema generation is dependent on the ontological definitions for particular application requirements.

For example, in order to represent a road network system, the application ontology must contain concepts such as street, highway, motorway, traffic signal and vehicles. The computer representation of the road network system has to recognize relationships such as "to connect motorway M1 from highway through ABC bypass", "this is one way street" and "heavy vehicles are not allowed on this road"

Spatiotemporal applications [13] can be categorized according to the types of data they manage.

- Applications may involve moving objects where the position of the object changes but there is no change in the shape of the object.
- Applications may involve objects with discrete changes in space with respect to time. In this type the change in position of the object in space and time occurs discretely.
- Applications may involve objects integrating continuous motion of objects along with the changes in shape of the object.

2.2 Related Work

Spatio-temporal data model and application development has been one of the important research area in the last two decades and various spatio-temporal models have been proposed [7,14,15]. We can categorize those models as application specific and application independent. Most of the proposed generic (application independent) models are conceptual models and logical frameworks, where domain information is very much restricted. However, there are implementations of spatio-temporal data models and applications specific to a certain application domain [16-18].

The ontological concepts are well defined and gave a good review of spatio-temporal data models. Peuquet [19] proposed an ontology model for managing spatio-temporal data content and proposed a query language (SOWL) which uses spatial and temporal operators and provide support for managing ontology structure.

DISTIL is a design tool to build spatio-temporal data model on the basis of given user requirements. It integrates the given requirements with the conceptual data model. Thomas [8] proposed an axiomatic formalization for top-level relations between entities (individuals, universals, collections). SNAP (Supplemental Nutrition Assistance Program) and SPAN (Suruhanjaya Perkhidmatan Air Negara) [20] deals with dynamic spatial ontology [5] proposed integration approach that employs formal ontologies merging. Some of the important spatio-temporal database ontologies and models are [21,22].

Most of the DBMS vendors have incorporated capabilities to manage spatial data which includes Oracle Spatial, STOC (Spatio-Temporal Oracle Cartridge), Informix Geodetic Data Blade and IBM DB2 extenders [16,23].

3. CONCEPTUAL FRAMEWORK FOR SPATIO-TEMPORAL DATABASES

Our proposed framework is divided into four important phases (Fig. 1). First task is to develop domain ontology, which is related to a certain domain and application. Domain ontology [24] identifies the objects, events, characteristics and underlying relationships between different entities. It can be developed if we have the relevant domain knowledge, which can be obtained from domain experts and with the help of standards, guidelines and procedures. For example modeling of cancer growth in human body is spatio-temporal in nature because it occupies a certain region in our body and it grows with the passage of time. For this we have to understand the medical concepts, terminologies and operations to formulate this into a spatio-temporal data model [25]. This phase is totally DBMS (Database Management System**)** independent; however it plays a very important role in building database model.

The second phase is to differentiate among different concepts in alignment with the domain application and the corresponding domain ontology is to identify the spatial objects, entities and relationships in a given application. Spatial objects are either represented in 2D, 3D or even higher dimensions depending upon the coordinates system. For example in a road network we have vehicles which move around and the location is

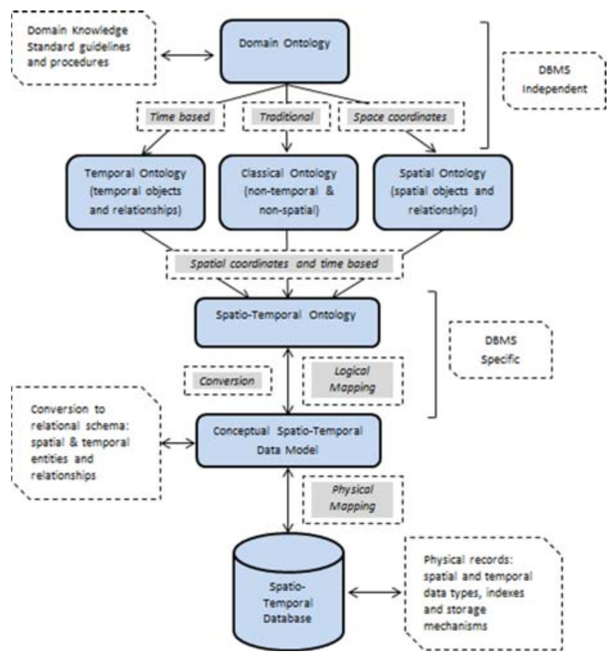

FIG. 1. STDM-ONTOLOGY: CONCEPTUAL FRAMEWORK

identified by its coordinate system. Vehicle represents a spatial point and in medical domain cancer covers a certain region and represents a spatial region.

