

# AN ALGORITHM FOR BUILDING FULL TOPOLOGY

Chaoying HE<sup>1,2</sup>, Jie JIANG<sup>2</sup>, Gang HAN<sup>2</sup>, Jun CHEN<sup>2</sup>

<sup>1</sup>College of Remote Sensing and Information Engineering, Wuhan University, Wuhan, China 430079,  
hechyng@hotmail.com

<sup>2</sup>National Geomatics Center of China, 1 Baishengcun, Zizhuyuan, Beijing, China, 100044  
(jjie□hangang, chenjun) @nsdi.gov.cn

**KEY WORDS:** Navigation, Databases, Algorithms, Full Topology, ITS

## ABSTRACT

Traditional polygon-arc-node topological relationships (TRs) is standard in vector GIS. That has been explicitly represented by many commercial GIS systems. In the case of Intelligent Transportation System (ITS), a full topology is defined by an international standard with which road network data are topologically structured. One important part of ITS application is place searching and path finding that is based on the connectivity of road segments and TRs between road segments and certain area features, such as zoos. Therefore, we need to construct arc-node topology to record From-Node and End-Node of one edge, node-arc topology to record edges at the node, and 'special' area topology. The former two are similar to the definition in the past, but the last one is different. Since the required topologies in ITS application are different from that of the traditional methods, the required algorithm is different. Based on the analysis of the requirements and characteristics of ITS application, the present paper proposes an algorithm for building the topological relationships between spatial objects in road network. Compared with other methods, the topologies defined in this paper can describe TRs between spatial objects in road network more accurately; the present algorithm is simplified and more efficient. Experiments demonstrate that the efficiency of the proposed algorithm is improved by 150% in contrast with other methods.

## 1. INTRODUCTION

The term "topology" has been used in GIS to describe one kind of spatial relationships among spatial objects, which might be expressed as 0-dimension (nodes), 1-dimension (arcs) or 2-dimension (polygons) (Chrisopher M. Gold, 1994). In general GIS topological data model, such as the one used in ARC/INFO, one of the most popular GIS software, people build topological relationships (TRs) between nodes and edges, as well as TRs between edges and polygons. This kind of TRs, which we called as traditional TRs, can meet most of the requirements in GIS applications. However, in certain application, such traditional TRs are not always totally applicable. For example, in Intelligent Transportation System (ITS), owing to the characteristics of such application, the TRs between edges and polygons are not always necessary. So different TRs need to be built in ITS field (Jie JIANG, 2003).

In ITS applications, one of the most important functions is place searching and path finding. For example (Fig.1), one person wants to drive from National Geomatics Center of China (NGCC, point A) to Beijing Zoo (area M) and he doesn't know where the Zoo is. In this case, he must at first search for the location of Beijing Zoo, and then seek the road segments that are adjacent to M, and then find out the access to the Zoo along the road segments. In fig.1, point P is one of the enter point of the Zoo. Then, he should find a shortest route between A and P in the given road network.



Fig. 1 An example of path finding

In this process, two kinds of relationships between spatial objects will be used. One is the adjacency between road segments and the Zoo (M), which are used to find the road segments around the Zoo. The other is the connectivity of road segments in the road network, which is used to calculate the shortest route between A and P. As we describe in section 3, these relationships can be represented as 'special' area topology, arc-node topology, and node-arc topology in ITS application. "Special" area topology in this definition is different from the traditional TRs. It records the TRs between some area features and the around road segments rather than the TRs between area features and all their boundaries. Moreover, topological relationships in ITS application need to be constructed fast and automatically. The traditional methods, which are time-consuming and inefficient, cannot satisfy these requirements. In a word, the traditional TRs haven't considered the characteristics of ITS application and they don't suit for ITS applications very well. Therefore, we should study the specific topological relationships in ITS application and find out efficient algorithm to build topological relationships fast and automatically.

The rest of the paper is structured as below. In section 2, the traditional methods for building topological relationships and the limitation of such methods are introduced. The third and fourth section expounds the topologically structured data model and the algorithm for building full topology. The experiments and corresponding results are given in section 5. The sixth section is the summary.

