

## THE EXPRESSION OF ROAD NETWORKS FOR VEHICLE NAVIGATION

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### ABSTRACT

The Graph Theory has long been employed in the modeling of transportation networks. Generally, roads are represented by the edges and crossways the vertices (or nodes). A typical application of this model is the determination of the shortest (or optimum) path in the network. Several algorithms had been developed including the famous Dijkstra algorithm.

The above-mentioned expression of road networks renders insufficient under certain circumstances like vehicle navigation. A highway comprises several lanes and a crossways is not a node that one can arbitrarily move into and out of - turning left on some important crossroad is against the rule.

A naive method has been proposed in this article to make a better representation. Sub-graphs are used to represent various crossways including cloverleaf junction. A discussion on the data structure has also been made.

### 1. Introduction on Vehicle Navigation and GIS data

#### 1.1 Brief review on Vehicle navigation and its function

Vehicle Navigation has always been an important and cardinal part in the recent spate of Intelligent Transportation System study because of the vast and ever-growing capacity of automobile traffic. And practical products had already appeared in the market and can be found attached to or incorporated into many cars. By definition, a Vehicle Navigation System is different from a Vehicle Monitoring System and other systems in that it must provide convenient services and sufficient guidance to the driver to facilitate a better traffic. And basic and important functions of a Vehicle Navigation System would at least include planning routes, which in turn requires representing the reality of the target transportation system to a satisfactory extent.

#### 1.2 Road network in vehicle navigation and its representation

Using Graphs in the Graph Theory has been a natural and efficient way of modeling the road networks. Here, in this article it will continue to be used since it embraces all the topological information of any road network and topological information suffices the goal. Generally, a road is represented by an edge and a crossways a vertex (or node). A typical application of this model is planning the optimum path in a road network. Classical algorithms had been developed including the famous Dijkstra algorithm.

However, with the development of road traffic, the matter becomes complicated, some sophisticated structures had appeared. A highway now comprises several lanes which runs parallel to each other but can not be trespassed and a crossways is not always a node that one can arbitrarily move into and out of — turning left on some important crossroad can be against the rule. And what's more, there are stereo crossways — the viaducts. And the classic expression of road networks seems to be insufficient to express the above cases.

### 1.3 The key point of the problem

Corresponding to edges in the Graph Theory, the expression of multi-lane roads can be achieved relatively more easily. A road network that has multi-lane segments can be expressed by the use of an oriented multi-graph in which there may exist more than two edges between a pair of nodes. It should be noted that this kind of expression seemingly eliminates the possibility of using adjacency matrices or distance matrices, but in fact, only two reverse lanes (if there are two) of the minimum costs are needed for each pair of nodes. And multiple-lane structure is only a provision for the situations where different criteria for the cost is needed or where, in some other cases the full representation are needed. In a word, multi-lane roads can also be expressed by traditional distance matrices.

Unfortunately, the generally mentioned nodes in the Graph Theory cannot sufficiently express the situations where road segments meet. When there is no limitation on the direction of turning and when the cost of passing crossways can be ignored, a node suffices crossways. But when it happened that there do exist some crossways that do not conform to the requirement, a node fails to represent it. The reason is simple: a node has no structure of any kind. One solution would be to endow the nodes with a sort of structure and expand the node, into a sub-graph.

Let's take a look.

### 2. The crossways and general representation, situation analysis

As mentioned above, a node can not express all the crossways. And in fact, it is possible for us to expand the nodes to sub-graphs to represent all situations.

A typical 4-branched intersection would look something like illustration 1.