Time is another important aspect to a model, time is complex in nature and time has many dimensions. Application of time based data into the database is termed as temporal database. There are different approaches for time handling in database systems. Temporal models are categorized as valid time and transaction time, time point and time interval, tuple time stamping and attribute time stamping system [10,26]. Lot of emphasis is being made to develop temporal database systems incorporating inherent temporal features in relational and object oriented model over the past decades. Development of SQL3 is one of the major contributions and the commercial databases have included some of the important temporal features.

Spatial objects also have temporal behavior, object changes its trajectory with respect to time [27]. For example movement of vehicle on a road network, changes its position with time, a storm moves from one place to another weakens or strengthens as time progresses. Therefore spatio-temporal ontologyis required for translating the real situation into a spatio-temporal model.

Third phase is to translate the spatio-temporal ontology into a database model either object oriented or relational data model. Our focus is on the relational model because of its strong mathematical foundation and implementation. All concepts spatial, temporal and spatio-temporal are now converted into a conceptual database model in terms of entities (spatial, temporal, classical) and spatial and temporal attributes are to be incorporated in alignment with the database product. New kind of relationships and hierarchies would be evolved and the complete semantics of the mini world is represented with appropriate assumption and axioms.

Last phase is to translate the conceptual spatio-temporal model to a physical database by mapping the corresponding spatial, temporal and spatio-temporal entities into relations and constraints must be enforced. This phase is more dependent on the database product and its capability to accommodate these complex objects in a smooth manner. New data types may be required, new constraints may be defined and an extended query language support is required to access such data. Different architectures are presented in the literature focuses on the implementation issues of spatio-temporal data concepts. Although there is no universal framework or architecture for managing moving objects in the literature, however, there are few very interesting implementations of spatio-temporal database applications in different domains. This is a preliminary and first work that presents a generic model that links spatio-temporal databases with ontology using relational database management approach for a case study of land parcels.

4. PROPOSED METHODOLOGY

In this section, we propose our methodology of building spatio-temporal data base modelling using ontological approach as relational database. We first describe spatial ontology aspects then temporal and finally spatio-temporal in three subsections.

4.1 Spatio-Temporal Ontology

Spatio-temporal ontology deals with the spatial objects that move or change their space coordinates with respect to time. Fig. 2(a-b) represents partition of land on timeline and tree formation. For example in an environmental system a storm is emerging from south east 500 km away from the city at time 13:00 EST. the size and speed of the storm is 300 km/hour and the related spatial attributes are recorded. It is for sure that the intensity and range of that storm is not constant and it increases or decreases over a span of time. Data is collected for every hour and this information is really helpful in predicting the future course of action of that storm. In this case it is really important to understand the key concepts related to this environmental system and to develop an ontology for spatio-temporal objects like storm and wind and to translate this ontology into the information system for better knowledge representation and information retrieval [10].

5. CULTIVATED LAND PARCELS: EXAMPLE CASE STUDY

The objective is to develop spatio-temporal data model for cultivated land parcels in a certain region. The cultivated land parcels (land pieces) is the declared land for cultivation which belongs to a person or any other entity. Cultivated land parcels (Fig. 3) can be represented as spatial objects having a specific boundary represented by the combination of boundary points (coordinates).