## 2. TRADITIONAL METHODS FOR BUILDING TOPOLOGY

It's well known that TRs can facilitate spatial query, error detection, and produce valuable derived statistics for revealing graph or surface properties (Mark, Egenhofer, 1995; Kimfung Liu, Wenzhong Shi, 2003). In the past years, two key issues related to TRs, which are topological data model and algorithm for building topology, have been discussed widely. On the one hand, many topological data models have been developed and applied, such as DIME model of the US Census Bureau for the 1970 census, POLYVRT structure used by the ODYSSEY system of Harvard University, and ARC/INFO topological data model (Laurini Robert, Thompson Derek, 1992). In these models, topological relations are generally recorded and stored in a tabular format. For example, ARC/INFO defines different feature attribute tables, such as PAT, AAT, NAT, TAT, to describe TRs of different features, namely polygon, line, point, node and annotation. Generally speaking, these models are related to certain application fields (Ayse Can, 1996; Michael J. Mineter, 2003; Serafino Cicerone, Eliseo Clementini, 2003; S. Dowers, B. M. Gittings and M. J. Mineter, 2000), that is, different application has different topological data models. On the other hand, traditional algorithms for building topology can be divided into three kinds. The earliest method for creating topology tables depends on manual edits during the process of digitizing (LI LIN, 1987). It often appears excessively labor consuming and tedious. With the development of computer technology, researchers begin to make a study of a half-automatic method. They proposed to figure out topological relations from line intersection computation, which release people from the heavy and dull job. However, such methods cannot, by themselves, handle islands or self-intersecting arcs (Gold et al., 1994). Subsequently, Gold proposed an approach based on voronoi diagram to generate the adjacency relationships between each atomic element of the map. Although it also has the ability to extract the traditional polygon-arc-node topology, it contains an excess of information and its storage requirements almost several times larger than for the previous methods (Gold et al., 1991, 1994). Moreover, whichever method described above consider the boundaries of the area features when building the polygon topology. If we adopted such methods in ITS application, we would need another table besides the traditional polygon-arc-node topology to represent the relationship between road and area features because the

boundaries of these features are not always the road segments. That's complicated and may cause data redundant.

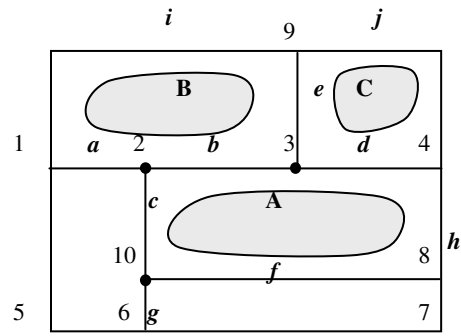
In this paper, the authors proposed three topological tables suitable for ITS application and one efficient algorithm for constructing such tables.

### 3. TOPOLOGICAL DATA MODELS FOR ITS APPLICATION

Topological Data Model is the foundation of topology generation. While constructing topological data model, we need to select feature types and topology according to the requirements of certain application. In the case of ITS, most popularly used data model is GDF (Geographic Data File) model, defined in ISO IS 14825. In GDF data model, three types of graph topology are defined, that are non-explicit topology, connectivity topology, and full topology. Compared with the other two types, full topology can perform network operations in a very efficient way, and also can integrate area information in network operations.

According to the definition of full topology and the characteristics of ITS application described in section 1, we define three tables to store the topological relations between the features in ITS applications (Fig. 2). The first one is edge-node topology to record From-Node and End-Node of one edge. Another is node-edge topology to record edges at one node. And the third one is 'special' area topology. The former two are similar to the definition in the past, but the last one is different. In the past, the ordered set of boundaries of area features are searched and stored in area topology. However, because area features themselves are not required in ITS application, the traditional area topology isn't necessary. The "special" area topology proposed here only records the relationship between area features and road segments. Then, not the relationship between all area features and road segments are required. So, the required area features need to be identified and the relational tables between the identified points and the around road segments need to be built. These topological relations are described in the following tables.

