A REVIEW ON SPATIOTEMPORAL DATA MODEL FOR MANAGING DATA MOVEMENT IN GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

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Abstract: This paper reviews the development of spatiotemporal data models. Geographic data encompasses all information related to phenomena in the real world including temporal information. In this paper, we focus on the spatiotemporal data where spatial data changes over time and involves geographic movement. From our review, we found twelve classifications of geographic movement. To manage geographic movement information we require a good data model. A good data model provides for good data management. The spatiotemporal data model is a suitable to use in GIS for making easy data management of geographic data to support spatiotemporal analysis. Our review revealed nine spatiotemporal data models which can be used to manage geographic movement data or change activities in the world. Some of the models are extended from the spatial data model by including time and some are new models based on the event. Spatiotemporal data models can be use to replace current spatial data models in the GIS. We have done a comparative study with the nine models and the results of this comparison are presented in this paper.

Keywords: Geographical Information System (GIS), Spatiotemporal GIS, Spatiotemporal Data Model, Database Management System, Spatial Databases

1. Introduction

Geographical Information Systems (GIS) is an important application for the analysis of phenomena on the earth. GIS improvement has been growing rapidly science 90's. Time is a very important factor to make analysis about the earth. Time cannot be separated from the geographic data. GIS must have the capability to do analysis regarding time. Substantial research regarding space and time has been done by previous researchers to define their relationship such as (Hawking, S.,1998;, Langran, G.,1992). In order to manage space-time data in GIS efficiently, spatiotemporal data model play an important role for managing space-time data (Thomas, and Swiaczny, F.,2001). In this paper, nine spatiotemporal data models are compared and discussed. These models have different styles and problem solving approaches. Some of the models are designed for the specific purposes and some are for general purposes. However, the primary function of the spatiotemporal data is similar which is to store and manage space-time information and changing attributes.

This paper is organized as follow. Sections 2 explain about definition of the spatiotemporal data and geographic movement, section 3 explain about the literature review of the spatiotemporal data model and their implementation. Result of the comparative study of the model will be explained in the section 4. Section 5 is a discussion about the result and lastly section 6 is a conclusion.

2. Spatiotemporal Data and Geographic Movement

Spatiotemporal data is spatial data that changes with time. When space changes over the time, spatial data will become spatial data that has a temporal element. Figure 1 shows description of spatiotemporal data.

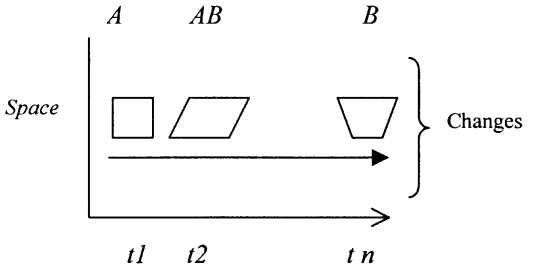

Figure 1: Descriptions of Spatiotemporal Data

From figure 1, we can see that object *A* in time *t1* changes to object *AB* in the time *t2*, object *AB* then changes again to become object *B* in time *tn*. The object keep changing depend on the situation and scenario. Spatiotemporal data is series of spatial data changes. Changes will happen until the n^{th} time where *n* is the end of the changes process.

$$f(spatiotemporal) = (spatial\ t1, spatial\ t2, .. spatial\ tn) \quad (1)$$

Which are:

Spatial t1 = is a spatial data in time 1

Spatial t2 = is a spatial data in time 2

Spatial tn = is a spatial data in time n

Spatiotemporal data is part of the geographic movement. Geographic movement can be defined in mathematics using differential mathematics. Geographic information *(gi)* is containing space information *(space)*, attribute information *(attribute)*, and time information *(t)*. Space describes location and shape. Attribute describing type of feature, name and other information related to geographic, which are the object of study. Time not only describes as a changing milestone but more important than that it defines behavior of change, and the period of changes whether changes is continuous, cyclical and intermittent. In mathematical definition, we can describe it as:

$$f(gi) = f(space) + f(attribute) + t \quad (2)$$

However, time is always changing. So, time is related to all components in the geographic movement and time can be by itself. It means space and attribute are related to time. In mathematical definition it can be described as:

$$f(gi) = tf(space) + tf(attribute) + t \quad (3)$$

Geographic movement relates to changes. It can be described by the collection of changes that happen in geographic information *(gi)*. In mathematical definition, we describe it as:

$$\frac{df(gi)}{dt} = \left[\frac{dtf(space)}{dt}\right] + \left[\frac{dtf(attribute)}{dt}\right] + \left[\frac{dt}{dt}\right] \quad (4)$$

$$f(gm) = \left[\frac{f(gi)}{dt}\right]_1 + \left[\frac{df(gi)}{dt}\right]_2 + \left[\frac{df(gi)}{dt}\right]_3 + \ldots\ldots + \left[\frac{df(gi)}{dt}\right]_n \quad (5)$$