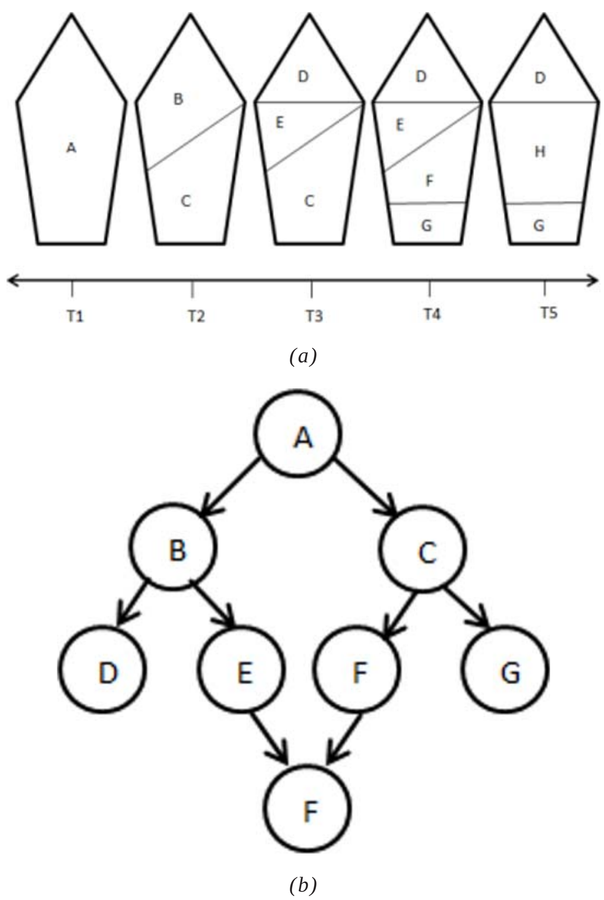

FIG. 2. BEHAVIOR OF SPATIO-TEMPORAL

The land parcels belongs to a certain owner may be connected or on different locations in a specific region. The cultivated land grows and shrinks due to natural changes in the ecological and environmental changes and also due to human interventions with respect to time so it has a temporal nature. The land associated to a certain owner may also change with respect to time. We have defined the key concepts with meaning for agricultural land parcels presented in Table 1.

5.1 Conceptual Workflow Model

The systematic conceptual workflow model in Fig. 3 represents the working of our system. The land parcels are the spatial objects and has specific boundaries. These land parcel boundaries distinguish one land parcel with the other land parcel in a specific region. Land parcels boundaries are stored with the help of boundary points (spatial coordinates) and the combination of these points form boundary lines which can represent a cultivated land parcel. The total cultivated area associated to a particular entity is obtained by combining the cultivated land parcels within that region.

TABLE 1. DOMAIN ONTOLOGY AND CONCEPTS OF AGRICULTURAL LAND PARCELS

Concepts/Assumptio-ns	Specification: Meaning
Land parcel	Represents land parcel not covered with water and can be categorized as cultivated and non-cultivated land parcel
Cultivated land parcel	Represents piece of land parcel where cultivation is going on
Non-Cultivated land parcel	Represents piece of land parcel where no cultivation is going on for any reason
Water course	Represents water flow cannels, lakes, river
Land parcel area	Spatial extent of land parcel area
Land parcel boundary	Spatial extent of cultivated land boundary
Land boundary points	Spatial points (coordinates) of land
Land boundary lines	Spatial lines of cultivated land parscels separates with other land parcel
Owner	To whom land parcel belongs to may be state, individual or institutional
Land type	Cultivated or non-cultivated

5.2 Entity Relationship Model

Entity relationship model is the best way to construct conceptual data model for relational database environment. Many extensions of ER model have been proposed over a period of time to represent spatial and temporal semantics in the model. After building the domain ontology it is important to represent entities which have spatial, temporal or spatio-temporal semantics. We have constructed an example EER model (partial view) (Fig. 4) for cultivated land parcel system which represents spatio-temporal behavior. Owner has only temporal characteristic whereas boundary points and boundary lines are spatial attributes. We have opted for bi-temporal model [10] and included both valid and transaction time dimensions.

5.3 Physical Architecture

Physical architecture of spatio-temporal database system is the last phase of our conceptual framework (Fig. 5). The design and implementation of the system architecture depends upon the application and the user requirements. There are many complex issues to be dealt with which includes spatial and temporal data types, spatial and spatio-temporal constraints, generic indexing, query access path mechanisms and physical storage. Spatio-temporal database architectures are mostly the extensions of traditional database architectures and mainly categorized into layered architectures, monolithic architecture and extensible architecture. Our proposed architecture works on both application level and also supports internal definitions. Spatial and temporal features such as data types, granularities, constraints definitions and transformation functions are supported. A spatio-temporal layer is provided to overcome the functionalities which are not supported by the database product and it is transparent to the user.

6. RESEARCH ISSUES AND CHALLENGES

Although, lot of research work published by the research community in spatio-temporal domain especially in the field of geographical information systems and moving object databases. Most of the research is focused on There are still many research issues to be resolved.

