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A Design of Spatio-Temporal Data Model for Simple Fuzzy Regions

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***Abstract*- Most of the real world phenomena change over time. The ability to represent and to reason geographic data becomes crucial. A large amount of non-standard applications are dealing with data characterized by spatial, temporal and/or uncertainty features. Non-standard data like spatial and temporal data have an inner complex structure requiring sophisticated data representation, and their operations necessitate sophisticated and efficient algorithms. Current GIS technology is inefficient to model and to handle complex geographic phenomena, which involve space, time and uncertainty dimensions. This paper concentrates on developing a fuzzy spatio-temporal data model based on fuzzy set theory and relational data models. Fuzzy spatio-temporal operators are also provided to support dynamic query.**

I INTRODUCTION

Most of the real world phenomena are constantly change over time. A large amount of applications are dealing with data characterized by spatial, temporal and/or uncertain features. Non-standard data like spatial, temporal data have an inner complex structure requiring sophisticated data representation, and their operations necessitate sophisticated and efficient algorithms. For specialized systems like geographic information systems (GIS), spatial database systems the development of formal models for spatial objects and for topological relationships among these objects is a topic of great importance. Current GIS technology is inefficient to model and to handle complex geographic phenomena, which involve space, time and uncertainty dimensions. Therefore, modeling spatial objects which change cover time and have uncertain characteristics is a currently interested issue.

In the GIS community, a number of data models [2-3][5][7] have been proposed for spatial objects with indeterminate boundaries, but these models do not accommodate the time dimension[1] of geographic data. This paper concentrates on spatial fuzziness, which captures the property of many spatial objects in reality, which do not have sharp boundaries. The objective is to propose a fuzzy spatio-temporal data model for simple fuzzy regions, which is based on fuzzy set theory, and relational data models. The proposed model has the capability of expressing fuzzy spatial relationship among fuzzy spatial objects by extending the 9-intersection model of binary topological relations between crisp regions [5]. To support dynamic query operations relating to varying-time fuzzy spatial objects an algorithm for fuzzy spatio-temporal operators is provided by integrating temporal predicates and fuzzy spatial predicates into a unified manner.

In the remainder of this paper, we summarize related works on some models for spatial objects with indeterminate boundaries, a definition for fuzzy regions, and their corresponding fuzzy spatial topological predicates in section II. Section III presents a fuzzy spatio-temporal data model together with a definition of spatio-temporal data scheme. Algorithms for fuzzy spatial operators as well as fuzzy spatio-temporal operators are described in section IV. Finally, we draw some conclusions and give a future work in section V.

II RELATED WORK

This section describes several models for spatial objects with indeterminate boundaries, a definition for simple fuzzy regions and their corresponding fuzzy spatial topological predicates.

A. Models for Objects with Indeterminate Boundary

So far, spatial data modeling implicitly assumes that the extent and hence the boundaries of spatial objects is precisely determined and universally recognized. In practice, however, there is no apparent reason for the whole boundary of a spatial object to be sharp.

There are a number of approaches available to represent vague objects. Exact models [2-3][5][8] transfer type systems for spatial objects with sharp boundaries to objects with indeterminate boundaries. The approaches in [2-3] extend the indeterminate boundary of a region into a boundary zone, called broad boundaries, which is situated around the region. These models treat the indeterminate boundary of a fuzzy region as a thick boundary. Therefore, finer distinctions

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between points (pixels) lying within the thick boundary cannot be made [11]. The concept of vague regions in [5] generalizes these approaches in the sense that such a vague region can be a pair of arbitrarily located and disjoint crisp regions. The *kernel* region describes the area, which definitely belongs to the vague region. The *boundary* region describes the area for which it is not sure whether it or parts of it belong to the vague region or not. This view presents a very coarse and restricted description of fuzzy regions since it differentiates only between three parts. The original gradation in the membership values of the points of the boundary gets lost [7]. Those approaches are not based on fuzzy set theory. Lately, there has been work [9] done on the spatio-temporal concepts with fuzzy logic

Fuzzy methods are considered as the primarily tools within geography as well as spatial databases for dealing with spatial vagueness [7-8]. Moreover, fuzzy set theory provides a promising logical foundation for intelligent GIS [9].

