Spatiotemporal Data Model for Managing Volumetric Surface Movement Data in Virtual Geographical Information Systems

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1. Introduction

In Virtual Geographical Information Systems (VGIS), a data model is the abstraction of real world phenomena according to a formalized, conceptual scheme, which is usually implemented using the geographical primitives of points, lines, and polygons or discretized continuous fields (Nadi, S., et. al. 2003). Data model should define data types, relationships, operations, and rules in order to maintain database integrity (Nadi, S., et. al. 2003). In VGIS, a data model is also used to enhance the focus on 3D data. Thus, a spatiotemporal data model in VGIS is an abstraction of managing 3D spatial with temporal elements. Spatiotemporal data model is very important in creating a good database system for VGIS which deals with space and time as main factors in the system (Rahim M.S.M, et. al, 2005).

A variety of spatiotemporal data model has been developed previously. For the purpose of this research, we have collected and analyzed 9 data models 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 (Commossi, E. et. al. 2003) and Feature-Based Temporal Data Model (Yanfen, L. 2004).

Several issues were addressed by these researchers and through our observation, the main criteria lacking in spatiotemporal data modeling is the foundation of understanding real world phenomena. In near future, a strong foundation of spatiotemporal data model will become a very crucial factor in developing real-time processes in GIS (Rahim M.S.M, et. al, 2005). We agree that in order to create a VGIS with a realistic process, a spatiotemporal data model should focus on the volumetric data and geographical movement behavior.

Other issue related to the capability of spatiotemporal data model is 3D visualization of volumetric spatiotemporal object. This is vital for increasing user understanding of geographic phenomena in creating simulations or future predictions. Therefore, a VGIS data model must have the capability of user query to visualize information in the form of 3D with movements. This is indeed a very challenging issue. It has also been addressed by Roddick , J. et. al. (2004) that the current development of techniques and tools are simply unable to cope when expanded to handle additional dimensions.

In this extended abstract, the discussion focuses on the volumetric surface movement in the real world, where we have developed a spatiotemporal data model suitable in managing volumetric surface movement data called the Volumetric Surface Movement Spatiotemporal Data Model.

2. Volumetric Surface Movement Data Model and Implementation

The first step in developing a volumetric surface movement data model is to obtain the required definition and parameters by focusing on the volumetric movement in the real world. Real world objects are in volumetric form where we can only see its surface. The surface is constructed by a combination of points that create lines, and lines that are joined together to create a surface. Each change that occurs in an object can only be seen on its surface. Thus, a surface (*s*) is an important component in presenting a volumetric object which makes it one of the parameters needed in defining volumetric surface movement.

A change is defined as a movement from one state to another where time is the main reference of the change. When an object *(v)* goes through a change where it moves from one state to another, from each movement, we can determine the duration of the occurring event, the starting point of the event and also its ending point. For example, based on Figure 1, the surface for object (*v*) occur changes where it is recorded at state t_1, t_2, and t_3. Thus, its starting point can be defined as start time (t_1) and the ending point as end time (t_3).

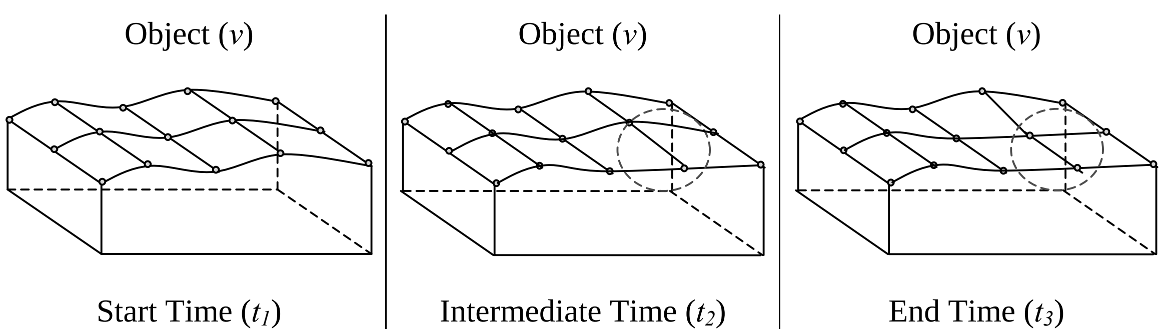


Figure 1: Movement Process in Volumetric Surface

Time and object is linked semantically and is a natural association that is tightly connected. A change that occurs on a surface of an object is in fact a change that occurs on the points that forms the object surface. The changes of these points allow changes to take place on the object surface. At which points and at what time these changes occur have to be clearly identified. Therefore, in general, time belongs to an object, or more specifically, the points that form the surface of an object.