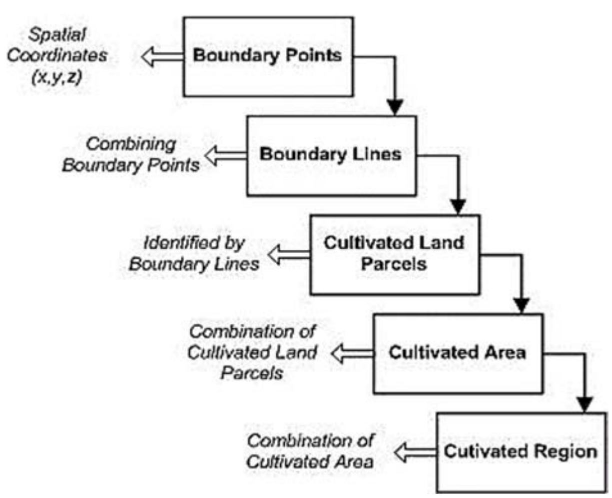

FIG. 3. CONCEPTUAL WORKFLOW MODEL

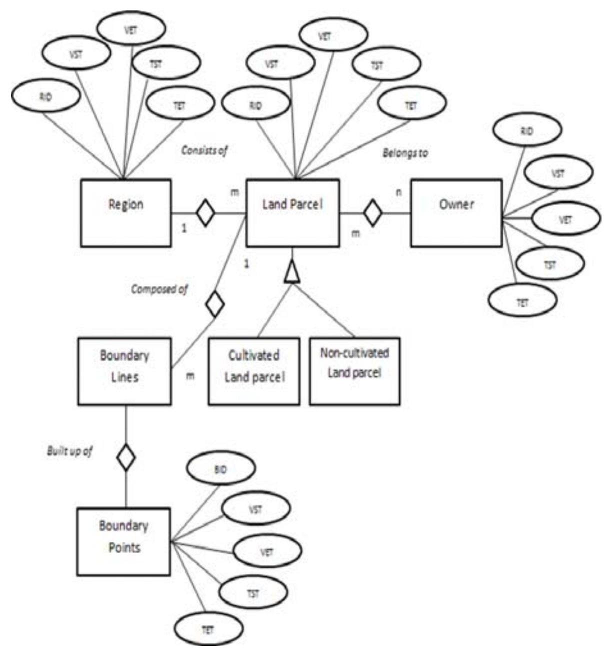

FIG. 4. EXTENDED ERM FOR LAND PARCELS

(1) Natural representation of spatio-temporal data (close to user view)

(2) Spatio-temporal relations

(3) Real time tracking of spatio-temporal objects

(4) Complete spatio-temporal query language

(5) Spatio-temporal data in distributed environment

(6) Query optimization

(7) Very huge database size (generate voluminous data)

(8) Managing moving objects in real time

(9) More generic ontology for spatio-temporal database

7. ASSUMPTIONS AND LIMITATIONS OF PROPOSED MODEL

We assume structured data only to best fit and function with proposed model. Therefore it has a limitation for unstructured data. One of the limitations is that we have used relational data model for modeling spatio-temporal data content and not covered the object oriented data model. In future this work may be further extended to implement physical model with full implementation along with spatio-temporal query language support. We applied this framework on land parcel used for agriculture to exhibit the spatio-temporal behavior of agricultural land and related entities.

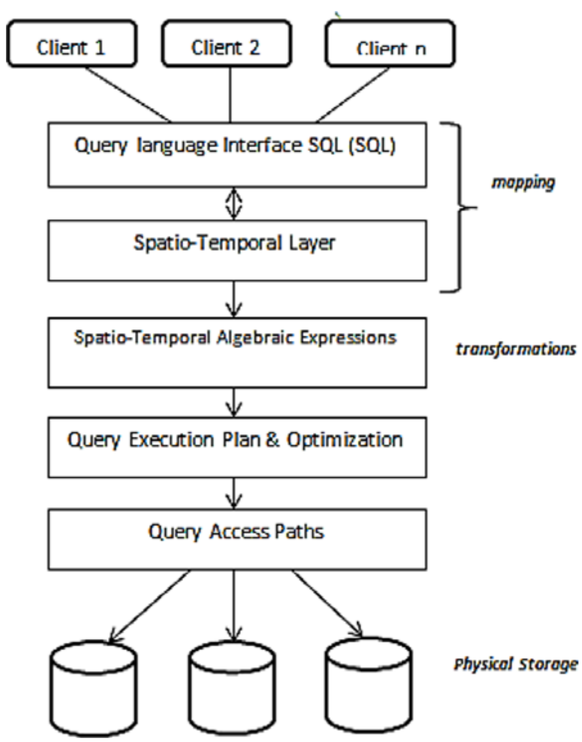

FIG. 5. PHYSICAL ARCHITECTURE

8. CONCLUSION

Integration and management of spatial and temporal data obtained from different sources for any real world application is a complex task. The development of spatio-temporal database models and applications are required for catering such data in an efficient manner. The paper highlighted the importance of ontological approach for modeling spatio-temporal data. Based on the ontological approach a generic conceptual model for dealing spatio-temporal data is presented. The proposed model is capable to understand the ontological and somehow epistimological commitments and to build spatio-temporal ontology and transform it into a spatio-temporal data model.

The mapping of spatial, temporal, and spatio-temporal ontology is well defined and integrated with the conceptual framework. Our approach is different from other frameworks as it provides a generic approach for designing spatio-temporal databases based on ontology.

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