Topological Relationship Operators on 4D Moving Object Databases*

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Abstract: In this paper we propose four-dimensional (4D) operators, which can be used to deal with sequential changes of topological relationships between 4D moving objects and we call them 4D development operators. In contrast to the existing operators, we can apply the operators to real applications on 4D moving objects. We also propose a new approach to define them. The approach is based on a dimension-separated method, which considers x-y coordinates and z coordinates separately. In order to show the applicability of our operators we show the algorithms for the proposed operators and development graph between 4D moving objects.
Keywords: 4D Development Operators, 4D Moving Object Database, Dimension-Separated Method.

1. Introduction

Recently, many researches on the applications using location information of moving objects such as Virtual Battlefield Analysis Systems, Weather Information Systems and Environment Information Systems, have been progressing actively according to the development of computer technology and sampling technique and device, such as Doppler radar, Senor, and GPS.

However, conventional works mainly have been focused on 2D moving objects in 2D space and some researchers have proposed 3D or 4D spatio-temporal operators [1,2,3] but we cannot apply these operators to the expression of the specific topological relationships between 4D moving objects because they were designed by extending basic 2D spatial operators temporally and dimensionally or for only historical data. In 4D moving object databases, for example, the following three cases represent different topological relationship respectively; the case that an object goes through the other object, the case that one goes under or over the other without any touch and the case that one goes by the other without any touch, but it is not possible to describe the difference among these cases by using the existing operators in the aspect of topological relationship.

In this paper, in order to solve these problems, we propose basic 3D spatial topological relationship operators designed by the dimension-separated method and 4D development operators that are for representation of temporal changes of topological relationships between 3D moving objects.

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2. Related Works

1) Definition Methods of Topological Relationships

Methods of defining topological Relationships are mainly distributed into the Dimensionally Extended Nine Intersection-Model (DE-9IM) [4] and Calculus based Method [5]. The canonical method of them is DE-9IM developed by Clementini and Felice, who dimensionally extended the 9 Intersection Model of Egenhofer. It is a mathematical approach that defines the spatial topological relationship between geometries of different types and dimensions. This model expresses topological relationships as pair- wise intersections of their interior, boundary and exterior denoted by *I(a)*, *B(a)* and *E(a)*, with consideration for the dimension of the resulting intersections. Egenhofer[4] has defined eight basic spatial topological relationships(disjoint, meet, overlap, equal, covers, coveredBy, inside and contains). These operators can be extended to three or four dimension but if extended just dimensionally, they cannot be used to express the specific topological relationships between three or four dimension objects.

2) Spatial and Spatiotemporal Relationships

So far, 3D spatial or spatiotemporal topological relationship operators have been proposed by several researchers [6,7,8,9] but they cannot be applied to real application required to express some specific topological relationships between 3D spatial objects because they were simply extended as three dimension.

Several researchers have proposed 4D spatiotemporal topological relationship operators and in Electronics and Telecommunications Research Institute (ETRI) has developed "EDGE-4D GIS Engine components" to commercialize it. However, their operators cannot be applied to moving objects because they are just for static historical objects like geographical features or facilities and further, they have applied Allen's seven temporal topological relationship concepts for adding temporal dimension to 3D spatial operators. For example, α.Within4D(β) returns True if they satisfy the relationship of α.tDuring(β) between valid-time α and β [2]. However, in fact the relationship of Within can be satisfied at the other temporal topological relationships like tOverlap and tEqual, that is, if two operands have some common valid time interval, the operation is possible. Therefore, in this paper we apply the common valid time concept.

3. 3D Spatial Operators

In order to define 3D spatial topological relationship operators, we propose Dimension-Separated 9IM, which extended with using x, y coordinates and z coordinates separately, that is, we use interior $I(a_{x,y})$, boundary $B(a_{x,y})$, and exterior $E(a_{x,y})$ of 3D spatial objects on x,y coordinates and introduce z_{top}, z_{bottom} coordinates concept. We define basic eight 3D spatial topological relationship operators, each seven operators represent cases that an object locates over the other object and cases that one locates under the other one. The following formulas show some definitions of our proposed 3D operators.