B. Definition of Fuzzy Regions and Fuzzy Topological Predicates

The definition of fuzzy regions [6][11] based on fuzzy set theory [10] is a collection of crisp α-cut regions. α-cut regions are crisp and nested. Let F be a fuzzy region, which is defined in two-dimensional space. The membership function of fuzzy regions is defined as $\mu_F : X \times Y \to [0,1]$.

An α-cut region F_α for an $\alpha \in [0,1]$ is represented as $F_\alpha = \{(x,y) \in IR^2 \mid \mu_F(x,y) \geq \alpha\}$. A fuzzy region, a collection of α-cut regions is then described as follows:

$$F = \{F_{\alpha i} \mid 1 \leq i \leq \Lambda_F\}$$
$$with\ \alpha_i > \alpha_{i+1} \Rightarrow F_{\alpha i} \subseteq F_{\alpha i+1}\ for\ 1 \leq i \leq | \Lambda_F | -1$$

in which Λ_F is the level set $\alpha \in [0,1]$ that represents distinct α–cuts of a given region F

A fuzzy region F is a *simple fuzzy region* if it is fully connected and convex. A fuzzy region is said to be fully connected if and only if its α-cut regions are connected for all α>0. The core of a fuzzy region F is the area in which each point has the membership function value of 1.

Fuzzy topological predicates are determined by computing the topological relationship between two collections of α-cut regions. Let $\pi_f(F,G)$ be the value representing the topological relation between two fuzzy regions. It is determined by the following formula:

$$\pi_f(F,G) = \sum_{i=1}^{N}\sum_{j=1}^{N}(\alpha_i - \alpha_{i+1})(\alpha_j - \alpha_{j+1})\pi_{cr}(F_{\alpha i}, G_{\alpha j})$$

in which N is the number of α-cut regions and $\pi_{cr}(F_{\alpha i},G_{\alpha j})$ is the topological predicate between two α-cut regions $F_{\alpha i}$, $G_{\alpha i}$. It is computed by the 9-intersection model of topological relations between two simple regions with no holes. Once the value of $\pi_{cr}(F_{\alpha i},G_{\alpha j})$ between all α–cut regions is determined, the aggregated topological relation between F and G can then be determined and the result value should belong to the interval [0,1]. Consequently, a set of eight fuzzy topological predicates T_f={*disjoint*$_f$, *meet*$_f$, *overlap*$_f$, *equal*$_f$, *inside*$_f$, *contains*$_f$, *covers*$_f$, *coveredBy*$_f$} between two fuzzy regions is obtained.

III THE FUZZY SPATIO-TEMPORAL DATA MODEL

This section gives a fuzzy spatio-temporal data model based on fuzzy set theory, relational data models.

Geographic entities are represented as a set of locations in space-time with a set of properties characterizing those locations. We examine the two-dimensional geographic space. Space-time is represented in three-dimensional geographic space.

The thematic data is associated to geographic entities and characterizing them depends on the application domain. The application domain defines a set of k lexical values characterizing a phenomenon. Each individual entity, related that phenomenon, is attached k degrees of membership, one for each lexical value. Those degrees are expressed in the rage [0,1].

The data model can be viewed as a hierarchy of data. At the highest level, there is a space-time cube, called *map*. The map is a library of space-time cubes, called *thematic layers*. Each thematic layer refers to a theme characterizing geographic entities. Each thematic layer consists of a set of space-time cubes, called *lexical layers*. Each lexical layer accommodates the degree of membership (d.o.m) value of each individual space-time location in the lexical layer characterizing a theme. All locations with: 1) a d.o.m value within a specified range [a,b], 2) geographic location within geographic space, and 3) temporal location with temporal space T, constitute a space-time region. Geographic entities of interest are presented by space-time regions and identified uniquely. In this paper, we provide a varying number of α-cuts for each space-time region, called a fuzzy region changing over time.

