A METHOD FOR LINKING ROAD-NETWORK INTERSECTIONS IN A MULTI-SCALE NAVIGABLE DATABASE

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Commission II, WG II/3

KEY WORDS: Road-network intersection, Multi-representation, Object link, Data matching, Spatial aggregation

ABSTRACT:

As an important component of ITS (Intelligent Transformation System), the road-network features in navigable database are characterized by multi-scale representations, which means that several representations from the same features in the real world exist synchronously in the database. In the context, the explicit link of these representations from the same features at different scales, especially in the case of the road-network intersections, plays a crucial role in improving query efficiencies and reducing data redundancies during the process of route planning and navigation, the process of linking road-network intersections is one of the most important and complex process in building multi-scale navigable databases. From the viewpoint of Geo-scientists, establishing link can basically be seen as a matching problem, but it works well only in the case of those objects at the similar scale, objects of different scales, however, are too difficult to match directly. Based on the description of key problems in links between representations of road intersections at different level of detail, this paper considers that this kind of link can be performed based on object spatial aggregation approach. Thus, before the matching itself, the semantic relations, especially the aggregation relation between multiple representations, have to be probed. By use of matching criterions, such as attribute, topological, geometrical matching technologies, the links between representations from the same road-network intersections can be established explicitly. In this context, a case in point is given for describing the strategies of linking road network intersections in detail.

1. INTRODUCTION

As an important component of ITS (Intelligent Transformation System), navigable database plays a critical role in route planning and road engineering. Compared with other traditional databases, navigable database is characterized by multi-scale road network features, which means that several representations at different levels of detail and scales representing the same feature in the real world are stored in the database. In order to provide users with the function of navigating across different details of level, ranging from overview screen to detailed views, it is necessary to link explicitly those different representations of the same road feature. Especially in the case of road intersection, which is one of the most complex and important components of road networks. As showed in fig1, an intersection represented by a point feature at scale 1 will correspond to several element features enclosed by the circle at scale 2. The explicit links between road intersections at different scales indicated the possible change of representations an intersection feature undergoes when moving from one representation to the next. These transformations are manifold: objects may keep their representation, they may change their geometry, type or attributes, merge with other objects, or disappear completely. Obviously, these changes are influenced by objects themselves, their semantics, their geometric properties, and the given application.

In order to establish the explicit links between road intersections at different scales, the Consistency between representations has to be maintained, this means that the critical step during linking process is to ensure the exact correspondences of the road intersections from one scale to another, and correspondences can be established at the level of individual object instances, at object class level, or at the geometry level.

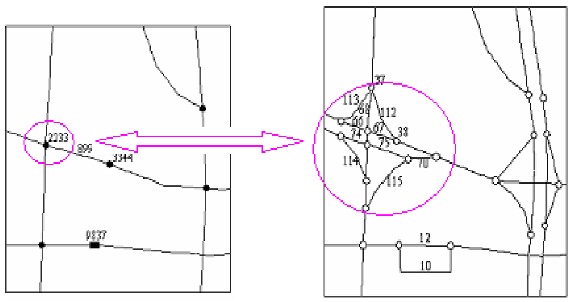

Figure 1. Different level of detail for the same Road Intersection

In this context this paper gives strategies for linking corresponding road intersections. The paper is organized as follows. After a review on previous work in section 2, section 3 analysis the key questions for links of corresponding road intersections at different level of detail and describes the aggregation method based on the semantic relations between representations of intersection features, and the correspondence can be established explicitly for each intersection by assign each object its corresponding partners at the other scale. Based on these principles, in section 4, a case in point is given for describing the strategies in detail. And in section 5, a discussion of this method concludes the paper.

2. RELATED WORK

The problem of linking different data sets is tackled in many research contexts. One important branch is in the domain of database generalization or model generalization (Sester etal, 1998). In traditional map series, corresponding object instances were only linked implicitly by a common spatial reference system, e.g. the national grid. In order to make these relationships explicit geo-science researchers and computer scientists have developed various strategies. In the computer science domain, *schema integration* has been the dominant methodology for database integration (Spaccapietra, etal 1992). That approach has been extended for geographic data sets (Devolege, 1998). Geo-scientists on the other hand have adopted methods from communication theory like *relational matching* (Sester, etal 1998), they supposed that linking could be basically seen as a matching problem, which means that primitives of the data sets should be matched each other. The word primitives could stand for a geometrical element as well as for an object structure. Objects in different representations can be assumed to share some metric, topological or attribute information, which is the principle of relational matching technique.