Equation 4 shows the definition of the geographic information in the world. Object (*space*) and information (*attribute*) is change over the time. Differential equation in equation 4 show, that the geographic information are change. For the geographic movement (*f(gm)*) in equation 5 is a combination of the geographic information was change over the time. This information will be store in the databases.

Spatiotemporal data is an important requirement in the GIS to do prediction, analysis and forecasting of the phenomena in the world. In order, to support these functions, the spatiotemporal data needs to be able to store the space and time data in proper and efficiently way.

3. Spatiotemporal Data Model

In GIS, data model is the abstraction of the real world phenomena according to a formalized, conceptual scheme, which is usually, implemented using the geographical primitives of points, lines, and polygons or discredited continuous fields (Nadi, S., et. al. 2003). Data model should define data types, relationship, operations, and rules to maintain database integrity (Nadi, S., et. al. 2003). Spatiotemporal databases deal with geometry changes over the time (Pfoser, D. and , Tryfona, N.,1998). Currently, GIS does not cater the time issues in the database. Thus, the time element in the spatiotemporal data model will be differentiating it from the traditional GIS.

Data model technology has been enhanced for supporting the complex data including spatial data. The spatiotemporal data requires more than just current data model. Requirement has been increased not only for the complex objects but it needs to be a multidimensional to manage changes in data. Figure 2 shows the evolution of the database model which supports the development of database management system. Relational Database Model has been used in a majority of the current GIS (Stojanovic, D. et. al. 2001). Issues being addressed by researchers on spatiotemporal data, difficulty to

store (Michinori, H. 2000; Pfoser, D., Tryfona, N.,1998; Stojanovic, D. et. al. 2001; Sellis,T. 1999; Mohd Rahim, M.S. et. al. 2004) and redundancy of the data (Mohd Rahim, M.S. et. al. 2004; Narciso,F.E 1999) relationship support within the object. Many GIS databases are using the relational data model. Relational database technology is not suitable for managing spatiotemporal data, which are multidimensional with complex structure and behavior (Pfoser, D., and Tryfona, N.,1998). Some researchers have moved to the Object Oriented Database Model (Pfoser, D., and Tryfona, N.,1998; Bonan, L and Guory C, 2002). One of the issue regarding the Object Oriented Database Model is that it does not fully support relationship of the objects (Pfoser, D., and Tryfona, N.,1998; Wang, X. et.al. 2000) but it can support the complex object like 3D objects. Currently, database model using Object Relational Database Model is being designed (Mohd Rahim, M.S. et. al. 2004). However, not many commercial database software support the Object Relational Database model except Oracle 9i and Informix Database (Koji,Y.2001; Mohd Rahim, M.S. et. al. 2004). The Object Relational Database Model is based can support both relationship and complex object. Figure 2 show the revolution of the database technologies until now.

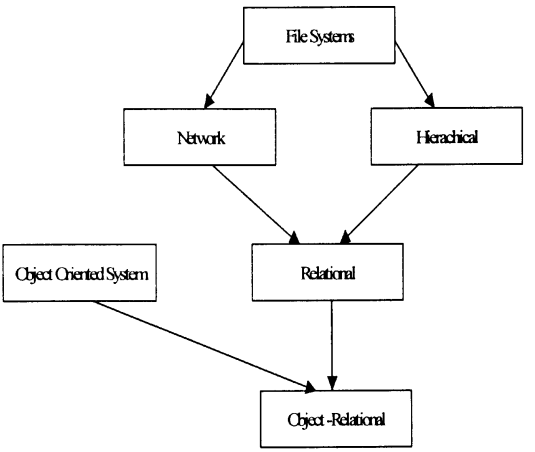

Figure 2: Revolution of the Database Model

In order to develop the database system, the data model plays important role. The process of developing a spatiotemporal data model involves the understanding of geography phenomena, space-time concept and geometry. Figure 3 shows the process of developing a data model in GIS.