[def.1] $a.3Doverlaps(b) \Leftrightarrow (I_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (I_{x,y}(a) \cap E_{x,y}(b) \neq \emptyset) \wedge (E_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (z_{top}(a) > z_{bottom}(b)) \wedge (z_{bottom}(a) < z_{top}(b))$

[def.2] $a.3DUoverlaps(b) \Leftrightarrow (I_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (I_{x,y}(a) \cap E_{x,y}(b) \neq \emptyset) \wedge (E_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (z_{bottom}(a) > z_{top}(b))$

[def.3] $a.3DLoverlaps(b) \Leftrightarrow (I_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (I_{x,y}(a) \cap E_{x,y}(b) \neq \emptyset) \wedge (E_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (z_{top}(a) < z_{bottom}(b))$

3Doverlaps in [def.1] means that two 3D objects intersect each other on x, y, z coordinates, 3DUoverlaps in [def.2] represents that an object locates over the other objects and they intersect each other on x, y coordinates but z coordinates and 3DLoverlaps expresses that an object locates under the other objects.

Fig. 1 shows our proposed twenty two 3D spatial topological relationship operators.

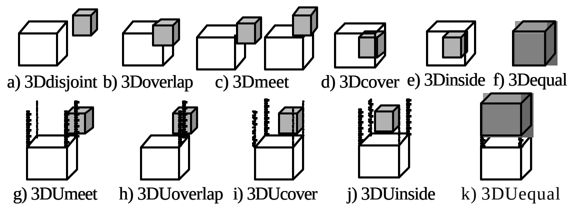

Fig. 1. Topological relationships between 3D spatial objects

Two of these operators, 3Dmeet and 3Ddisjoint need to other definition methods different from Dimension-separated method. [def.4] and [def.5] represent their definitions.

[def.4] $a.3Dmeet(b) \Leftrightarrow (I_{x,y,z}(a) \cap I_{x,y,z}(b) = \emptyset) \wedge ((I_{x,y,z}(a) \cap B_{x,y,z}(b) \neq \emptyset) \vee (B_{x,y,z}(a) \cap I_{x,y,z}(b) \neq \emptyset) \vee (B_{x,y,z}(a) \cap B_{x,y,z}(b) \neq \emptyset))$

[def.5] $a.3Ddisjoint(b) \Leftrightarrow (I_{x,y}(a) \cap I_{x,y}(b) = \emptyset) \wedge (I_{x,y}(a) \cap B_{x,y}(b) = \emptyset) \wedge (B_{x,y}(a) \cap I_{x,y}(b) = \emptyset) \wedge (B_{x,y}(a) \cap B_{x,y}(b) = \emptyset)$

4. 4D Spatiotemporal Operators

1) 4D Spatiotemporal Operators for moving objects

In this paper we use common valid time concept to extend our proposed 3D spatial operators to 4D Spatio-tempral operators for moving objects. [def.6] shows definition of CommonVa lidtime.

[def.6] $CommonValidtime(a, b) = BEGIN(Validtime(a)) \leq END(Validtime(b))$ and $END(Validtime(a)) \geq BEGIN(Validtime(b)))$

4D spatiotemporal topological relationship operators are defined by using CommonValidtime as follows.

[def.7] $a.4DOverlap(b) \Leftrightarrow (I_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (I_{x,y}(a) \cap E_{x,y}(b) \neq \emptyset) \wedge (E_{x,y}(a) \cap I_{x,y}(b) \neq \emptyset) \wedge (z_{top}(a) > z_{bottom}(b)) \wedge (z_{bottom}(a) < z_{top}(b)) \wedge CommonValidtime$

As the [def.7], 4D spatiotemporal operators are extended form twenty-two 3D spatial operators so they are twenty-two too. These operators are used to define 4D development operators of the next chapter. The algorithms of these operators are as follows.

Algorithm 1. 4DOverlap operator

```
Algorithm 4DOverlap(4DsourceObject, 4DtargetObject, TimeInterval)
Input : geometry type 4DsourceObject, 4DtargetObject, TimeInterval
Output : Boolean(true or false)
Boolean 4DOverlap(4DsourceObject, 4DtargetObject, TimeInterval)
{   get Oid of 4DsourceObject and 4DtargetObject}
      If(there are at least two objects during given TimeInterval){
         for(CommonValidtime of two objects){
                  If((z top(4DsourceObject)>z bottom(4DtargetObject))∧
                   (zbottom(4DsourceObject) < ztop(4DtargetObject))){
                  Store x, y coordinate value of two objects ;
                    If( Satisfy Overlap of stored objects on x,y coordi-
                  nate){ return true;   }
                  Else { return false; } }
               Else{ return false;  } } }
      Else { return false;   } }
```

Algorithm 2. 4DUOverlap operator

```
Algorithm 4DUOverlap(4DsourceObject, 4DtargetObject, TimeInterval)
Input : geometry type 4DsourceObject, 4DtargetObject, TimeInterval
Output : Boolean(true or false)
Boolean 4DUOverlap(4DsourceObject, 4DtargetObject, TimeInterval)
{   get Oid of 4DsourceObject and 4DtargetObject}
      If(there are at least two objects during given TimeInterval){
         for(CommonValidtime of two objects){
                  If(zbottom(4DsourceObject) > ztop(4DtargetObject)){
               Store x, y coordinate value of two objects ;
                    If( Satisfy Overlap of stored objects on x,y coordi-
                  nate){ return true;   }
                    Else { return false; } }
               Else{ return false;  } } }
      Else { return false;   } }
```

The biggest difference between two algorithms of the above is at how to deal with the z coordinate value. In these algorithms, time is applied as the same way.

