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Sequential Generation Method for *k*-order Network Voronoi Regions

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1 Introduction

Voronoi diagram (VD) is applied to various fields as in geographical information system GIS and computer vision. This type of VD is well-known as the oridinary VD. In the earlier literature, VD based on Euclidean distance has been researched. It is then extended Euclidean distance to network voronoi diagram (NVD) for the real road network, and practically used for queries in location based services. For instance, when a set of data points P and a query point q are given, while retrieving a nearest point to q, known as a nearest neighbor query (NN), the NN of q can be efficiently found based on generated NVD in such case.

High order NVD in a road network distance, in other words, k order NVD can be generated as an alternative. If the high order NVD is once generated, a range search for k nearear neighbor (kNN) of a query point q can effectively be performed by refering the NVD. However, the value of k is not always given beforehand and generally it is assigned once the searching invokes. Hence, generating k order NVD in advance before kNN search is not feasible in practice. Moreover, NVD for the entire road network is not always necessitated to upload for the searching and it is usually restricted to associate with a partial region of the road network if and only if NVD region is required partially in most cases. Therefore, this paper introduces a generation method of high order network voronoi region on demand.

2 Proposed method

2.1 Basic principles

Let S be a set of data points and $q(s_0)$ be any point $q \in S$. The voronoi region (VR_q) can be generated q as a query point. Here, VR_q is a set of links between q and its nearest points to q. Figure 1 shows the example of network voronoi region. White circles are road network nodes and black circles are data points ($\in S$) and the number attached

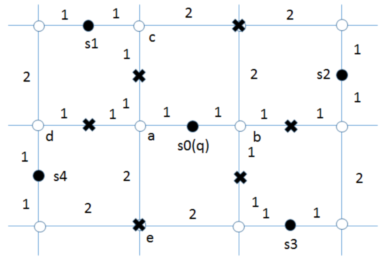

Figure 1: Network voronoi region

on each link is the cost of the link (for example distance). By this figure, s_0 is assumed as a query point q and NVR of q is generated. $\times$ symbol shows the voronoi region in which $q(s_0)$ lies.

The voronoi generation process can be done by the following steps:

1. The range of NN search expands farther by a similar way in Dijkstra's algorithm started from an adjacent point of q to a road network node (n) gradually.
2. For each visited point in the step (1), it is verified that whether q is its nearest neighbor in the road network distance or not.

If that visited point is satisfied with the above condition in step (2), its nearest neighbor points are enqueued into PQ. The following is a record format in PQ.

$$< c, n, p >$$

where n is a current point, c is cost(road network distance) from q to n and p is the previous point. The road network distance between q, and n is expressed as $d_N(q, n)$.

In Figure 1, (a, b) is two end points of a link on which q lies. For (a, b),

$$< 1, a, s_0 >, < 1, b, s_0 >$$

the above two records are intialized into PQ.

To expand the search, the element with the minimum cost is dequeued from PQ. Thus, $< 1, a, s_0 >$ is dequeued. Then, NNs of a are searched and verified whether these points are nearest to q in the road network distance. If NN of a is q, and then a lies in the voronoi region of q. Furthermore, records for all adjacent nodes to a are enqueued

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into PQ for further expansion. While a has three adjacent nodes (e.g., c, d, e are adjacent nodes of a), three records are enqueued into PQ.

$$< 3, c, a >, < 3, d, a >, < 3, e, a >$$

Next, if the current point n is b, $< 1, b, q >$ is dequeued from PQ. For all adjacent nodes of b, records are enqueued into PQ. In the next iteration, it is assumed that $< 3, c, a >$ is retrieved from PQ. At this point, s_1 is NN of c and c lies in the region of data point s_1. Hence, a border node on the link between q and s_1 is determined to seperate regions. The next dequeued record $< 3, d, a >$ has the same process for the border node determination. When the record $< 3, e, a >$ is dequeued from PQ, each distance from e to q, s_4, s_3 is three respectively. In this situation, e is determined as a border node. The voronoi region of q is generated by repeating the above mentioned process.

k order network voronoi region kNVR can simply be extended by the above process. When k number of data point set (P) is given, kNVR , in which all data points in P must be included in kNN of a query point q, is generated. Therefore, after every node n has been visited, kNN of n are checked whether these NNs are in P or not. The node expansion process only occurs until all data points in P are included in kNN result. While searching NN of the current visiting node n, if there might exist a data point in NNs of n which is not included in the kNN result, a border point is necessary to determine where this different result ocuurs. Thus, a border point on the link between n and its opposite endnode(previous node (*prev* of n) with the cost (the distance between a point which gives different result from kNN result and *prev*). When n is visited, a process verify(n, P) is invoked while checking all data points in P are included in kNN of n or not.

2.2 Improvement for processing time by SSMTA* algorithm

The basic process of NVR generation, invoking verify process for every node takes long processing time. For a current visited node n, kNN candidates of n are searched in the Euclidean distance and then these candidates are verified in the road network distances by using A* algorithm. However, in the verification step, several repeated searchs occurs in searching at least kNN number for each visited node n.

To improve the efficiency in terms of processing times, a single source multi targets A* algorithm can be applied in the verification step. SSMTA* [1] finds the shortest paths to multiple targets from a single query point s. Hence, it can be applied while verifying road network distances from a kNN candidate point p to multiple nodes n.

3 Experimental evaluation

To evaluate our proposed method, several experiments have been done by using the real road network data of Saitama city map whose nodes are 16,284 and links 24,914. We generated variety of POI data point sets on the road network links by pseudorandom sequences.

In Figure 2, D is 0.002 and the horizontal axis is for number of k.

Figure 3 shows the comparison of the processing time when the density of data points distribution (D) is set to 0.002 and the value of k is varied as shown in the figure. The comparison method has drastic increase in processing time when the number of k increases because verification step takes long processing time to be included all points in data point set P which are similar to kNN. However, the proposed method achieved the stable performance even k value increases.

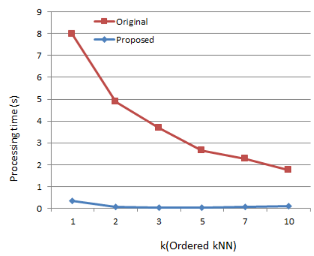

Figure 2: The processing time when D is 0.002

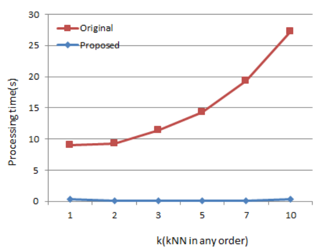

Figure 3: The processing time when D is 0.002

References

[1] H.Htoo et al., IEICE Trans., Vol.E96-D, pp.1043–1052 (2013)