In this study, we have found nine spatiotemporal data models that have been designed by the previous researchers from 1999 to 2004. The model are GEN-STGIS (Narciso, F.E, 1999), Cell Tuple Based Spatiotemporal Data Model (Ale,R., and Wolfgang, K,1999), Cube Data Model (Moris, K, et. al. 2000), Activity Based Data Model (Donggen, W and Tao,C. 2001), Object Based Data Model, Data Model for Zoning (Philip, J.U, 2001), Object Oriented Spatial Temporal Data Model (Bonan, L., and Guoray, C.2002), Multigranular Spatiotemporal Data Model (Elena, C, et. al. 2003) and Feature-Based Temporal Data Model (Yanfen, L. 2004). Every data model has own properties. However, GEN-STGIS is a model that has been proposed for general use. Appendix 1 show the conceptual model of data

model has been listed. Table 1 shows issues that arise in these data models in the implementation phase.

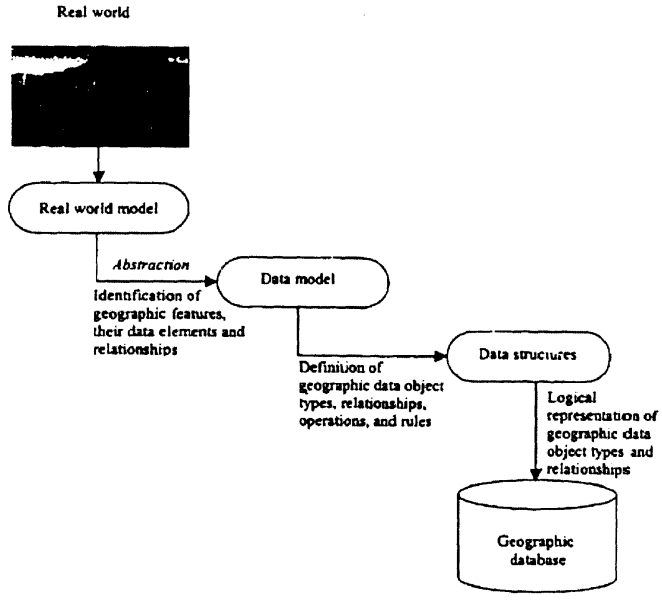

Figure 3: Process of Development Geographic Database

Table 1: Research Issues in Spatiotemporal Data Model

Data Model	Explanation/Issues
GEN-STGIS Data Model (1999)	• Needs to improve temporal and spatiotemporal query performance • Data model focuses on point, line and area; Need to test the model in volumetric data • Does not support continuous, cyclical and intermittent behavior • Data redundancy
Cell Tuple Based Spatio-Temporal Data Model: An Object Oriented Approach (1999)	• The spatiotemporal topology is stored all the time in an implicit manner and spatial-objects are treated uniformly. • This model is dimension independent and may generate a large number of tuples, but it is also expected that it would not affect the system performance because of its simple structure. • Difficult to implement in entire GIS software because model is too complicated •
Cube Data Model (1999)	• All attributes are assumed to be potentially time variant. • All point and line feature are time stamped. • Provides a completely generic data-independent structure around which to built equally generic tools for data visualization, analysis, retrieval and data loading.
Activity Based Data Model (2000)	• This model was able to manage large amount of activity data. • It can be applied to represent and model the dynamic behavior of objects with step-wise changes in general. • Data model focuses on point, line and area
Object Based Data Model (2000)	• Need to minimize redundancy of data • Data model focus on point, line and area; require to test volumetric type of data
Data Model for Zoning (2001)	• The master plan regions are stored in the same manner as zoning. • Data model focus on line and area

Table 1: Research Issues in Spatiotemporal Data Model (Cont..)

Object Oriented Spatial Temporal Data Model (2002),	• Inefficient in testing with query space and integration with time, space and theme. • Redundancy of the data • Data model focuses on point, line and area
Multigranular Spatiotemporal Data Model (2003)	• Needs to develop the model using Object Relational Model. • Using XML for the data model which will be more generic. • Cannot support topological issue in the spatiotemporal data • Data model focuses on point, line and area
Featured-Based Temporal Data Model (2004)	• Will add data editing, feature defining, and more visualization programs to the temporal GIS. • Most existing GIS are layered based and each layer has fixed spatial type-point, line or polygon while in this data model, spatial type of feature is not specified at table level, but at record level. • Data model focuses on point, line and area