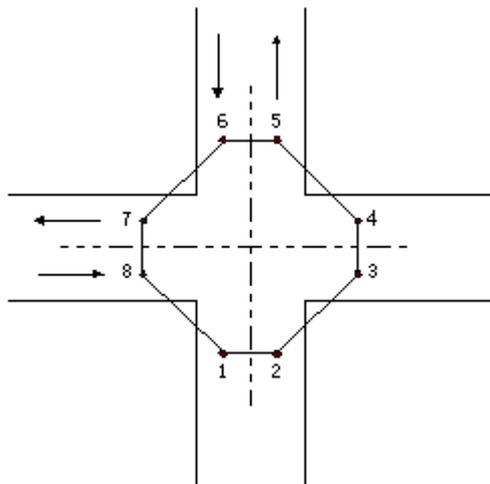


Illustration 1

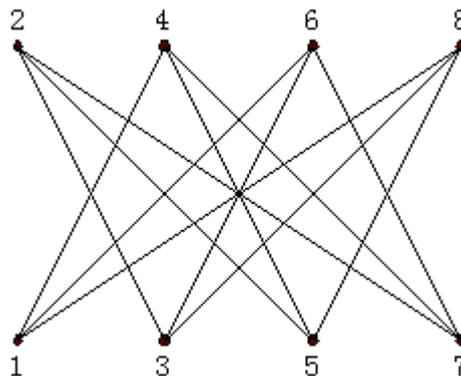


Illustration 2

As shown in illus.1, we assumed that each of the intersecting roads has two oriented lanes (designated by the dashed lines). And it can be, for example, expressed by a sub-graph constructed as the following and shown in illus. 2.

Each of the eight corners of the octagon in illus. 1 stands for the point where a lane enters the cross, and we call such points entrance points. To describe the traffic in the cross, these entrance points are by themselves sufficient to represent their corresponding lanes as shown in the following. Each of the entrance point in illus. 1 shows as a node in illus. 2 and each edge in illus.2 means the permission to switch from the its source node (correspondingly, the source entrance point or lane) to the target one.

For the sake of simplicity, the graph in illus. 2 takes the form of a non-oriented graph, but generally it should take the form of an oriented graph so that the turnings of two reverse directions can be distinguished. If there is a limitation that turnings left, say, from entrance 2 to entrance 7 is prohibited, the corresponding oriented edge from node 2 to 7 should then be removed. On the contrary, if there is none of such limitations at the cross, like in most crossways, the vehicle can then move arbitrarily there and there is in fact no need for using such a sub-graph.

There is a feature obvious in the sub-graph, that is, all nodes can be divided into two sets with no two nodes in the

same set related by any edge. In the terminology of the Graph Theory, the graph in illus. 2 is a bipartite graph. This is because all nodes can be classified into in-nodes and out-nodes according to whether they are leading into or out of the road segment they belong to. And a car must move out of one road way before entering another.

So far, we have not considered the cost of passing crossways, if this is to be taken into account we have to consider two types of crossways, planar crosses and the stereo crosses. The planar cross is the simpler case where roads on the layer of the same height meet, or intersect. In this case, the costs of turning at different directions have only minor differences. The stereo cross is the more complicated case where not only the common planar cross but also such stereo structures as viaducts are involved. A viaduct is different from an intersection in that it allows the vehicle to pass without stopping and it should be a preferable choice for a driver because it is faster and more convenient.

### 3. Data Organization

And now, it is time that we took a look at the overall data organization that is proposed.

#### 3.1 Full representation of the logical data structure and physical data structure

A major shortcoming of using such complex structures as mentioned above would be the high costs of sub-graphs and multi-line edges. To overcome this, two methods can be employed: the first is the separation of logical data structure and physical data structure; the second, as will be stated later, is proper simplifications.

Practically, the different lanes of the same road are geometrically undistinguishable and it is only natural that they should share the same geometric or spatial data. This can be accomplished by the use of IDs or pointers. Each line segment on the stratum of physical data structure should be given a unique ID. A record of lane segment will have a pointer field to reference this line segment-ID. And different lanes of a same road segment could reference a line-segment ID multiple times, hopefully.

Crossways, as mentioned earlier, can be represented by sub-graphs with entrance points representing lanes. But it should be noted that an entrance point does not always identify with a lane segment. In such cases where a viaduct is existent, a driver can have several possible entrances to turn to. That is to say, a lane-segment can be related with multiple entrance points. And if we divide a physical entrance into a number of entrance points according to the number of lanes entering it, we can describe the relationship between lane-segment and entrance points as a one-to-many relationship. And since lane-segments and entrance points are not identical, it can be concluded that each entrance point should also be assigned an ID number that is independent from the lane-segment ID.

