Volumetric Spatiotemporal Data Model

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Abstract

This paper summarizes the Volumetric Spatiotemporal Data Model which has been developed to manage surface movement in the Virtual Geographical Information Systems (VGIS). Volumetric is one type of spatial object in the VGIS, which is used to develop visualize 3D information. In order to develop real process in VGIS, temporal element is an important issue to integrate with 3D object. Here, we propose one spatiotemporal data model used to manage volumetric surface movement according to movement criteria used in VGIS. Time has been integrated with the data model and temporal version of volumetric surface data can be stored by using the model. This model has been implemented by developing prototype of visualization system using Triangulation Irregular Network (TIN) with integrated time in the TIN structure. Result shows that the data model which has been proposed can work with a visualization algorithm using linear interpolation and improvement TIN structure.

Keywords: Volumetric and 3D, Spatiotemporal Data Model, Database, TIN, VGIS.

1 Introduction

Virtual Geographical Information Systems (VGIS) is about the use of the computer graphic technology to improve presenting geographical information. So, Geographical Information Systems (GIS) become more realistic with a real process and real presentation exactly as in the real world.

In VGIS or GIS, volumetric and dynamic phenomena are, by definition, multi-dimensional, which means that they are conceptually and computationally challenging. Dynamic phenomena refer to movements which contribute to changes in geographic features. Some of the changes or movements may contribute to changes of the geometric object. The challenge becomes greater when we consider large-scale geographic processes. In many cases, simply introducing an additional orthogonal axis (Z) is convenient but insufficient, because important spatial and temporal characteristics and relationships may be indiscernible in this approach. Although visualization techniques for three or more dimensions have become popular in recent years, data models and formal languages have not yet fully developed to support advanced spatial and temporal analysis in multiple dimensions (Yuan M., et. al, 2000).

In this research, the discussion focuses on the volumetric surface movement in the real world, and we develop spatiotemporal data model which suitable to manage volumetric surface movement data call Volumetric Spatiotemporal Data Model. Besides that, the discussion also focuses on the implementation of Volumetric Spatiotemporal Data Model and development of prototyping application to simulate volumetric surface movement.

2 Spatiotemporal Data Model and Its Visualization

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). In the VGIS, data model also with the same meaning with enhancing to focus on the 3D data. Spatiotemporal Data Model in VGIS is an abstraction of managing 3D spatial with the temporal element. Spatiotemporal data model is very important to create a good database system for VGIS which deals with space and time as a main factor in the system (Rahim M.S.M, et. al, 2005).

Many spatiotemporal data model has been developed previously. We collected and analyzed 9 data models during the study namely, 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). They are several issues has been addressed from the researchers. In our observation, the spatiotemporal data modeling is lacking the foundation of understating real world phenomena. In the future, the foundation of spatiotemporal is very important to be considered to develop real-time process in GIS (Rahim M.S.M, et. al, 2005). Very interesting spatiotemporal data model should be focus on the volumetric data and geographic movement behavior in order to created VGIS with a realistic process.

Other issue which is related to the capability of spatiotemporal data model is visualizing 3D or volumetric spatiotemporal object in order to increase user understanding in the geographic phenomena and make some simulation or prediction in the future. Thus, data model must have capability to do user query for visualizing information on the 3D with movement in the VGIS. This is very challenging issue. This issue also addressed by John. et. al. (2004) to development of techniques and tools that are simply unable to cope when expanded to handle additional dimensions.

3 Formalism Volumetric Surface Movements

In the real world, all objects are volumetric. It is very difficult to manage the volumetric object. So, volumetric object can be presented in the 3D object. Focus of this discussion is to identify the movement criteria which can be use to develop spatiotemporal data model.

Volumetric surface movement always involve with transformation of the set of point in the surface. Figure 1 shows the process of movement in the volumetric surface.

Definition 1: A Volumetric Surface Movement (*mv*) consists of two parameters which are volumetric object (*v*), and time (*t*)

Volumetric surface object (*v*) is a set of geometric object which is created by the surface → triangle → line → point

Time (*t*) which represents the period of changes and duration of changes.

Definition 2: Time (*t*) changes continuously. When Object (*v*) and Attribute (*a*) change, time (*t*) acts as reference of the change process. Δt will present period of change. Δt has a start time t_s and end time t_e representing duration of a change.