A Volumetric Surface Movement is a combination of data sets where changes that occur are recorded under one object. These data sets contains points and lines that forms the surface, and each of the points and lines is accompanied by the time element that represents the change that occurred. These data will be stored and retrieved by using the equation (1) and (2) below, a combination of the surface set that is classified as a volumetric surface movement object. These equations will be the base in building a data model that manages surface movements data. It will also be the foundation in managing volumetric surface movement object in the real world.

$$f(mv)t_1, t_2, \ldots, t_m \rightarrow f(v, t_1)\ U\ f(v, t_2)\ U \ldots U\ f(v, t_m) \qquad (1)$$

$$f(mv)t_1, t_2, \ldots, t_m \rightarrow [\ \{ \langle x_1,y_1,z_1, t_1\rangle, \langle x_2,y_2,z_2, t_1\rangle, \ldots \langle x_n,y_n,z_n, t_1\rangle, \}\ U\ \{ \langle x_1,y_1,z_1, t_2\rangle, \langle x_2,y_2,z_2, t_2\rangle, \ldots \langle x_n,y_n,z_n, t_2\rangle, \}\ U \ldots U\ \{ \langle x_1,y_1,z_1, t_m\rangle, \langle x_2,y_2,z_2, t_m\rangle, \ldots \langle x_n,y_n,z_n, t_m\rangle, \}\ ] \qquad (2)$$

In real process though, not all of the points in the volumetric surface moves or changes. This raises the question as whether it is necessary to store all of the points which will increase the storage usage in the implementation. Therefore, in order to reduce storage and avoid data redundancy, the data model must be able to identify which point that has changed. To identify these points, data model must have the capability to check every point among the versions of data and capture the changing point. The conceptual identification is as follows:

If $\langle x_1,y_1,z_1,t_n\rangle - \langle x_1,y_1,z_1,t_{n+1}\rangle = 0$, *data at* t_{n+1} *equal to data at* t_n *,*
else If $\langle x_1,y_1,z_1,t_n\rangle - \langle x_1,y_1,z_1,t_{n+1}\rangle \neq 0$ *, data for* t_{n+1} *is* $\langle x_1,y_1,z_1,t_{n+1}\rangle$

The developed data model can be translated in a table form shown in Table 1 below.

v / t	P_1	P_2	P_3
t_n	(x_1,y_1,z_1)	(x_2,y_2,z_2)	(x_3,y_3,z_3)
t_{n+1}	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$
.	.	.	.
.	.	.	.
t_{n+m}	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$

Table 1 Conceptual Data Model

As stated, not all of the points that form the surface changes. Therefore to store data at time *t*, a comparison will be done to determine which points did change. The algorithm below will be used to identify redundancy in the database during implementation.

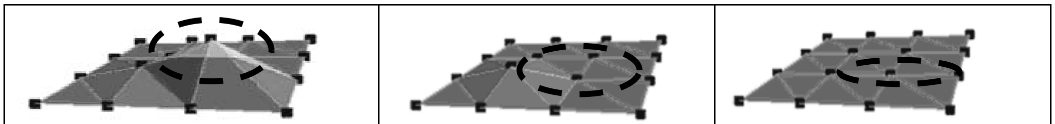
$$P1\ (x_1,y_1,z_1,t_n)\ \text{move} \rightarrow P1'\ (x_1,y_1,z_1,t_{n+1})\ \text{move} \rightarrow \ldots\ldots \rightarrow P1'\ (x_1,y_1,z_1,t_{n+m})$$

$$\text{If } (x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) = 0$$
$$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_n)$$
$$\text{Else if } (\ (x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) > 0\ )\ ||\ (\ (x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) < 0\ )$$
$$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_{n+1})$$

Thus, the next point will be stored in the storage for every point after movement occurs

$$\text{from } t_n \text{ until } t_{n+1} \Rightarrow (x_1,y_1,z_1)\ ||\ (x_1,y_1,z_1)'$$

By executing this process, movement data can be stored more easily and point which not involve with a change does not store again. Therefore, the data model developed will be less redundant and can manage changes on a volumetric surface more efficiently. Figure 2 bellow show visualization of the conceptual testing has been done to prove that data model has been tested.