Since the relationship between lane-segment and entrance points is of a one-to-many type, the connection information of lane-segments and entrances should be store in the crossway sub-graph's end.

#### 3.2 Simplifications (and the interface between different s-levels)

Although the scheme of full representation in 3.1 has the potential of expressing any crossways, its has a drastically increased cost on storage and speed. The expansion of nodes into sub-graphs multiplies the cost of nodes and practically makes the full expression impossible. However, for the sake of efficiency, we can confine the use of full representation only to the few cases of the complicated crossways that cannot be otherwise expressed with simpler forms, and apply simpler forms of expression to the more usual situations.

Generally, we can simplify the model to the following forms according to their various circumstances:

As roads are concerned, they can take two forms:

Non-lane road:

In this form, a road segment is exactly represented by a non-oriented edge. The form can be considered when the actual road segment is of low rank, has no separation of lanes at all and one can drive directly from one side of the road to the opposite one.

Double-lane road:

In this form, a road segment is represented by a pair of reverse oriented edges. This is the most common form where two lanes or two main lanes with shift-easy sideways are involved. This case is specially mentioned here because it is too common in urban area.

Multi-lane road:

In this form, a road segment is represented by multiple (more than two) oriented edges with each one identify with a lane. Multi-lane roads are common in highways and can be also found in a metropolis.

As mentioned in 1.3, only two reverse delegation lanes of the minimum costs are needed for each pair of nodes and

multi-lane roads can also be expressed by distance matrix. When multiple criteria of costs are involved, we can calculate the corresponding distance matrices respectively.

And crossways can take the following forms:

Node form:

In this form, a crossway is simply represented by a node. This is the common case where no limitation exists or rather it is possible to turn at any direction as when a roundabout is present.

4-branched impassability sub-graph:

This form is a simplified form of the complete sub-graph form. This form is to be used when the cross is only related to double-lane road or non-lane road and only two roads intersect at the cross. Its form is proposed because it is the most common case just like double-lane roads and also because most probably, turning right and moving straightforward is permitted and only turning left at some corners is disallowed at this kind of crossways.

This form of representation is in fact much simpler, and it requires only 4 records with each one containing an into-crossway-lane ID and a flag to show whether left-turning is allowed when moving into the crossways. And to distinguish which branch of the cross is to the left of the current one, the branches must be numbered in a clockwise (or anti-clockwise) order. And this can be easily accomplished by sorting the 4 branches by their azimuths local to the cross in descending (or ascending order).

Full sub-graph form:

This is the form mentioned in section 3.1. As have stated before, this form has the ability to express any crossways, but is rather costly. And it should be used only when simplification of any kind is impossible, as when multi-lane roads are involved or more than 4 branches are related.

### **3.3 Integrating different forms of representation**

The various forms mentioned above renders useless if they could not be integrated into one structure. And in fact, the integration of these forms of representation can be accomplished by a mechanism similar to precision conversion from integers to floating point numbers. The above mentioned expressions of roads and crossways are in parallel with each other. And a list of descending precision reads: (Non-lane road, Node form crossway), (Double-lane road, 4-branched impassability sub-graph), (Multi-lane road, Full sub-graph). Note that lower order representation of road or crossways can always be converted to higher order form in a rather natural way. And if a complex road expression joins a crossway expression that is not complex enough to accommodate it, just upgrade the node to a higher rank of complexity. In this way, the various forms of expression can now be integrated into one compound expression

## **4. Alternation of algorithm for optimum path-finding**

As the traditional expression of road network has been altered, the algorithm for optimum path finding would also have to be adjusted to adapt to the new data structure. But, only minor alternations are needed. And take the classical Dijkstra algorithm for example.

The Dijkstra algorithm is typically based on distance matrix, and the new way of expression is in fact only different from classical expression in the expression of nodes. The sub-graph expression of nodes enables us to avoid illegal turnings and in the term of algorithm, to enforce the program to choose from only legal neighboring nodes. To implement the program is a problem of details and beyond the scope of this article.

## **5. Conclusions**

Through the discussion in this article, we can conclude that the proposed method of expressing road networks is suitable for the complicated situation.

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