Definition 3: When volumetric objects (v) change, all parameters (surface → triangle → line → point) and time as a major parameter in the object to identify period and duration of change will change accordingly. Time (t) belonging to object represents changes or movement events. The basic requirement for construction of a volumetric object is a point (p). So, for reconstruction of the volumetric moving object, we must add time parameter in the representation of the point (p), i.e., (x, y, z, t).

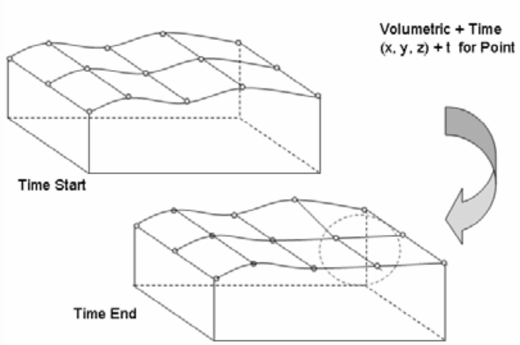

Fig. 1. Volumetric Surface Movement

From the definitions, we can say that movement on the surface happens during point which is created the volumetric surface. We can precisely shown, as in Figure 2, that movement will change location of the point to a new point and generate a new line which contribute to changes the volumetric surface.

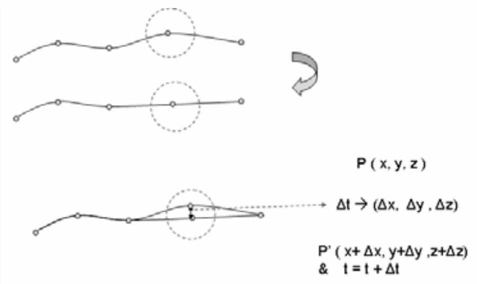

Fig. 2. Transformation of point within one line

The movement process can be described as $\Delta t = t' - t$ which represent time changes, $\Delta x = x' - x$ which is represent the changes along the x axis, $\Delta y = y' - y$ which is represent the changes along the y axis, and $\Delta z = z' - z$ which is represent the changes along the z axis. Direction of movement can be defined based on the modules value of the x, y, and z axis. Table 1 show the direction of movement when volumetric surface object was changing from one state at certain time to another time.

Table 1: Description of Transformation Point in Volumetric Surface Movement

No	State of Point Movement	Direction of Movement
1	$(\|\partial x\|$ & $\|\partial y\|$ & $\|\partial z\|) = 0$	-
2	$(\|\partial x\| > 0)$ & $(\|\partial y\|$ & $\|\partial z\|) = 0$	X axis
3	$(\|\partial x\|$ & $\|\partial z\|) = 0$ & $\|\partial y\|) > 0$	y axis
4	$(\|\partial x\|$ & $\|\partial y\|) = 0$& $(\|\partial z\|) > 0$	z axis
5	$(\|\partial x\|$ & $\|\partial y\|) > 0$ & $\|\partial z\|) = 0$	x & y axis
6	$(\|\partial x\|$ & $\|\partial z\|) > 0$ & $\|\partial y\|) = 0$	x & z axis
7	$(\|\partial y\|$ & $\|\partial z\|) > 0$ & $\|\partial x\|) = 0$	y & z axis
8	$(\|\partial x\|$ & $\|\partial y\|$ & $\|\partial z\|) > 0$	x & y & z axis

Movement can be visualized simply by using the linear interpolation model. Figure 3 show the process of interpolation.

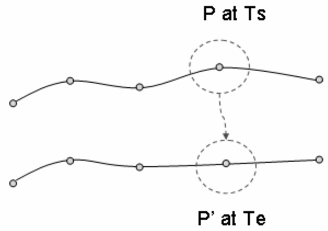

Fig. 3. Linear Interpolation Process for Simulating Movement

Based on the figure 3, Let *P(x, y, z)* at time start *Ts* and move into *P'(x',y',z')* at *Te*. So, the movement process changes within the three axis which are $\Delta x = x' - x$, $\Delta y = y' - y$, $\Delta z = z' - z$ and $\Delta t = Te - Ts$. The next point *P'*, is the previous point *P*, and added with differences within the axis. The next point can be calculate as $x' = x + \Delta x$, $y' = y + \Delta y$, $z' = z + \Delta z$, and $Te = Ts + \Delta t$.