Definition: Spatio-Temporal Database Scheme

The feature relation FRi' and the feature history relation FRi'' for the i[th] layer describe a vector of spatial data <fid,f_2,..F_n,Geo_i> in which fid represents object identifier, f_1,f_2,…,f_n are geometric elements describing the spatial extent of the object, Geo_i identifies the actual shape and size of the object in a metric sense.

The attribute history relation AR_i'' for the i^{th} layer presents an attribute vector of non-spatial data <fid, A_i,VT,prev>, where A_i is an attribute vector for the spatial object fid of the i^{th} layer <fid, $a_1,a_2,\ldots,a_m$>, a valid time vector VT=<VTs,VTe> denotes the beginning and ending time of valid time and prev is an historical pointer of a feature in an historical relation.

The attribute relation AR_i' for the i^{th} layer is described by an attribute vector of non-spatial data <A_i,VTs,pre>. A merge relation MR_i describes an historical pointer vector of merged objects, <fid,hid,VT> in which hid denotes the historical pointer of the spatial object determined by fid in attribute history relations. The merge relation MR_i stores only historical information of spatial objects in which merge relation occurs.

IV ALGORITHM FOR FUZZY SPATIO-TEMPORAL OPERATORS

This part introduces an algorithm for fuzzy spatio-temporal operators. The idea is to integrate temporal predicates and fuzzy spatial topological predicates into a unified manner.

A. Temporal Operators

Incorporating time values into query languages is to determine the temporal relationships between objects. Defining temporal comparison operators allows one to determine these relations. A complete set of time period relations is given in [1]. We denote a and b be two time periods. The semantics of the period-period operators are described in the following table

Temporal Operators	Temporal Semantics Expression
a before b	End(a)<Begin(a)
a equals b	Begin(a)=Begin(b) $\wedge$ End(a)=End(b)
a meets b	End(a)+1=Begin(b)
a overlaps b	(Begin(a)<Begin(b) $\wedge$ End(a)>Begin(b) $\wedge$ End(a)<End(b)) $\vee$ (Begin(a)>Begin(b) $\wedge$ Begin(a)<End(b) $\wedge$ End(a)>End(b))
a during b	(Begin(a)>Begin(b) $\vee$ Begin(a)=Begin(b)) $\wedge$ (End(a)<End(b) $\vee$ End(a)=End(b))
a starts b	Begin(a)=Begin(b) $\wedge$ End(a)=End(b)
a finishes b	Begin(a)>Begin(b) $\wedge$ End(a)=End(b)

B. Fuzzy Spatial Operators

We now explain how to check fuzzy spatial condition which is used in 'where' clause of spatial query. As presented in section II, fuzzy spatial predicates are embedded into SQL-like query languages by using linguistic description, called *quantified fuzzy spatial predicates*. Each fuzzy quantifier is represented by an appropriate fuzzy set with a membership function $\mu_\gamma : [0, I] \rightarrow [0,1]$

Firstly, we define a classification for fuzzy quantifiers:

> **Create** Classification **fq**(*not, a little bit, somewhat, slightly, quite, mostly, nearly completely, completely*);

Then, activate it: **Set** classification **fq**;

Function defines quantified fuzzy spatial predicates as below description.

