Network Analysis Modeling Towards GIS Based on Object-Relation Database

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ABSTRACT  This paper compares the differences between the mathematical model in graph theory and GIS network analysis model. Thus it claims that the GIS network analysis model needs to solve. Then this paper introduces the spatial data management methods in object-relation database for GIS and discusses its effects on the network analysis model. Finally it puts forward the GIS network analysis model based on the object-relation database. The structure of the model is introduced in detail and research is done to the internal and external memory data structure of the model. The results show that it performs well in practice.

KEYWORDS  network analysis; GIS; object-relation database

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Introduction

With the wide application of GIS in fields of city transportation, pipeline network, electricity, telecommunication, more enhancements need to be added to the current GIS spatial analysis, especially network analysis. The basic data in these fields have one common feature; they are net data constructed by points and lines. To fully describe these net data and relationship between them, more powerful and flexible network analysis functions in GIS, including routing analysis, resource allocation, connection analysis, flow analysis, are required[1].

Many scholars have done much theoretical work about the efficiency of network analysis algorithms, such as the classical algorithm of shortest path searching—Dijkstra. However, the implementation of theoretic algorithms always depends on certain kind of data organization. The organization of spatial data consists of spatial data model and spatial data structure. And the research in data model and data structure plays a kernel role in GIS[2]. Presently, the widely used object-relation database in GIS is built on the object-relation model. It does not store the topological relation of spatial objects, thus the previous network analysis model needs to be extended.

To meet the various demands of special fields, people tend to combine the theoretical models defined in maths with the practical problems. After using GIS as a tool for management and presentation of spatial data, another problem arouses the interest of researchers: the problem of designing a flexible network analysis model as a middle layer between the mathematical model and practical application which can be easily customized, modularized and a platform easy for enhanced development.

Focusing on the problems that GIS network analysis model needs to solve, this paper presents an extended network analysis model based on the object-relation database. And a network...
application test is done to demonstrate how this model works well.

1 Problems that GIS network analysis model needs to solve

In the graph theory, network is abstracted to the graph. Thus the data structure of network is in great touch with the data structure of graph. It is well known that there are always differences existing between theoretic models and realistic models. So the differences between the network analysis model in GIS and mathematical model in the graph theory need to be known firstly, and these are exactly what the network analysis model primarily aims to solve (Table 1).

| Difference                        | Model                                |
|-----------------------------------|--------------------------------------|
|                                  | Mathematic model in graph theory     | GIS network analysis model           |
| Data                             | moderate volume, symmetric           | large volume, asymmetric             |
|                                  | distributed                          | distributed                          |
| Spatial position of arc and node | unmeaningful                         | meaningful                           |
| Weight of arc                    | monotone                             | multiple                             |
| Weight of node                   | nonexistent                          | existent                             |
| Weight of turn                   | nonexistent                          | existent                             |
| Dynamic segmentation             | nonexistent                          | existent                             |
| Topological relation             | simple                               | complex                              |

Below is the detailed explanation to Table 1.
1) Data: Usually the spatial data is large-scale and asymmetrically distributed. The model must be carefully designed to meet the demands for both efficiency and memory in network analysis.

2) Spatial position of arc and node: The original data that GIS manages is geographic spatial data, so the arc and node derived from the original data can not deviate from the geographic meaning of the spatial data and can map the features of the real world.

3) Weight of arc: Differing from the monotone weight of the graph theory, the weight of arc in network analysis model is affected by several factors depending on the practical problems. For example, both the length of route and the velocity of car must be included when considering the cost of car travel. At this time, functions are often used to represent the weight value of arc in network.

4) Weight of node: The nodes in network may also influence the flow of resources in network.

5) Weight of turn: The turn is defined as a way that some kind of resource flows through a node from one arc to another. In a realistic world, the different turns in a road crossing correspond different costs.