Approaches for matching spatial data are already realized in geo-information systems. One of the first approaches of matching spatial data from different data models is the work of the Bureau of the Census in Washington DC (Saalfeld, 1988). A system was developed to merge digital data sets provided by the Bureau of Census and the United States Geological Survey (USGS). During the past ten years, many algorithms have been developed to solve different practical matching problems, and these algorithms have used different matching criteria. According to the predominant criterion used in matching correspondent features, these algorithms can be classified into three kinds: geometric, topological and attribute method (V.Walter, etal 1997; M.Sester, etal 1998; YUAN and TAO, 1999;K.J.Dueker, etal 2000).

The method to match spatial data of similar scale works well, if the data is captured using the same data model or criteria by which to define road features, but is still difficult to solve the complicated problem in practice. What's more, it is not a satisfactory way in the case of representations at different scales, for the difference between representations of the same objects at different scale will lead to the difference in class level, object level, geometry level, even attribute and attribute values level. So those features at different scales cannot be matched directly.
In the context of hierarchical data structure, multi-scale or multi-level data structures already exist on a low level, e.g., quadtrees (Samet, 1989) or hierarchical triangulated networks (Dutton, 1997), and topological structures (Bruegger and Frank, 1989). Those structures show aspects of hierarchically organized data but only for one type of hierarchies, namely for aggregation hierarchies. Oosterom (1993) proposed to use a Reactive-tree coming from R-tree for storage of less detailed objects, for this structure Oosterom proposed an 'importance' characteristic, but it could be used only in the case that objects ordered by importance are represented in a strict data structure.

3. THE KEY QUESTIONS AND STRATEGIES FOR INTERSECTIONS LINKS

The problem of linking corresponding objects at different levels of detail becomes one of schema integration if the conceptual schemata of the databases schemata differ. Links between datasets at different levels of detail can be represented by scale-transition relationships if the database schemata are the same and if the datasets are consistent (Devogele *etal*, 1996). This paper focuses on the latter.

The previous section has revealed that objects from different scale cannot be directly matched. So in terms of multi-scale data sets, this paper proposes that it is necessary to transform both data sets to a similar scale, which is related to semantic knowledge. Basically there are three kind of semantic knowledge in multi-scale database, namely aggregation, association, classification, of which aggregation plays an important role in linking the representation of spatial objects at several scale levels. Aggregation is a special form of association between objects, where the composite object at the coarser level is considered to be assembled from others at the detailed level. An aggregation shows how composite objects can be built from elementary objects and how these composite objects can be put together to build more complex objects and so on. In literature on semantic modeling, the upward relationships of an aggregation hierarchy are called "part of" links. These links relate a particular set of objects to a specific composite object and on to a specific more complex object and son on. For composite spatial objects the *PARTOF* links might be based on two types of rules involving the thematic and the geometric aspects of the elementary objects (Molenaar, 1996).

Spatial aggregation is a special case of aggregation in which topological 'whole-part' relationships are made explicit. The usage of this kind of aggregation imposes spatial integrity constraints regarding the existence of the aggregated object and the and the corresponding sub-objects, the observation of these aggregation rules contributes to the maintenance of the semantic 'whole-part' in multi-scale database, in the context of geography, spatial aggregation is also called topological "whole-part", the geometry of each part is entirely contained within the geometry of the whole. Also, no overlapping among the parts is allowed and the geometry of the whole is fully covered by the geometry of the parts (Borges, etal 2001). Based on the principles of spatial aggregation, the aggregation for links of road intersections may be based on two types of rules, as follows:

1) Rules specifying the classes of elementary objects building a composite object and
2) Rules specifying the geometric characteristics (such as point, line) and topological relationships of these elementary objects (i.e. adjacency, connectivity, proximity, etc.)

So the strategies for linking road-network intersections in a multi-scale navigable database include :

1) Search for the semantic relation of the corresponding road network intersections.
2) Establishment of explicit links rules;
3) Formal representation and description of the rules;
4) Implement of the links;

4. A CASE IN INTERSECTIONS LINKS IN GDF

In this section, an example will show how the corresponding road network intersections from a medium- scale to a large-scale in navigable database are linked based on predefined semantic rules. in view of the general, we take the format of GDF as the basic conceptual schema.

4.1 A Brief Description of GDF

There are several GIS data models used for transportation applications, one of which is the famous GDF (Geographic Data File Standard) having been developed specially for transportation. GDF, for all intents, is a fully topological and conceptual data model that requires full specification of cartography, topology, and attributes for any useful data sharing to occur. There is no explicit support for multi-link objects inside the transmission protocol.