(a) A graph containing node, edge and polygon



Edge-node Topology		
Edge ID	From Node	End Node
a	1	2
b	2	3
c	2	10
.....	.....	.....

(b) Edge-node topology

Node-Edge Topology	
Node ID	Associated Edge
2	a, b, c
3	b, d, e
10	c, g, f
.....	.....

(c) Node-edge topology

Special Area Topology	
Identified Point ID	Around Roads
A	f, h, d, b, c, f
B	b, e, i, a, b
C	d, j, e, d
.....	.....

(d) Special area topology

Fig. 2 The topological tables defined in our methods

## 4. ALGORITHM FOR BUILDING FULL TOPOLOGY

### 4.1 Overview

The foundation of this algorithm is the topological relation tables described above. It works on the premise that all roads have been broken at the intersection. The input data include the coordinates of the nodes and identified points, the coordinate sets of edges. Table 3 describes the structure of the input data.

Coordinates of Nodes	Coordinate Set of Edges	Coordinates of Identified Points
Node ID	Edge ID	Identified Point ID
x coordinate	The coordinate sets of points in one edge	x coordinate
y coordinate		y coordinate
z coordinate		z coordinate

Table 3 Structures of Input Data

To build Edge-Node relation table, the essential idea is coordinate matching. If the coordinates of nodes match the coordinates of the from nodes or the end nodes in the set tolerance, note down the node ID in Edge-Node relation table. And the Node-Edge relation table is based on the former one. According to the from-node and end-node Id of every edge, we can easily get the edges at every node.

The crux of the algorithm is to build what we define as special area topology, that is, to search the road segments around the area feature that are closest to it. From Fig. 4, we know that if we draw a radial downwards from the identified point (A), the edge (BC) that intersects with the radial first is one edge we want. So we may think that if the radial is dense enough, we can find all required road segments around the area feature (Fig.4). However, the fact is that we cannot draw all radials. In our algorithm, we transform the problem to the following steps. Above all, specify the begin edge of the search process by drawing a vertical radial as we describe above. Then, set the begin edge as the edge of current disposal (current edge for short) and identify the begin node and end node of current edge according the rules defined in our algorithm. Set the end node as the current node of the searching process. And then search another edge that is connected to the current edge at the current node and closest to the area feature based on Qi operator. And then set the searched edge as the current edge, the end node of the edge as the current node. The searching process circulates until the end node of the current edge is equal to the begin node of the begin edge. During the searching process, we employ Qi operator because it is more efficient than angle operator used before. We also need to correctly dispose the

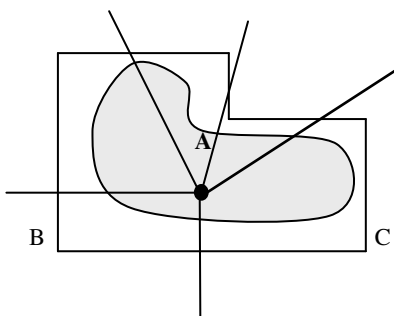


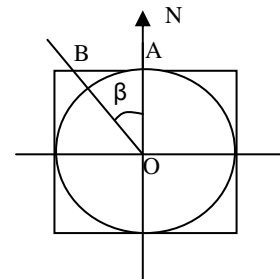
Fig. 4 An intuitionistic method to search the road segments around the area feature

dangle edges that are valid to road network. More details can be gotten in the following section.

## 4.2 More Details

**Specify the begin edge and identify the begin node and end node of one edge:** Draw a vertical radial downwards from the identified point. The Edge which intersects with the radial first is the begin edge in our algorithm. This process can be optimized by excluding the edges that cannot intersect with the radial rather than computing the intersect points between the radial and all the edges. The begin node of one edge is the frontal node of one edge in the counter-clockwise. In Fig. 4, BC is the begin edge that intersects with the vertical radial first and B is the frontal nodes of edge BC in the counter-clockwise. So B is the begin node of edge BC and C is the end node of edge BC.