4 Volumetric Spatiotemporal Data Model

By using a formalism which has been defined in the section 3, Volumetric Spatiotemporal Data Model will be proposed and discussed. In the data model, it is important to define the geometric of the object for storing and retrieval purpose. Based on the formalism, every point must have a time as an entity which requires answering user query based on time.

Usually data are collected based on the version approach. We need to manage especially in term of the volumetric surface movement. It means that, every time data was collected, user had identified the movement or changes happened in a space. This will be a basic of the spatiotemporal data model development. This situation can be transform into mathematical equation to define fundamental of proposed data model.

Definition 4: Assume that version of spatial data are f(t1), f(t2),., f(tm).

Object at time 1:

$F(t1) = \{ \langle x1,y1,z1,t1\rangle, \langle x2,y2,z2,t1\rangle, \ldots \langle xn,yn,zn,t1\rangle, \}$

Object at time 2:

$F(t2) = \{ \langle x1,y1,z1,t2\rangle, \langle x2,y2,z2,t2\rangle, \ldots \langle xn,yn,zn,t2\rangle, \}$

Object at time:

$F(tm) = \{ \langle x1,y1,z1,tm\rangle, \langle x2,y2,z2,tm\rangle, \ldots \langle xn,yn,zn,tm\rangle, \}$

Definition 5: Let *f(mv)* is define as volumetric surface movement process. So, Set of Volumetric Movement data is union of all set of version data.

$$\begin{aligned} f(mv) = \{ & \langle x1,y1,z1,t\rangle, \langle x2,y2,z2,t\rangle, \ldots \langle xn,yn,zn,t\rangle\} \; U \\ & \{ \langle x1,y1,z1,t2\rangle, \langle x2,y2,z2,t2\rangle, \ldots \langle xn,yn,zn,t2\rangle, \} \; U \\ & \{ \langle x1,y1,z1,tm\rangle, \langle x2,y2,z2,tm\rangle, \ldots \langle xn,yn,zn,tm\rangle, \} \end{aligned}$$

In real process, not all the points in the volumetric surface changing or move. The question is, is it necessary to store all the points, which will increase the storage usage in the implementation? To avoid data redundancy, the data model must be able to identify which point has been changing. To identify, data model must have capability to check every point among version of data and capture the changes point. To perform this task, the formalism in the section 3 will be used. The conceptual identification is:

If $\langle x1,y1,z1,tn\rangle - \langle x1,y1,z1,tn+1\rangle = 0$, *data at tn+1 equal to data at tn, else* $\langle x1,y1,z1,tn\rangle - \langle x1,y1,z1,tn+1\rangle \neq 0$, *data for tn+1 is* $\langle x1,y1,z1,tn+1\rangle$

Volumetric Spatiotemporal Data Model is designed based on the common data structure of the volumetric object normally use in computer graphics. The model simply define that surface at volumetric object stated in definition 3 in section 3. Enhancement on the model is by adding time as an attribute in the every points and the model is an incorporate structure of data model as formalize in definition 4 and 5. Figure 4 show the conceptual model of the Volumetric Spatiotemporal Data Model.

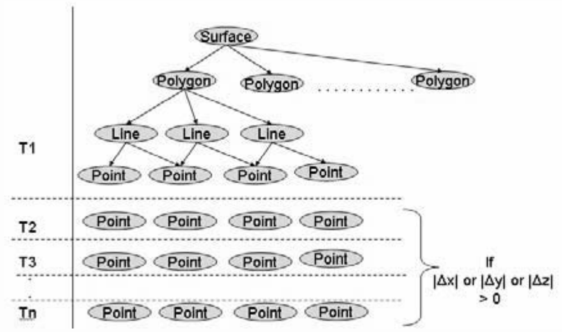

Fig. 4. Volumetric Spatiotemporal Data Model

5 Data Model Implementation and Results

In the implementation phase, data model has been developed by using Relational Database Model which has been acceptable for many databases systems. Prototyping of visualization system has been developed with it's data format for visualizing the volumetric surface movement data.