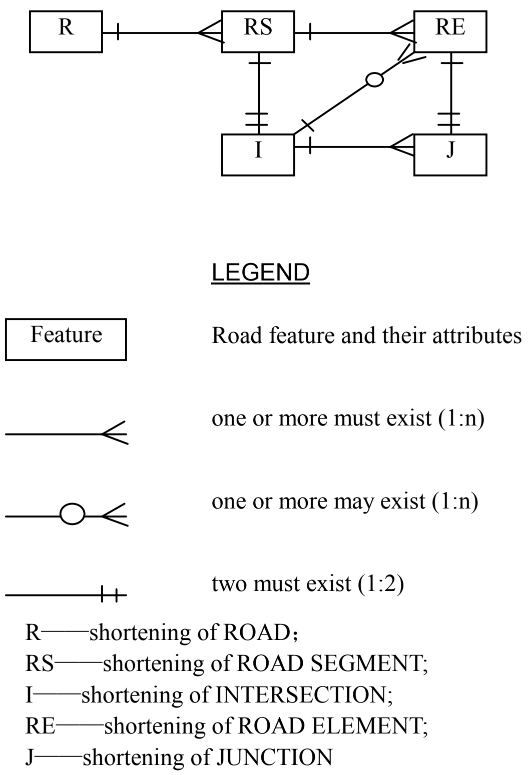

Figure 2. Road network model in GDF

As showed in Fig2, Entities are the things about which we wish to store information—as shown in boxes, while the relationships between entities are shown using lines. Each entity type has been identified by a special style. Each relationship type has been shown using descriptive text and connection symbols. Each group of entities for a single type can be treated as a stand-alone entity class.

Road is an entity class of real world Road and is divided into several Road Segments, which meet at Intersection. A Road Segment has two and only two Intersection. An Intersection could be owned by more than one Road Segments. Road Element describes the basic components of the road network. A Road Element is a piece of Road Segment, homogeneous in value with respect to the set of attributes and relations.

JUNCTION describes points in the road network where traffic conditions change, thus delimiting road elements. A Junction is the begin- or the end-extremity of a road element. A Junction can be a crossroad, a traffic circle, a toll, a dead end, or a point where the value of some attribute of the road changes. A Junction can delimit several road elements, each road element has one and only one begin Junction and one and only one end Junction.

4.2 Matching Strategies for Linking Road Intersections

According to the above, the matching strategy on linking corresponding entities representing the same road intersections is subdivided into four steps, as follows.

1). Search for the semantic relation of the corresponding road network intersection features

The semantics follows that an Intersection at the lower level scale must correspond to one or more Junctions and at the same time may correspond to one or more road elements at the upper scale.
In this context, the descriptions for road network features are showed in table 1-table 5.

Field	type	description
J-ID	Integer	Junction identification number
I-ID	Integer	INTERSECTION Identification Number
J-Level	Integer	JUNCTION Level
…		

Table 1. the description for Junction（J）feature

field	description
I-ID	identification number
I-Level	The scale level
J-ID	Corresponding Junction identification number
…	

Table 2. the description for Intersection（I）feature

field	type	description
R-name	char	Road name
R-ID	integer	Road identification number
R-level	integer	Road level
…		

Table 3. the description for Road（R）feature

field	type	description
RS-name	char	Road Segment name
RS-ID	integer	Road Segment identification number
RS-level	integer	Intersection level
FI-ID		First intersection ID
TI-ID		Terminate intersection ID
…		

Table 4. the description for Road Segment（RS）feature

2) the establishment of explicit link rules

Based on the above semantic relations between corresponding features, the reference rules are as follows,

a) the geometry position of the candidate Junction locate the buffer the Intersection create at the scale S2 ;
b) If both junctions of a road element belong to the buffer, then the road element is one part of the corresponding entities.

field	type	description
RE-ID	integer	RE identification number
RS-ID	integer	RS identification number
FJ	integer	First Junction ID of RE
TJ	integer	Terminate Junction ID of RE
…		

Table 5. the description for Road Element（RE）feature

3) the formulation of rules

The formulation clauses can be split into two parts. The first clause gives the general description about corresponding relation between the dataset s1 at the lower level of detail and the dataset s2 at the higher level of detail, and the following two clauses describe the first clause in detail. For purpose of concision, we deal those with the help of SET.

$$S1.Intersection \subseteq S2.SET(\ [1:n]Junction, [0:n]RoadElemnet) \quad (1)$$

$$SET([1:n)]Junction) = \{w / w \in Junction \wedge w.geometry\ INSIDE\ BUFFER(Intersection, resolutionS2)\} \quad (2)$$

$$SET([0:n)]Roadelement) = \{s / s \in Roadelement \wedge s.FJ \in SET([1:n)]Junction) \wedge s.TJ \in SET([1:n)]Junction)\}$$

Concretely, the first clause specifies that every intersection instance in database S1 with lower scale s1 correspond to a multi-sorted set of DB2 instances. The second clause specifies that for each intersection instance one or more Junction instances 1/, which is one junction of a road element, and 2/ whose geometry lies within a given buffer surface enclosing the intersection geometry, should be considered. The second predicate restricts road element instances to those whose junctions both belong to the candidate junctions.