**Qi Operator:** To search the next edge based on the current edge and the current nodes, we need an operator to compute the most appropriate edge, that is, the closest one to the polygon in the direction. Angle operator is employed in the original methods. In these methods the angle operator,  $\tan^{-1}(x)$ , needs to be computed. The computation of  $\tan^{-1}(x)$  is time consuming. The present paper adopts Qi operator (Qi Hua, Liu WenXi, 1996) that saves the time and heightens the efficiency. The basic ideas of Qi operator are to represent the corresponding polyline on the boundary rectangle of the unit circle as the azimuth of the radial. The center of the unit circle is the end node of the current edge. In the Fig. 5, the coordinate of point O is  $(X_0, Y_0)$ . The point B, the coordinate of which is  $(X_i, Y_i)$  is the intersect point of the radial from O and the boundary rectangle. Set  $\Delta x_i = X_i - X_0$ ,  $\Delta y_i = Y_i - Y_0$ . In the different eight directions, the Qi operator of the azimuth can be represented as the following formula.



(1) Sketch map

(2) Formula

Fig. 5 Qi Operators

$$Q_i(x, y) = \begin{cases} \Delta x_i / \Delta y_i, & (\Delta y_i > 0) \wedge (\Delta x_i > 0) \wedge (\Delta y_i > \Delta x_i) \\ 2 - \Delta y_i / \Delta x_i, & (\Delta y_i > 0) \wedge (\Delta x_i > 0) \wedge (\Delta y_i \leq \Delta x_i) \\ 2 - \Delta y_i / \Delta x_i, & (\Delta y_i \leq 0) \wedge (\Delta x_i > 0) \wedge (\Delta x_i > -\Delta y_i) \\ 4 + \Delta x_i / \Delta y_i, & (\Delta y_i < 0) \wedge (\Delta x_i > 0) \wedge (\Delta x_i \leq -\Delta y_i) \\ 4 + \Delta x_i / \Delta y_i, & (\Delta y_i < 0) \wedge (\Delta x_i \leq 0) \wedge (\Delta y_i \leq \Delta x_i) \\ 6 - \Delta y_i / \Delta x_i, & (\Delta y_i \leq 0) \wedge (\Delta x_i < 0) \wedge (\Delta y_i > \Delta x_i) \\ 6 - \Delta y_i / \Delta x_i, & (\Delta y_i > 0) \wedge (\Delta x_i < 0) \wedge (\Delta y_i \leq -\Delta x_i) \\ 8 + \Delta x_i / \Delta y_i, & (\Delta y_i > 0) \wedge (\Delta x_i \leq 0) \wedge (\Delta y_i > -\Delta x_i) \end{cases}$$

When searching for the next edge in the clockwise based on the current edge, we at first compute the value of  $Q_i$  operator of every edge that is related to the end node of the current edge. Then sort them ascending. If  $Q_i$  is in the front of  $Q_j$ , the edge whose  $Q_i$  operator values  $Q_i$  is the next edge of the one whose  $Q_i$  operator values  $Q_j$ .

**The disposal of Dangle Edge:** Generally speaking, the dangle nodes should be removed before building the polygon topology. But in the road network, the dangle edge is permitted, such as the dead road. Therefore, while building the special area topology, we should dispose the dangle edges distinguishingly to ensure that the search process continues. In our methods, we at first judge whether the number of the edge related to the current node is only one. If it is, the current edge is dangle edge. Change the current node to the other node of the current edge and search unceasingly. Fig. 6 describes the disposal process of dangle edge. The arrows identify the search direction.

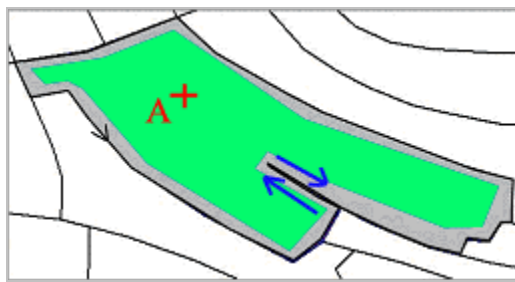


Figure 6 the disposal of dangle edge

## 5. EXPERIMENTS

The algorithm has been tested in our experiment environment. The development environment is Delphi 6.0 and MapX. The experiment data is the road network data within the second ring of Beijing. And the experiment is completed in the personal computer that has PII CPU, 256M memory and Win2000 OS. Table 7 is the result in comparison with the traditional methods.