2) 4D Development Operators

In this chapter, we describe definitions of 4D development operators. They can be concisely defined as sequential combination of 4D spatiotemporal operators we have proposed in chapter. 4. by using symbol $\triangleright$. However, it is impossible to describe all of 4D spatiotemporal operators because the large numbers of relationships can be defined. Hence, we only describe some operators that will be frequently used in real application and propose development graph between moving volume objects as Fig. 2. in order to represent all of possible development relationships. Users are allowed to define and give a name to new operators according to their needs.

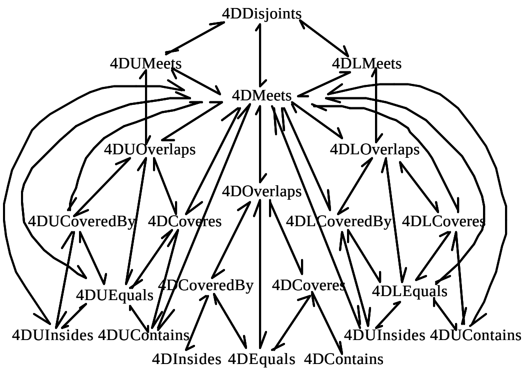

Fig. 2. Development Graph between 4D moving volume objects

The following is to show the definitions of main 4D Development operators.

[def.8] 4DEnters =: 4DDisjoints $\triangleright$ 4Dmeets $\triangleright$ 4Doverlaps $\triangleright$ 4DcoveredBy $\triangleright$ 4DInsides

[def.9] 4DUEnters =: 4DDisjoints $\triangleright$ 4DUMeets $\triangleright$ 4DUOverlaps $\triangleright$ 4DUCoveredBy $\triangleright$ 4DUInsides

[def.10] 4DUCrosses =: 4DDisjoints $\triangleright$ 4DUMeets $\triangleright$ 4DUOverlaps $\triangleright$ 4DUInsides $\triangleright$ 4DUOverlaps $\triangleright$ 4DUMeets $\triangleright$ 4DDisjoints

[def.11] 4DIntersects =: 4DEnters or 4DCrosses or 4DLeaves

5. Query Scenario

In air traffic control system, weather conditions are very important for safety of passengers and airplanes. Hence, we assume that weather conditions like a typhoon, a fog, a snowstorm and a cloud are stored in databases and give a query with 4D development operators. For a query, we use the relation as follows.

flights(id:string, alocation:4Dmpoint), typhoons(id:string, wlocation:4Dmbox)

Here, id is an identifier of a flight and a typhoon, alocation is a trajectory of a flight and wlocation is a trajectory of a typhoon. We can make a query with our 4D development operators as follows.

[Q.1] "Retrieve all flights that passed through typhoon Rusa(id=1015) between 6:00 am and 11:00 am."

SELECT f.id FROM flights f, typhoons t
WHERE t.id = 1015 and **4DCrosses**(f, t, 9:00-11:00)

[Q.2] "Retrieve all flights that crossed over typhoon Rusa(id=1015) between 6:00 am and 11:00 am."

SELECT f.id FROM flights f, typhoons t
WHERE t.id = 1015 and **4DUCrosses**(f, t, 9:00-11:00)

[Q.1] is to retrieve flights that passed through a typhoon with being affected by it, and [Q.2] is to find flights that crossed over a typhoon without any affection by it. Through these queries, we can know which flight made a flight more safely.

6. Conclusion and Future works

Existing topological operators cannot be used for expressing possible specific and complicate topological relationships between 4D moving objects so they can be applied to real application.

In this paper, in order to solve this problem, we proposed basic 3D spatial topological relationship operators and 4D development operators. And also we presented development graph between moving volume objects in order to show all of possible development relationships and devised a new method to define 3D spatial topological relationships. Finally we showed how our proposed operators could be applied to real application through query examples.

As a result of these works, we improved expression power on topological relationships of 4D moving objects.

In future work, we will implement the operators and then apply them to real systems.

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