Function Boolean Fuzzy_Spatial_Operator(PFR, SFR, Fquantifier, Sop)
Input: Primary Fuzzy Region (PFR), Secondary Fuzzy Region (SFR), a fuzzy quantifier (FQuantifier), and Spatial operator (Sop)
Output: a Boolean value
Begin
  Step1: Compute the aggregated relations between two fuzzy regions PFR and SFR.
    - Let *result* be the calculated value of the aggregated relation between PFR and SFR
    - Repeat
      Compute the spatial predicate *Sop* between two crisp α-cut regions F_α, G_α of PFR and SFR respectively.
    Until spatial relations between all α-cut regions are determined
  Step 2 : **If** (*result* satisfies the predefined values for the fuzzy quantifier *Fquantifier* in the classification **fq**) **then** return 'true'
      else return 'false'
End

C. Fuzzy Spatio-Temporal Operators

Fuzzy spatio-temporal operators are employed in the 'where' clause of query statements. The function FST_Operators() defining Fuzzy Spatio-Temporal Operators firstly checks whether spatial objects satisfy temporal predicate Top. If the temporal condition is satisfied then continue to check fuzzy spatial predicate FQuantifier.Sop of spatial objects. If spatial objects also satisfy fuzzy spatial condition this function returns a Boolean value 'true', otherwise 'false' value is returned.

Function Boolean FST_Operator(PFR, SFR, FQuantifier, Sop, Top)

Input: Primary Fuzzy Region (PFR), Secondary Fuzzy Region (SFR), a Fuzzy Quantifier (FQuantifier), Spatial operator (Sop), and Temporal operator (Top)
Output: a Boolean value *fst_predicate*
Begin
  Initialize *fst_predicate*=false;

Step1: Check temporal condition
- Get time periods of the first region and the secondary one (VTs,VTe) and (begin,end) respectively;
- Check the temporal relation between the two regions whether it satisfies the time condition *Top* by using the semantics expression in table 1;

Step 2: Check fuzzy spatial condition
If (the temporal condition is satisfied) **then**
Call function Fuzzy_Spatial_Operator() with parameters PFR, SFR, and FQuantifier and Sop;
If (Fuzzy_Spatial_Operator()=true) **then**
fst_predicate=true;
return *fst_predicate*;
End

D. Fuzzy spatio-temporal query

The following example illustrates how fuzzy spatio-temporal operator is applied in 'where' clause of select query statement. The usefulness and significance of our proposed operators is that users can display complex queries concisely and friendly.

Assuming that we have a relation *Pollution*, which stores the blurred geometry of polluted areas as fuzzy regions, a relation *LandUse*, which keeps information about the use of land areas whose vague spatial extents are considered as fuzzy regions and valid time. We denote valid time as a vector (VTs,VTe) indicating the starting time the ending time.

LandUse(ID, category, region, VTs, VTe)

A query can be to find all inhabited areas where people are rather endangered by pollution during years /1/1999-1/1/2002.

Select LandUse.ID
From Pollution P ,LandUse L
Where L.category=inhabited **and**
FST_Operators(P.region, L.region, *quite*, *Overlaps* , (L.VTs,L.VTe) *overlap* (1/1/1999, 1/1/2002));

This query is answered by using fuzzy spatial operator FST_Operators() with the first region inputted from *Pollution* relation and the second region from *LandUse* relation. Inhabited regions are outputted if their existing time period (VTs,VTe) *overlap* the given time period (1/1/1999, 1/1/2002) and spatially *quite Overlaps* inputted polluted regions.

V CONCLUSIONS AND FUTURE WORK

This paper introduced a fuzzy spatio-temporal data model along with the definition of spatio-temporal database scheme. Fuzzy spatio-temporal operators were proposed to provide users with close, flexible dynamic query operations. Since a fuzzy region is defined as a collection of α-crisp regions, existing algorithms in either a rater-based GIS or a vector-based GIS can be directly applied to this fuzzy region. Our work can be also applied into the management systems and query processor of natural resource data, environment, geographic information, and so on.

In the future work, fuzzy spatio-temporal join processing and query optimization to support more efficient query processing will be studied. With those works application system will become intelligent and flexible to satisfy the requirements of users with high performance.

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