6) Dynamic segmentation: In conventional GIS, one arc always corresponds to one record of attribute data. However, in the road information management field, the arc may correspond to several attributes while each attribute records the property of sub-arc of that arc. To describe the sub-arc of an arc, a linear reference frame is introduced and a specific field in the attribute data is used to record sub-arc position in this reference frame. These sub-arcs are not digitized separately, so they are not the conventional arcs. We usually call sub-arcs dynamic segments, and this kind of record is named as dynamic segmentation. Thus it must be considered in network analysis model, too.

7) Topological relation: Points make up of arc, and arcs are linked by point. Such kind of topological relation is stored in GIS. The GIS software must afford the additional costs of maintaining these topological relations. This is also a research division of dynamic GIS that how the designed model can keep the real-time update of topological relation when editing the geometric and attribute data.

2 Object-relation database

Relation database is a kind of perfect database...
both in theory and practice. However, it is not
efficient when directly using relation database
management system (RDBMS) in GIS without
any additional improvement made by GIS soft-
ware such as spatial index. Presently object-orien-
ted model is the best model to describe and
manage the spatial data. It can afford not only
the management of changeable length record but
also the inheritance and congregation of informa-
tion. It also permits the customized object defi-
nition, object structure and object operation.
Yet there are still many theoretical and techno-
logical problems unresolved in the object orien-
ted database system.

Now many database management system
(DBMS) software companies make extensions to
their current RDBMS and present the object-re-
lation database which can directly store and man-
age the nonstructural spatial data (i.e., point,
line, polygon etc.). This kind of database sup-
ports the object-oriented data model. Thus we
can query the nonstructural spatial data in its ap-
lication user interface.

Because the extensions are made by database
software companies, the efficiency of manage-
ment to changeable length record is higher than
the older one which make use of binary block.
Now it is widely used. However, it still can not
resolve the problem of object-embedding, so the
topological relation can not be described fully.
The spatial data structure still can not be cus-
tomized. These problems limit the further use of
it. Furthermore, data of different attribute
types or geometric types are stored as different
types of feature classes in object-relation data-
base, yet it needs to integrate them into one en-
vironment when doing network analysis. In view
of these demands, additional processions are
necessary for network analysis.

3 Extended network analysis model
based on object-relation database

To solve the previous problems, this paper
presents an extended network analysis model.
The structure of this model is shown in Fig. 1.

As illustrated in Fig. 1, the whole model is di-
vided into two layers, geometric network layer
and topological network layer. The geometric
network layer stores the original geographic net-
data in forms of feature classes. The man-
agement, query, editing and display of spatial
data, i.e., presentation, are implemented basd
on this layer. The object-relation database does
not store the topological relation of spatial data,
so each geometric network layer corresponds one
topological network layer for network analysis.
In topological network layer there are no layers
of feature classes existing in geometric network
layer. It abstracts the feature classes of the same
geometric type into a uniform element collection
in network, but maintains the topological rela-
tion of elements. The analyses of the whole net-
work (namely the implementation of network
analysis algorithms) are conducted in this topol-
ogical layer. The topological relation can be
stored either in database or in file. The detailed
illustration is shown in Fig. 2.

3.1 Geometric network layer

The geographic spatial data are represented as
line feature classes, point feature classes and
some attribute tables (such as turn attribute ta-
ble) in this layer. Each feature class is assigned
a unique global feature class ID in an object-rela-
tion database. In every feature class each point
or line feature with independent attributes has a
unique object ID (OID). As shown in Fig. 2, the
road's feature class ID is 1. The two features in
it have the OID $g_1$, $g_2$, respectively. The geom-
3.2 Topological network layer

Topological network layer derives from geometric network layer according to the topological features of the geographic spatial data. It is mainly composed of three parts: net element table, topological relation table, weight table.

3.2.1 Net element table

The elements of the whole network are divided into three types in this layer: arc, node, turn.