As a result of the above formulation, new sets are created, depicted as a matrix M, and M is denoted as M2={J1，J2，…. J_{m1},RE1，RE2…RE_{m2},}, in which m_1 denotes the number of the corresponding junctions and m_2 denotes the number of the corresponding Road Elements.

4) Establishment of link relation between corresponding intersections

In terms of the above implement, the matching result for corresponding intersections from different scales can be observed, as showed in table 6.

field	type	description
I-ID-1	Integer	Intersection ID at scale 1
M2-ID	Integer	The corresponding entities set ID at scale 2

Table 6. the structure of correspondence between Scale 1 and scale 2

5. SUMMARY AND OUTLOOK

As an important research topic of multi-scale navigable database, the links of different representations from the same road intersection features have been addressed. Firstly, we consider that links of multi-scale representations from the same geographical features can basically be seen as a matching question, but the corresponding objects representing the same reality features from different scales cannot be matched directly by use of matching technologies. In this context, we propose that the link questions can be solved with the help of semantic relations, especially by use of spatial aggregation relation between corresponding features. So a primary step is the provision of the necessary knowledge used for the semantic links. Which is then followed by the explicitly rules and implement strategies in detail.

Further research has to focus on defining a multi-scale road-network database model and also on the use of this model for hierarchical transportation analysis: in order to gain an overview of a given situation, small scales are consulted; only in regions of interest is a further zooming performed where the details can be investigated leading to the natural coarse-to-fine-treatment of problems.

ACKNOWLEDGMENTS

The research has been supported by the project 'The construction of national multi-scale navigable database system ' and by the National Natural Science Foundation of China under grant No.69833010.

REFERENCES

Bruegger B. P. and Frank A. U., 1989. Hierarchies over Topological Data Structures. *ASPRS-ACSM*. .Baltimore. pp. 137-145.

Dueker, K.J. and Butler, J.A., 2000. A framework for GIS-T Data sharing. www.upa.pdx.edu/cus/.

Dutton and Geoffrey. 1997. Digital Map Generalization Using a Hierarchical Coordinate System. *ACSM/ASPRS*, Seattle. pp. 367-376.

Karlaa.V.Borges, Clodoveu A.Davis JR. and Alberto H.F.Laender, 2001. OMT—G：An Object-Oriented Data Model for Geographic Application. *Geoinformatica*, l5(3), pp.221-260

Molenaar, M., 1996. Multi-scale approaches for geodata. *International Archives of Photogrammetry and Remote Sensing*. Vol. XXXI/B3.pp542-554.

Saalfeld, 1988. Automated map compilation. *Int. J. Geographical Information Systems*. 2(3), pp. 217-228.

Samet H., 1989. *The Design and Analysis of Spatial Data Structures*. MA: Addison-Wesley Publishing Company.

Sester, M., Anders, K. and Walter, V.. 1998. Linking Objects of Different Spatial Data Sets by Integration and Aggregation. *GeoInfomatic*. 2(4), pp.335-358.

Spaccapietra, S., Parent, C. and Dupont, Y., 1992. Model independent assertions for integration of heterogeneous schemas. *VLDB Journal*, Vol1, pp. 81-126.

Thomas Devolege. 1998. On spatial database integration. *Int. J. Geographical Information Science*. 12(4), pp.335-352.

Thomas Devogele, Jenny Trevisan and Laurent Raynal. 1996. Building a multi-scale database with scale-transition relationships. *Spatial Data Handling, SDH*.section6, pp.19-31.

Timpf, Sabine, 1998. *Hierarchical Structures in Map Series*. Doctor dissertation. Vienna Technical University, Austria.

Van Oosterom, 1993. *Reactive Data Structures for Geographic Information Systems*. Oxford University Press.

Walter, V. And Fritsch, D., 1997. Matching strategies for integration of spatial data from different sources. Y.C.Lee & Zhi-lin Li, editors. *Proceedings of the International workshop on Dynamic and Multi-Dimensional GIS*. Aug.25-26, Hongkong, pp. 215-228.

YUAN Shuxin amd TAO Chuang, 1999. Development of conflation components. *The Proceedings of Geoinformatics'99 Conference*, Ann Arbor, 19-21 June, pp. 1-13.