Start (t_s)	Intermediate (t_i)	End (t_s)

Figure 2: Visualization of the Volumetric Surface Movement Data from Spatiotemporal Database

3. Conclusion

The main highlight in this discussion is the capability of a data model in managing surface movement spatiotemporal data. Spatiotemporal systems consist of parameter x, y, z (space element) and t (temporal element). In summary, our main contribution in this research is the proposed Spatiotemporal Data Model. This data model has been tested and proved of its capability by using a VGIS prototype to simulate the volumetric surface movement. Test result show that by using this model, data redundancy is avoided whenever changes of data in the same area is stored in the database.

However, there are several areas that can still be improved such as data indexing to improve retrieval time, capability to manage and visualize volumetric surface with uncertainty data. Nonetheless, this technique did manage to present ideas in improving VGIS applications.

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5. References

ALE, R., and WOLFGANG, K., 1999, Cell Tuple Based Spatio-Temporal Data Model : An Object Oriented Approach, Geographic Information Systems, Association of Computing Machinery (ACM) Press New York, NY, USA, 2-6 November, p.p 20-25

BONAN, L., and GUORAY, C., 2002, A General Object-Oriented Spatial Temporal Data Model, Symposium on Geospatial Theory, Processing and Applications, Ottawa, March.

COMMOSSI, E., BERTOLOTTO, M., BERTINO, E., and GUERRINI, G., 2003, A Multigranular Spatiotemporal Data Model, GIS'03, New Orleans, Louisiana, USA, November 7-8, p.p 94-101.

DONGGEN, W. , and TAO, C.,2001, A Spatio-temporal Data Model for Activity-Based Transport Demand Modeling, International Journal of Geographical Information Science, Vol. 15, p.p: 561-585.

MORIS, K. , HILL, D. , and MOORE, A., 2000, Mapping The Environment Through Three-Dimensional Space and Time, Pergamon, Computers, Environment and Urban Systems Vol 24 , p.p 435-450

MOUNTRAKIS G., AGOURIS P., and STEFANIDIS A., 2005, Similarity Learning in GIS: An Overview of Definitions, Prerequisites and Challenges, Spatial Databases Technologies, Techniques and Trends, Idea Group Publishing, p.p 295-321

NADI, S., and DELAVAR, M.R., 2003 Spatio-Temporal Modeling of Dynamic Phenomena in GIS, ScanGIS 2003 Proceeding, p.p 215-225

NARCISO, F.E., 1999, A Spatiotemporal Data Model For Incorporating Time In Geographical Information Systems (GEN-STGIS), Doctor of Philosophy in Computer Science and Engineering, University of South Florida, April.

PARENT**,** C., SPACCAPIETRA**,** S. , and ZIMÁNYI, E. 2006, Conceptual Modeling for Traditional and Spatio-Temporal Applications, The MADS Approach, Springer-Velleg, ISBN-10: 3-540-30153-4

PHILIP, J.U., 2001, A Spatiotemporal Data Model for Zoning, Masters of Science Thesis, Department of Geography, Brigham Young University

RAHIM M.S.M, SHARIFF A.R.M, MANSOR S., and MAHMUD A.R., 2005, A Review on Spatiotemporal Data Model For Managing Data Movement in Geographical Information Systems (GIS), Journal of Information Technology, FSKSM, UTM, Vol 1, Jld 9, December, p.p 21 -32

RODDICK, J., EGENHOFER, M.J, HOEL E., PAPADIAS D, and SALZBERG, B., 2004, Spatial, Temporal, and Spatiotemporal Databases, SIGMOD Record Web Edition, Vol 33, No. 2, June 2004.

YANFEN, L., 2004, A Feature-Based Temporal Representation and Its Implementation with Object-Relational Schema for Base Geographic Data in Object-Based Form, UCGIS Assembly.

YUAN, M., D. M. MARK, M. J. EGENHOFER, and D. J. PEUQUET, 2004, Extensions to Geographic Representations. Chapter 5 in R. B. McMaster and E. L. Usery (eds.), A Research Agenda for Geographic Information Science, Boca Raton, Florida: CRC Press, 129-156