In the table,  $T_{N-E}$  is the node-edge topology and  $T_{A-E}$  is the special area topology. And TM represents the traditional Methods; PM represents the present methods. From the experiment result, we know that when building the node-edge topology the time efficiency of the present algorithm is similar with that of the traditional one. But when building the area topology, the present algorithm saves us much more time. Moreover, the constructed area topology is more appropriate to the ITS application.

Time Data	$T_{N-E}$ (s)		$T_{A-E}$ (s)	
	TM	PM	TM	PM
Edge□104 Node□68	1"	0.9"	3"	1"
Edge□1,128 Node□736	3"	2"	13"	4"
Edge□12,485 Node□8768	12"	8"	125"	18"

Table 7 The Experiment Results

## 6. DISCUSSION AND CONCLUSION

The experiment indicates that the algorithm presented in the paper has the following advantages. Firstly, the proposed topological relationships, which are composed of edge-node topology, node-edge topology and "special" area topology, are more appropriate to ITS application because they consider the characteristics of such applications. Then, the proposed algorithm is more efficient because  $Q_i$  operator rather than Angle operator is employed in the search process. In a word, based on the defined table above, the time efficiency of the algorithm has been improved to great extent, which can satisfy better the requirements of ITS application.

The ITS application requires to build the topological relationships of road network on the fly. And the efficiency of the algorithm is related to the organization and index of the data. Therefore, the scheme of the road network data is need to be researched to improve the efficiency of the algorithm. Moreover, the current algorithm constructs the topology of all the data when the geometry of any data changes. So, how to only build the topology of the changed data is what we should research in the next step.

## ACKNOWLEDGEMENT

The work is jointly supported by National Natural Science Foundation of China (40171076) and National Science Fund For Distinguished Yong Scholars (40025101).

## REFERENCE

- Ayse Can, 1996. Weight matrices and spatial autocorrelation statistics using a topological vector data model. *I.J.GIS*, 10(8): 1009-1017.
- Chrisopher M. Gold, 1991. Problems with Handling Spatial Data - the Voronoi Approach. *CISM Journal*, v. 45 no. 1, pp. 65-80.
- Chrisopher M. Gold, 1994. Three approaches to automated topology, and how computational geometry helps. In: *Proceedings, Sixth International Symposium on Spatial Data Handling*, (Ed.: Waugh, T. C. and Healey, R. G.), Edinburgh, Scotland, pp.145-158.
- David. M. Mark, and Max J. Egenhofer, 1995. Topology of Prototypical Spatial Relations Between Lines and Regions in English and Spanish. *ACSM/ASPRS*: pp.245-254.
- Jie JIANG, 2003. The Navigation Data in LBS (in Chinese). *Geomatics World*. 1(3): 9-13.
- Kimfung Liu, and Wenzhong Shi, 2003. Analysis of topological relationships between two sets. *Proceedings of The 2nd International Symposium on Spatial Data Quality*. pp.61-71.
- Laurini Robert, and Thompson Derek, 1992. *Fundamentals of Spatial Information Systems*. Academic Press Limited. San Diego.
- LI LIN, 1987. Topological Relation on Map. In: *Proceedings of International Workshop on Geographical Information System*, Beijing: pp.280-290.
- Michael J. Mineter, 2003. A software framework to create vector-topology in parallel GIS operations. *I.J.GIS*, 17(3): 203-222.
- Qi Hua, Liu WenXi, 1996. The Algorithm for building arc-arc topological relations at nodes. *ACTA GEODAETICA et CARTOGRAPHICA SINICA*. 25(3), 233-23.
- Serafino Cicerone, Eliseo Clementini, 2003. Efficient Estimation of Qualitative Topological Relations based on the Weighted Walkthroughs Model. *GeoInformatica*, 7(2): 211-227.
- S. Dowers, B. M. Gittings and M. J. Mineter, 2000. Towards a framework for high-performance geocomputation: handling vector-topology within a distributed service environment. *Computer Environment and Urban System*, 24(5): 471-486.