Structure of the databases has been design to store a series of point which created a surface with the line and the polygon. Every point which stored in the database will be incorporated with time entity. There are fours major entities: point, line, polygon, and surface. In the database, a simple structure of database has been design as bellow:

Points (Id_point, Time, x, y, z)

Line (Id_line, Point 1, Point 2)

Polygon (Id_polygon, Line 1, Line 2, Line 3)

Polygon is based on the TIN structure which created triangle surface

Surface (Id_Surface, Time, Polygon 1, Polygon 2, ... Polygon n)

Query processing has been designed to retrieve data from database by using area identification. The database has *Id_Surface* in the *surface* entity with a start time and end time. Result from this query is a set of points which represents volumetric surface from the start time and the end time.

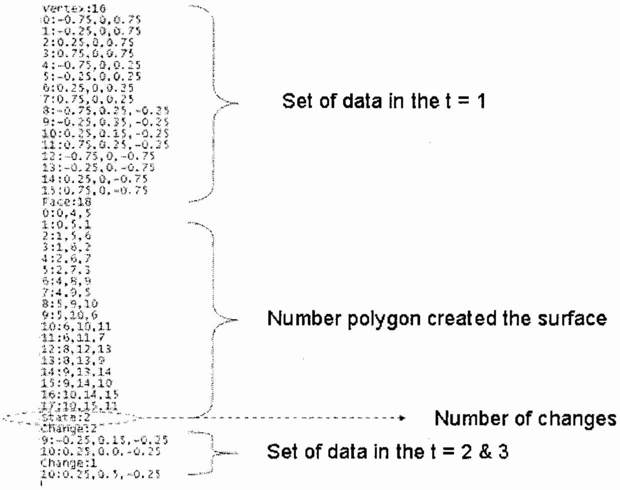

Fig. 5. Data Format Use to Visualize Volumetric Surface Movement

This data will then be transformed into a file format which will be used to visualize the volumetric surface movement interactively by navigation of time. Figure 5 show the conceptual data format. The file format that we proposed contains a set of point which created volumetric surface at the start time, followed by number of movement data that has been identified through query.

Prototype of visualization application has been developed based on the linear interpolation to present a simple morphing or movement of the surface. Triangulation Irregular Network (TIN) visualization including time factor in the TIN to give user opportunity to navigate spatiotemporal data through the time has been presented. Figure 6 show the example of the visualization in the three stages of volumetric surface movement.

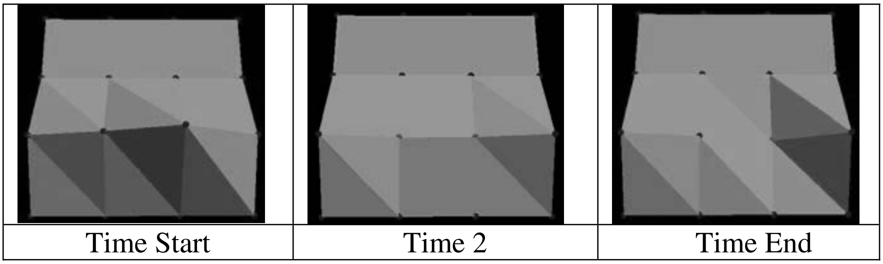

Fig. 6. Visualization of Volumetric Surface Movement

6 Conclusion and Future Works

According to Mountrakis, G., et. al. (2005), a successful GIS query process should be able to support difference user preferences in spatiotemporal scene queries, and do not have a fixed-metric approach where all users are considered equal. These required spatiotemporal databases can integrate all of series of data. Volumetric Spatiotemporal Data Model can be an idea to resolve this kind of issue. All changes of the volumetric surface movement had been integrated into single database system which reduces their redundancy of data. This will give advantages in design analysis and manipulation of the spatiotemporal data based on the user requirement. In the near future Volumetric Spatiotemporal Data Model will be tested with a real application related with morphology of limestone are which involve suitable to evaluate the data model as well as prototyping of visualization application.

In the future, proposed model need to be modified to take into account the uncertainties in data movement in the surface. This data model can handle only fix number of points only, which may not the case in real dynamic world. Currently when this issue arises, we coordinate the number of point to become the same with previous data. Besides that, improvement of the Volumetric Spatiotemporal Data Model can be done in the implementation aspect. Several issues need to be enhanced to index the spatiotemporal data which is always increasing, and formalize spatiotemporal query according to surface movement.

As a conclusion, our major contribution in this paper is, proposing spatiotemporal data model which has the capability to manage volumetric surface movement. Besides that, the TIN structure has been used with slight modification with temporal element which requires development of visualization system.

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