Node table: All point feature classes of geometric network layer are sorted as the element set of Node table. Each feature of feature classes is mapped here with a unique node element ID (EID). Since the node EID in the node table records the corresponding feature class ID and object ID, the typedef struct tagNodeInfo(Node structure) relation to the original spatial data is established.

Arc table: All line feature classes of geometric network layer are sorted as the element set of The arc table. Each feature of feature classes is mapped here with a unique arc element ID (EID). The Arc EID in the arc table also records the corresponding feature class ID and object ID. The SubID in the arc table can be used to identify the sub-part of one line feature.

Turn table: Since the line feature OID in the turn attribute table will be converted into the Arc EID in the topological network layer, the turn can be represented by from Arc EID and to Arc EID.

3.2.2 Topological relation table

Topological relation table can be regarded as the representation of the widely used united structure of node-arc in network analysis below, though it is illustrated as forms of table in database.
The characteristics about the structure are described as follows.

1) Instead of storing the geometric and attribute values, the structure builds relations with spatial data through feature class ID and object ID, thus greatly decreases the memory cost.

2) It can integrate spatial data from different feature classes into one analysis environment and build a uniform network element description.

3) The type of weight values is variable.

4) It provides support for full consideration of node weight value and bidirectional arc weight value.

3.2.3 Weight table

The weight in network analysis model directly affects the analysis results. The attribute values in the geometric network layer mainly contribute to dynamic segmentation and the attainment of weight values. There is a set of global weight ID in the topological network layer (Fig. 3).

| Weight name | Weight ID | Weight type |
|-------------|-----------|-------------|
| Net Time    | 1         | double      |
| Net Length  | 2         | double      |

Weight definition in network

| Weight ID | Table name      | Field name |
|-----------|-----------------|------------|
| 1         | Roads           | time       |
| 1         | Railroads       | time       |
| 1         | Cities          | time       |
| 1         | Turn Attribute table | time     |
| 2         | Roads           |            |
| 2         | Railroads       |            |

Mapping of weight to table fields

Fig. 3 Network weight

Each weight ID represents one type of weight that user defines, and it will be mapped to one field of the feature classes in the geometric network. Then users can get each net element’s weight value by taking it from the mapped field. Finally the weight table according to each weight ID is established to store net elements’ weight values (weight tables in Fig. 2).

3.3 Relationship between geometric network layer and topological network layer

In the geometric network layer, spatial data of different geometric types are stored in different feature classes. As shown in Fig. 2, there is a road feature class and a railway feature class in one network. Conventional network analysis is carried out in only one line feature class. This can not reflect the practical demands. People always need to take into account many factors in a network such as roads, railways and bridges when doing network analysis. So this model can integrate different types of spatial data and do the network analysis in a uniform topological network layer.

Users only need to consider the algorithms in the topological network layer. After finishing the analyses, the results of this layer can be reflected into the geometric network layer for visualization and reports. Of course, the alteration of spatial data in the geometric network layer must correspond to the change of table records in the topological network layer in order to keep the consistency of topology.

Taking into account the complexity of real world problems, the model can afford various kinds of applications, and the results of analysis will be more reasonable.
4 Experimental system and results

Based on the theoretical studies, an experimental system for this model is conducted on business GIS software GeoStar using the technique of COM. The full-considered model needs more complicated implementation and then the efficiency of it is always negatively affected. But it can still get satisfactory results when memory optimization techniques and reasonable data structure are adopted. Based on this model, the author implements the common network functions like route analysis, resource allocation and connection analysis successively. Results show that it performs well in practice. As shown in Fig. 4, that is the result of service areas function. The data are roads data in Beijing (1 123 nodes, 1 811 arcs (bidirectional)). The configuration of PC is: CPU frequency (400MHz), HD (10G), Memory (256M). The time of calculation is less than one second when computing the service areas (in 170 unit) of 26 gas stations if the time cost of results display is not considered.

Fig. 4 An example of network analysis

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