4. Result of Comparative Study Spatiotemporal Data Model

Comparative study has been done in order to support geographic movement data in the real world. In the comparative study, there are four attributes that are compared among the nine models. These are:

i) Type of Data – to identify all of types of spatial data used in the model (Point, Line, Area, and Volumetric)

ii) Type of Change – to identify type of changes considered in the model (Discrete, Continuous, Cyclical and Intermittent)

iii) Flexibility of Data Model – to identify if the model can be extended for other application (extendable or not)

iv) Change Management - efficiency in managing changes in data, temporal resolution and historical data. (Efficient or Not Efficient)

Table 2: Result of Comparative Study

Data Model	Criteria			
	Data Type	**Change Type**	**Flexibility**	**Change Management**
GEN-STGIS Data Model (1999)	Point, Line, Area	Discrete	Extendable	Not Efficient
Cell Tuple Based Spatio-Temporal Data Model: An Object Oriented Approach (1999)	Point, Line, Area	Discrete	Extendable	Not Efficient
Cube Data Model (1999)	Point, Line, Area	Cyclical	Extendable	Not Efficient
Activity Based Data Model (2000)	Point, Line, Area	Continuous	Not	Not Efficient
Object Based Data Model (2000)	Point, Line, Area	Discrete	Extendable	Efficient
Data Model for Zoning (2001)	Point, Line, Area	Discrete	Not	Not Efficient
Object Oriented Spatial Temporal Data Model (2002),	Point, Line, Area	Discrete	Extendable	Efficient
Multigranular Spatiotemporal Data Model (2003)	Pont, Line, Area	Continuous	Not	Not Efficient
Featured-Based Temporal Data Model (2004)	Point, Line, Area	Discrete	Extendable	Efficient

From Table 2, we summarize that spatiotemporal data model should have the capability to manage change of information efficiently. This is because the main difference between the spatiotemporal data model with the spatial data model is managing temporal data effectively. Our findings show that all models have considered point, line and area data. There are no models that focus on the volumetric information. There are six models that focus on the discrete changes of behavior and two are continuous, one is for cyclical. This result shows that most of the models do not consider behavior of movement in the data model. In the other perspective, most of the data models have been developed for general used. There are six models developed model can be extended for various applications. We can see that it is very difficult to achieve efficiently management in database system because of many factors, which are an increasing amount of data, large amounts of data, speed of accessing large data and multi temporal resolutions. However, models are in the efficient category; these models have used object oriented architecture. This means, in order to provide a good spatiotemporal and temporal data management, Object Oriented is good approach to be considered. In the near future, the Object Relational can be used in the spatiotemporal data modeling to solve issues regarding relationship that are currently problematic in the Object Oriented Database Model.

5. Discussion

Spatiotemporal data model is very important to create a good database system for GIS which deals with space and time as a main factor in the system. The basic principle of the modeling spatiotemporal data is managing change information of the spatial data. Pfoser, D., Tryfona, N.,(1998), mentions details about the requirement of spatiotemporal data modeling.

In this section, we want to focus on the requirements for the modeling on the geographic movement activity which happens in the real world. To develop the spatiotemporal data model for geographic movement, we need to identify the properties of the spatiotemporal data required for geographic movement. The properties are present in the Table 3.

Table 3: Properties of Spatiotemporal Data for Modeling

Properties	Contains
Space	Shape – Point, Line, Area, Volume Location Place
Time	Real World Time Transaction Time Database Time
Space-Time	Continuous Cyclical Intermittence
Scale	Duration Period
Non-spatial Data	Time Series Data Information will explain data
Historical	Time data was change

As mention in the Table 1, the spatiotemporal data modeling still have issues. In our observation, the spatiotemporal data modeling is lacking the foundation of understating real world phenomena. In our opinion, classification of geographic movement by Yattaw, N.J. (1997), can be used to create the theoretical foundation. In the future, the foundation of spatiotemporal is very important to be considered for develop real-time process in GIS. Now, GPS and Remote Sensing can be integrated with the GIS to provide a real-time system. In this case, spatiotemporal data model which is very stable will be required in the creation of software and application for managing real-time data.

6. Conclusion

In this paper, we have presented the nine spatiotemporal data models from different use and background. We also presented the comparative analysis between these nine models. From the review of the models, we have found future research should be focus on the volumetric data and geographic movement behavior. These results give a new direction to GIS in the future. Its potential impact is that GIS can be presented more realistic as required by the users.

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